On the perception of time trends in resource outcome

Its importance in fisheries co-management, agriculture and whaling

Wim L.T. van Densen

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Abstract

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Fishermen have different perceptions than management authorities of long-term trends in resource outcome. This complicates co-management between individual resource users and these authorities. In this study the capacity to perceive trends is formalised with the statistical power to detect a true trend. This power is larger where trends are steep, the variance around trends is small, the number of years in the series is large, and when a greater risk to wrongfully conclude for a trend is accepted (Type I error). In order to predict which trends and patterns are visible and for whom, variability in daily, monthly and annual catches is assessed and compared for different types of fish and fisheries. This study shows that inter-annual variability and the persistence therein are responsible for a 'governance dilemma' that is found in the choice between costly draconic measures with a large impact and thus public proof of their legitimacy rather than more feasible but less effective measures. Authorities have an 'administrative gain' over individual fishermen in the perception of time trends, because they use spatially aggregated data that contain less variability. Recommendations are given on how to overcome this difference in the capacity for trend perception by enlarging the 'evaluative capacity' of both fishermen and authorities, especially where the two cooperate in co-managing a fishery. These problems in trend perception exist as well in agriculture. For instance, variability of annual crop yield in rainfed agriculture is high, and downwards trends due to soil degradation therefore hard to perceive for the individual farmer. Finally, the example from 17th and 18th century whaling illustrates how cognitive limitations because of ignorance of graphical and statistical tools, together with extremely high inter-annual variability, also constrain the perception of time trends in resource outcome.

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ON THE PERCEPTION OF TIME TRENDS IN RESOURCE OUTCOME

ITS IMPORTANCE IN FISHERIES CO-MANAGEMENT,
AGRICULTURE AND WHALING

PROEFSCHRIFT

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Voor Brechje en Inse

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Chapter 1

Introduction

"Good catches of eel this year!" the fishermen's representative said emphatically. It sounded like his falsification of the downward trend in eel catches repeatedly mentioned by the fisheries scientist in the 'Advisory Board for the Management of the Lake IJssel Fisheries'. True, that for evaluating the economic viability of a fisherman's enterprise it might not seem very relevant to evaluate long time series of annual landings of eel from the lake as fisheries scientists do. Economic conditions change over the years and fishermen progressively adapt their fishing techniques and the way they organize their fishery. Fishermen might thus be more inclined to compare catches on a year by year basis, in a small time window. Evaluation of annual landings in a time window of many decades, longer even than their own career in the fishery, seems irrelevant to them. But when fishermen from Lake IJssel are persuaded to make such an evaluation, it is clear to them, as much as to the fishery scientist, how alarming the decline in annual catches has already been for many years (Fig. 1.1). The explanation for this decline is a gradual increase in fishing effort and a decrease in the number of elvers entering the lake (Dekker 1991, 1996).

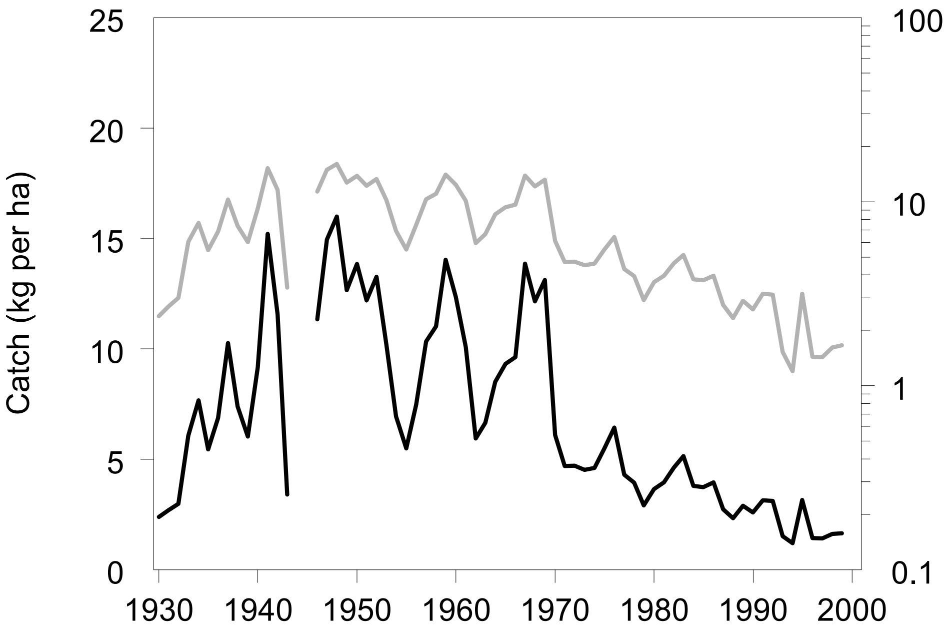


Fig. 1.1 Landings of eel (kg/ha) from Lake IJssel, the Netherlands 1930 - 1999. The grey line refers to the logarithmic scale on the right Y-axis.

There is considerable variability around the downward trend in eel catches from Lake IJssel. In a smaller time window the trend might therefore not be perceived because the signal to noise ratio then becomes too small. When regulatory measures are taken to rebuild the stock, the same inter-annual variability might similarly constrain the perception of a step trend towards higher catch levels. The authorities will be as impatient as the fishermen to see, from an increase in resource outcome, whether measures taken are shown to be effective. However, here too the time window, in this case the total number of years before and after a change in management, might necessarily be large, and both authorities and fishermen have to wait until later for ultimate evaluation. As some fish stocks, and thus fisheries, are notably more variable than others, so the perceptibility of trends and step trends in the outcome of these fisheries, will vary (Sissenwine 1984).

When it comes to a discussion on the state and management of a fishery every fisherman will refer to the development of his own catch rates. Authorities, however, only refer to developments in the fleet's total or average catch, as obtained through a Catch and Effort Data Recording System (CEDRS). Since fishermen's catches are, in effect, samples from a large fish biomass that redistributes itself continuously throughout the resource area, variability is greater in the annual catches experienced by each fisherman separately than that in the average for the fleet. Fishermen thus have a lower capacity to perceive trends and step trends in annual catches and thus in stock size.

Disparate perceptions of developments in the fish stock and the fishery constrain communication between authorities and fishermen concerning problem identification and which measures to take in a fishery. This communication is, however, of paramount importance in fisheries co-management, where both the authorities ánd fishermen take responsibility for managing a fishery. This co-management is increasingly considered the answer to the many problems faced by present day fisheries, such as the costly practice of data gathering, the inflexibility of centralised management, and the tiresome enforcement of effort regulations (Jentoft 1989, Pomeroy 1994). Fisheries co-management implies sharing responsibilities in all phases of the decision-making process and should thus include the evaluation of time trends in resource outcome by the fishermen as well as the authorities.

In this study an attempt is made to explain why more balanced capacities in the perception of trends and step trends by authorities and fishermen is a pre-condition for co-management of fisheries (Chapter 2), how we could systematize our thinking about this capacity and how to compare such capacities quantitatively (Chapter 3). Subsequently, which variabilities in catches are experienced at various time scales are assessed (Chapters 4, 5 and 6) and how the resultant trends are perceived (Chapter 6), why the trend perceptions of fishermen and authorities differ and how the situation can be improved, in the context of co-management situations (Chapter 7), how variabilities experienced in agriculture compare to those in fisheries and affect the perception of trends and step trends in agricultural production (Chapter 8), and how, in the 17th and 18th centuries, the perception of a downward trend in a whale stock, now extinct, could have been obscured for both whalers and administrators (Chapter 9). The study ends with an examination of the dilemmas for management resulting from poor and disparate perceptions of trends and step trends in resource outcome by resource users and, sometimes, also by the authorities, and with recommendations on what action to take to improve on the situation (Chapter 10).

Chapter 2

Co-management and the perception of time trends

In this chapter:

1. Conditions for fisheries co-management are listed, amongst which is the possibility for fishermen and authorities to develop a clear perception of developments in resource outcome. **2.1**
2. Fisheries management is described as a continuous decision-making process for which information is always required on total catches and catch rates, and with uncertainties in this information with which fisheries managers will always have to deal, as well as with the risks involved when it comes to taking regulatory measures. **2.2**
3. The environmental perception of resource users, as based on a sequence of experience, categorisation and judgement, is discussed as are the ways in which system complexity affects the perception of causal relations between human activities and future resource outcome. **2.3**
4. The willingness of fishermen to support management measures as a change of rules is related to their capacity to perceive long-term trends in the fishery and the fish stocks over time. **2.4**
5. The position of the individual fisherman in an information network about the fishery is sketched, as is the information he acquires through his own fishery. **2.5**
6. The capacity of individual fishermen and of authorities to perceive long-term trends is related to the character of the resource, to the mode of resource exploitation and to the administrative position of the fishermen and of the authorities as partners in fisheries co-management. Finally, three major questions are formulated and the approach taken in answering them is briefly outlined **2.6**

2.1 Conditions for co-managing fisheries

Co-management by authorities and fishermen is increasingly considered the major answer to today's problems in fisheries management. Sharing management responsibilities with, and delegating responsibilities to, fishermen would be an efficient way for the authorities to tackle problems such as the costly monitoring of the fishery and the fish stocks, the inflexibility of centralised management in reacting to (eco)system changes and the costly and tiring enforcement of management measures. These problems are particularly large in more dispersed, small-scale fisheries in developing countries. Co-management and co- and community-based management even, where fishermen have full responsibility, is therefore frequently propagated now in tropical fisheries (Bailey & Zerner 1992, Siar *et al.* 1992, Ruddle 1993, Nikijuluw & Naamin 1994, Pomeroy 1994, Ali 1996, Machena & Kwaramba 1997, Mahon 1997, Pomeroy & Carlos 1997, Morris *et al.* 1995). Co-management ideas also accord well with the perceived need for decentralisation in the management of temperate zone fisheries (Jentoft 1989, 1994, Scott 1993, Pinkerton 1994, Jentoft & McCay 1995, Sen & Raakjær Nielsen 1996, Smit 1996).

It is the way in which the decision-making process is organised that distinguishes co-management from centralised management of fisheries. In co-management a share of the management responsibilities, for monitoring, evaluation and enforcement, is assigned to individual fishermen, their communities or their organisations (Fig. 2.1). This share, is, however, not the same at every step in the decision-making process. Fishery authorities will be more inclined to delegate responsibilities for the enforcement of restrictions on fishing effort, than to give fishermen equal responsibility for evaluating the state of the stocks (Phillipson 1996). The science-based perception of the authorities, concerning the state of the stocks, is generally assumed to be far superior to that of the fishermen.

There are, however, two reasons why the perception and judgement of fishermen regarding the state of the fishery and the fish stocks should also be considered of relevance. First, local situations may be data-poor, in that the official Catch and Effort Data Recording System (CEDRS) does not cover the local resource area properly, or when the CEDRS does not produce data which have the temporal and spatial resolution necessary for the management of a local fishery. Here, experiences of the fishermen and their possible data gathering could help (Ticheler *et al.* 1998, Neis *et al.* 1999). Second, evaluation of catch data by authorities ánd fishermen together, could make the authorities understand how the perceptions of the fishermen of the state of the stocks are shaped. Such understanding is most advantageous in discussions and joint decision-making by both authorities ánd fishermen of what measures to take in co-managing a fishery.

Most publications on co- or community-based management propagate the idea in a normative context. Few, if any, offer a methodology with which to assess the potential for these types of management in each particular situation. This potential will vary with the characteristics of the fish stocks, the fishery and the social structure and functioning of the fishing communities. How can these characteristics be identified, how to scale them, and how can they be used to assess the potentials and constraints for fisheries co-management?

Fig. 2.1 Progressive stages of co-management between centralised and community-based management, with an increasing share of management responsibilities assigned to the fishermen (adapted from Sen & Raakjær Nielsen 1996).

Theory building for co-management has so far concentrated mainly on institutional and organisational aspects (Raakjær Nielsen *et al.* 1996, Sverdrup-Jensen & Raakjaer Nielsen 1998, Hønneland 1999, Barticados & Agbayani 2000, Jentoft 2000, Karlsen 2001). In their proposal for a research framework for co-management situations Raakjaer Nielsen *et al.* (1996, p. 7) phrase the purpose of such a framework as: " ... to describe and characterise the key factors which influence the institutional and organisational aspects of fisheries co-management arrangements appropriate for different situations." The outcome of such an exercise would, according to these authors, enable:

- The identification of the existing property rights system, to determine who defines rights to explore the resource, who has access and are rights transferable?
- The assessment of the scale and level of user group involvement to determine ways in which user groups do or can participate.
- The assessment of the nature of representation of user groups in the decision-making process. Who are legitimate participants and who can claim rights?
- The assessment of the type of management organisation to determine the type of co-management arrangement most appropriate for a particular fishery.

These institutional and organisational arrangements should ensure the sustainability of the fisheries co-management via stewardship and resilience in the community of fishermen (Hanna 1995, Raakjær Nielsen *et al.* 1996). Stewardship is the capacity of the resource users to maintain the productivity and ecological characteristics of the resource. It encompasses the capacity to expand time horizons beyond the short-term, monitoring of the effects of management and, where necessary, the enforcement of measures taken. Resilience is then the ability to deal with changes and shocks in the fishery via flexibility of rules, structural adaptation and market adaptation. It is stated here that stewardship, in expanding time horizons and in monitoring management effects, requires a clear perception of developments in the fishery and in the fish stocks. In fact, both stewardship ànd resilience warrant such perception, with stewardship requiring the capability to take a longer view.

It is precisely the perception of developments in the fishery and the fish stocks, and the capacity of both authorities ànd of fishermen to develop such perceptions, that are the themes of the present study. It is considered a major condition even, for co-management to succeed, that fishermen and authorities agree, or at least communicate effectively, on how they perceive the historical developments in total catches and catch rates. It is their common ground for discussion, for evaluation, for negotiation and for ultimate decision-making. The perception of time trends in resource outcome is also the starting point in the following elaboration of conditions for fisheries co-management, which centre around the need, availability and use of information on the resource:

1. All those involved in the decision-making should be able to develop a clear and possibly similar perception of the developments in the fishery and the fish stocks.
2. They should agree, where it exists, on a causal relationship between the outcome of the fishery and human activities, mostly fishing pressure, as distinct from natural factors which also affect the outcome of fisheries.
3. They should be able to identify and agree upon feasible and effective measures to take so as to enhance the fishery.
4. They should apply a systematic evaluation procedure, by which fishermen and authorities assess the efficiency of management measures taken and adjust them, where and when necessary.

2.2 Information requirements, uncertainties and risks

As with every type of resource management, fisheries management is also a continuous decision-making process with information requirements and use, with the handling of uncertainties therein and with risks associated with any decisions taken (de la Mare 1998). The organisation of this decision-making process may differ with each situation but its basic structure, however, is always and everywhere the same (van Densen 1990, Fig. 2.2). The decision-making centres around the regular evaluation of a clearly defined, quantitative management objective. This management objective is formulated as either a target reference point – e.g. so many kilograms per ha annual yield from a reservoir - or a limit reference point – e.g. no smaller spawning stock biomass than so many tonnes, set as a lower limit (FAO 1993, Caddy & Mahon 1995). Regular evaluation of the whether management objectives are reached requires the supply of proper information, first and foremost on the performance of the fishery: information on developments in catch and effort. The outcome of the evaluation is that either the fishery continues as it was, or that measures will be taken to meet the objectives after all. Whether these measures, such as effort restrictions or mesh size enlargements, are effective must be evident from a change in catch rates and with that from evaluations in the years to come.

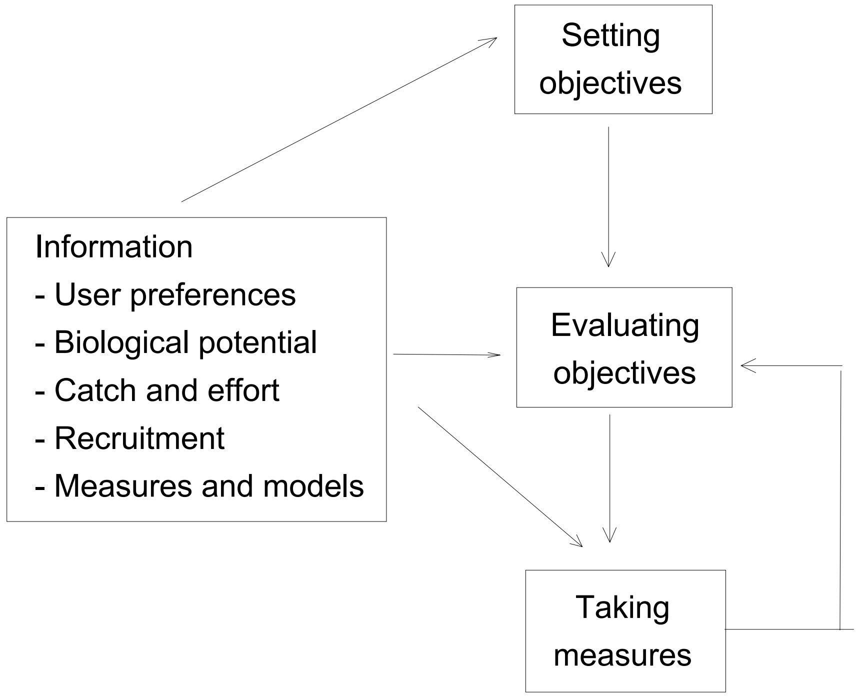


Fig. 2.2 Structure of fisheries management as a decision -making process with types of information needed.

Information is needed at every step in the decision-making process: for setting objectives, for evaluating objectives and for selecting and taking management measures. First, for setting quantified management objectives, the fishermen's preferences for fish species and sizes must be combined with realistic expectations of catch levels from the stocks to be exploited. To quantify these expectations, information is required on ecosystem productivity or on catch rates as gained over the years for that particular, or for biologically comparable, water bodies.

Second, as already stated, the kind and detail of information needed for the evaluation procedure are dictated by the objectives set, but catch and effort data are indispensable. Catch rate or Catch per Unit Effort (CpUE) as a ratio of output over input - e.g. kg fish caught per 1 night fishing with 1000 meter of gillnet - is both an indicator of the technical efficiency of the fishery and a sample indicator for developments in the biomass of the fish stock (see Box 2.1). Each time series of total catch or of Catch per Unit Effort contains a degree of uncertainty, that arises from inter-annual variability in the size of the exploited stock. This variability is often attributed to strong variability in the annual recruitment of younger age groups to these stocks. Where appropriate and affordable, catch and effort data are therefore combined with information obtained from fishery-independent surveys of recruitment or young-fish. These recruitment surveys function as early warning systems for changes in the annual catch in the years to come.

Third, in order to select a particular management measure, information is needed on the expected effectiveness and feasibility of all theoretically possible management measures. Simulation modelling could help here in predicting the probable outcome of a fishery in response to any measures taken. Types of measures vary widely: from effort and gear restrictions in space and time, to quotas for professional and bag limits for sport fisheries, to habitat protection and manipulation, and to species introductions and stocking in inland waters. The pros and cons of the various measures are best weighed and compared in a 'menu' of optional measures. A major constraint in deciding on a regulatory measure is the temporary, but inevitable, drop in the catch as a consequence of either enlarging the mesh size (reduction in total catch ànd catch rates) or reducing fishing effort (reduction in total catch). Information on the extent of such a drop, of its duration, and of the duration of the period required to 'earn back the loss', can be obtained via simulation modelling, when all population and fishery parameters are available (Buijse *et al*. 1992, Pet *et al*. 1996, Mous 2000).

Whether the effectiveness of a regulatory measure can be easily demonstrated to both the authorities and fishermen co-managing a fishery, depends greatly on the type of fishery and on the selection of a performance parameter. Some fisheries have more variable outcomes than others, and the effectiveness of a regulatory measure is less easily visible in such cases. Furthermore, communication is far easier in the case of performance parameters such as catch rate, because of the relevant experience of the fishermen, than about minimum spawning stock biomass or fishing mortality rate. The latter two are performance parameters with their own limit reference points in the management of North Sea fisheries. Thus information on developments in performance parameters which are more obvious to the resource users facilitate communication.

Before elaborating further on the role of information in fisheries management, it is important to distinguish clearly between information as such, and data and knowledge. Data, information and knowledge are part of a continuum for which Davenport (1997) gave definitions that apply equally to their use in fisheries (Table 2.1). Data are only "observations of states of the world", as for example a series of daily catches recorded by a fisheries officer. Data are relatively easy to capture, communicate and store. Information is "data endowed with relevance and purpose" by humans who can choose any form of presentation of the data, normally in response to clearly defined information requirements. A bar diagram with annual catches with a reference level indicated as well, invites a first, quick evaluation of developments in resource outcome over the years. We talk about knowledge when somebody has given the information a context and has reflected on it, when people have added their own wisdom to it, and have considered its wider implications. Thus, continuous interpretation of bar diagrams with annual catches from a lake, and the comparing of these diagrams with those made for similar lakes and for which conclusions were drawn earlier, leads to a growing body of knowledge. Obviously, the amount of human involvement increases when moving along the continuum of data - information - knowledge.

Table 2.1 Characteristics of data, information and knowledge (from Davenport 1997, his Table 1.1)

Data	Information	Knowledge
Simple observations of states of the world ▪ Easily structured ▪ Easily captured on machines ▪ Often quantified ▪ Easily transferred	Data endowed with relevance and purpose ▪ Requires unit of analysis ▪ Need consensus on meaning ▪ Human mediation necessary	Valuable information from the human mind, includes reflection, synthesis, context ▪ Hard to structure ▪ Difficult to capture on machines ▪ Often tacit ▪ Hard to transfer

As explained above, for any decision to be made information is required. At these moments, the ideal decision maker (*Homo economicus*) would (de Leeuw 1982):

- Know what he wants;
- Overview all possible actions;
- Have unlimited capability for processing information;
- Be completely informed about the causal relationships between possible management actions and their outcome.

In fisheries management, however, the ideal decision maker, thus defined, is far away. First, the objectives of fisheries management are not always (clearly) defined in quantitative terms, which would prepare the ground for systematic evaluation. Second, without complete information on how the fishery operates, not all possible management actions are can be surveyed. Third, not all the information needed is that easy to collect and process, amongst other reasons because of the limited capacity of an administration to record collect and process fisheries data of high temporal and spatial resolution into an informative and condensed format, ready for evaluation and decision-making (Mahon 1997). Fourth and last, the effectiveness of management actions is not easily predictable from strict causal relationships between measures and future catch rates. There are many uncertainties attached to such causal relationships, as well as to present and future catch rates, due to time lags in the response of catch rates to measures taken and due to sometimes high inter-annual variability. Even when the predictability of resource outcome in response to measures taken could be increased, using more and detailed information, the costs of adequate data acquisition and its processing are sometimes considered too high. Managers must then be satisfied with a situation of 'bounded rationality'.

Fisheries managers as decision-makers have to deal with various types of uncertainty when planning for the future (Hilborn 1987, Caddy & Mahon 1995, Francis & Shotton 1997). A generally accepted definition of uncertainty in a fisheries context is "The incompleteness of knowledge about state or processes (past, present and future) of nature" (FAO 1995). The six types of uncertainty one could come across in fisheries management are those associated with processes, observations, models, estimations, implementations and institutions (Francis & Shotton 1997). Process or system uncertainty is not controllable and arises from natural variability. The commonly given example in fisheries science is the generally large variability in annual recruitment. Observation uncertainty arises in the process of data collection, through measurement and sampling error, and is controllable to some extent. It will be obvious that sampling parts of the fishing fleet for an estimate of the average daily catch per fishing unit inevitably leads to sampling errors. So, system uncertainty induced by variation in annual recruitment is irreducible, but observation uncertainty in annual recruitment could be reduced by enlarging sample sizes in, in that case also more costly, recruitment surveys.

Model uncertainty then refers to the lack of information on the correct structure of a population model and on parameter values used in the model. One such highly uncertain parameter is the natural mortality of the youngest age groups of fish. Estimation uncertainty relates to the process of parameter estimation, which derives from the above mentioned system, observation and model uncertainties. Implementation uncertainty is uncertainty about the extent to which management policies will be successfully implemented, for instance because of enforcement problems for measures taken. Finally, there is institutional uncertainty arising from the interactions between individuals and groups that participate in the management process.

As stated in the above definition of uncertainty, it is the incompleteness of knowledge about the state or process of nature, which causes uncertainty. It is not the complete absence of such knowledge, because in most cases we are capable of capturing uncertainty within the boundaries of a probability distribution. As an example, consider a probability distribution for the size of next day’s or next year’s catch. Such probability distributions have a median value and a percentage range within which 50 or 95% of catches will fall. From these probability distributions, risk can be derived as the percentage probability that the future catch is below a certain threshold value. In fisheries, risk is defined as "the probability of something undesirable happening", thus combining probability with severity of the event (FAO 1995).

In a situation where fisheries scientists have a distinct role to play, in addition to authorities and fishermen in the management of a fishery, they are the ones who generate the information used for assessing uncertainties and risks. The criteria for these risks, however, should first be formulated by the fisheries managers, the actual risk managers (Francis & Shotton 1997). The role separation between scientists as those assessing, and authorities as those managing, risks hardly exists in small-scale fisheries for which separate research activities are hardly affordable. Local fishery authorities then combine the role of information gatherers and of decision-makers in managing these fisheries under uncertainty, and in formulating and taking risks. These roles become even more combined and mixed in co-management situations, where local authorities ánd fishermen share management responsibilities and decide together what risks to take.

In conclusion, fisheries management, and thus fisheries co-management too, implies decision-making on setting objectives, on evaluating these objectives and on taking measures, using sometimes highly imperfect information and thus taking a certain amount of risk.

2.3 Perceptions and the problem of imperfect knowledge of causal relationships

The perception of any time trend in the outcome of a fishery will be affected by the information contained in the time series and by the skill of the observer in evaluating such a series. Therefore the perception of time trends may differ between fishermen and authorities because these two groups differ in the information they have available and in their skill at processing such information which is endowed with uncertainties. This, in turn, will bear on the alertness of both to the conclusion that annual catches are falling and that regulatory action should be taken. The same holds for their capacity to detect the step trend in catch rates expected after such measures have been taken.

It is hard to give an unequivocal definition of perception. The various meanings of this word seem to fall into two categories: perception through the senses only, and perception in the wider context of observation and successive evaluation, interpretation and appreciation of all information captured (Table 2.2). Perception of time trends in resource outcome is taken here as the personal evaluation of all information on resource outcome captured over time. As some fishermen only have their mental memory with which to store such information, it will be remembered and used selectively. Further, the context in which the information is evaluated may change continuously, ensuring that the perceptions are also subject to change, irrespective of the amount and quality of the information.

Table 2.2 Meanings of perception in three dictionaries. 1. Cambridge International Dictionary of English. Cambridge University Press, 2. Longman Dictionary of Contemporary English. Longman Dictionaries, 1995, 3. Chambers 21st Century Dictionary. Chambers, 1996.

	Through senses	Wider context
1	• An awareness of things through the physical senses	• A person's perception is their ability to notice and understand things that are not obvious to other people.
2	• The way you notice things with your senses	• The way you regard something and your beliefs about what it is like. • The natural ability to understand or notice something quickly.
3	• The process whereby information about one's environment, received by the senses, is organised and interpreted so that it becomes meaningful. • Response to a stimulus.	• One's powers of observation, discernment, insight. • One's view or interpretation of something.

Environmental perception and judgement of the current condition of a resource by resource users themselves is rarely the subject of investigation nowadays (Pálsson 1998). Recent efforts to systematise and value such perceptions (Nazarea *et al*. 1998) are critically approached (Marlor *et al*. 1999). Remarkably enough, environmental perception, so under-exposed now, was a focus for environmental studies in the 1970s (UNESCO Man and Biosphere Programme, Whyte 1977). At that time it was stressed that to increase the efficiency of local resource management, the perceptions of the resource users need to be taken explicitly into consideration, along with those of experts or officials. In that context, environmental perception was used to mean human awareness and understanding of the environment in a general sense. Whyte mentioned that many natural resource scientists involved in the UNESCO MAB-Programme, were unfamiliar with the possibilities for systematic observations in the field of subjective perceptions. It seems, they still are today. Whyte summarised the role of environmental perception research as:

- Contributing to the more rational use of resources by harmonising local knowledge and that available from outside;
- Increasing understanding on all sides of the rational bases for different perceptions of the environment;
- Encouraging local involvement in development and planning;
- Preserving or recording the rich environmental perceptions that are rapidly being lost in many rural areas;
- Acting as an educational tool and agent of change as well as providing a training opportunity for those involved in the research.

It appears as if these contributions, formulated in the 1970s, refer to the same type of resource management propagated so many years later as co-management, but that in the 1970s the perception of resource dynamics was given more thorough attention.

In his general model for environmental perception Whyte (1977) distinguished a number of state variables, which are projected along two dimensions (Fig. 2.3): distance from the point of decision-making, and the societal scale of decision-making. The distance from the point of decision-making decreases from right to left where perception begins with the 'experience' of the resource user. The societal scale of decision-making increases from bottom to top, from the individual resource user making decisions on behalf of himself or his household, to the collective resource manager acting on behalf of many others. In this conceptual framework 'Experience', 'categorisation' and 'judgement' are three distinct stages in environmental perception, which prepare for ultimate decisions and choices.

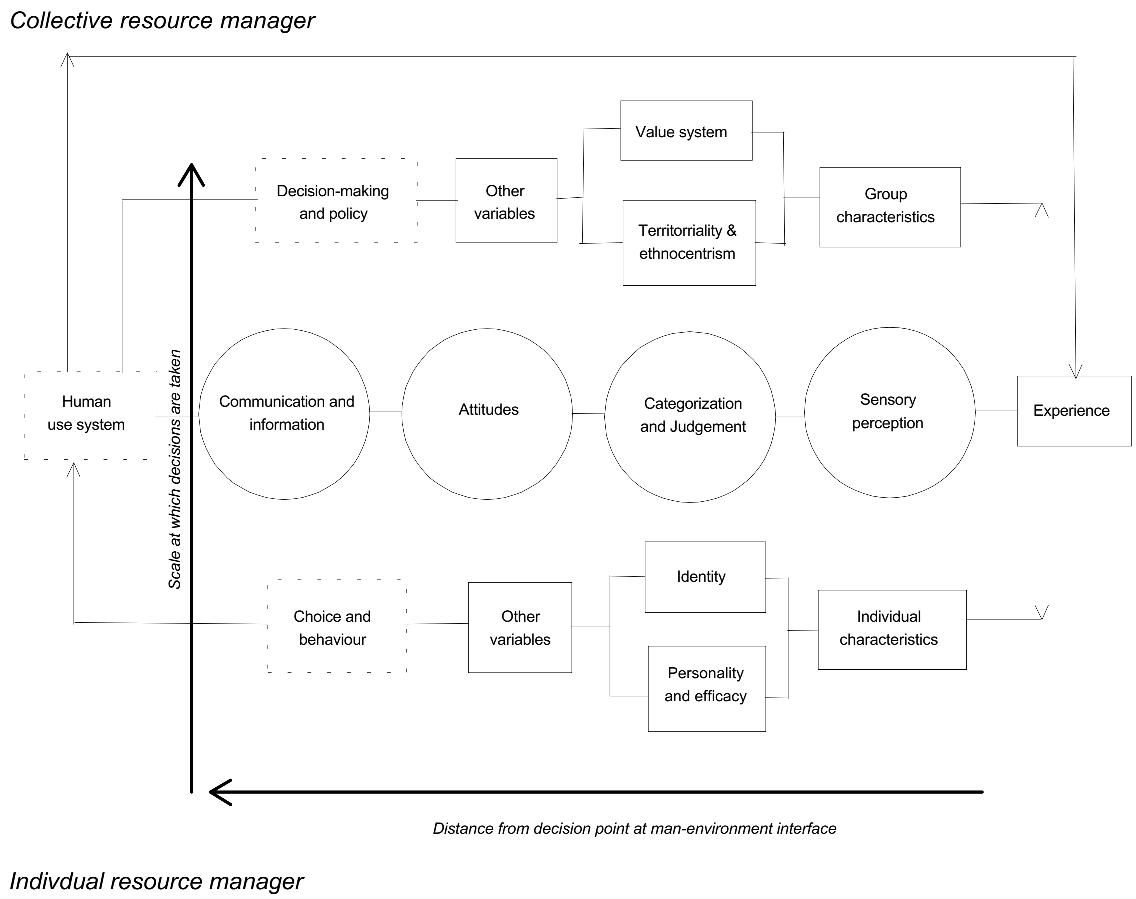


Fig. 2.3 Model of environmental perception with two dimensions (from Whyte 1977).

First, 'experience' is gained through time and becomes part of the attributes of an individual and of social groups, sometimes learned from each other's experience through communication. Although experience with variation in resource outcome is gained through time, time itself is experienced differently by separate cultures and individuals. Cultures and societies are known to differ in their perception of time duration, simultaneity and rhythm of time, and of time horizons (Whyte 1977). Perpendicular to this cultural or societal dimension, there is also a historical dimension in the growing capacity to perceive trends from time series data within each society (Tufte 1983, Klein 1997).

Second, 'categorisation' is the means by which diverse phenomena are arranged in some order. As Whyte put it, by creating classes, which are meaningful to the individual or group, categorisation enables the linkage of separately known objects or events and the assimilation and classification of new phenomena. So categorisation is a cognitive process. Fishermen categorise their catches by type, size and value of fish, and sometimes their categorisation turns out to be more subtle than the scientifically-based species distinction. Fishermen from Lake Tana, Ethiopia, for example, distinguish various classes in their catch of what, with scientifically-based taxonomy, was categorised as one species of barbel, *Barbus intermedius intermedius* Rüppel, 1836 (Banister 1973). These Ethiopian fishermen categorised the fish on the basis of their external morphology (Wudneh 1998). These morphological features were later used for distinctions within what turned out to be a complete species assemblage of these barbels (Nagelkerke 1997).

More difficult to categorise than groups in the catch, are the spatial and temporal patterns in the size of the catch; how much more productive is the inshore zone than the open water, or how much higher are catch rates in the rainy season than in the dry season? Most studies of environmental perception deal with spatial rather than with temporal patterns. Taking it in a wider cultural context, people seem to be more fascinated by spatial patterns in the landscape (Forman 1995, Schama 1995, Levin 1999) than by patterns in the outcome of resources over time (Klein 1997). Probably the most difficult to categorise, much more difficult than recurring patterns such as seasonality, are trends and uncertainties in the size of the catch as experienced over the years; how uncertain is tomorrow's catch, or how fast did catch rates fall over the last decade?

Third, 'judgements', in terms of evaluations, are values assigned to the outcome of the categorisation. These judgements can be formally and informally expressed as words or numbers in terms of probability, utility, cost-benefit analysis and risk assessment (Whyte 1977). In the management of natural resources with sometimes large uncertainty in their outcome, judgements of probability - how likely something is to occur - are as important as judgements of utility or cost-benefit. For example, take the categorisation of a series of daily catches by weight, into a catch frequency distribution. The coefficient of variation (standard deviation over the mean) of daily catches, as a measure for their variability, can be valued as either 'high' or 'low' depending on the subjective criterion used to distinguish between the two. For the perception of time trends the same triad of 'experience', 'categorisation' and 'judgement' can be applied. Also, the size of a downward trend has a certain probability distribution, from which it can be concluded whether the trend exists at all or is steeper than a given trend size, combining a statistical criterion with the probability distribution.

What is not articulated in the perception model of Whyte is the insight of resource users into the functioning of natural processes and into the causal relationships between present intensity of resource use (fishing effort) and future resource output (catch rate). If such a causal relationship is strong and is clearly perceived, it would pave the way for a greater willingness of fishermen to reduce fishing effort so as to rebuild an over-exploited fish stock. We have only a vague notion, so far, how close the knowledge of resource users, their 'local knowledge', comes to the scientific understanding of how resource dynamics is affected by environmental variability as distinct from exploitation pressure. Without this understanding it is hard to develop a long-term view on the use and management of the resource.

System complexity hinders the development of insight into causal relationships and thus of a long-term view in resource management. Some (Balland & Platteau 1996) take it that system complexity is the cause of many situations in which resource users ànd authorities are both ill-informed about resource dynamics. According to Balland & Plateau, both resource users and authorities have imperfect knowledge and are seldom fully aware of the ecological processes at work. Unfortunately for the many developing countries, as Balland & Plateau say, the environmental complexity of tropical ecosystems is usually much greater than that of temperate zone ecosystems. This is certainly true for tropical fisheries, where system complexity is primarily due to the generally large number of interacting species and the more continuous recruitment of juveniles to the exploited stock. Continuous recruitment hampers the use of the more simple age-structured yield models as developed in fisheries science for temperate zone ecosystems, where fish populations are clearly age-structured due to the shortness of the annual spawning period.

Notwithstanding system complexity, resource users will always develop ‘local knowledge’ of the character of their resource through their long-term experience with its exploitation. But Balland & Plateau (1996) question the 'romantic view' according to which resource users are perfectly informed about their resources, simply because of proximity. As they state, it cannot be inferred, from the fact that in many village communities rules exist for regulating access to the resource in an equitable way, that these communities are also able to devise rules for the management of the resource in the long-term. Fishermen generally have a fair knowledge of the spatial patterns in abundance and availability, but there seems to be little local knowledge of fish population dynamics (Sverdrup Jensen & Raakjar Nielsen 1998). Where understanding of population dynamics by resource users, which involves abstract concepts and causal reasoning, is inadequate, Balland & Plateau suggest that education could improve local resource management. Resource users may need help anyway to draw together a number of field observations, and to organise these observations into meaningful causal sequences. Such assistance seems to be especially needed where natural resources are not localised, not easily visible, and are rather unpredictable, as is the case with many fishery resources.

Even in those communities where the impact of exploitation on future resource outcome is recognised, one may have to reckon that there is still genuine uncertainty around this causal relationship (Balland & Plateau 1996). Exogenous factors, such as large-scale ecosystem changes due to alterations in water currents and temperature, which are beyond man's control but which affect resource dynamics, could even be responsible for accelerated resource depletion. The developments in the herring fishery in the North Sea in the 1960s and 1970s is a clear example of how difficult the distinction between these natural and man-induced changes can be (Corten 1990). Due to such difficulty and uncertainty resource users may exploit their resources without becoming too preoccupied with the ecological consequences of their own harvesting behaviour. According to Balland & Plateau the state may be justified, in these situations, in laying down strict rules to insure against the risk of irreversible degradation of the resource. This could be interpreted as that Balland & Plateau (1996) take for granted the superiority of the authorities in rationalising and managing the exploitation of resources with highly variable outcomes. It would also imply that co-management is less attractive for the management of resources with such highly variable outcomes.

In conclusion, the perception of recurring temporal, and certainly of spatial, patterns in resource outcome, for which Whyte (1977) developed a conceptual model, is relatively more easy to study than the perception of long-term trends in resource outcome. This holds even more for the perception of causal relationships between resource outcome and exploitation pressure. These perceptions are constrained by system complexity, which could be overwhelmingly great as in many species-diverse tropical fisheries.

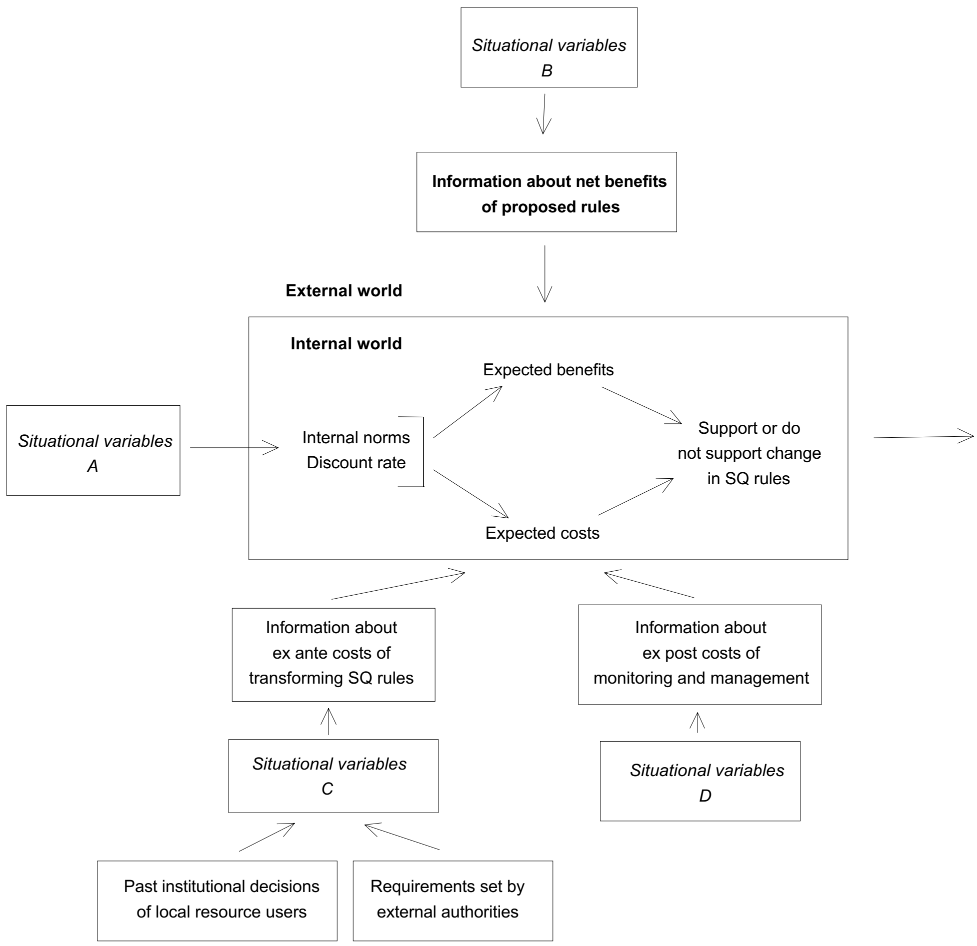
2.4 Perception of trends and the support for a change of rules

Poor perception of time trends in the aquatic resource and of causal relationships between present day fishing effort and future catch levels, reduces the willingness of fishermen to support management measures such as a change in the rules. In such a situation it is difficult for them to believe that management measures might work and be demonstrably effective. Poor perception of the sate of the resource, and imperfect knowledge, interfere with their balancing of the pros and cons of a change in the rules for operating their fishery. Ostrom (1990) pays particular attention to this balancing, in her conceptual framework for institutional arrangements in the use and exploitation of Common Property Resources (CPRs), such as ground water, forests and also fish stocks.

Resource users, according to Ostrom, have their internal and their external worlds (Fig. 2.4). In their internal world they balance the pros and cons of a change of rules in resource exploitation, based on their internal norms and discount rates. Thus, in the internal world they balance expected benefits and costs. In an internal world with strong norms against opportunistic behaviour, resource users are less wary about the dangers of possible opportunistic exploitation of the resource by others, but some with high discount rates and little mutual trust, will act more independently and are not likely to join strategies beneficial to the community ('Free riders'). For example, discount rates of trap fishermen are therefore expected to be lower than those of trawl fishermen, because the more sedentary trap fishermen discount the future benefits from their resource more than mobile trawl fishermen will do.

The balancing of pros and cons in the internal world is, according to Ostrom (1990), influenced by four categories of so-called situational variables in their outer world. The first of these (A), amongst which the proximity of the resource (A1), directly affects the internal norms and discount rates in the internal world. The second category (B), amongst which information on temporal and spatial variability of resources and their current condition (B3, B4), affects the judgement of 'benefits' expected by the resource users before the implementation of management measures. This category (B) is the most relevant here, because such judgements are much influenced by the perception of the current condition of the resource and the variability therein. The situational variables in categories (C) and (D) affect the judgement of 'costs', as expected by the resource users. Monitoring, as meant under (D), refers to the monitoring of each other's activities, which monitoring is associated with the sanctioning of activities, and is not biological monitoring or monitoring of resource outcome. Shared norms that reduce the cost of monitoring and sanctioning activities is sometimes viewed as a kind of social capital, which local communities can utilise in solving their management problems.

Through the application of the concept of internal and external worlds in analysing the management of various common property resources Ostrom (1990) came up with community characteristics which favour the adoption of a change of rules. For that purpose she referred to a theoretical situation that comes close to community-based management. The likelihood that local resource users will adopt changes in operational rules to improve their joint welfare, would be higher when:



A. Situational variables affecting internal norms and discount rate
1. Resource users live near the resource
2. Resource users involved in many situations together
3. Information made available to resource users about opportunities to exist elsewhere

B. Situational variables affecting judgement about the benefits of an institutional choice
1. Number of resource users
2. Size of the resource
3. Temporal and spatial variability of resource units
4. Current condition of the resource
5. Market conditions for resource units
6. Amount and type of conflict
7. Availability of data about (1) through (6)
8. Status quo rules in use
9. Proposed rules

C. Situational variables affecting judgement about the costs of transforming status quo rules
1. Number of decision makers
2. Heterogeneity of interests
3. Rules in use for changing rules
4. Skills and assets of leaders
5. Proposed rule
6. Past strategies of resource users
7. Autonomy to change rules

D. Situational variables affecting judgements about monitoring and enforcement costs
1. Size and structure of the resource
2. Exclusion technology
3. Resource use technology
4. Marketing arrangement
5. Proposed rules
6. Legitimacy of rules in use

Fig. 2.4 The internal and external worlds of a Common Property Resource situation with the position of the situational variables A, B, C, D in the external world, which affect the internal norms and discount rate (A) and the judgement about benefits (B) and costs (C, D) in the internal world (Composed from Figs 6.2 to 6.5 in Ostrom 1990). SQ = status quo.

1. They share a common judgement that they will be harmed if they do not adopt an alternative rule;
2. They will be affected in similar ways by the proposed rule changes;
3. They value highly the continuation of activities related to the resource, so have low discount rates;
4. They face relatively low information, transformation, and enforcement costs;
5. They generalise norms of reciprocity and trust that can be used as initial social capital;
6. The group exploiting the resource is relatively small and stable.

The common judgement, the first characteristic, will be based on the individual expectations, by resource users, of future developments in the stock, extrapolating from developments in the resource, or in resource outcome experienced so far. Resource users will therefore support management measures, and so adopt new rules restricting their resource use, when there are clear indications of resource degradation, or when their leaders are able to convince them that a "crisis" is impending (Ostrom 1990). But, once again, how well do local resource users, fishermen in particular, perceive downward trends in their resources? How well informed about their resource are fishermen anyway, not only by their experience with their own fishery, but also by assimilating information from their fellow fishermen in the community, and from all other possible sources? Maybe the best way in which to stress that there is a gap in the literature, on co-management with respect to the handling of information on the resource itself, is to cite Holm *et al.* (2000, p. 362, italics by the authors): "Moreover, co-management, while presented as an alternative model for fisheries *resource* management, tends to include the management of almost anything but the resource itself – be it space, conflicts, or fish markets".

2.5 Fishermen in an information network

To assess how information captured from various sources builds the fisherman's perception of possible trends in resource outcome, one needs to first characterise the position of the individual fisherman in an information network (Fig. 2.5). His primary source of information is the outcome of his own fishery in terms of catch per unit of effort, and in terms of the species and size composition of that catch (experience). His second source of information is his bycatch, containing both under-sized and non-target fish. The bycatch of under-sized juveniles of target species, for instance, functions as an early warning system for future developments in the stocks of these target species. His third source of information comprises the signals on environmental quality that a fisherman receives from the ecospace in which he operates, such as changes in water transparency, vegetation cover, presence of birds etc. (Pyrovetsi & Daoutopoulos 1990, Goudswaard & Wanink 1993). His fourth source of information is his communication with fellow fishermen with whom he shares experiences of catching success and environmental changes in the resource area. His fifth and last source of information is the array of institutions such as the local or national administration, the research institutes, the press and the fishermen's organisations, all of which report in one way or another on the performance of the fishing fleet as a whole.

So fishermen capture information from many sources. A full analysis of how individual perceptions of developments in the fish stocks and the fishery are shaped, would require an in-depth survey, including the assessment of sometimes complex and diffuse communication patterns. Such full coverage of the topic is not the objective of the present study. The intention here is to assess first, how perceptions of long-term trends by individual fishermen and authorities develop on the basis of their experiences with actual catches (fishermen) or with catch records (authorities) only. Subsequently, it is possible to compare such theoretical perceptions with ultimate or 'true' perceptions, assessed through interviewing fishermen and administrators and through probing their communication channels (Pet-Soede *et al.*. 2000). Theorising on the disparity between theoretical and 'true' perceptions in the light of technical, cognitive and communicative factors could then contribute to a more complete and consistent framework for studying the perception of resource dynamics and outcome.

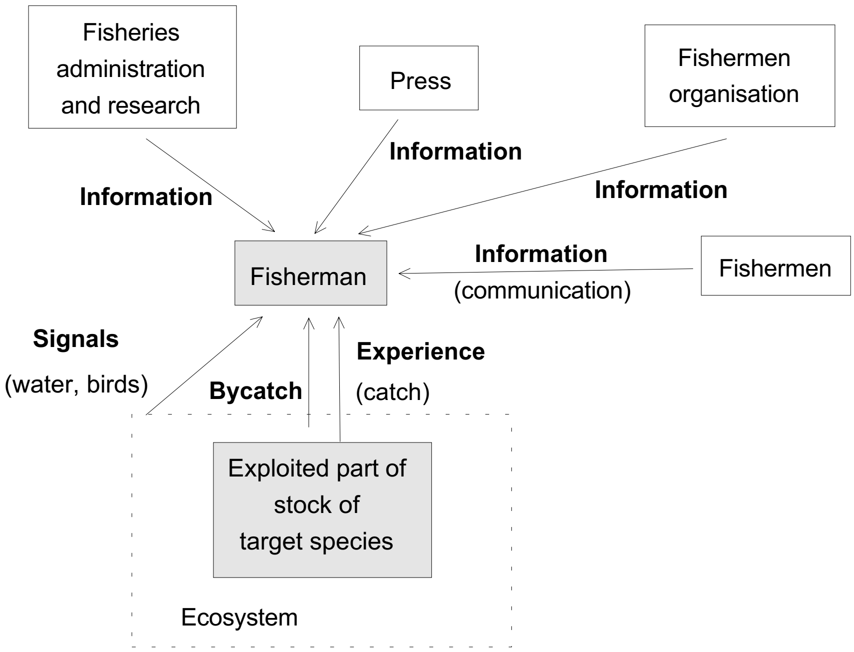


Fig. 2.5 The individual fisherman in the information network. Individual fishermen capture information via: (1) Experience with individual or aggregated catches of target species, (2) Their bycatch of juveniles of target species, non-target species and other catch categories, (3) Signals they capture from the environment containing information on the state of the system or the fish stocks, (4) Communication with fellow fishermen and (5) Reporting by governmental agencies, research institutes, the press and fishermen's organisations.

2.6 Theorising on the perception of time trends and three questions

In the context of this study time trends are either trends or step trends in total catches (C) or catch rates (C/f). A trend is a more or less gradual uni-directional change over time with a certain degree of, mostly natural, variability around it. A step trends is a more sudden change from one catch level to the next, but also with variability around it. Large variabilities obscure the perception of true trends or step trends.

Downward trends may occur in both total catches and in catch rates and are mostly the consequence of increasing fishing pressure (Box 2.1). In a developing fishery total catch initially increases, but once fishing effort becomes more than the effort that could produce the maximum sustainable yield, total catches fall. Catch rates always fall with increasing fishing pressure because the total biomass of a fish stock decreases monotonically once exploited. Step trends in total catch or catch rate follow after measures have been taken to rebuild the stock.

'Perception' is defined here as the outcome of an evaluation of developments in the fishery or in the stocks based on the experiences of either individual fishermen or authorities, which evaluation is affected by technical and cognitive factors, and by criteria chosen for categorisation and judgement. The 'experience' of fishermen or authorities is broadly defined as the experience gained by the handling of a succession of individual or aggregated catches, as kgs of fish, or as catch records.

One of the technical factors which affects the perception of time trends is the quality of the memory in which the experience with catches or catch records is stored. These memories can take various forms (mental, written, electronic). The quality of a mental memory is constrained by selective remembrance and its disproportionalities. Everybody tends to selectively remember the more extreme events he has experienced (winters, river floods). Hence, the perception of long-term trends in catch rates will certainly change when fishermen start to keep records of their own catches and use a written memory. Some fishermen practice such recording on their own initiative in search of regularities or trends in the productivity of their enterprise. In large-scale fisheries catch recording has become compulsory, as for instance for fishing units in EU waters of the North Sea. There are as yet no systematic observations on how this compulsory recording of individual catches has possibly influenced the environmental perceptions of these fishermen.

Fishermen who keep records of the outcome of their fishery generally process catch data into tables as being the simplest format. But how helpful is such tabulation of data for the fisherman to perceive possible long-term trends in his fishery? Without systematic evaluation, the data are meaningless. In other words, they do not turn into information. In a study on participatory analysis, monitoring and evaluation for fishing communities (Maine *et al*. 1996) and in a handbook on community-based management of coastal resources (IIRR 1998), suggestions are given for the processing and presentation of fisheries data by fishermen themselves. The very basic and sketchy nature of these suggestions demonstrates that there is still considerable scope for improvement in the skills of fishermen and their organisations in processing catch data and in evaluating information on the performance of their fishery.

In view of this, the capacity of individuals or authorities to perceive long-term trends in the size or in the outcome of a resource is thought to be governed by the biological characteristics of the resource, by the technical mode of its exploitation, and by the capacity of the observer, for trend perception which is related to his administrative position:

- *Resource character*. Long-term trends in resources with a more variable outcome will be more difficult to perceive. Fishermen experience variability in catch rates at various time scales, from day to day, form month to month and from year to year. The variability in the catch from day to day will be more random, and mainly due to the behaviour of individual fish, or schools of fish, at the smaller spatial scale of the fisherman's resource space. This day to day variability will differ between fish species and ecosystems. Besides the random variability in the catch from day to day, there is more predictable variability due to the periodicity in catch rates as related to tides, lunar cycles and seasons. This periodicity is a characteristic of the resource or system as well. Periodicity enlarges the total variance in catch rates that a fisherman experiences during a full year fishing. Finally, inter-annual variability, mainly due to changes in stock size over the years, will further enlarge the total variability in catch rates as experienced by a fisherman in the largest time window of many years.
- *Mode of exploitation*. Some modes of exploitation lead to higher variability in day to day catches than others. Catches obtained with passive gear, such as traps and gillnets, will vary more because they are more dependant on spatial aggregation and mobility of the fish. The use of active gear, such as trawls, in combination with fish finding devices like sonar, which direct fishing effort towards the more profitable sites, will thus reduce this variability in the catch from day to day. Further, differences between fishermen in size and capacity of their fishing gear, but also in their personal skill, translate into differences in catchability (see Box 2.1) between them, and so into a larger variability in daily catches as recorded by the administration for each fishermen individually.
- *Administrative position of observer.* Fishery authorities more than fishermen, and certainly those higher up in the administration, are expected to perceive long-term trends better because they evaluate series with catch data as aggregated and averaged for the fleet as a whole. These series based on aggregated data are expected to contain less variability because random variability between fishing units is averaged out, and also, these series are generally longer, so probably more informative. However, not all data aggregation leads to more informative data series. The statistical area, or administrative space, for which data are aggregated does not necessarily coincide with the distribution area of a particular fish stock under exploitation (ecological space). Really large administrative spaces will encompass several independently varying stocks per species or catch category. Aggregation in ever larger administrative spaces thus reduces overall variability, but the resultant time series become less meaningful for the management of distinct fish stocks, and with that, the fisheries over which data are merged.

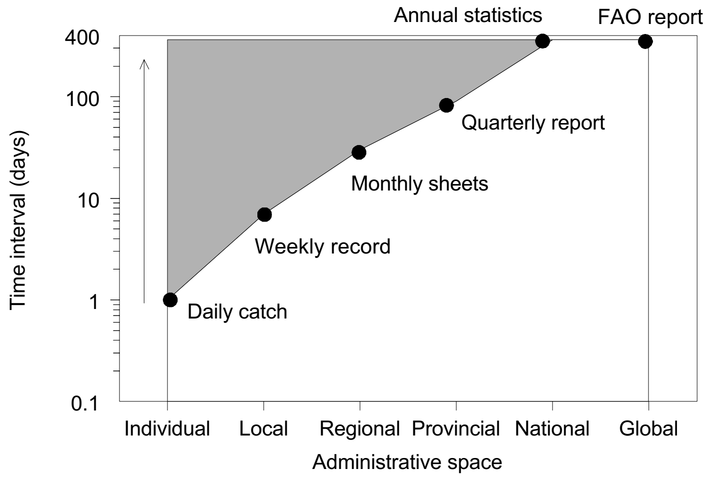


Fig. 2.6 The administrative space-time environment for data aggregation. A fisherman aggregates his catch records over various time intervals for his one and only resource space (arrow). The statistical service system aggregates catch data in increasingly larger administrative spaces and over concomitantly increasingly larger time intervals (line connecting dots). At the same time catches per species are generally accumulated into less and more general categories, ending up with the world annual catch of "fish".

The above reasoning on the perception of time trends in resource outcome leads to the three major questions of this study:

1. *Which trends and step trends are just detectable, given the sometimes high inter-annual variability in resource outcome?*
2. *What are the reasons for the greater capacity of the authorities ('administrative gain'), compared to that of individual fishermen, to perceive true trends and step trends in resource outcome?*
3. *How to improve on the perception of time trends, in co-management situations in particular?*

The approach to answering these questions was to formulate the capacity for trend perception on statistical grounds (Chapter 3), to make an inventory of all variabilities in catch rates experienced in the fishery at different time scales (Chapters 4, 5 and 6), to assess which can be perceived in what time windows, given the range in variabilities (Chapter 6), to examine why perceptions differ between fishermen and authorities, and to discuss how to improve on that situation, on behalf of co-management (Chapter 7). In Chapters 8 and 9 variabilities and trend perceptions in other types of resource use are discussed, before the governmental dilemma that arises from poor and disparate perceptions of resource outcome is discussed and recommendations are formulated (Chapter 10).

Box 2.1 - Catch, Catch per Unit Effort and stock dynamics

Every fisherman aims for the highest efficiency attainable in the performance of his fishery. Efficiency, in bio-technical terms, is indexed with the ratio of output (C, catch) over input (f, fishing effort), known as catch rate or as Catch per Unit of Effort (CpUE = C/f). Catch as output is generally expressed in terms of weight (e.g. kilograms or tonnes of fish, fresh weight), mostly specified per catch category after grading by fish species and size. Fishing effort as input is expressed in units of effort, which are standardised as much as possible in order to monitor developments in CpUE in a meaningful way. Examples of such standardised units of effort are: (a) number of hours trawling with a trawl of specified dimensions and mesh size, (b) nights gillnetting with a gillnet of specified length, depth, ply and mesh size, (c) trials with a purse seine of specified dimensions and mesh size to catch fish at night around a Fish Attracting Device (FAD), outfitted with a lamp, or (d) hours angling with specific tackle and bait by an angler with a certain amount of experience and skill .

When the unit of effort is properly defined, relative changes in biomass of the exploited stock can be followed from changes in CpUE, because per unit of effort a constant proportion (q) of total stock biomass (B) is caught. Biomass (B) is generally expressed in tonnes, for the stock as a whole, or in kg per ha when biomass density needs to be indexed. The proportion q is generally very small. If the unit of effort is 1 day trawling, then the proportion taken by a fleet of 100 trawlers during 1 day is 100*q. So the catchability coefficient relates CpUE to B according to (Fig. B2.1):

$$CpUE=\frac{C}{f}=q\cdot\overline{B}$$

where,
C = catch, in terms of weight per time interval
f = total unit of efforts applied during that time interval,
q = catchability coefficient,
$\overline{B}$ = average biomass, in terms of weight during that time interval.

The product of total fishing effort (f), for all fishermen and days combined, and catchability coefficient (q) is the instantaneous fishing mortality coefficient (F), which represents total catch (C) as a proportion of average biomass present ($\overline{B}$)over the time interval for which the total catch (C) is recorded:

$$C = f\cdot q\cdot\overline{B} = F\cdot\overline{B}$$

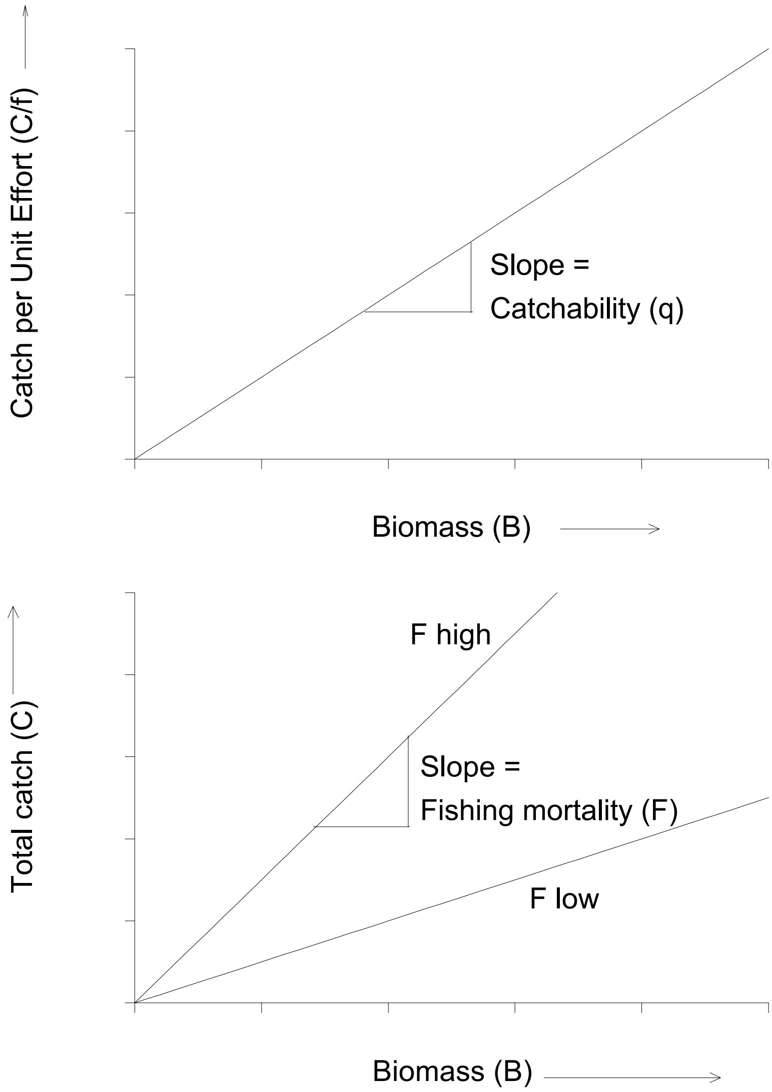


Fig. B2.1 Top: Catch per Unit Effort (CpUE) as a function of the biomass (B) of the exploited stock; Bottom: Total Catch (C) as a function of the biomass (B) of the exploited stock for high and low fishing mortality F.

Stock biomass per species changes over time due to both natural causes and to man-induced changes, mainly the exploitation by a fishery. Net change in biomass ($\Delta B / \Delta t$) is influenced by four rates: recruitment (number of newborns), growth in weight, natural mortality and fishing mortality (Fig. B2.2). The generally large fluctuations in the number of newborns from one year to the next translate into natural changes in total stock biomass over the years. The mechanisms which cause the mostly stochastic variability in the annual recruitment of most fish species are still poorly understood (Bakun 1996). Gradual changes in the medium- and long-term could, for instance, be due to changes in large-scale patterns in oceanic circulation and river runoff. Relationships between annual recruitment and adult stock biomass (stock-recruitment relationships) are hard to assess, because of the mostly predominant influence of environmental factors, such as water temperature, on annual recruitment which obscure any underlying relationship between recruitment and the parent stock.

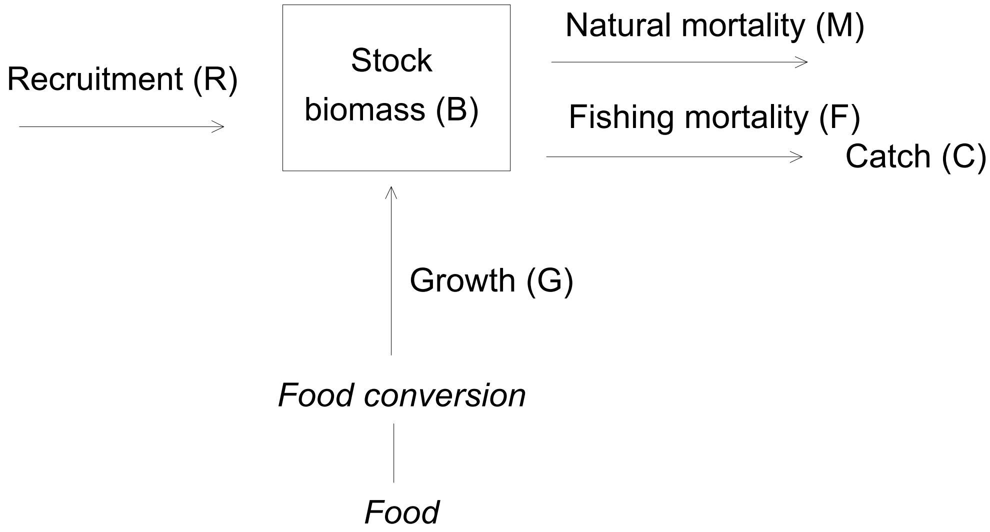


Fig. B2.2 Factors affecting changes in fish stock biomass.

Growth as the increase in individual body mass, summed for the whole stock, is called "biological production" (P). This is the production of all body tissue combined irrespective of its ultimate destiny, as food for predators, death from disease or senility or catch by fishermen. The ratio of biological production (P) and average total biomass present during a predefined time interval is named "productivity" ($P/\overline{B}$) and is expressed with a proportion per unit time (1/t). Fish stocks dominated by faster growing fish species are more productive. Also, stocks dominated by younger fish are more productive, because these younger fish grow relatively faster than their older conspecifics. Younger fish are generally more efficient at converting the food resources available into new body tissue. Exploitation by the fishery causes a shift towards, on average, smaller and younger fish and thus towards a more productive stock, which is more efficient in using the limited aquatic resource base.

Mortality is either natural or man-induced. Predation by piscivourous fish is the major cause of natural mortality, certainly for juveniles. Other possible causes are temperature shocks and starvation in the early, larval stages and senility in the older stages. For the sub-adult and adult stages of commercial species vulnerable to the fishing gear, fishing mortality is generally by far more important than natural mortality. The mesh size of the gear applied determines from what size and age onwards the fish becomes vulnerable to the combined effect of natural and fishing mortality. Instantaneous total mortality rate (Z) is calculated as the sum of instantaneous natural (M) and fishing mortality rates (F):

$$Z = M + F$$

Total biomass mortality is expressed as:

$$Z.\overline{B} = M.\overline{B} + F.\overline{B}$$

Man-induced changes in total fish stock biomass and composition encompass the effects of increasing fishing intensity, species introductions, eutrophication, habitat alterations, global warming etc. Although fishing intensity has the largest impact in many situations, its effect is, in general, reversible in the short term. Less easy to reverse are the more persistent changes in the stocks due to species introductions and to eutrophication resulting from diffuse external loading of nutrients.

Fisheries science and management, building on the analytic framework of fish population dynamics, relates total catch (C), catch rates (CpUE) and stock biomass (B) to total fishing effort applied (f) (Fig. B2.3). In the first (development) phase of a fishery the total catch realised by all fishing units together increases. Then total catch reaches a maximum (Maximum Sustainable Yield = MSY) for optimal effort (f_{opt}) in the second phase. In the third and last phase, total catch and catch rate fall with time because of progressive over-exploitation. One should be aware that the relationships between total catches (C) or catch rates (CpUE) and fishing effort (f) in Fig. B2.3 reflect equilibrium situations. Such equilibrium situations are characterised by a balance between net biological production or surplus production of the exploited stock (P − M.B) and the total catch (C) taken, attained after several years with constant fishing effort exerted on the stock. In many fisheries, fishing effort has actually increased monotonically and the annual catch (C) or catch rates (CpUE) recorded are biased as being too high relative to the equilibrium catch or catch rate for a given amount of total effort.

In conclusion, with fishing effort (f) increasing over the years, total catches (C) rise, reach a maximum and fall, whereas catch rates (C/f) decrease monotonically once a fishery has started. A fall in total caches (C) is therefore alarming, with the Maximum Sustainable Yield or Catch as a reference point. For catch rates (C/f) the alarm signal does not arise from the decrease in catch rates as such, but from the extent of such decrease in comparison with the highest catch rates in the initial phase of the fishery as a reference point.

The signalling effect of a fall in total catches or in catch rates is not easily captured by fishermen, or by the administration recording catch and effort data, for three major reasons: (1) the high variability in catches or catch rates, (2) the poor species resolution in catches recorded and (3) the poor definition of the fishing area where catches were obtained. First, large inter-annual variability masks any trend in total catches and catch rates. Second, in an expanding fishery fishermen shift from the larger, higher-valued to the smaller, lower-valued fish species and when the catch category is broadly defined, for example as ‘mackerels’ or even ‘pelagics’, over-exploitation of a particular fish species is not easily apparent from the development in total catches or catch rates. Third, in an expanding fishery, fishermen venture into more offshore waters, when catch rates in the inshore, coastal waters fall. With poor documentation of exactly where catches were obtained, catch rates thus appear stable, although total fishing effort, and thus fishing mortality, has increased.

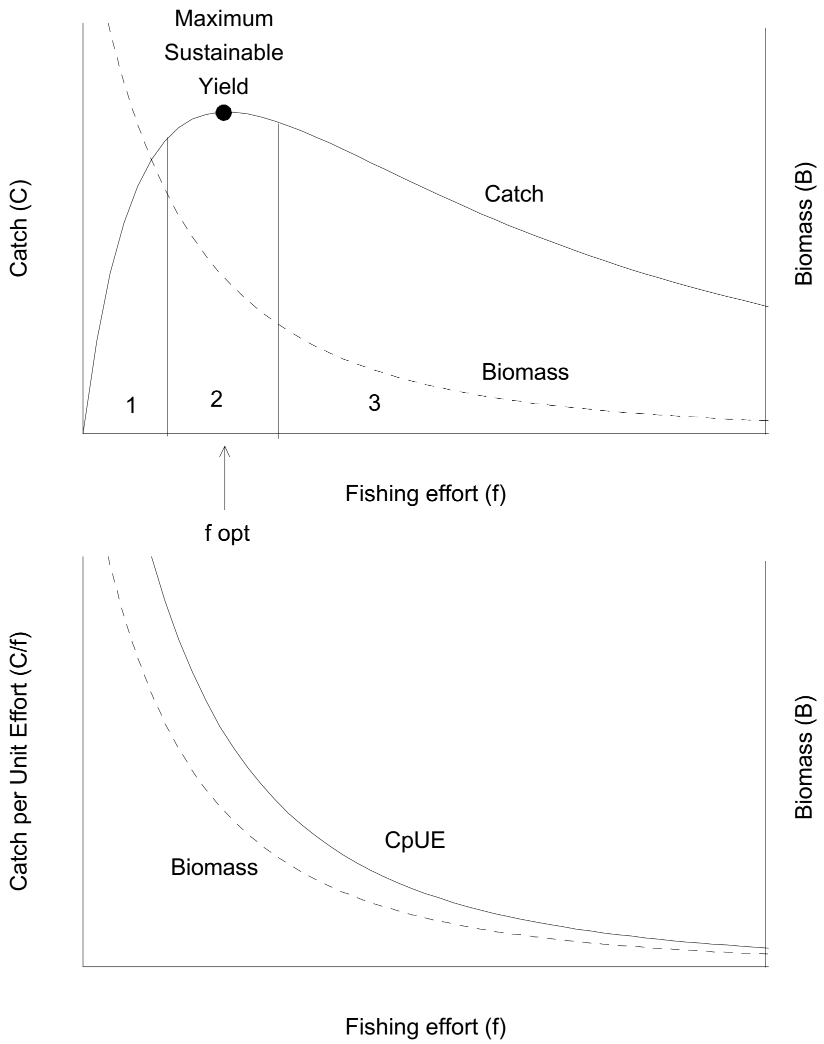


Fig. B2.3 Top: Total catch (C) and biomass (B) of the exploited stock as a function of fishing effort (f). Numbers refer to development stages of the fishery (see text). Bottom: Catch rate (CpUE or C/f) and stock biomass (B) as a function of fishing effort (f). All graphs represent equilibrium situations and assume a constant catchability coefficient (q = constant).

So for a meaningful interpretation of developments in catch rates (C/f) as an index for stock biomass (B), much depends on an articulated, properly standardised unit of effort. Although every fisheries administration will aim for standardisation of the unit of effort, it is hard for them to keep up with technical developments in a fishery. In the earliest stages of a fishery many fishermen target the largest sizes of fish, mostly predatory fish, which are caught with baited hook and line and with relatively low effort. Due to the slower growth rate of the largest and oldest specimens, the largest size category is the most vulnerable to exploitation. In a developing fishery, fishermen therefore gradually shift to smaller species caught with nets of smaller mesh sizes, in order to maintain their initial catch weight per day of fishing. The unit of effort, however, has changed meanwhile, as has the definition, and thus the size, of the exploited stock, now encompassing smaller species and sizes as well. Simply monitoring catch rates in terms of kg per fishing day of an individual fisherman would thus bias the observation of a downward trend in total stock biomass. Such bias in catch rates and in the character and size of the stock under exploitation, also occurs when fishermen, after having over-exploited nearby fishing grounds, move to offshore waters. These offshore waters become more accessible after motorisation of the fleet, thus enlarging the size of the stock under exploitation.

Finally, a serious bias in using catch rates to index developments in stock biomass over the years, as a proportionality indicator for stock biomass, arises from the use of fish finding devices, such as sonar (Fig. B2.4). These devices direct the spatial allocation of fishing effort most efficiently. Concentrations of spatially aggregated, schooling pelagics like herring and sardines, are then easily traced and fished out. To monitor developments in stock biomass.from the CpUE fishing effort (f) would then be better referred to the searching time taken to locate a school of pelagics, than to the total time spent fishing.

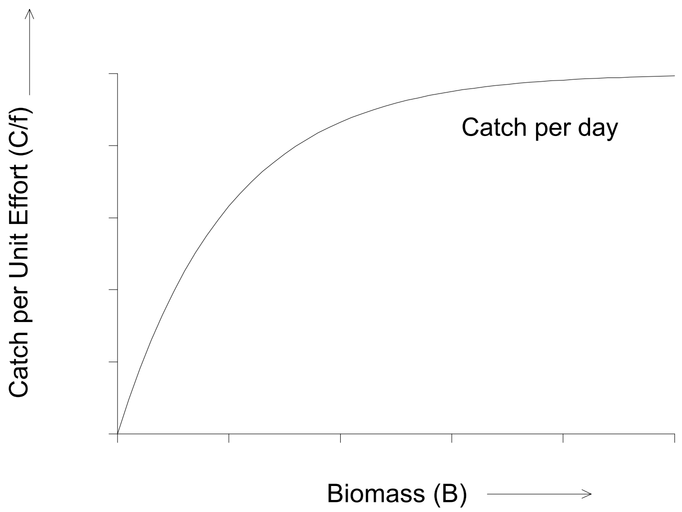


Fig. B2.4 Depensation effect. Catch per Unit Effort (CpUE) as a function of the biomass (B) of the exploited stock. When in a fishery for schooling pelagics using fis h finding devices, the unit of effort is poorly defined, e.g. as one day fishing, developments in the stock are difficult to read from proportional changes in the average catch per day, the more so when stock biomass has been fished down to low levels.

Chapter 3

Capacity to perceive a time trend

In this chapter:

- Capacity to perceive a time trend is translated into the statistical power (1 - β) as the probability that a true trend will be detected. **3.1**
- Procedures for estimating the size of trends and step trends and of the variance in the residuals around these trends are given. **3.2**
- Statistical power for trend detection is shown to be dependent on the size of the trend, the variance in the residuals around it, the length of the time series and the critical value α that one concludes that there is a trend where there is not. **3.3**
- Types of variances around long-term trends in catch rates are categorised as: variability in the catch from day to day (basic uncertainty), variability as due to periodicity such as seasonality, and variability in the catch from one year to the next including the blue and red noise therein. **3.4**
- Analysis of variance is discussed as a statistical technique with which to decompose total variance in log-transformed daily catch rates, with residual variance as an approximation for the basic uncertainty in catch rates from day to day. **3.5**
- The effect of data aggregation in time and space on the resultant variability and on the statistical power of the authorities to perceive trends and patterns in resource outcome is discussed. **3.6**
- Questions per chapter are articulated as: how large is the variability at the time scale of days (Chapter 4), months (Chapter 5) and years and what trends then to perceive (Chapter 6), what explains the disparity in the capacity for trend perception between fishermen and authorities and how to improve on the situation (Chapter 7), how do variabilities and trend perceptions in agriculture compare with those in fisheries (Chapter 8), and what factors constrained the perception of a long-term downward trend in the historical whaling of the 18th century, including the ignorance of statistical tools and of the making of graphs (Chapter 9)? **3.7**

3.1 Statistical power as the capacity to perceive a true trend

It would be very damaging if fishermen and fishery authorities did not perceive a true, and strongly downward, trend in the size of the exploited stock from the development of catch rates. It would mean that they were not sufficiently alarmed in time to take regulatory action, and thus prevent further resource degradation. Whether or not such a true downward trend, of a particular size, is perceived, depends on the capacity of the observer to detect such a trend. This capacity can be formalised as the statistical power to perceive a truly existing trend (Cohen 1988, Peterman 1990). The statistical power is quantified with the probability (1 - β) that a false H_0, which states that the stock does nót decline, will be rejected with the data available and with the statistical test applied. It will be obvious that the statistical power is large, and thus a true trend more easily perceived, when the trend is strong, the number of observations (n) large and the variance (s^2) around the trend small. Certainly the picture is not that clear to be perceived in all situations and with the data available one could erroneously conclude that a trend exists where there is none, or the reverse.

When evaluating a series of catches for a possible trend over time, fishermen and authorities could thus make two types of error (Table 3.1). Either they conclude there is a trend where there is not (Type I error with probability α) or they do nót conclude for a trend that does exists (true trend) (Type II error with probability β). Scientists generally try to minimize the risk α of making a Type I error by choosing, subjectively, a low 'critical value' for α. Mostly this value is set at $\alpha = 0.05$. It means that a Type I error is made in, at the most, 1 out of 20 occasions. So the probability of correctly accepting a true H_0 should then be at least 1 - α or 0.95.

Table 3.1 Consequences of accepting or rejecting a true or a false null hypothesis (H_0). Probabilities ($0 < p < 1$) for making Type I errors (α) and Type II errors (β) (after Sokal & Rohlf 1981).

	H_0 accepted	H_0 rejected
H_0 true	Correct decision (1 - α)	Type I error (α)
H_0 false	Type II error (β)	**Correct decision (power 1 - β)**

In the management of natural resources the consequences of making a Type II error (not alarmed in time) are generally considered as more severe than those of making a Type I error (unnecessary alarm). This generalisation certainly holds for the evaluation of time series of abundance data for species of high nature conservation value, such as birds, butterflies and marine mammals (van Strien *et al*. 1994, van Strien *et al*. 1997, Wilson *et al*. 1997). Given the danger of irreparable damage done to these populations or having to wait a long time for their recovery, it is important to keep the probability of making a Type II error, and therefore the critical value β, as small as possible with the power (1 - β) as high as possible. Setting $\beta = 0.10$ and thus statistical power required at $(1 - \beta) = 0.90$ is a widely applied criterion.

Due to the generally high natural variability and uncertainty of observation, current methods of estimating aquatic populations have a low probability (1 - β) of detecting a significant trend or step trend in abundance, should one occur (Peterman 1990). To stress this Peterman referred, amongst others, to an impact assessment study on the postulated effects of changes in fish recruitment, due to the operation of electric power plants, which cause fish mortality because of the intake of cooling water (Vaughan & van Winkle 1982, Barnthouse *et al*. 1983). Given the generally high variability in annual recruitment of fish, time series of juvenile density estimates have to be unrealistically long for the statistical power (1 - β) to become acceptably high. An example closer to resource exploitation to which Peterman (1990) refers, is the "New Management Procedure" of the International Whaling Commission (IWC) of 1983. This procedure stated that as long as a linear trend in catch rates (C/f) for a particular whale stock was not significantly different from zero in a time window of 10 years, that stock would be classified as a sustained management stock. Harvest rates could then be maintained. Monte Carlo simulations showed that IWC-scientists would have a high probability (β) of nòt rejecting the H_0 of constant whale abundance, even when the stock had decreased dramatically (de la Mare 1984) (Type II error). So the statistical power (1 - β) for observing true trends in these situations was generally low.

The power (1 - β) of a statistical test for trend detection is not only higher when the trend is strong, the length of the series large and the variance around the trend small, but also when one accepts a higher risk α of concluding erroneously for a trend where there is none. In other words lowering α means lowering (1 - β), and greater fear of making a Type I error thus means a higher probability (β) of making a Type II error. To optimise the balance in preventing the two types of error, in monitoring programmes for organisms of high nature conservation value, not only is statistical power required but sampling costs are also taken into account (Vos *et al.* 1993, Bult 1999). Mathematical formulae for statistical power (1 - β) in trend detection should include all four parameters (trend size, n, s^2, α). The mathematical formulae for statistical power in general primarily relate to the types of test such as t-tests, F-tests, Chi-square tests etc, both parametric and non-parametric, but all contain the above mentioned elements where trend size could be replaced by any other effect for which one likes to assess statistical power in detecting true effects (Lettenmaier 1976, Gerrodette 1987, Cohen 1988, Sheppard 1999, www.mpl-pwrc.usgs.gov). These formulae are used to assess statistical power *a priori* and *a posteriori* the collection of data.

In this chapter, the estimation procedures for trends (gradual change) and step trends (sudden change) in resource outcome are first described, together with those for the estimation of variances around these trends (section 3.2). Hów the four parameters mentioned influence statistical power for trend detection exactly is formulated and exemplified in section 3.3. One of these parameters is the variance around the long-term trend, which in the case of fisheries contains daily, monthly and annual variance (section 3.4) (Box 3.1). One way of assessing the relative contribution of these three types of variance in catch rates, relative to the variance caused by a possible long-term trend, is by applying an Analysis of Variance (ANOVA) (section 3.5). Data aggregation, as for instance summing all daily catches into catches per week for the whole of a resource area, then mostly reduces the variability (s^2) in catch rates, but at the same time reduces the number (n) of observations as well. These two effects of data aggregation have different bearing on the statistical power (1 - β) for trend perception (section 3.6). Finally, departing from the various ways in which statistical power for trend detection is influenced, the two major questions of this study, as formulated at the end of Chapter 2, are elaborated on, leading to questions per chapter (section 3.7).

3.2 Trends and the residuals around them

There are roughly two types of trend: trends as a gradual unidirectional change, and step trends as more sudden changes. Trends in resource outcome can be observed both through time and space. Fish catches or crop yields can exhibit trends in space when going from one locality to the other, but the following text focuses on time trends in fisheries. The formulations are generally applicable.

3.2.1 Trends

Trends in total catches or in catch rates are either linear or non-linear. For linear trends, estimated directly by linear regression of untransformed values, it is assumed that the residuals around the trend are normally and homoscedastically distributed. When trends are apparently non-linear and bend downwards, log-transformation is the simplest method with which to linearise them. The trend in back-transformed annual catch rates (antilog) then follows an exponential curve and the implicit assumption is that residuals are log-normally distributed around this exponential curve. For both linear or exponential trends, total catches (C_t) or catch rates are written as a function of time (t, year). For linear trends this is formulated as:

$$C_t = C_0 + \beta_1 \cdot t + \varepsilon$$

and for non-linear, exponential trends:

$$\ln C_t = \ln C_0 + \beta_1 \cdot t + \varepsilon$$

where C_t = catch in year (t), C_0 = theoretical catch at t = 0, ε = error term and β_1 = slope of the regression line corresponding with:

$$\beta_1 = \frac{dC_t}{dt} \quad or \quad \frac{d \ln C_t}{dt}$$

The unbiased estimate for the slope β_1 is:

$$b_1 = \frac{\sum_{i=1}^{n} \left(t - \bar{t}\right)\left(C_t - \overline{C_t}\right)}{\sum_{i=1}^{n} \left(t - \bar{t}\right)^2} \quad \text{or} \quad b_1 = \frac{\sum_{i=1}^{n} \left(t - \bar{t}\right)\left(\ln C_t - \overline{\ln C_t}\right)}{\sum_{i=1}^{n} \left(t - \bar{t}\right)^2}$$

where n is the number of years in the time series (‘time window’) when catches are annual catches, while the estimate b_1 is normally distributed with:

$$E\left(b_1\right) = \beta_1$$

and variance:

$$\sigma_{b_1}^2 = \frac{\sigma^2}{\sum \left(t - \bar{t}\right)^2} \tag{3.1}$$

The σ^2 refers to the variance in the residuals around the regression line for which it is assumed that they are distributed normally and homoscedastic with mean = 0 and variance σ^2:

$$\varepsilon \propto N\left(0, \sigma^2\right)$$

For the estimate of the variance in the residuals:

$$\sigma^2 = \frac{1}{n} \sum^{n} \left(C_t - \hat{C}_t\right)^2$$

and in case of exponential, non-linear trends:

$$\sigma^2 = \frac{1}{n} \sum^{n} \left(\ln C_t - \hat{\ln} C_t\right)^2 = \ln\left(\eta^2 + 1\right)$$

where η is the coefficient of variation (CV = standard deviation/mean) in the distribution of back-transformed (anti-logged) residuals. The coefficient of variation (η) in log-normal distributions relates to the variance (σ^2) in the normal distribution of log-transformed observations according to (see section 3.4.1):

$$\eta = \sqrt{e^{\sigma^2} - 1}$$

The sample coefficient of determination (r^2), or the proportion of total variance in catches explained by the trend, is calculated via the estimated catch at a given moment in time according to the regression ($\hat{C}_t$):

$$r^2 = \frac{\sum \left(\hat{C}_t - \overline{C}\right)^2}{\sum \left(C_t - \overline{C}\right)^2}$$

A trend becomes more apparent and statistically more significant when, with the same number of observations, the trend is large relative to the variance in the residuals ("noise"). In other words when the trend-to-noise ratio (b/s), as the slope over the standard deviation in the residuals, is high.

The condition of homoscedasticity, or independence of successive observations, is seldom met in the residuals around trends in catches or catch rates. It regularly occurs that the residuals are correlated, which explains part (ρ^2) of the variance in the residuals. Serial correlation is defined here as autocorrelation with a time lag of $\Delta t = 1$. Such serial correlation points to the presence of short-term trends or persistence. Persistence in daily catches for instance could be due to a concentration of fish residing in the resource area for a number of days. At a much larger time scale, persistence in annual catches can arise from the dominance of one strong year-class in the population for a number of years in succession. For the estimation of serial correlation, the residual for a particular moment in time (t) is written as a linear function of the residual for the previous year (t - 1) (Neter *et al*. 1985):

$$\varepsilon_t = \rho\varepsilon_{t-1} + u_t$$

where the correlation parameter $|\rho| < 1$, and u_t is a new error term, or independent random normal variable, with mean zero and constant variance σ_ε^2. The serial correlation parameter ρ equals the coefficient of correlation between ε_t and ε_{t-1} (Neter *et al* 1985, p. 450). Under this model, the variance in the residuals as a series of independent observations representing only stochastic variance can be approximated with:

$$\sigma_\varepsilon^2 = \frac{\sigma^2}{1-\rho^2}$$

Other methods for regression analysis in which serial correlation in the residuals is accounted for could also affect the estimation of the slope or trend (Neter et al. 1985).

If C_t is recorded at regular intervals, for instance years, the independent variable time (t), can be renumbered, without loss of generality, 1, 2, 3, …., n. Then the variance in the independent variable time (t) can be calculated as (Gerrodette 1987):

$$\sigma_t^2 = \frac{(n+1)(n-1)}{12} = \frac{n^2-1}{12} \qquad (3.2)$$

Example

Catch and effort data for the purse seine fishery for small-, medium, and large-sized pelagics in Lake Tanganyika, Burundi sector, were well documented (van Zwieten *et al*. 2002). The unit of effort was one month's fishing by one purse seiner. The fish category 'small' contains two short-lived pelagic clupeids *Stolothrissa* and *Limnothrissa* and the juveniles of a pelagic piscivore *Lates stappersii*. The mono-specific category 'medium' contained only *Lates stappersii*. The category 'large' contains a number of large piscivorous species, all of the genus *Lates*.

Catch rates of 'small' fish fell and that of 'large' fish fell dramatically from the 1950s to the 1990s (Fig. 3.1, Table 3.2). The probably most vulnerable, large *Lates* species disappeared from the landings at the high rate of 11% per year. There was no long-term trend in the catch rates for the mono-specific 'medium' fish; the variability was large (CV = 1.14) and there were pronounced short-term trends in the 1970s. But the catch rates of a detrended annual series of both "small" and "large" fish also showed marked persistence.

Table 3.2 Trend (b, per year) in ^{10}log-transformed CpUE (kg per vessel-month averaged over a year), variance explained by the trend (R^2), variability around the trend (CV(s)), trend to noise ratio (b/s) and serial correlation (ρ^2) in the residuals around the trend, for three size categories of fish and for total catch in the purse seine fishery for pelagics in Lake Tanganyika (from van Zwieten *et al*. 2002).

	Small	Medium	Large	Total
B	-0.00891	-	-0.0530	-0.01052
R^2	0.202	n.s.	0.835	0.395
CV(s) (n = 35)	0.454	1.139	0.630	0.329
b/s	0.047		0.211	0.076
ρ^2 (n = 33)	0.346	0.258	0.270	0.262

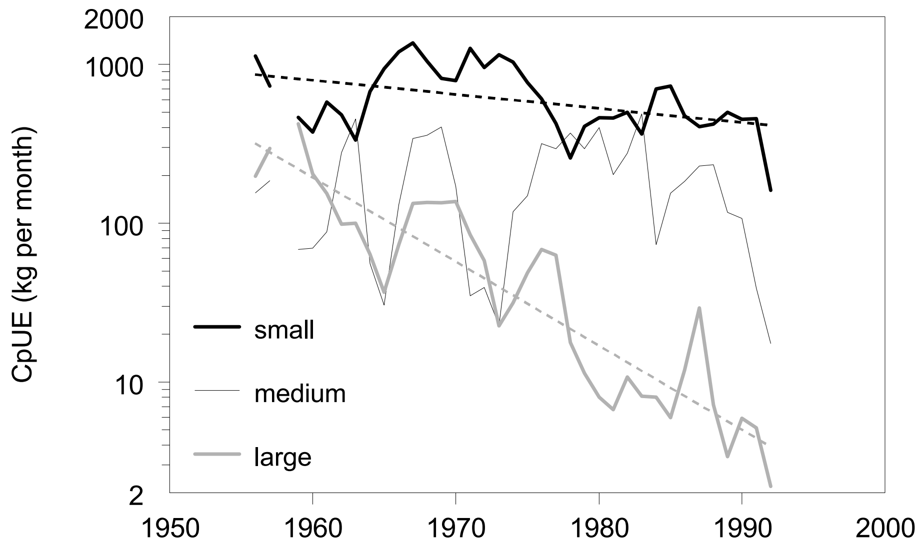


Fig. 3.1 CpUE (kg/month) per size category (small, medium, large) in the purse seine fishery for pelagics in Lake Tanganyika. Data in van Zwieten *et al*. 2002.

3.2.2 Step trends

Step trends, as sudden changes in annual catches, are most likely to occur after the rigorous implementation of a management measure. The major management measures used to counter over-exploitation are restrictions on effort and mesh size enlargement. Both are meant to increase the exploitable stock and, with that, the total annual catch and the annual catch rates. The effectiveness of these measures should be evident from a clear increase in catch rates. This is all the more important where fishermen need to be convinced that the management measures were worth implementing. Also, here it is important to assess *a priori* how large the statistical power of the recording scheme is for detecting a change in catch rates of a particular size.

The sudden change, expressed as a difference (d) or step in the average annual catches in the years (n_1) before and the years (n_2) is denoted with:

$$d = \overline{C_2} - \overline{C_1}$$

or after log-transformation:

$$d = \overline{\ln C_2} - \overline{\ln C_1}$$

The variance in the estimate for this difference or step trend is:

$$\sigma_d^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

When the variance in annual catches ($\sigma_1^2 = \sigma_2^2 = \sigma^2$) and the number of observations ($n_1 = n_2 = n$) is the same before and after the change, the variance in the estimate for the step trend simplifies to:

$$\sigma_d^2 = 2\frac{\sigma^2}{n}$$

In a particular management situation the observation periods before and after the lag phase need not necessarily be the same ($n_1 \neq n_2$). In case of such inequality, the number n of years in the above equation should be deduced from (Ham & Pearsons 2000):

$$n = \frac{2n_1 n_2}{n_1 + n_2}$$

The test statistic is denoted as:

$$t = \frac{d}{\sigma}\sqrt{\frac{n}{2}}$$

The step trend to noise ratio is d/σ.

Serial correlation in the annual series affects the test statistic in the same way as for the estimate of a trend.

Example

Data for Fig. 3.2, with 10 years (n_1) before and 10 years (n_2) after a sudden change in average catch rates, were drawn randomly from a lognormal distribution with mean = 0, and with a standard deviation $s\,{}^{10}\log(C/f) = 0.3$ (CV(s) = 0.78). The antilog of the annual catch rates was multiplied by 2 from year 11 onwards.

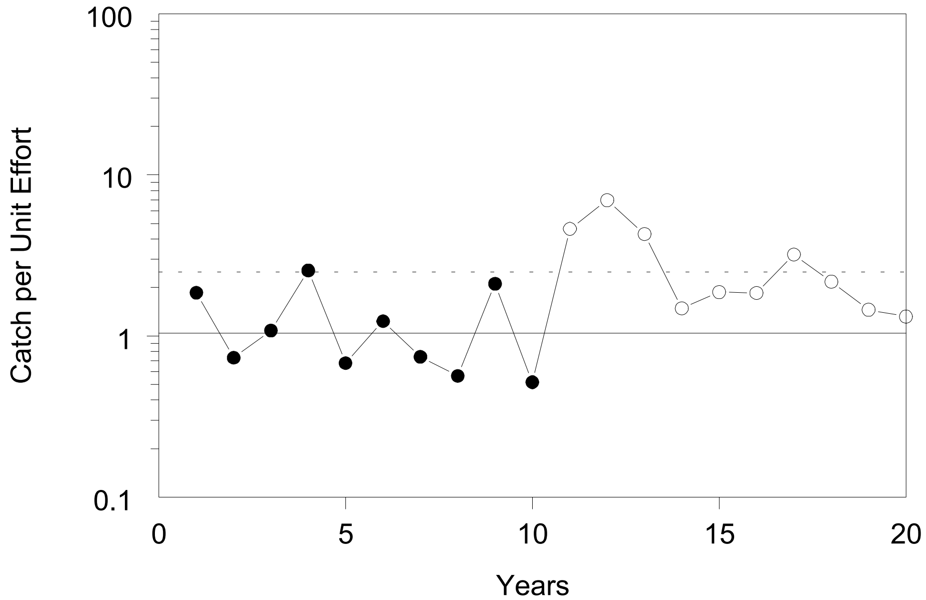


Fig. 3.2 Series of annual catch rates (Catch per Unit Effort = C/f) based on a theoretical example (see text). Before and after the change between years 10 and 11 the arithmetic means were 1.21 and 2.92 (d = 1.70), geometric means 1.04 and 2.50, means of ^{10}log-transformed annual catch rates 0.02 and 0.40 (d = 0.38), standard deviations in untransformed catch rates 0.72 and 1.85, coefficients of variation 0.60 and 0.63, and standard deviations in the ^{10}log-transformed catch rates 0.25, both before and after the change. The step trend to noise ratio in the log-transformed catch rates was d/s = 0.38/0.25 = 1.52.

3.3 Four factors governing the statistical power for trend detection

3.3.1 Trends

The statistical power of tests for the trend parameter β_1 was developed following Neter *et al.* (1985, p. 64) (see also Fig. 3.2). Since the regression coefficient b_1 is normally distributed, the standardised statistic:

$$\frac{b_1 - \beta_1}{s_{b_1}}$$

is a standard normal variable distributed as *t* with n - 2 degrees of freedom.

Tests concerning β_1 can be set up in the usual fashion, using the *t*-distribution. In the case of the general problem:

$$H_0 : \beta_1 = \beta_{10}$$

$$H_a : \beta_1 \neq \beta_{10}$$

where, according to the H_0, β_{10} is either 0, or has some specified non-zero value. The general test statistic employed then is:

$$t^* = \frac{b_1 - \beta_{10}}{s_{b_1}}$$

and the decision rule for the level of significance α in a two-tailed test where $\beta_{10} = 0$, thus detecting either a positive or negative trend, is:

$$\text{If } |t^*| \le t\left(1 - \frac{\alpha}{2}; n-2\right), \text{ conclude } H_0$$
$$\text{If } |t^*| > t\left(1 - \frac{\alpha}{2}; n-2\right), \text{ conclude } H_a$$

When β_{10} has some specified non-zero value, e.g. a trend as a particular norm, α replaces $\alpha/2$, and one deals with a one-tailed test.

The power (1 - β) of the test is the probability ($0 < P < 1$) that the decision rule will lead to acceptance of H_a where H_a indeed holds, given by:

$$P\left\{|t^*| > t\left(1 - \frac{\alpha}{2}; n-2\right) \middle| \delta\right\}$$

where δ is a measure of noncentrality - i.e., how far the true value of β_1 is from β_{10}:

$$\delta = \frac{|\beta_1 - \beta_{10}|}{\sigma_{b_1}}$$

The probability P is taken from the cumulative distribution function of a standardised Student's t-distribution with ν degrees of freedom, here df = n - 2.

To reduce the statistical errors to the specified levels of probability α of making a Type I error and the probability β of making a Type II error, one should have the following inequality (after Lettenmaier 1976):

$$t_{\beta,\nu} \ge \left|\frac{b_1 - \beta_{10}}{s_{b_1}}\right| - t_{\alpha/2,\nu}$$

Suppose it should be tested whether a trend exists anyhow, either increasing or decreasing, so for $\beta_{10} = 0$ and with a two-tailed α, after rewriting the inequality reads as:

$$\frac{(b_1 - 0)^2}{s_{b_1}^2} \ge \left(t_{\alpha/2,\nu} + t_{\beta,\nu}\right)^2$$

combined with (equation 3.1) and (equation 3.2):

$$\frac{b_1^2\left(n^3-n\right)}{12\sigma^2} \geq \left(t_{\alpha/2,\nu}+t_{\beta,\nu}\right)^2$$

where σ^2 is the variance in the residuals around the trend. Given any four of the five parameters b, n, σ, t_α and t_β, the fifth can be found (Fig. 3.4). For estimating the statistical power (1 - β), first the critical value t_β must be calculated from the other four parameters:

$$t_{\beta,\nu} = \left|\frac{b_1}{\sigma}\right|\sqrt{\frac{n^3-n}{12}} - t_{\alpha/2,\nu} \qquad (3.3)$$

where b_1/σ is the "Trend to noise ratio". For large n, the t_β-value is, by approximation:

$$t_{\beta,\nu} = \left|\frac{b_1}{\sigma}\right|\sqrt{\frac{n^3}{12}} - t_{\alpha/2,\nu}$$

In a case where the trend is expressed as the absolute change (B) in the dependent variable during the full period of n time intervals, e.g. years, under consideration, so with $B_1 = n.b_1$, the equation reads as:

$$t_{\beta,\nu} = \left|\frac{B_1}{\sigma n}\right|\sqrt{\frac{n^3-n}{12}} - t_{\alpha/2,\nu} \quad \text{or for large n} \quad t_{\beta,\nu} = \left|\frac{B_1}{\sigma}\right|\sqrt{\frac{n}{12}} - t_{\alpha/2,\nu}$$

When the residuals around the trend are serially correlated, the true homoscedastic variance in the residuals is $1/(1 - \rho^2)$ times larger than the variance calculated directly from the residuals (see 3.2), and thus:

$$t_{\beta,\nu} = \left|\frac{b_1}{\sigma}\right|\sqrt{\frac{\left(n^3-n\right)\left(1-\rho^2\right)}{12}} - t_{\alpha/2,\nu} \qquad (3.4)$$

The statistical power (1 - β) is inferred from the corresponding t_β-value, using Students t for variable degrees of freedom (ν). From the formula above it is now easier to read how statistical power increases with: a stronger trend, a larger number of observations, less variance in the residuals around the trend and less serial correlation therein, and a larger acceptable risk of rejecting a true H_0, so smaller $t_{\alpha/2}$ (Figs 3.3, 3.4, 3.5).

For example, if one wonders about the time trend that can be detected in a 5 year time period (n = 5) with a power (1- β) = 0.9, given constant variability around the trend and for $\alpha = 0.1$, equation 3.3 can be rewritten:

$$|b| = \sigma\sqrt{\frac{12}{n^3-n}}\left(t_{\alpha,\nu}+t_{\beta,\nu}\right)$$

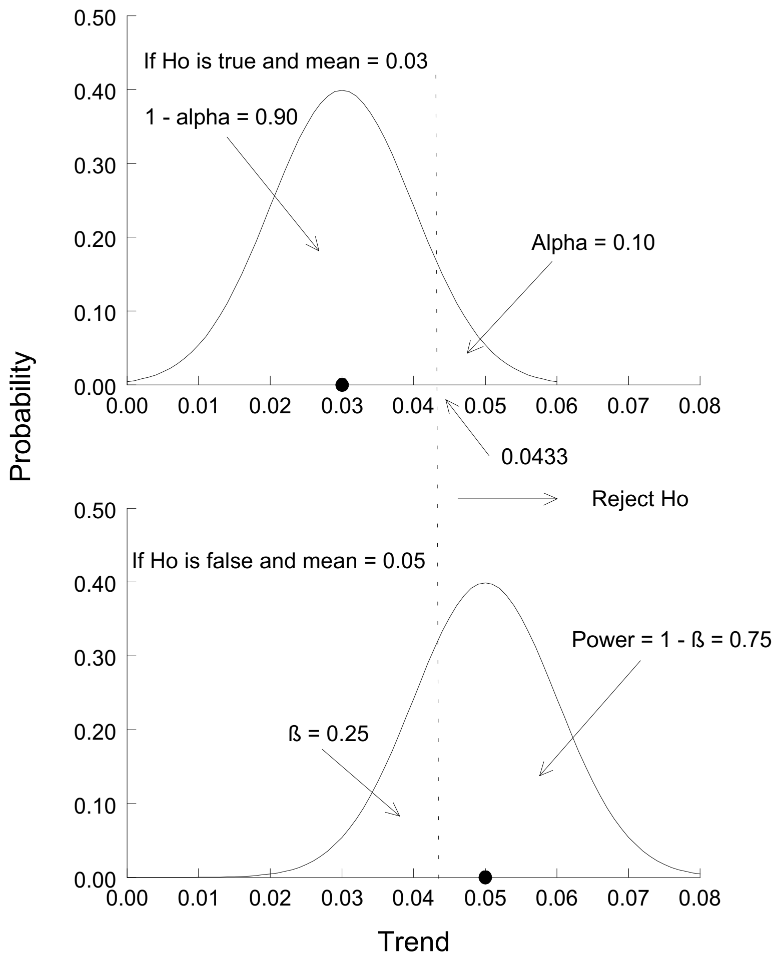


Fig. 3.3 Accepting and rejecting H_0 or H_a with 20 years of observation (df = 20 – 2 = 18). The H_0 for a trend could be either 0 (decision: trend or no trend; two-tailed α) or could have a preset value, as is exemplified here with β_{10} = 0.03 (decision: trend not larger than 0.03, one-tailed α). In this example the variance around the trend $\sigma^2 = (0.01)^2$ (modified after Peterman 1990).

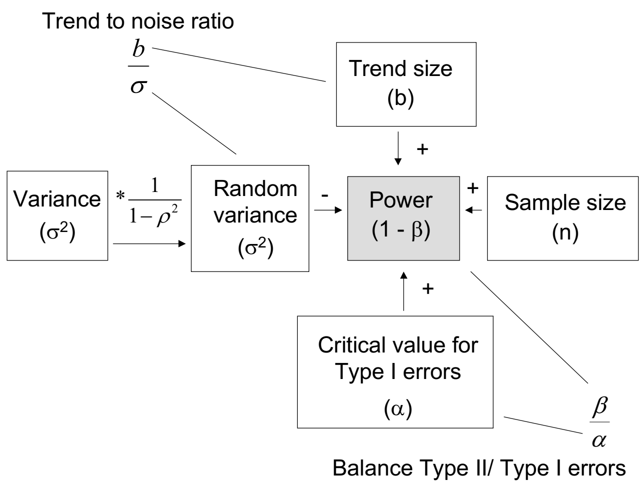


Fig. 3.4 Factors governing the statistical power (1 - β) to detect a true trend, as either enlarging (+) or reducing (-) power.

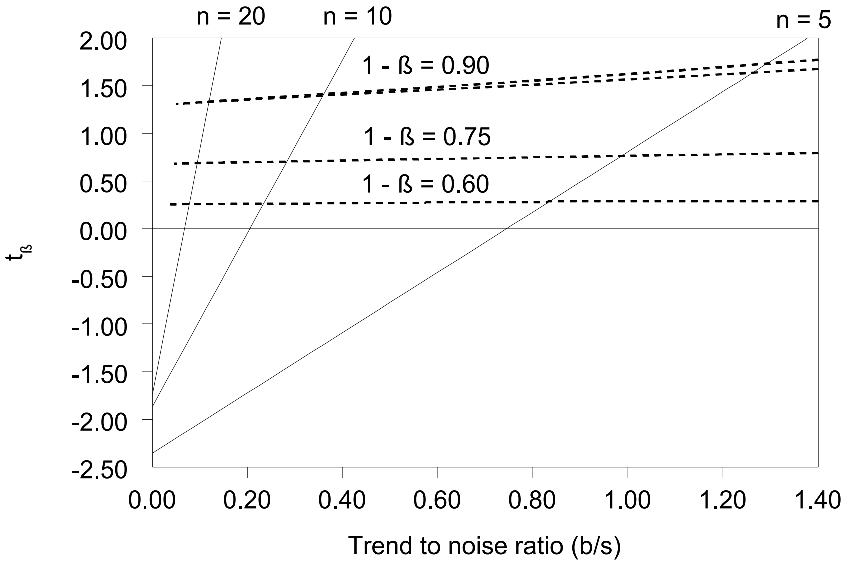


Fig. 3.5 Values for t_β corresponding with the statistical power (1 - β) as a function of the 'Trend to noise ratio' (b/s) or 'effect size', for a variable number of years in the series (n = 5, 10, 20), without serial correlation ($\rho^2 = 0$) and for detecting either positive or negative trends with critical value $\alpha = 0.10$ ($t_{\alpha/2,\nu}$ = intercept). The open circles refer to combinations with the same statistical power (1 - β) = 0.90.

For (n-2) degrees of freedom:

$$|b| = 1.036s$$

The trend to noise ratio ($|b|/s$) is a constant which, for time windows of 5, 10, 15 and 20 years, is 1.036, 0.308, 0.161 and 0.133 respectively.

When observations are ^{10}log-transformed the decrease can be characterised with the proportion (S) of the initial quantity, according to the trend, left after n years as a proportion of 1 (Fig. 3.6):

$$S = 10^{nb}$$

How a larger "Trend to noise ratio" (b/s) reduces the number of years (n), after which a trend can be detected with a power (1 - ß), given test criteria for α and β, can be inferred via iteration after rewriting (equation 3.4) (Fig. 3.7):

$$n^3 - n = \frac{12\left(t_{\alpha/2,\nu} + t_{\beta,\nu}\right)^2}{\left(1-\rho^2\right)}\left(\frac{\sigma}{|b_1|}\right)^2$$

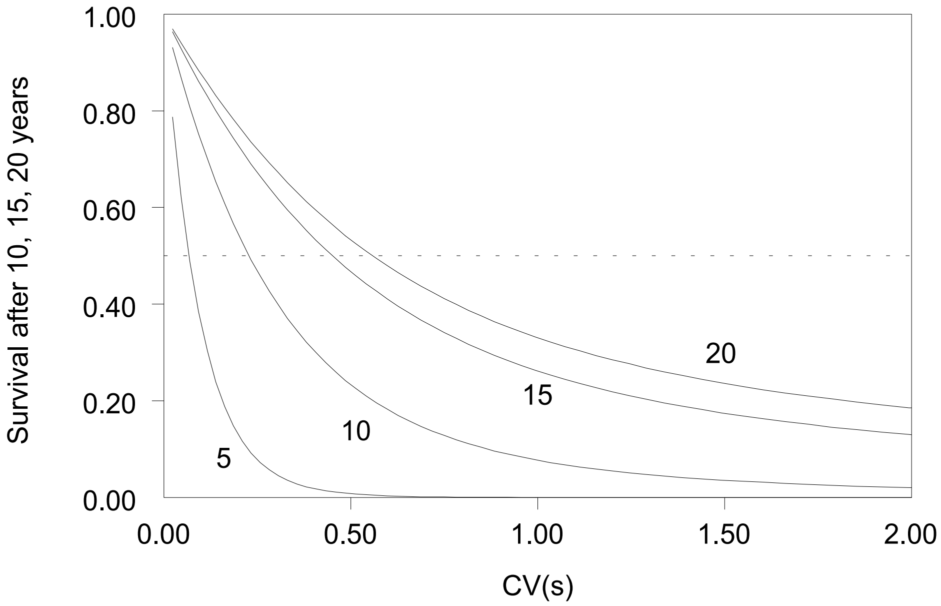


Fig. 3.6 Proportion (S) of the initial quantity left after 5, 10, 15 and 20 years, which can just be detected for a range in variabilities (CV(s)) under conditions $\alpha = \beta = 0.1$.

It appears that serial correlation and a two-tailed, instead of a one-tailed, test only marginally enlarge the number of years for which catches have to be recorded, before a trend can be perceived with the trend expressed relative to the variability around it, as a "Trend to noise ratio".

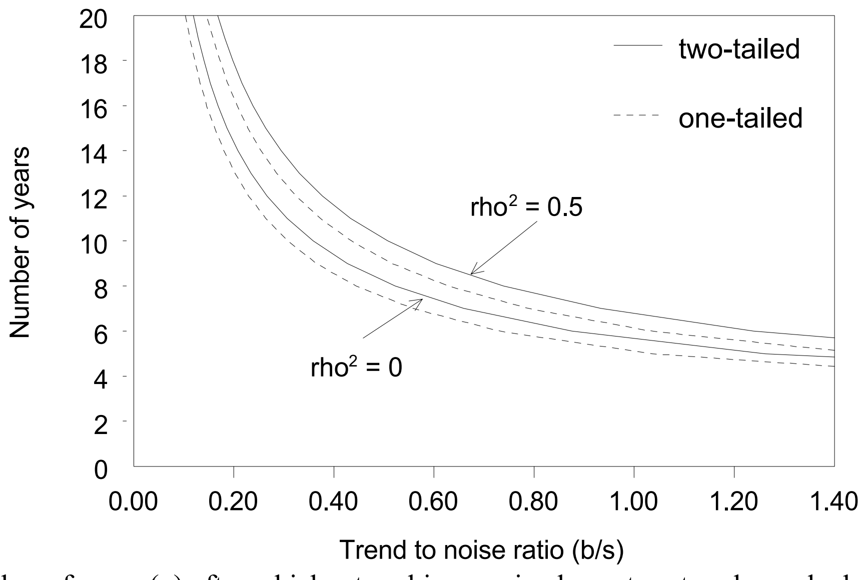


Fig. 3.7 Number of years (n) after which a trend is perceived as a true trend, graphed as a function of the trend to noise ratio (b/s) without ($\rho^2 = 0$) and with serial correlation ($\rho^2 = 0.5$) and for two-tailed and one-tailed tests under conditions $\alpha = \beta = 0.10$.

3.3.2 Step trends

To assess the statistical power ($1 - \beta$) to perceive a change of a factor a in catch rates ($a = C_2/C_1$), and now via a one-tailed test with $2(n - 1)$ df, the corresponding t_β-value is calculated as:

$$t_{\beta,\nu} = \frac{|\log a|}{\sigma}\sqrt{\frac{n}{2}} - t_{\alpha,\nu} \qquad (3.5)$$

If managers wish to assess which step trend, as a relative change (multiplier a) in catch rates, can be perceived in how many years (n_2) after the change with preset statistical power (1 - β) and critical value α, the variability (s^{10}logC, CV) and the length of the reference period (n_1) have to be preset as well (Fig. 3.8). See section 3.4.1 for the relationship between the two measures of variability. The ratio loga/σ is equal to the 'effect size' of Cohen (1988, p. 25-26), who distinguishes small (0.2), medium (0.5) or large effect sizes (0.8).

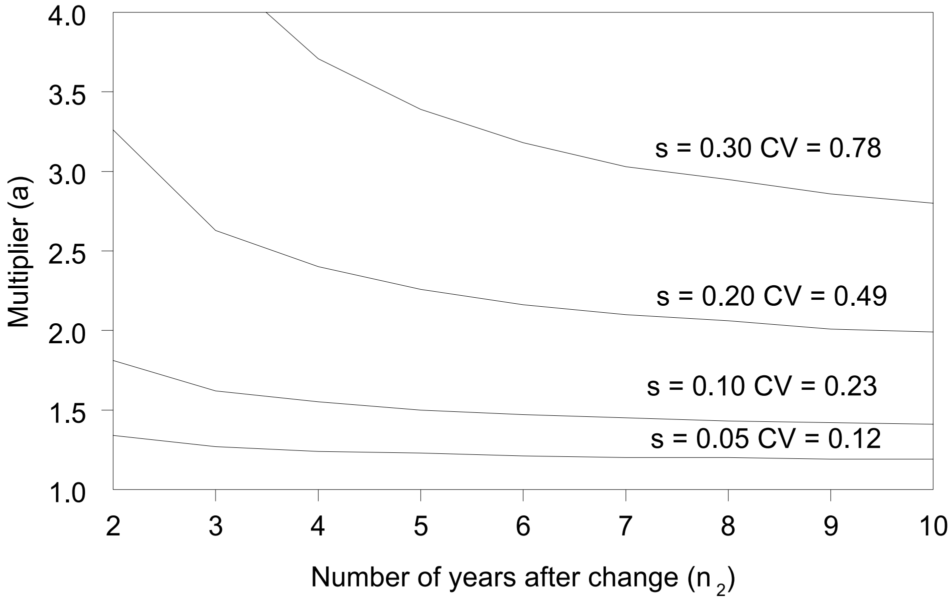


Fig. 3.8 Step trend as a relative change (multiplier a) in annual catch rates, which becomes just detectable after a given number of years after the change (n_2), where the reference period lasts 5 years (n_1 = 5) for four levels of variability in annual catch rates. Conditions are α = β = 0.10, so for statistical power (1 - β) = 0.90. s = standard deviation in ^{10}log-transformed annual catch rates.

Another way of representing the relationships between the various factors which determine statistical power is to assess the total number of observations, which refers to the total monitoring period ($n_1 + n_2 = 2n$) necessary to just detect a step trend of a particular size for a range in inter-annual variabilities. For that purpose equation (3.5) can be rewritten:

$$n_{tot} = \frac{1}{|\log a|^2}\left(t_{\alpha,\nu} + t_{\beta,\nu}\right)^2 \sigma^2$$

with 2(n -1) degrees of freedom. The t-values are influenced by the dependent variable (n_{tot}), so the relationship is assessed for each value n_{tot} (Fig. 3.9).

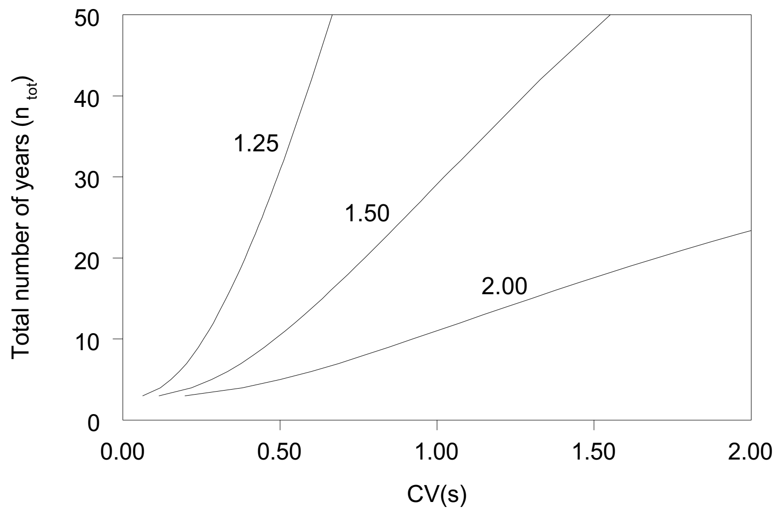


Fig. 3.9 Total number of years (n_{tot}) necessary to detect a step trend by a factor 1.25, 1.5 and 2 increase in the average between two series of observations in relation to the variability (CV(s)), which is the same for both series, and for $\alpha = \beta = 0.1$.

3.4 Variances around a long-term trend

Fishing is a daily operation and catches are generally recorded on a daily basis. Variance is one of the four factors which govern the statistical power to perceive a possible long-term trend in these daily catches. This variance has four components:

1. Variance in the catch on the short-term from day to day.
2. Variance in the catch on the longer term of weeks or months due to periodicity, such as moon cycles and seasons.
3. Variance in the catch from one year to the next due to short-term changes in stock size and in fishing practice.
4. Variance in the catch due to the long-term trend itself.

3.4.1 Variance in the catch from day to day

Many fishermen will consider the variance in their catch from day to day, their ‘basic uncertainty’, a nuisance. This is certainly true of subsistence fishermen, who rely on their daily catch for the livelihood of their families. But possibly, for some fishermen the basic uncertainty is an exciting incentive for their fishing practice. For instance, it is an indispensable element of angling as a recreational activity. Day to day variability in the catch of an individual fisherman is mainly governed by the spatial behaviour of individual fish or of fish schools encountering his fishing gear, and due to fluctuations in the catchability (q) of this fish.

The variability in daily catches is inferred from a ‘catch frequency distribution’. This distribution is obtained by grouping the catch (C_j) per day (j) and per fisherman into size categories for the catch (e.g. 10-20 kg). Catch frequency distributions for a series of daily catches are mostly positively skewed. These distributions can be characterised mathematically with functions for continuous (e.g. weight) and binomial distributions (numbers). The lognormal as a continuous distribution is commonly used for catch weights in professional fisheries, whereas binomial distributions are used for the numerical catches in sport fisheries and whaling.

Lognormal distribution

The lognormal distribution, which according to Johnson *et al*. (1994) is better called the antilognormal distribution, is in many cases a proper descriptor for these skewed frequency distributions (Fig. 3.10). The corresponding probability (0 ≤ P ≤ 1) function for ln-transformed catches is denoted as:

$$P(C_j) = \frac{1}{\sigma_0 \cdot \sqrt{2\pi}} \cdot e^{-\frac{1}{2}\left(\frac{\ln Cj - \mu_0}{\sigma_0}\right)^2}$$

where μ_0 and σ_0 are mean and standard deviation in the ln-transformed catch (C_j) on day j.

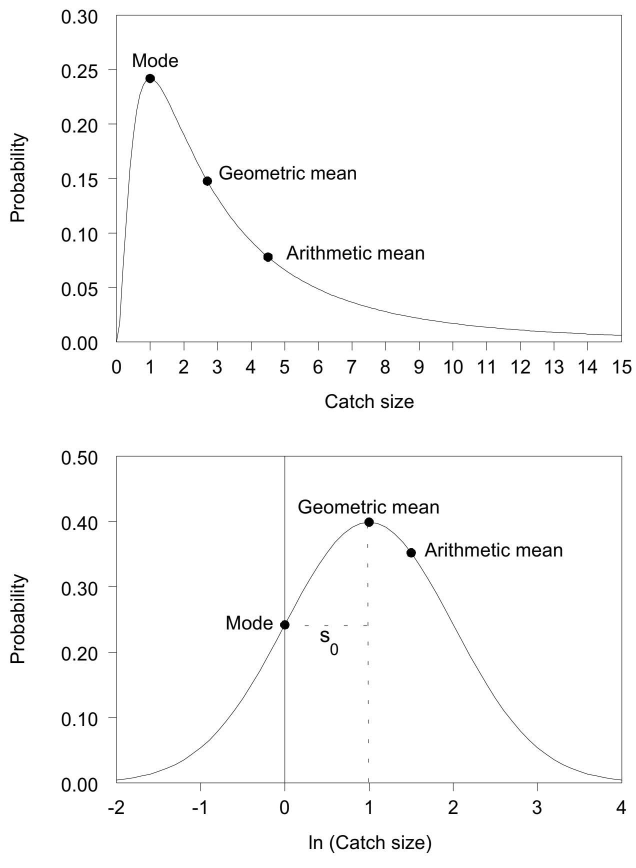


Fig. 3.10 Top: Lognormal distribution describing the probability for a certain size of the da ily catch. Bottom: Probability density function for ln -transformed daily catches. Mean and standard deviation in ln-transformed daily catches here are μ_0 =1 and σ_0 = 1. In the lognormal distribution modal catch size = 1 (= e^0) , geometric mean catch size = 2.7 (= e^1) and arithmetic mean catch size = 4.5 (= $e^{1.5}$) (see text for corresponding formulae).

The lognormal distribution has no value for $C_j = 0$. The modal catch is:

$$C_j = e^{\mu_0 - \sigma_0^2}$$

the geometric mean catch:

$$C_j = e^{\mu_0}$$

and the arithmetic mean catch:

$$C_j = \mu = e^{\left(\mu_0 + \frac{\sigma_0^2}{2}\right)}$$

The variance in this catch frequency distribution is:

$$\sigma_j^2 = e^{\left(2\mu_0 + \sigma_0^2\right)} \cdot \left(e^{\sigma_0^2} - 1\right)$$

For lognormal distributions, as for all other types of distributions, the extent to which catches are distributed over catch size categories - in other words the variability in the catch - can be indexed with a coefficient of variation (CV = σ/μ, denoted with symbol η). Throughout this study CV is used for comparing various types of resource exploitation by their characteristic variabilities. For very small sample size this measure can be adjusted via (Sokal & Rohlf 1983, p. 139):

$$\eta_{adjusted} = \left(1 + \frac{1}{4n}\right)\eta$$

The standard error in the variability measure is:

$$s.e._{\eta} = \frac{\eta}{\sqrt{2n}} \sqrt{1 + 2\eta^2}$$

For example, when $\eta = 0.5$ and $n = 10$, the $s.e._{\eta} = 0.08$.

The CV of a lognormal distribution is determined by the shape parameter (σ_0) of the distribution, being the standard deviation in ln-transformed catches, according to:

$$CV(s) = \sqrt{e^{\sigma_0^2} - 1}$$

For a ^{10}lognormal distribution the CV(s) corresponds with the shape parameter as the standard deviation in ^{10}log-transformed catches (σ_0) according to (Fig. 3.11):

$$CV(s) = \sqrt{e^{2.303\sigma_0^2} - 1} = \sqrt{201^{\sigma_0^2} - 1}$$

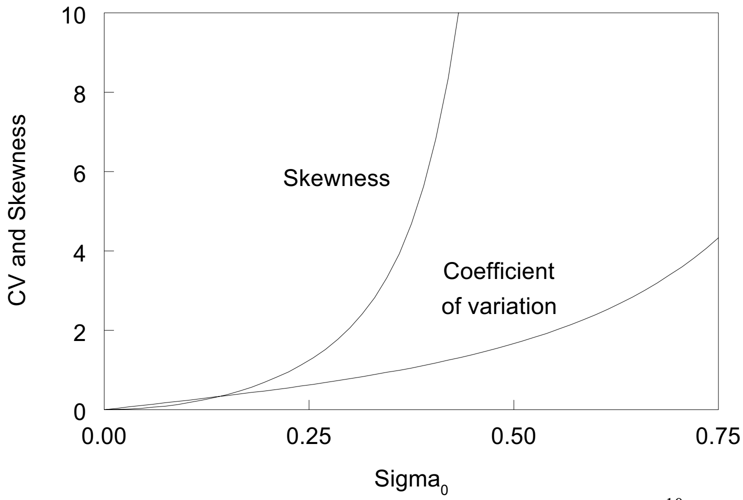


Fig. 3.11 Coefficient of variation (CV, η) and skewness (ζ_1) in the ^{10}lognormal distribution as functions of the shape parameter σ_0.

Basic uncertainty in the catch from one day (C_t) to the next (C_{t+1}) can also be expressed with the average ratio between the two (C_{t+1}/C_t). For the individual fisherman this ratio is a more proxy indicator of his basic uncertainty than intangible statistical measures like the coefficient of variation. To assess the relationship between this ratio and the variability (CV(s)) in a lognormal distribution, the ratio was calculated for 50,000 pairs in random series of 100,000 catches with variability ranging from $s^{10}\log C = 0.1$ to 0.6 with 0.1-intervals, so from CV(s) = 0.23 to 2.40, acknowledging that the ratio must equal 1 for CV(s) = 0 (Fig. 3.12).

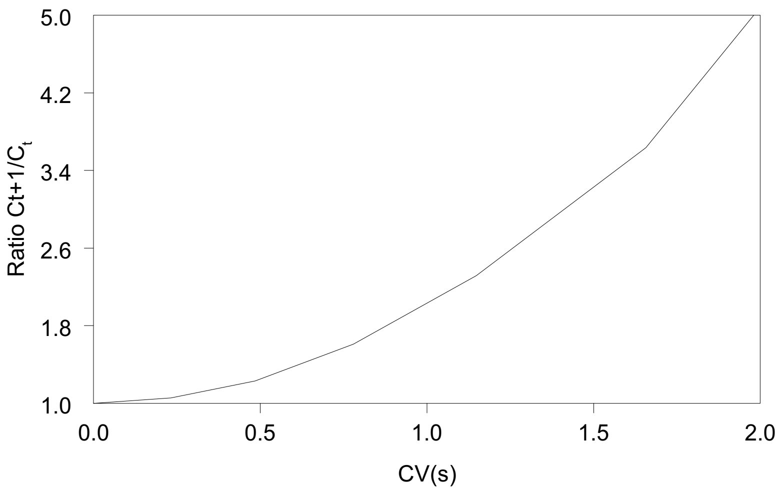


Fig. 3.12. Average ratio in the catch from one day to the next (C_{t+1}/C_t) in relation to the variability in daily catches (CV(s)), where the catch frequency distribution follows the lognormal distribution.

The positive skewness (ζ_1) of a lognormal distribution can be written as a function of its coefficient of variation (η), and thus of its shape parameter (Fig. 3.11):

$$\zeta_1 = \eta^6 + 3\eta^2$$

In a lognormal distribution the frequency of small catches is low. For 0-catch ($C_j = 0$) the lognormal has no frequency, because $\ln C_j$ does not exist for 0-catch. However, in some fisheries 0-catch for a days fishing occurs regularly, and certainly in recreational angling. An option then is to combine the lognormal distribution for non-0 catches only, with the proportion δ (0 ≤ δ ≤ 1) of 0-catches into a so-called delta distribution with a mean, coefficient of variation and skewness for which 0-catches are included (0in):

$$\mu_{0in} = (1-\delta)\cdot\mu$$

$$\eta_{0in} = \sqrt{\frac{\eta^2+\delta}{1-\delta}}$$

$$\zeta_{1_{0in}} = \frac{(1+\eta^2)^3 - 3(1-\delta)(1+\eta^2) + 2(1-\delta)^2}{\sqrt{1-\delta}\cdot\sqrt[2]{(\eta^2+\delta)^3}}$$

Binomial distributions

In sport fisheries catches are mostly scored as numerical catches instead of by weight category. In this respect sport fisheries differ from professional fisheries, and compare with whaling or with the fishery for large tunas, where catches are also scored in numbers. To describe catch frequency distributions from sport fisheries, various binomial distributions have been tried, such as the positive binomial (Cryer & Maclean 1991), Poisson (Cryer & Maclean 1991) and negative binomial (Bannerot & Austin 1983, Kell 1991). The proportion δ of 0-catches, the coefficient of variation and the skewness of these distributions are all functions of the distribution parameters (Table 3.3). When p → 0 the positive and when k → ∞ the negative binomial approaches the Poisson distribution and variability decreases with the average catch ($\overline{C}$) according to $CV = 1/\sqrt{\overline{C}}$ (Fig. 3.13). Actually in all three discrete probability distributions the variability (CV) decreases when the average catch ($\overline{C}$) increases (see Table 3.3).

Table 3.3 Mean, proportion of 0-catches δ, coefficient of variation and skewness as functions of the parameters in discrete probability distributions.

Distribution	Distribution Parameters	Mean (μ)	Proportion of 0-catches (δ)	Coefficient of variation (η)	Skewness (ζ_1)
Positive binomial	N, p	$N\cdot p$	$(1-p)^N$	$\sqrt{\frac{1-p}{p\cdot N}}$	$\frac{1-2p}{\sqrt{Np(1-p)}}$
Poisson	λ	λ	$\frac{1}{e^\lambda}$	$\frac{1}{\sqrt{\lambda}}$	$\frac{1}{\sqrt{\lambda}}$
Negative binomial	μ, k	μ	$\frac{1}{\left(1+\frac{\mu}{k}\right)^k}$	$\sqrt{\frac{1}{\mu}+\frac{1}{k}}$	$\frac{1+\frac{2\mu}{k}}{\sqrt{\mu+\frac{\mu}{k}}}$

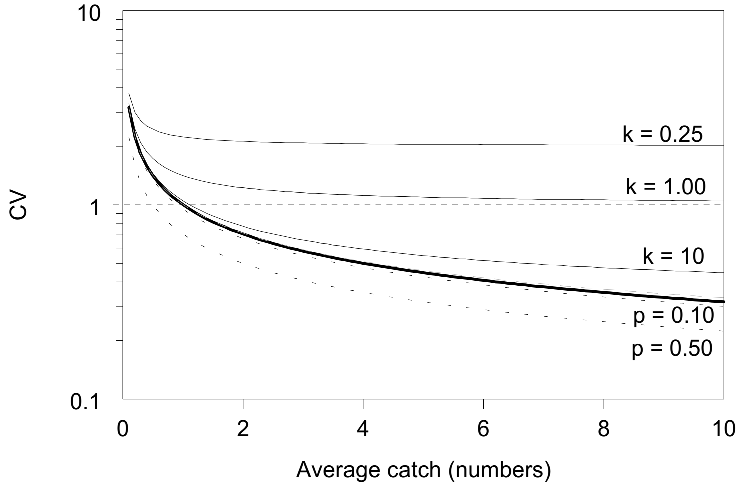


Fig. 3.13 Variability (CV) as a function of the average catch when catch frequency distributions follow different binomial distributions. Bold line - Poisson, Normal line – negative binomial (k), dashed line– positive binomial (p).

When the positive binomial (p, N) is used to describe a catch frequency distribution for daily angler catches, it is assumed that only one fish can be caught during a predefined time interval, for which the probability of capture (p) is a fraction between 0 and 1. This time interval should preferably correspond with the processing time of the angler for catching, landing and preparing for the next catch. Cryer & Maclean (1991) tried the positive binomial and choose a time interval of 15 minutes, but they found that most anglers managed to catch more than one fish per 15 minutes. Therefore they thought the one parameter Poisson distribution (λ) a better description of the catch frequency distribution with many infinite small time intervals ($N \rightarrow \infty$), inferring a very low catch probability per time interval ($p \rightarrow 0$). In ecological studies the two-parameter negative binomial (μ, k) is usually applied for describing spatial patterns on the basis of numbers per unit of sampling effort, a kind of CpUE. The parameter k is in this case a measure for the crowding of individuals (Elliott 1983, Power & Moser 1999).

In the literature on sport fisheries it is common practice to visualise the uneven distribution of numerical catches among individual anglers, and so the variability amongst them, with a Lorenz curve (Fig. 3.14). This Lorenz curve is constructed with the cumulative proportion (p) of the total number of anglers on the X-axis ($0 < p < 1$) and the cumulative proportion L(p) of the total numerical catch as obtained by these anglers on the Y-axis ($0 < L(p) < 1$) (Fig. 3.14). The area between the Lorenz curve and the line for which L(p) = p, in other words the line which would be obtained when all anglers would catch the same amount of fish, is the "concentration area". The ratio between this "concentration area" and the total area under the line L(p) = p, which is equal to 0.5, is the Gini coefficient or Gini concentration index. In formula:

$$G = 1 - 2\int_0^1 L(p)dp$$

In case of a ^{10}lognormal distribution, the Gini coefficient is almost equal to the shape parameter (σ_0) in the range $0 < \sigma_0 < 0.75$, and is independent of the arithmetic mean (μ) in the distribution (Fig. 3.15).

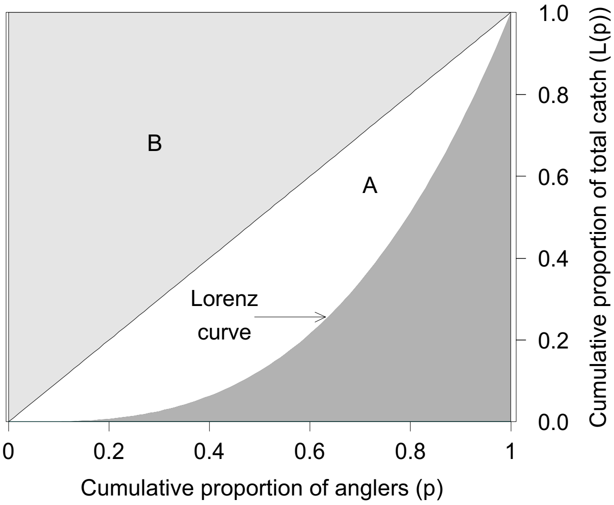


Fig. 3.14 The Lorenz curve with the "concentration area" A. The Gini coefficient = A/B (see text for further explanations).

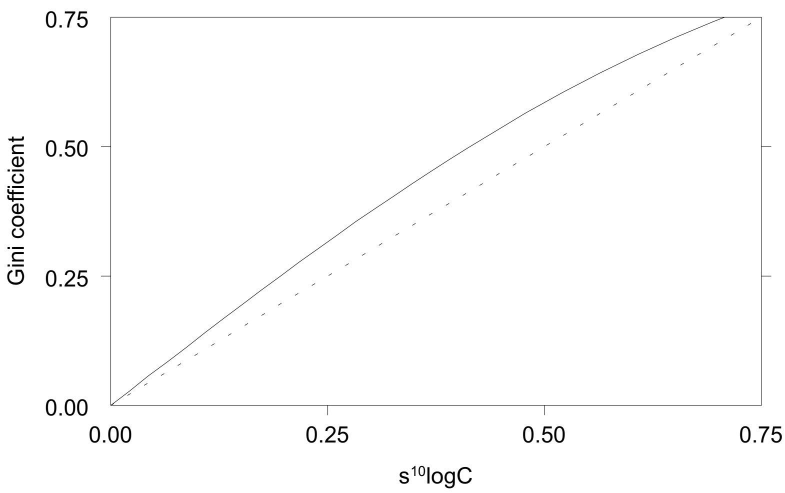


Fig. 3.15 The Gini coefficient as related to the shape parameter σ_0 in the ^{10}lognormal distribution (based on figures in Table A1 in Aitchison & Brown (1957)).

Summarising, the variability in daily catches from a fishery is most easily indexed with the CV, which for lognormal distributions is a function of the shape parameter σ_0 and is independent of the mean catch. Where the series of daily catches contains a proportion δ of 0-catches, the overall CV can be easily calculated from this proportion and the variability in 0-catches. Attempts have been made to capture the numerical catches of sport fishermen in discrete distributions, such as the positive binomial, Poisson and negative binomial distribution, where the variability (CV) is a function of the mean, as is the proportion of 0-catches ($0 < \delta < 1$).

3.4.2 Variance in the catch from month to month

Periodicity in catch rates appears at various time scales, and relates to tides (within days), to moon cycles (within months) and to seasons (within years). Periodicity adds variance to the variance that is already experienced as the basic uncertainty in the catch from day to day. It can be indicated with a multiplier (P_j) for the average catch ($\overline{C}$) per day, month or year, necessary to obtain the actual catch rate (C_j) for time intervals of hours, days and months:

$$C_j = \overline{C} \cdot P_j$$

where P_j has average 1, and is 0 for periods when the fishery is not practiced, for instance during full moon in a light fishery or during winter when certain species are too immobile to be caught in traps. One comes across seasonality as a major type of periodicity in almost every fishery. It is most clearly evident from catches totalled or averaged per monthly intervals.

A representation for seasonality as a gradual development in daily catches over the year is a sinus model for the multiplier P_j with amplitude a and for 365 days per year:

$$P_j = a \cdot \sin \frac{j}{365} \cdot 2\pi + 1$$

The ratio R between the periods with highest and lowest catch rates is related to the amplitude a according to:

$$R = \frac{P_{j_{\max}}}{P_{j_{\min}}} = \frac{1+a}{1-a}\text{, so}$$

$$a = \frac{R-1}{R+1}$$

For the calculation of seasonal variability (CV), the multiplier P_j is calculated for monthly intervals first (Fig. 3.16).

Sometimes seasonality is evident as an abrupt change, with a more sudden shift in catch rates going from the low to the high season and *vice versa*. The multiplier for the annual average then is:

$$P_j = \frac{2R}{R+1} \text{ for the high season and}$$

$$P_j = \frac{2}{R+1} \text{ for the low season}$$

For the shift model the variability (CV) is inferred from:

$$s^2 = \frac{\sum X^2 - n.\overline{X}^2}{n}$$

For high and low seasons of equal duration the mean equals:

$$\overline{X} = \frac{R+1}{2} \text{ , so}$$

$$s^2 = \frac{\frac{n}{2}.R^2 + \frac{n}{2}.1^2 - n.\left(\frac{R+1}{2}\right)^2}{n} = \frac{R^2 - 2R + 1}{4} = \frac{(R-1)^2}{4} \text{ , so}$$

$$s = \frac{R-1}{2} \text{ , and}$$

$$CV = \frac{R-1}{R+1} \text{ (Fig. 3.16)}$$

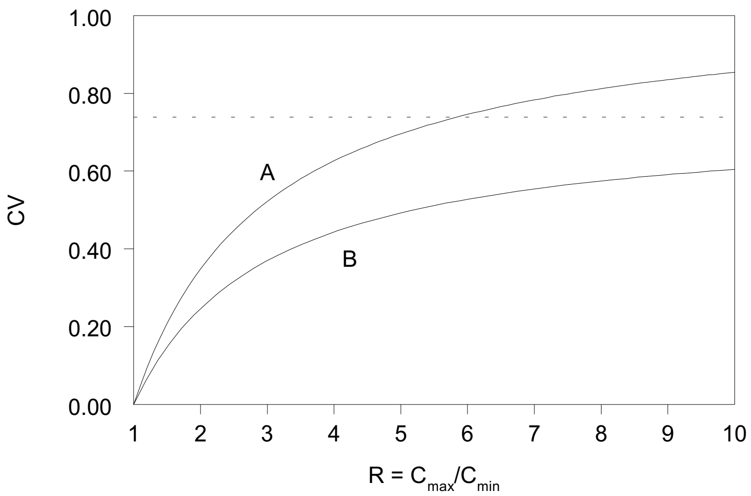


Fig. 3.16 Coefficient of variation (CV) in monthly catch rates according to an abrupt change between two half-year-seasons (A) (shift model) and according to a gradual change (sinus model) (B), both as functions of the ratio R between the maximum and minimum catch rates during the year. In the shift model the coefficient of variation in the average catch rate per month has a maximum of CV = 1, in the sinus model the maximum corresponds with CV = 0.739 (dashed line).

The timing of the seasonality in catch rates mostly relates to the timing of the seasonality in environmental variables, such as water temperature, water level, river flow, vegetation cover etc. Fishermen experience seasonality in their daily catches, but certainly also seasonality in these environmental parameters. The most pronounced and extensive environmental changes are probably experienced by fishermen operating in the seasonally inundated floodplains of large, unregulated rivers with highly unpredictable river flow. To compare different regimes for river flow, Talling & Lemoalle (1998) used two non-dimensional indices: a ratio of the monthly mean river flow to the annual mean river flow, similar to the above multiplier P_j, and a ratio between the highest and lowest monthly mean river flow, similar to the above ratio R. Comparing regimes of discharge for 10 tropical rivers they calculated R-values between 1.7 and 143.

Although largely predictable, there is also a degree of uncertainty in seasonality, because timing and strength (amplitude) may differ between years. The timing of the seasons could be offset from one year to the next. So in a particular year the start of the high season in the fishery, which in many tropical river fisheries coincides with the start of the rainy season, could be either delayed or advanced. Also, the ratio R between the seasonal high and low may differ between years. These inter-annual differences in both timing and amplitude of seasonality as intra-annual variability, add further uncertainty to the basic uncertainty that is already experienced in catch rates from day to day. These differences, however, do not necessarily contribute to the variability in annual catch rates, because theoretically the same total amount of fish may be caught every year. The extent of this uncertainty in the timing and amplitude of the seasonality can be demonstrated by comparing developments in monthly catch rates between years, after correction for the year's averages.

In conclusion, the seasonal variability in a year-round fishery will theoretically seldom be larger than CV = 0.8. But seasonality makes for a more complex world for the individual fisherman. Seasonality implies that fishermen can only compare between years on the basis of catch rates for the same months or seasons. Although seasonality in itself is highly predictable, inter-annual differences in the timing of the seasons and in the ratio between the seasonal high and low in daily or monthly catch rates still add uncertainty on top of the basic uncertainty in the catch from day to day.

3.4.3 Variance in the catch from year to year

After de-trending, in other words after correction for a possible long-term trend in annual catches, a series of residuals remains, of which the variability is expected to be characteristic for that particular fishery. This series will show that next year's catch is generally unpredictable although there might be short-term trends. These short-term trends are caused by serial correlation in the series of residuals and part of the variability is explained by ρ^2. However, it depends on the time window of the series chosen for evaluation, whether such a short-term trend is perceived at all. Too small a time window could make it that only a short-term trend, with relatively small variance around it, is grasped.

Short-term trends cause serial correlation in the residuals around a long-term trend. They could also be of variable duration. Those of shorter duration generally occur more frequently and cause so-called blue noise in the residuals, referring to the periodogram in spectral analysis. More persistent trends of longer duration that occur less frequently cause the more reddish noise in the series, where white noise indicates random variability. See Lundberg *et al*. (2000) for further explanation, especially their Box 3.

Short-term trends in series for the annual catch are due in many cases to the incidental appearance of a strong year-class that dominates the catch for a series of years after its recruitment to the exploited stock. The more persistent ones, of longer duration, are more related to shifts in the whole ecosystem as a result of, for instance, changes in river flow or in oceanic circulation.

Persistence in the annual residuals, however, not only arises from ecological phenomena such as strong year-classes, but could be merely the consequence of fitting a too simple linear or exponential model to a long series with e.g. decades of annual catches. In that case, fitting a model with more parameters seems a logical step (Grainger & Garcia 1996, Fiorentini *et al*. 1997, Baisre 2000). Extending the linear regression model with a quadratic term could alone lead to a better fit with less residual variance and persistence (van Strien *et al*. 1997). However, it depends on the purpose of the model fitting, in combination with the time window under consideration, whether it is appropriate to choose this solution for a more complex model, with the aim of reducing both variance and serial correlation in the residuals.

When the purpose is to estimate inter-annual variability in the really short term, as from one year to the next, fitting a more complex regression model may be appropriate when the time window is large. A more complex model actually leads to another representation of the residual variance due to uncertainty from one year to the next relative to the variance that is due to persistent short-term trends. The inclination to try more complex models for an ever better fit, is counteracted by some analysts, with the consistent application of the Akaike Information Criterion. With this criterion the gain in goodness of fit through the increase in model complexity by adding new parameters is balanced by penalising the addition of each new parameter (Hilborn & Mangel 1997). The wise use of the criterion in cases of time series of annual catch data, however, requires not only statistical considerations but also more subtle ecological knowledge. For instance, in which time window could one expect that trends in annual catch rates become apparent as persistent short-term trends?

In conclusion, variability in de-trended series of annual catches contain uncertainty in catch rates from one year to the next and predictability due to serial correlation in the residuals. Serial correlation or persistence is most probably due to ecological phenomena such as incidental strong year-classes persisting in the catch for a series of years in succession. It depends on the time scale at which persistent short-term trends perform, relative to the full width of the time window, how residuals of a more complex model emphasise either mere uncertainty or persistence as well.

3.5 Decomposing the total variance in catch rates

With an analysis of variance (ANOVA) it is theoretically possible to asses how much these different types of variance in daily catches, including the variance due to the possible long-term trend, contribute to the total variance in the daily catches (Table 3.4). When the factor *year* contributes significantly with SS_y to the explanation of total variance expressed as total sum of squares (SS_{tot}), it, in essence, only tells us that the average catch rate of one or more years differs significantly from the average catch rate in one or more of the other years. Multiple range tests will show which years these are. Whether these inter-annual differences, and which part of them, is due to a monotonous long-term trend over the years, either linear or non-linear, can only be assessed via regression of annual averages against time.

When the factor *month* contributes significantly with SS_m to the total variance in catch rates, this is most probably explained by seasonality. Inter-annual differences in the timing of a season, like a delayed start of the rainy season, could show up from a significant interaction term *year*month*. It relates to the uncertainty in catch rates averaged by month.

The proportion (r^2) of the total variance (total sum of squares) which is explained by the model, thus by significant effects of the factors *year*, *month* and possibly *year*month*, leaves a proportion ($1 - r^2$) of unexplained variance in daily catch rates which is calculated as:

$$1 - R^2 = \frac{SS_{er}}{SS_{tot}}$$

This unexplained variance relates to the basic uncertainty in daily catch rates, as indicated with the coefficient of variation (CV) and as estimated from the Mean Square Error (MS_{er}) in an ANOVA for ^{10}log-transformed daily catch rates via:

$$MS_{er} = \frac{SS_{er}}{df_{er}}, \text{ and}$$

$$CV = \sqrt{201^{MS_{er}} - 1}$$

Time series of daily catches collected for scientific purposes rarely cover a time window larger than one or two years. They therefore only allow for assessing basic uncertainty in catch rates from day to day and for assessing periodicity at a smaller time scale, such as those related to tides and moon phases. For assessing any consistency in seasonality, time series of one or two years are too short.

Table 3.4 ANOVA-table for daily catches recorded during a series of years.

Source	Sum of squares (SS)	Degrees of freedom (df)	Mean square (= SS/df)	F-value	$p_r > F$
Year	SS_y	df_y = N years - 1	MS_y	MS_y/MS_e	From table
Month	SS_m	$df_m = 12 - 1 = 11$	MS_m	MS_m/MS_e	From table
Year*Month	SS_{ym}	df_{ym} = (N years -1)*11	MS_{ym}	MS_{ym}/MS_e	From table
Error	SS_{er}	$df_{er} = df_{to} - df_y - df_m - df_{ym}$	MS_{er}		
Corrected total	SS_{to}	df_{to} = N daily catches - 1	MS_{to}		

Where total variability in daily catches is only governed by day to day variability as basic uncertainty (CV_1) and by variability due to seasonality (CV_2), overall variability (CV) can be obtained from:

$$CV = \sqrt{CV_1^2 + CV_2^2}$$

This is inferred from the summing of variances for uncorrelated (r = 0) variables with the same average (x) (Sokal & Rohlf 1983, p. 573):

$$\frac{s^2}{x^2} = \frac{s_1^2}{x^2} + \frac{s_2^2}{x^2} + \frac{2rs_1s_2}{x^2}$$

3.6 Variability reduced after data aggregation

Aggregation means summing catches per species into totals or averages for longer time intervals or for larger spatial entities. It generally brings about less variability and this enhances statistical power to perceive time trends. At the same time the number of observations reduces and this in contrast weakens statistical power. In the following sections variability reduction is elaborated on for aggregation over larger time intervals (3.6.1), over larger spatial entities, with sometimes additional spatio-temporal variability (3.6.2), and over catch categories (3.6.3), after which conclusions are drawn (3.6.4).

3.6.1 Aggregation through time

If all individual daily catches for one particular species belong to the same catch frequency distribution and are independent, there is a monotonous and predictable tendency towards lower variability in the totals or averages calculated for aggregated data. Basically, aggregating or averaging daily catches per species into new catch frequency distributions produces new, more narrow and ever less positively skewed, so more normal frequency distributions (see also Box 3.2).

The averaging of catch rates over fixed time intervals parallels the calculation of sample averages for samples of the same size, taken repeatedly from any particular distribution. According to the Central Limit Theorem, the distribution of such sample averages approximates a normal distribution when sample size is large enough. Irrespective of the character of the starting or mother distribution, after aggregation over fixed time intervals the number of observations becomes A times smaller but the variability in the resultant distribution reduces according to:

$$CV_A = \frac{CV_1}{\sqrt{A}}$$

where A = number of successive, but independent daily catches aggregated for new totals or averages, and CV_1 = coefficient of variation in the starting or mother distribution of daily catches. So for weekly totals or for catch rates averaged per week the variability indicated with coefficient of variation (CV) reduces by a factor 2.6 (= $\sqrt{7}$). Also irrespective of the character of the starting distribution, the proportion of 0-catches ($0 < \delta < 1$) reduces according to:

$$\delta_A = \delta_1^A$$

As mentioned earlier the lognormal distribution is commonly used to describe catch frequency distributions of daily catches. Aggregation within a series of daily catches, which all belong to the same lognormal distribution with shape parameter σ_0, results into a new lognormal catch frequency distribution, now with a smaller shape parameter (σ_{0_A}) according to:

$$\sigma_{0_A} = \sqrt{\ln\left(\frac{\eta^2}{A}+1\right)} = \sqrt{\ln\left(\frac{e^{\sigma_{0_1}^2}-1}{A}+1\right)} \qquad (3.6)$$

where the subscript 1 for σ_0 refers to the shape parameter of the starting distribution (A = 1). To assess the combined effect of the reduced number of observations and of the lower variability in catch rates on the statistical power for trend perception, one should take a look at their expression in equation 3.3. The t_β -value from which statistical power can be estimated changes after data aggregation according to:

$$t_{\beta,\nu} = b \cdot \sqrt{\frac{\left(\frac{n}{A}\right)^3 - \frac{n}{A}}{12\ln\left(\frac{e^{\sigma_{0_1}^2}-1}{A}+1\right)}} - t_{\alpha,\nu}$$

This formula implies that statistical power (1 - β) decreases monotonically with increasing aggregation level (A), the extent of which can be read in Fig. 3.17.

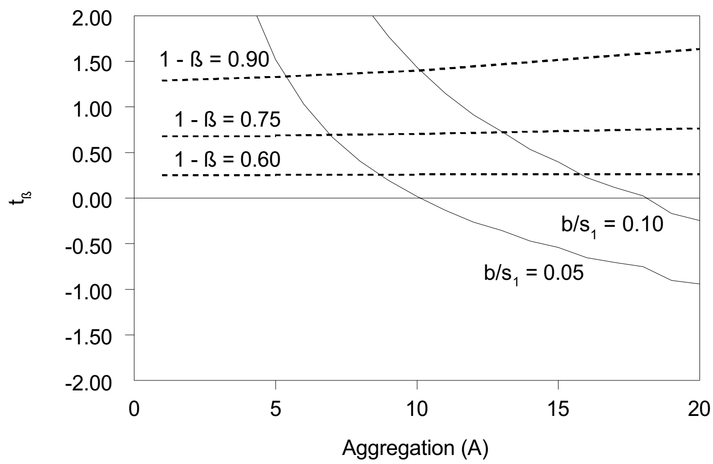


Fig. 3.17 Development in the value of t_β related to the statistical power (1 - β) for trend detection after data aggregation in a series of 100 observations equally spaced in time for which the trend to noise ratio b/s = 0.05 or 0.10.

Any data aggregation over more than one statistically homogenous time stratum leads to another course in variability reduction than the simple reduction sketched above and formulated with $CV_A = CV_1/\sqrt{A}$ (Fig. 3.18). Take for instance a light fishery in which the catchability of the fish is influenced by the moon cycle with lowest catches during full moon (Fig. 3.18). This leads in its most simple form to a series of daily catches as a succession of 14 days periods with high (new moon) and low catches (full moon). The variability in the non-aggregated series of daily catches with periodicity due to the moon cycle will initially be larger than in a series with mere, although the same, basic uncertainty. But once the aggregation level surpasses the duration of the periodic moon cycle, so when A > 28, the variability reduction due to further data aggregation will follow the same course as in the non-periodic series (Fig. 3.18).

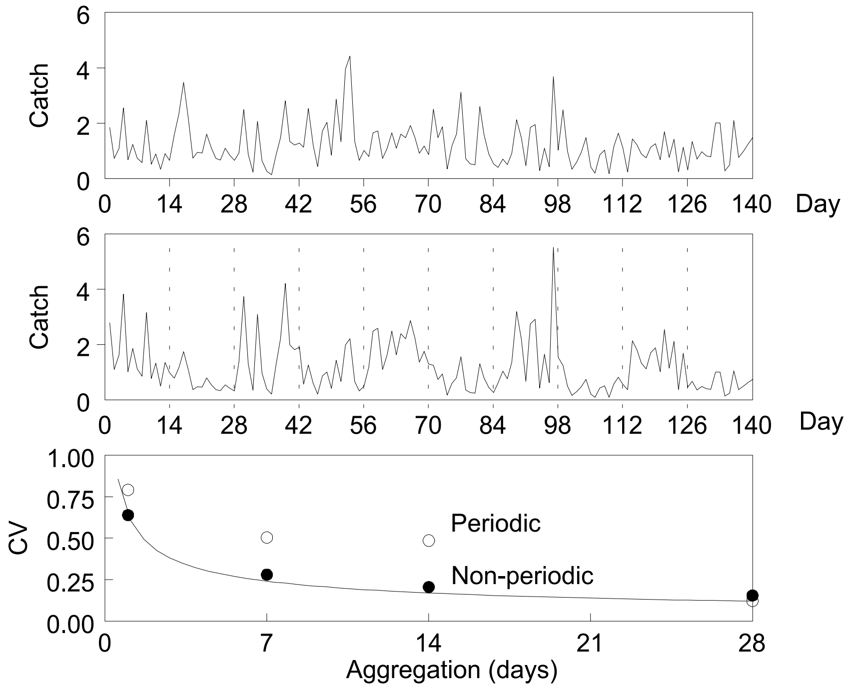


Fig. 3.18 Variability reduction in two series of daily catches. Upper: a series of daily catches with variability due to basic uncertainty without periodicity (GM = 1, s $^{10}\log C$ = 0.25, CV(s) = 0.64), Middle: a series with the same basic uncertainty but now with 14 days periods with high (*1.5) and low (*0.5) catches, Lower: Variability reduction after data aggregation in the non -periodic series (closed symbols) and in the periodic series (open symbols). The cur ve indicates variability reduction according to $CV_1/\sqrt{A}$.

3.6.2 Aggregation through space

Now fisheries statisticians not only aggregate catch data through time, but also through space. First, aggregation of all catches of a particular species obtained at a particular day by all fishermen fishing with the same gear in one and the same resource space, generally leads to the same reduction in variability as when aggregating daily catches of one fisherman throughout time ($CV_A = CV_1/\sqrt{A}$). The premises are that all catches are independent and belong to the same statistical population (stratum). In the presence of spatial distribution patterns of the fish, the variability reduction due to spatial aggregation, starting from the finest grid with variability CV_1, would develop in a similar way as with aggregation in a time series with temporal patterns. In spatial aggregation it is the larger spatial entity encompassing the smaller spatial patterns, that dictates the junction point with a predictable, common development in variability reduction with increasing spatial aggregation thereafter (*cf.* Elliott 1983).

How exactly inter-annual variability reduces in the process of spatial aggregation can be assessed empirically by evaluating time series of catch data for successively larger administrative spaces. It will then turn out that at some steps in the process of data aggregation for ever larger spatial entities variability reduces more strongly than at other steps. These irregularities in variability reduction can be interpreted as important changes in the character of the areas for which data are aggregated then. The diagnostic use of these irregularities resembles that of irregularities in marginal variance reduction functions for aggregating daily river runoff into ever larger time intervals (Torfs & Middelkoop 1996).

To exemplify the above for a fisheries situation we start with a small lake and successively enlarge the administrative space for which catch data are aggregated. The small lake is the one 'ecospace' to which a particular fish stock is confined. In this lake all fishermen are free to move around and are mobile enough to set their nets at every site in the lake. The fishermen most probably will experience the same inter-annual variability in their catches and strong co-variance as well (Figs 3.19 and 3.20). Although the average annual catch may differ between individual fishermen, as due to differences in the size of their boat or their personnel skill, this still not necessarily affects the extent of the inter-annual variability as experienced by each fisherman, nor the co-variance in their annual catches. Most important, aggregating and averaging annual catches here does not lead to a reduction in inter-annual variability for the lake as a whole.

Even when the fishermen in the small lake are nòt free to move around and where each fisherman is assigned his own resource area, the variability could be the same for each of them and the co-variance in their annual catches will still be high. This is the case where either the spatial distribution of the fish is homogenous or where fish distribution patterns exist but do not change from one year to the next. In these situations annual catches will only differ between fishermen and within years, due to their more or less profitable fishing location. But the annual catch of each of them would still change with the same proportions over the years. Once again, there is no variability reduction and so no 'administrative gain' in this respect after data aggregation.

Now, once fishermen in the same small lake situation operate in their own individual resource area ànd the fish distribution pattern changes from one year to the next, the variability in the annual catches aggregated for the whole lake will be less than that for each individual fisherman. Here each fisherman experiences a common inter-annual variability due to changes in stock size but, in addition, with individual variance due to the redistribution of fish in addition. Such changes in the spatial distribution of the fish could arise from changes in environmental parameters, like water temperature or transparency, which govern this distribution or from young and old stages of the same species residing in different habitats within the lake. In the latter case a strong year-class growing through the population, will then cause spatio-temporal variability in the availability of fish biomass throughout the lake.

The 'administrative gain' of lesser inter-annual variability in aggregated data is reduced again, when fishermen fish randomly throughout the whole of the lake, or know how to respond via their effort allocation on the unpredictable changes in the spatial distribution of fish. The responding behaviour is known to exists at the smaller spatial and temporal scale, where fishermen search continuously for locations with higher fish densities and their fishing operations spread according to the "Ideal free distribution", an ecological concept applied in fisheries science (Gillis *et al*. 1993). At the larger spatial and temporal scale fishermen target spawning concentrations of fish. In these cases the CpUE becomes a poor indicator of changes in stock size (Gillis & Peterman 1998). The variability in annual catches of individual fishermen can become smaller even than the inter-annual variability which the authorities infer from fishery-independent estimates of stock size like larval or echo surveys. Overall, situations with dynamical patterns in the spatial distribution of fish and of fishing activities, are probably the more realistic ones.

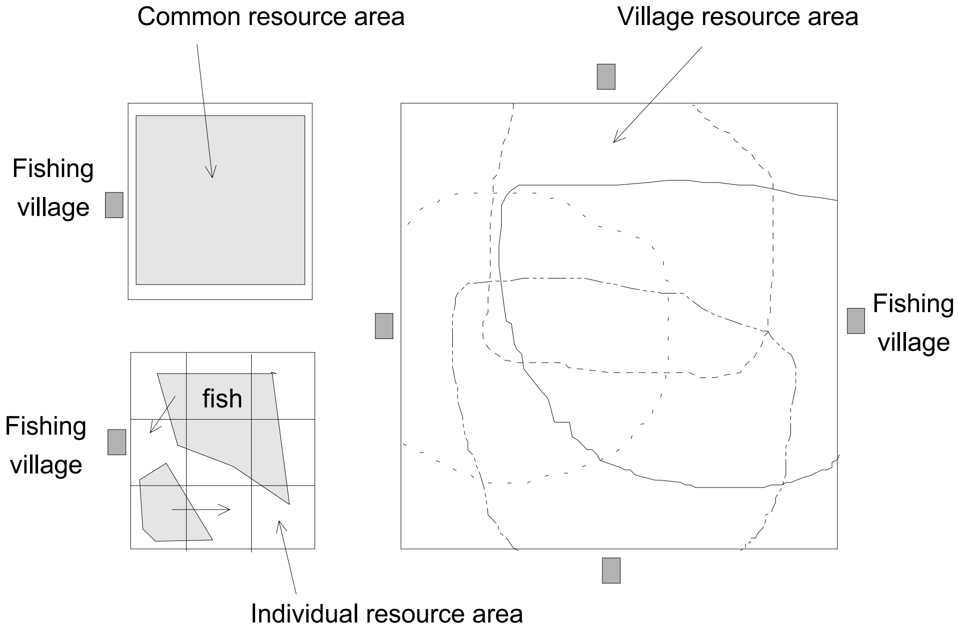


Fig. 3.19 Spatial distributions of fish and of fishing activities. Top-left: Small lake, which is the common resource area of all fishermen in the fishing village. Bottom-left: Small lake with 9 fishermen assigned a fixed individual resource area each, and spatial distribution patterns of fish which could change from one year to the next. Right: Large lake with 4 fishing villages, from where fishermen exploit the lake population as available in their own village resource area.

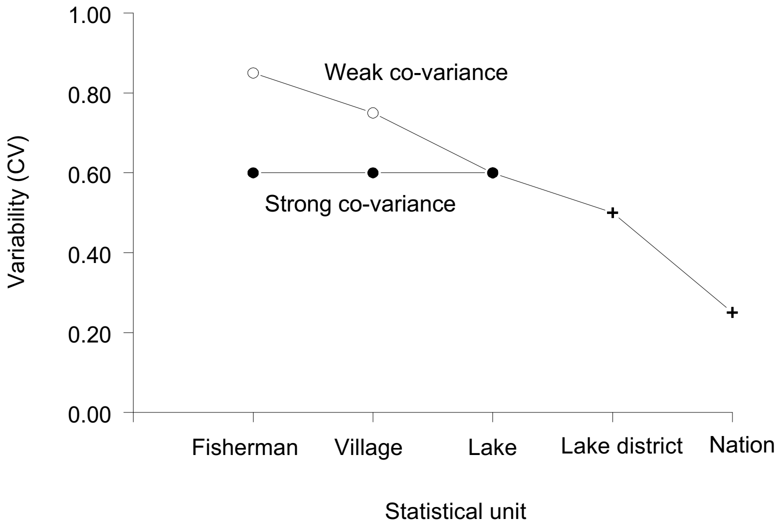


Fig. 3.20 Theoretical representation of the reduction in inter-annual variability in average catch rates with increasing size of the statistical unit for which catch data are aggregated. Closed symbols: strong co-variance in annual catch rates in a lake with a consistent pattern in the spatial distribution of fish and of fishing activities. Open symbols: weak co-variance in annual catch rates in a lake where spatial distribution patterns of fish change from one year to the next.

Next comes aggregation of annual catches throughout the administrative space of a large lake, which corresponds with an ecological space again, and which is bordered by a number of fishing villages. Suppose fishermen from each village exploit the fish in the village resource area, which areas have some overlap (Fig. 3.19). If the fish is completely homogeneously distributed, it would result, once again, in strong co-variance between annual catches at three administrative levels, now: fisherman, fishing village and the lake as a whole. In that case inter-annual variability would hardly decrease, going from one administrative or aggregation level to the next: from individual fisherman to fishing village, to the whole lake. Hence, capacity for trend perception in as far as inter-annual variability in the catch is concerned, also would not improve from one administrative level to the above.

But when in the larger lake patterns in fish distribution do exist and change from one year to the next, there will be a reduction in inter-annual variability in the time series of aggregated catch data, which brings an 'administrative gain' in trend perception for the authorities. The mechanism is similar to the small lake situation with individual resource spaces and changing distribution patterns. Only the spatial scale is larger now.

Further spatial aggregation in ever larger administrative spaces, comprising more than one distinct ecospace, most certainly brings about a reduction in inter-annual variability. The mechanism behind this reduction is different from that in the lake example, and has to do with summing resource outcome for units which outcome varies independently through time. Where the fisheries administration for instance, groups a series of lakes situated in a 'lake district', into one administrative space or statistical unit for which data are aggregated, co-variance in annual catch rates between lakes probably are weak. Inter-annual variability in annual catches averaged for the whole of this 'lake district' will be smaller than per lake, because of what could be considered a 'portfolio effect' (Bernstein 1996).

The concept of the 'portfolio effect' was formalised in a recent debate on the stabilising effect of biodiversity on total resource outcome, referring to the advent of a more diverse investment strategy at the stock market (Doak *et al*. 1998, Tilman *et al*. 1998, Lehman & Tilman 2000). The formalisation starts from the general relationship between variance (s^2) and average (x) with constants a and b:

$$s^2 = a \cdot x^b,$$

from which it can be inferred that variability (CV = s/x) relates to the average according to (see also Tilman *et al*. 1998):

$$CV = a^{1/2} \cdot x^{(b-2)/2},$$

which is constant for b = 2. For numerical densities in ecology and agriculture the exponent is around 2 and seldom smaller than 1 (Taylor *et al*. 1988). The variance in the total for n series with the same average (x/n) each and without co-variance between the series then is:

$$s_{tot}^2 = n \cdot a \cdot \left(\frac{x}{n} \right)^b,$$

and variability:

$$CV_{tot} = a^{1/2} \cdot x^{(b-2)/2} \cdot n^{1-b/2}$$

Variability reduction or stabilisation after aggregation then occurs when $CV_{tot}/CV < 1$, where:

$$\frac{CV_{tot}}{CV} = n^{1-b/2}$$

and thus when b > 1. Due to the portfolio effect as it generally occurs, the capacity to perceive a possible trend in catches for the 'lake district' as a whole increases, because variability reduces. However, the information value of catch data aggregated for larger administrative spaces, encompassing several ecological spaces, is less because the fisheries management will not be able to read whether some of the stocks are seriously on the decline.

Some co-variance in the annual catch rates from the distinct lakes in the lake district may still occur as due to weak synchronisation in the annual fluctuations in fish stock biomass. This may arise, where summer temperature is the major factor governing the numerical strength of a year-class (Lehtonen & Lappalainen 1995, Lappalainen *et al*. 1996). But strong synchronisation in the ultimate annual catches, so strong co-variance, is still unlikely, because of the uniqueness of each particular lake, its fish community and its fishery. These lake-specific factors lead to lake-differential survival and individual growth of the same year-classes and thus to the loss of synchronisation in biomass development per lake.

Lakes and lake districts were taken as examples for which the consequences of data aggregation through ecological and administrative spaces could be explained most clearly. In the marine environment aggregation of catch data through increasingly larger administrative spaces should essentially lead to the same reduction in annual variability, where stock behave independently. The management-relevant ecospaces in the large and more open marine environments, however, are generally harder to identify and to delineate than in case of the lake situations. The difficulties with stock identification and distribution areas of marine species are already large, those having to do with the spatial distribution of sub-units of the same stock, where each sub-unit may have its own spawning area are even larger (Begg *et al*. 1999, Stephenson 1999).

3.6.3 Aggregation over catch categories

Fisheries statisticians aggregate catches through time and space, and across gear and catch categories. In a Catch and Effort Data Recording System gear categories (e.g. trawls, gillnets, seines etc.) are often identified as strata, each with a distinct catch frequency distribution. As with temporal and spatial strata, means and variances are combined so to estimate a total catch and the variance therein (Caddy & Bazigos 1985).

More general is that fisheries statisticians aggregate or, better, accumulate catches over catch categories, mostly species, into a total catch for a new category. This accumulation process results into totals or averages for ever broader catch categories, e.g. from herring *Clupea harengus* → clupeids → pelagics → marine fish → fish. So the categorisation is not necessarily by Linnean grouping of species, but could be based on ecological (e.g. demersal, riverine) and on user-oriented grouping (e.g. industry fish, size grade, price grade) as well.

The fishing on several species at a time brings about the welcome reduction of variability in a fisherman's catch and thus income. The explanation is that when the daily catch per species fluctuates randomly and catches per species do nót co-vary, the variability in the total catch for species combined is reduced because of the 'portfolio effect' (see under 3.6.2). When there is co-variance in the daily catch per species for a fisherman, this suggests either spatial association of the different fish species or that the catch per species is subject to an overriding effect of day to day changes in catchability, as for instance related to wind action or water transparency.

The 'portfolio effect' must be effective as well in case of the total annual catch as an accumulation of the annual catches per species. The reason is that the inter-annual variability in the stock size per species is seldom if ever synchronized. So multi-species fisheries are profitable because of the stabilisation effect, and specialisation sometimes imposed by the fisheries management, is thought harmful even for the sustainability and survival of fishing communities (Hilborn *et al*. 2001).

In accumulating catches into broader catch categories, we loose management-relevant resolution in the catch data, which is necessary to perceive possible alarming trends in catch rates per species. The total catch for species combined may perform weaker trends with a slow, but continuous shift towards smaller species and sizes in the catch (Fig. 3.21). These species and size categories are sequentially exploited and over-exploited, using ever smaller mesh sizes to catch smaller and more productive species (Welcomme 1999). More productive is meant here as having a higher biological production per unit biomass (see also Box 2.1). In these situations the average size of the fish in the catch, all species combined, is possibly a more easy to use indicator for resource quality than is Catch per Unit Effort, where effort is not corrected for the changing selectivity of the gear (Pauly *et al*. 2001).

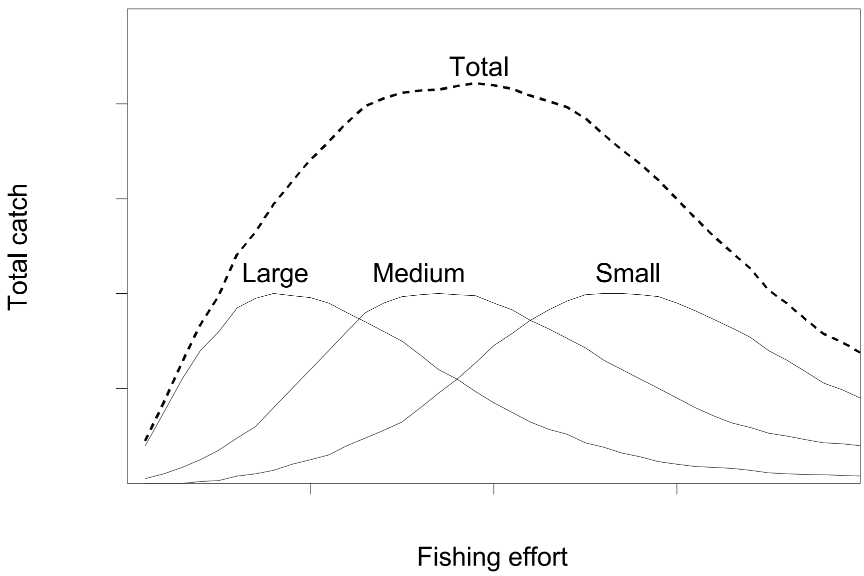


Fig. 3.21 Successive exploitation of ever smaller and less -valued fish species using fishing gear with ever smaller mesh sizes. Total catch remains more or less constant.

Aggregation across catch categories and for ever larger administrative spaces, which trespass national and supra-national boundaries, ends with the total world catch for all gears and catch categories combined (Fig. 3.22). Inter-annual variability in de-trended global landings of fish is small, as small as the variability in the global production of cereals (CV = 0.03) (see Chapter 8).

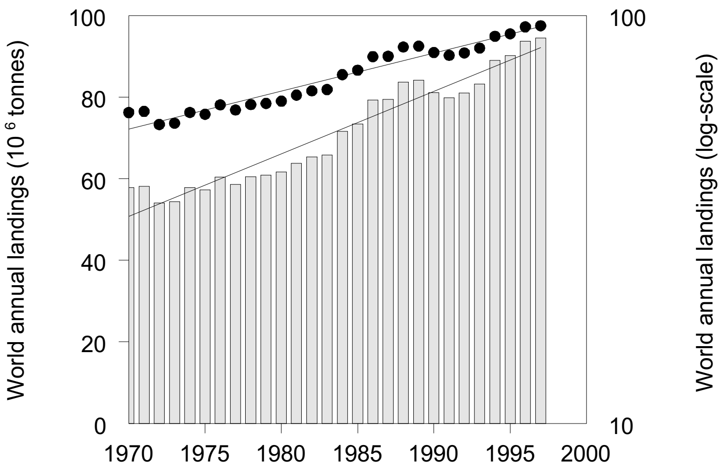


Fig. 3.22 World annual landings of fish, totalled for marine and freshwater, in 10^6 tonnes. Bars: untransformed landings, left Y-axis; Dots: ^{10}log-transformed landings, right Y-axis. The standard deviation in the residuals before and after ^{10}log-transformation is sd = 3.44 and $s\,^{10}\log C$ = 0.0197, corresponding with inter-annual variabilities of CV = 0.048 and CV(s) = 0.030 respectively. There is clear serial correlation in the residuals of the detrended series. Data from www.fao.org

3.6.4 Conclusion on variability reduction after data aggregation

Aggregation of catch data within one time or space stratum results in a smaller variability (CV) in the aggregated data but due to the lesser number of observations into lower statistical power still. Aggregating and averaging annual catches per fisherman and species through one small ecological space, such as a small lake, is expected not to lead to a reduction in inter-annual variability and thus also not to a clearly better perception of possible long-term trends by the authorities, when only variability matters. Once there is additional variability in the annual catch for each fisherman because of inter-annual changes in the large-scale distribution of the fish, an 'administrative gain' can be expected because of a reduction in inter-annual variability after data aggregation for the whole of the resource area. Spatial aggregation of catch data over ever large administrative spaces, encompassing several distinct ecospaces, is expected to lead to a marked reduction in inter-annual variability due to the portfolio effect when summing the outcome of units which vary independently through time. The information value of these aggregated data for fisheries management, however, lowers as they are not stock-specific anymore. All the more so when at the same time catch data per species category are accumulated into broader catch categories, resulting in variability reduction as well.

3.7 Questions per chapter

The three major questions formulated at the end of Chapter 2 were:

1. *Which trends and step trends are just detectable, given the sometimes high inter-annual variability in resource outcome?*
2. *What are the reasons for the greater capacity of the authorities ('administrative gain'), compared to that of individual fishermen, to perceive true trends and step trends in resource outcome?*
3. *How to improve on the perception of time trends, in co-management situations in particular?*

Fishermen experience variability in catch rates from day to day, form month to month and form year to year. In **Chapter 4** an attempt is made to assess possible consistent differences in the variability in the catch from day to day ('basic uncertainty') between four different fishing modes: trawling, gillnetting, light fisheries and sport fisheries. It is expected that basic uncertainty is high in small-scale tropical fisheries with light attraction, targeting schooling pelagics but operating from fixed stations without fish finding devices to locate concentrations of fish. In contrast, basic uncertainties are expected to be small in technically advanced, highly mobile trawl fisheries for non-schooling demersals, taking several hauls a day at different sites. Passive types of fisheries such as gillnetting and angling are expected to show intermediate variability. Part of the day to day variability in catch rates for the fishery as a whole may be due to personal skill, which is expected to vary more between sport fishermen than between professional fishermen (Hilborn 1985). That is why in the section on sport fisheries particular attention is given to angling skill as a possible explanatory variable for the variability between anglers.

The questions for Chapter 4 are:

- *Does scaling of basic uncertainty by the coefficient of variation reveal distinct ranges in basic uncertainty per fishing mode: trawling, gillnetting, fisheries with light attraction and angling?*
- *To what extent is variance in individual catches of anglers the result of basic uncertainty and to what extent of personal angling skill?*

Seasonality leads to variability in catch rates from month to month and is a second source of variability around possible long-term trends in catch rates. In **Chapter 5** a number of fisheries are analysed for the extent of their seasonality and, for consistency, in seasonality from one year to the next. Seasonality in fisheries, which are driven by hydrological regimes, are expected to be more or less consistent from one year to the next depending on the predictability of the hydrological regime.

The questions for Chapter 5 are:

- *How and to what extent does seasonality add to the variability in daily catch rates as experienced by individual fishermen in the long-term?*
- *Can the consistency in the seasonal pattern in catch rates be inferred from the consistency in environmental seasonality, where fisheries are driven by a hydrological regime?*

The variance in annual catch rates has three components: a possible long-term trend, unexplained variability in the residuals around that trend (white noise), and persistent short-term trends in these residuals (blue or red noise). In **Chapter 6** an array of fisheries situations is analysed for possible long-term trends (b) in annual catches or catch rates, for the variability around these trends (s) and for the signal-to-noise ratio in these trends (b/s). The coloured noise in the residuals around the long-term trend, which constrains perception further, is discussed from a population and an environmental point of view. From the inter-annual variability as assessed for various fisheries it is inferred which trends and step trends can be perceived and in which time window under the decision levels of $\alpha = \beta = 0.1$.

The questions for Chapter 6 are:

- *How to scale fisheries on the basis of inter-annual variability in catch rates and what proportion of that variability can be explained from short-term persistence (coloured noise)?*
- *Which trends and step trends can be perceived in what time window under conditions set by decision levels for α and β, given variabilities in annual catches?*

Long-term trends are more clearly perceived in larger time windows, with less variance around the trend, and with a greater risk (α) taken that one concludes for a trend where there is none. Chapter 7 discusses why these traits generally differ between authorities and fishermen and so lead to a differing capacity to perceive true trends. Following that, how to improve on the evaluative capacity of fishermen and how authorities could anticipate the discussions on developments in resource outcome in co-management situations, is discussed on the basis of the same traits,.

The questions for Chapter 7 are:

- *What explains the 'administrative gain' of the authorities in trend perception in view of their larger time window, smaller inter-annual variability and the larger critical value α they select? How does this critical value α relate to the application of the "Precautionary approach" in resource use?*
- *Which activities of both fishermen and authorities contribute to a more balanced capacity in trend perception in co-management situations?*

All those who exploit or manage natural resources will evaluate the effectiveness of the management measures from trends and step trends in resource outcome. As much for fishermen as for farmers, it can be maintained that such evaluations are affected by the inter-annual variabilities around these trends. Farmers, more than fishermen, are capable of reducing the dependence of their resource outcome on the impact of environmental variability, through tillage, sowing practices and irrigation. In **Chapter 8** inter-annual variability in crop production is assessed for various types of crops and agricultural systems at various spatial scales, from the sub-field level for one particular crop up to the global production of all cereals combined. As in fisheries, data aggregation into larger statistical areas is expected to lead to a reduction in variability ('portfolio effect') and thus to a greater capacity for the administration to perceive long-term trends in crop yields such as those resulting from soil degradation. Intra- and inter-annual variability in rainfed crop production in dryland areas is related to the variability in rainfall at various spatial scales. The same assessment of variability in resource outcome and the same linkage with variability in rainfall is made for forage production and for milk yield from the nomadic herds on the common meadows in the drylands of East-Africa. Finally the insecurity of resource outcome experienced by farmers is compared to that of fishermen.

The questions for Chapter 8 are:

- *How large is inter-annual variability in crop production at field level as experienced by the individual farmer, going from the rainfed crop production in the most marginal areas of the Sub-Sahel to the highly controlled types of crop production in temperate zone agriculture? How does variability in resource outcome of nomadic herds compare to this?*
- *How large is the variability in crop production between fields, how important is the spatial variability in rainfall therein and how does variability in annual crop production reduce after data aggregation into ever larger statistical areas?*

Chapter 9 discusses the perception of time trends in resource outcome in the 17th and 18th century when neither graphical representation of time series, nor the quantitative assessment of inter-annual variability in resource outcome, existed. The intra-annual variability in the catch of bowhead whales between individual whalers and the inter-annual variability in the catch per whaler for the Dutch fleet operating near Spitsbergen as a whole, are assessed from the contemporary, meticulously recorded catches. The Spitsbergen stock of bowheads was exploited, over-exploited and finally exterminated in the period from around 1600 to 1900. Whether, and how clearly, this depletion could have been experienced by an individual whaler from his own catch record and by the administrators in the Netherlands from their listings with annual averages ('administrative gain'), depends on the intra- and inter-annual variabilities. Historians have already pointed out a particular investment strategy used in the whaling industry, in response to the very high variability of catching success, which is comparable to a lottery.

The questions for Chapter 9 are:

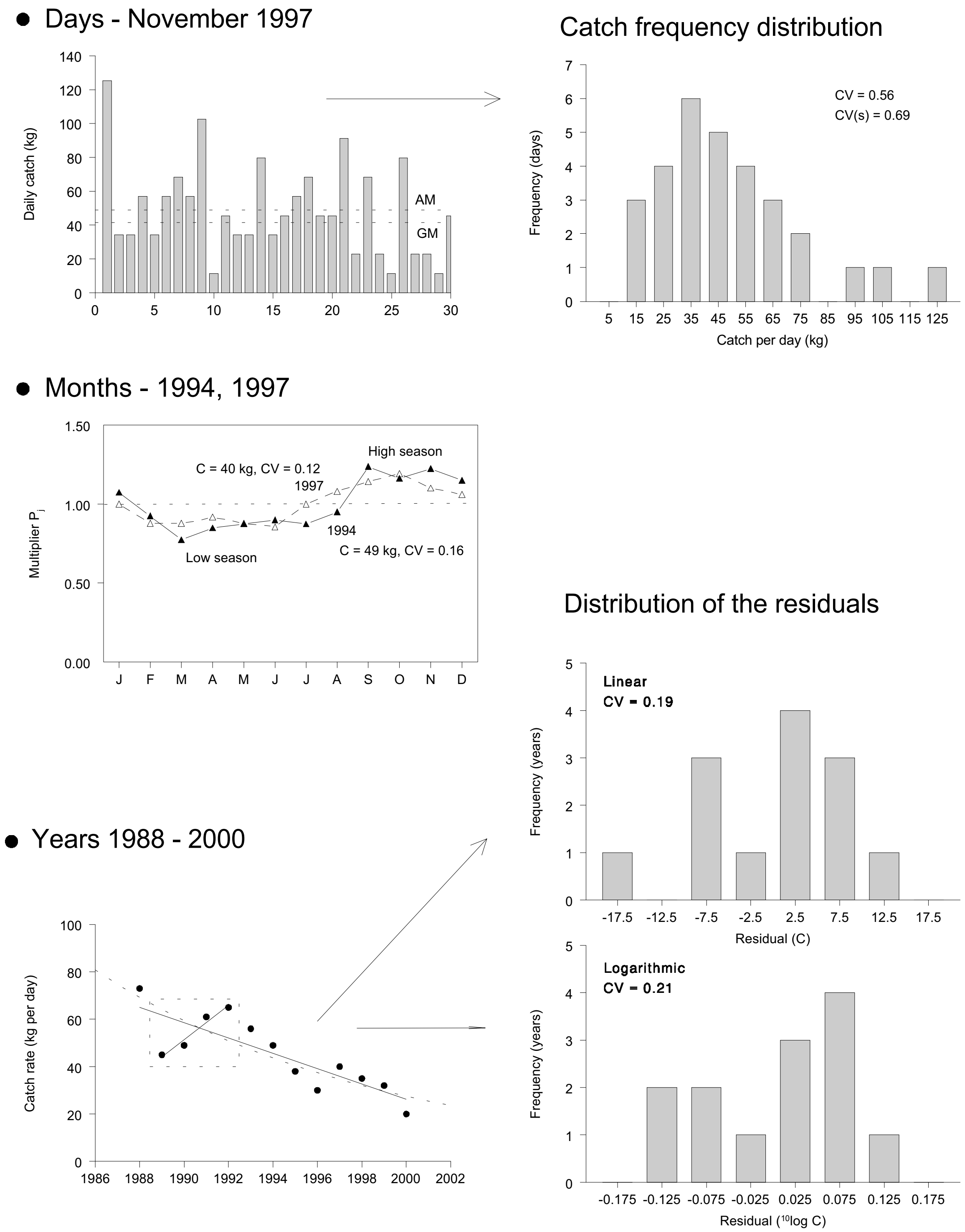
- *How large was the intra-annual variability between individual whalers in the number of whales caught during their circa 5 month trips to the Arctic? What part of this intra-annual variability was perhaps explained by individual differences in whaling skill?*
- *How large was the inter-annual variability in de-trended series of average catch per whaler, and were there any short-term trends that might have obscured the possible long-term trend in catch rates due to stock depletion?*
- *How large was the 'administrative gain' for the administrators in the Netherlands in aggregating and averaging catch rates per individual whaler in time windows that were several times larger than the career of an individual whaler in this fishery?*
- *How could the complete lack of capacity to evaluate time trends with the aid of graphical representation, statistics and probability theory, have constrained the perception of any long-term downward trend in the stock of bowhead whales in the 17th and 18th century?*

In **Chapter 10** conclusions are drawn as to the consequences for public proof of wise and efficient management, of the sometimes poor perception of trends and step trends, and of the difference between resource users and authorities in this respect. This touches on the power of governance as affected by the character of the resource.

Box 3.1 - Variabilities in catch rates in three time windows

The total variability in daily catch rates that a fisherman experiences throughout the years is composed of three types of variability, which are described in the example below.

1. In the smallest time window of one month, November 1997, the random variability in the catch from day to day for one particular fisherman, that is, his 'basic uncertainty' is CV = 0.56. It is CV(s) = 0.69 if one assumes that the positively skewed catch frequency distribution follows a lognormal distribution, and the coefficient of variation is inferred from the shape parameter σ_0 therein.
2. In the time window of one full year the variability in the catch from month to month, as averaged for the fleet as a whole, is governed by seasonality. The exact shape of the seasonality differs between years (1994, 1997) and this adds randomness to overall variability in catch rates. If the monthly series would have been based on the daily catch records of the individual fisherman under 1, who experiences day to day variability of CV = 0.56 and fishes 30 days a month, there would have been random variability left in the monthly series as well (CV = $0.56/\sqrt{30}$= 0.10).
3. In the largest time window of 13 years, with annual averages, there is variability due to a long-term trend and due to the variance around it. In this example it hardly matters whether catches are ^{10}log-transformed before regression (r^2 = 0.70) or not (r^2 = 0.69). In the case of ^{10}log-transformation, the trend b = -0.0335 per year, corresponding to a 7.4% reduction per year. Inter-annual variability is calculated after regression of untransformed annual averages (CV = sd in the residuals/average of the full series = 0.19) and of log-transformed annual averages (CV(s) = 0.21). The residuals are not completely independent. In a smaller time window of 1989-1992 a confusing short-term trend can be observed (R^2 = 0.95), followed by a persistent short-term downward trend.



Days - November 1997
Daily catch (kg)
140
120
100
80
60
40
20
0
0 5 10 15 20 25 30
AM
GM
Catch frequency distribution
Frequency (days)
7
6
5
4
3
2
1
0
CV = 0.56
CV(s) = 0.69
5 15 25 35 45 55 65 75 85 95 105 115 125
Catch per day (kg)
Months - 1994, 1997
Multiplier P
1.50
1.00
0.50
0.00
J F M A M J J A S O N D
High season
C = 40 kg, CV = 0.12
1997
1994
C = 49 kg, CV = 0.16
Low season
Distribution of the residuals
Frequency (years)
Linear
CV = 0.19
-17.5 -12.5 -7.5 -2.5 2.5 7.5 12.5 17.5
Residual (C)
Logarithmic
CV = 0.21
-0.175 -0.125 -0.075 -0.025 0.025 0.075 0.125 0.175
Residual (10log C)
Years 1988 - 2000
Catch rate (kg per day)
100
80
60
40
20
0
1986 1988 1990 1992 1994 1996 1998 2000 2002

Box 3.2 - Less variability after aggregating and averaging daily catches

Suppose we start from a time series of 360 daily catches, all from one particular fisherman, fishing 7 days a week and 30 days a month. Aggregation of this series into a new series of daily catch rates, now averaged per weekly interval, not only lowers the number of observations by a factor 7 but reduces the variability in the new series as well (Fig. B3.3.1). Also, the catch frequency distribution on the basis of this new series becomes less skewed. Subsequent aggregation and averaging into daily catch rates, now averaged per monthly interval, makes the tendency to lower variability, and to normality in the catch frequency distribution, even more apparent. These tendencies towards lower variability and greater normality after data aggregation relate to the Central Limit Theorem. This theorem explains in more general terms that the distribution of sample means tends to smaller variance and to normality, when one draws many samples from any distribution no matter what statistical distribution.

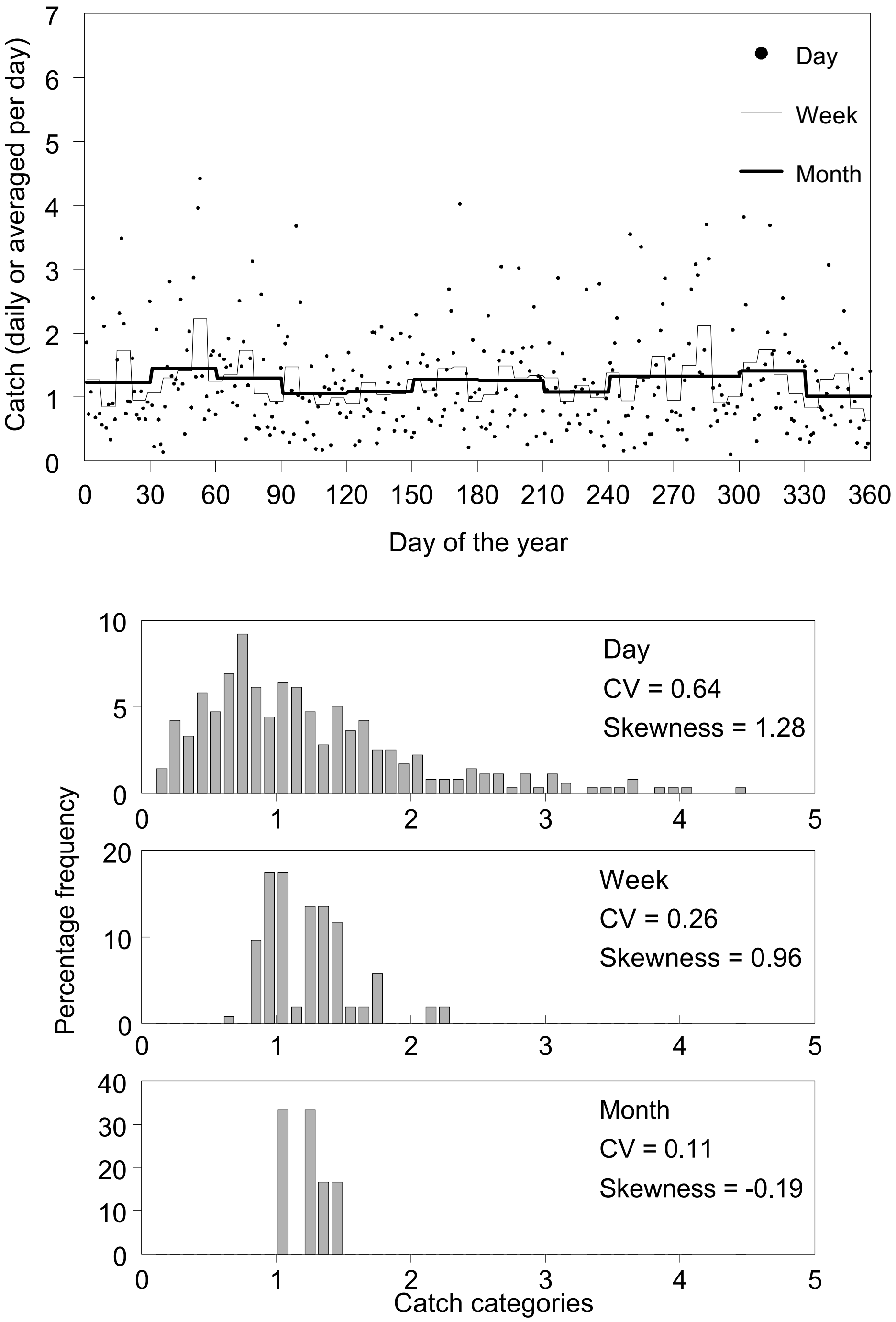


Fig. B3.2.1 Top: A series of 360 daily catches drawn randomly from a theoretical catch frequency distribution, which follows a ^{10}lognormal distribution with $s\,^{10}\log C = 0.3$, so with a theoretical variability of CV(s) = 0.78. The lines represent daily catches as averaged per week and per month. Bottom: Catch frequency distributions before and after aggregation in the series of 360 daily observation

Chapter 4

Variability in daily catches

In this chapter:

- It is theorised how resource character, fishing mode and scale of operation might affect the variability in catch rates from day to day ('basic uncertainty)'. **4.1**
- Based on case studies from trawl fisheries it is assessed in what range day to day catches vary in this active and very mobile fishery, which is generally operated at a larger scale. **4.2**
- Based on case studies from gillnet fisheries it is assessed in what range day to day catches vary in this most widespread, passive fishery that can be operated with minimal inputs and facilities and whereby nets are set during one night at locations that change from one day to the next. **4.3**
- Based on case studies from fishing with light attraction it is assessed in what range day to day catches vary in this passive night fishery generally operated at a small scale whereby lamps are used as light bait and the mainly pelagic fish is taken from the water with liftnets, purse seines and beach seines. **4.4**
- Based on case studies from sport fisheries with rod-and-line it is assessed in what range day to day catches vary in this passive, really small-scale fishery operated from a fixed location, and which part of this variability is to explain from systematic differences between anglers possibly due to individual angling skill. **4.5**
- The full range in day to day variability is assessed, as are systematic differences between fishing modes and the influence of resource character and scale of the fishery on the variability per fishing mode. **4.6**

4.1 Four fishing modes

Variability in the catch from day to day or 'basic uncertainty' is expected to depend on the character of the resource or fish species, on the fishing mode and on the scale at which the fishery is operated. The variability will be higher when the fish species is spatially more aggregated, the fishing mode a stationary one, and is operated at a small-scale covering a smaller area. These three factors, resource character, fishing mode and operational scale are to some extent interrelated. For example, trawling for highly aggregated small pelagics requires a large scale operation. The four fishing modes for which day to day variability is assessed and compared in this chapter are thought to cover the full range of basic uncertainty one could potentially come across. These modes are trawling, gillnetting, fishing with light attraction and angling.

Trawling is an active fishing mode, which requires a powerful boat. The smaller the individual size of the fish to be caught, the smaller the mesh size, the larger the drag of the net and, therefore, the more powerful the trawler should be. Beam trawlers such as those in use in the Dutch fishery for bottom fish need to be particularly powerful, because the fish is chased up from the bottom with heavy tickler chains. Trawl fisheries for which basic uncertainty is assessed here are: the Dutch beamtrawl fishery for bottom fish in the North Sea (4.2.1), the Dutch large-scale fishery with stern trawlers for concentrations of pelagic herring in the Eastern Channel (4.2.2), the trawl fishery for semi-demersal silverhake, a gadoid, on the Scotian Shelf (4.2.3), and the trawl fishery for a mixed assemblage of pelagic, demersal and bottom fish in the Eritrean waters of the Red Sea (4.2.4).

Gillnets are pieces of netting stretched at the water surface and set overnight to catch pelagic fish, or set at the bottom to catch demersal fish. Gillnets are easy to set and haul and are relatively cheap, as is their operation. In calm waters a small rowing boat is sufficient. It is possible that the low-input characteristic of this type of fishery makes fishermen prone to accept a relatively high variability in day to day catches. The efficiency of gillnets in terms of catchability (q) of fish present, has increased over the years with the change in the material and thickness of the ply from which the net is made, from cotton, to multi-filament and to 1.0 mm Ø mono-filament netting. Modern multi-mono gillnets can catch and hold large specimens. Gillnet fisheries vary greatly in their scale and technology ranging from the manual setting and hauling of only a few hundreds meters of netting by Ethiopian fishermen from their small papyrus boats, to the setting of tens of kilometres of gillnet and and hauling them with hydraulically powered reels from large open sea gillnetters. As with trawlers, daily catches of schooling pelagics by gillnetters are presumed to be more variable than daily catches of more homogenously distributed demersal and bottom fish. For the same species and situation, longer gangs of gillnets aggregate over larger areas and should thus lead to lower variability in catch rates.

The four freshwater gillnet fisheries for which basic uncertainty is assessed here, are all small-scale and the fish are landed every morning. These fisheries include the Dutch gillnet fishery for pikeperch, a predatory percid (4.3.1), the gillnet fishery for Nile perch, a large centropomid, in Lake Victoria, Tanzania (4.3.2), the gillnet fishery for the small and abundant, herbivorous tilapia in a Sri Lankan reservoir (4.3.3), and the multi-species gillnet fishery for larger tilapia, barbs and catfish in Lake Tana, Ethiopia (4.3.4). The two marine gillnet fisheries are the coastal fishery in the Red Sea, Eritrea, where gillnet fishermen land a mixture of demersal and reef fish (4.3.5), and the gillnet fishery for highly-valued shrimps and for finfish in the Nicoya Gulf, Costa Rica (4.3.6).

The third mode of fishing is the fishery using light attraction, a mixture of passive and active fishing. Fishermen use a 'light bait' to attract the fish and active gear such as purse seines, liftnets, beach seines and scoop nets to haul the fish in once they are concentrated near or under the fishing unit. Catching success is much influenced by environmental conditions such as the phase of the moon and water currents. Light fishermen in the tropics mainly target pelagic fish in marine coastal waters. Light fisheries for small pelagics in freshwater lakes and reservoirs would enable the full utilisation of freshwater fish production, including the smallest and most productive fish (Duncan 1999). It depends on the species whether fish are caught gradually by attracting more or less homogenously dispersed individuals, or that randomly moving fish schools are suddenly 'captured' by the light source. For the more homogeneously distributed fish, total catches will gradually increase to a maximum through the night, in a similar way to the catch curve for trap fisheries (Miller 1990), and variability in daily catches is expected to be small. When fish are spatially aggregated and the fishing units lack fish finding devices, day to day variability is expected to be high.

The light fisheries for which basic uncertainty is assessed here, are operated in freshwater lakes and in marine coastal waters. The two freshwater examples refer to a small freshwater cyprinid in Lake Victoria, Tanzania, the number one species in the landings from the lake which is captured with lift nets, beach seines and scoop nets (4.4.1), and a small centropomid caught with purse seines in Lake Tanganyika, Burundi (4.4.2). The two examples from marine waters refer to light fisheries for anchovies, sardines and other pelagics caught with purse seines, lift nets and beach seines in Indonesian coastal waters (4.4.3, 4.4.4).

The fourth fishing mode to be examined is angling with rod and line. Rod, line and bait are more and more adapted to the target species and to the environment, and in skilled hands the tackle will certainly enlarge the catchability of the fish present. Fish finders and catch detectors, which alarm the angler with light and sound once a fish has swallowed the bait, are among the equipment of more advanced anglers. Nevertheless, anglers remain “small-scale fishermen”, who apply a small effort during 4-6 hours per day on average and mostly at one particular site.

In the absence of series with daily records of angling success in one particular water for one angler or a group of known anglers, angling tournaments are used to infer day to day variability from the variability between anglers. Where possible an attempt was made to adjust this variability for possible differences in angling skill. For that purpose, numerical catches of pikeperch tournaments in two Amsterdam town waters (4.5.1), and the catches recorded as total weight per angler during National Angling Championships in British rivers and canals, were used (4.5.3). Further, an evaluation was made of whether the statistical power of national monitoring schemes was large enough to distinguish between waters from the angling success recorded per water (4.5.2, 4.5.4).

The chapter ends with an overall comparison of basic uncertainties and with generalisations based on fish species, fishing modes and operational scales.

4.2 Trawl fisheries

4.2.1 Beam trawling for plaice and sole in the North Sea

Dutch fisheries in the North Sea mainly target flatfish with beam trawlers and pelagics with stern trawlers. There are circa 400 beam trawlers, which have on average a crew of five on board. Their fishing trips last about four days and most vessels land their catch on Friday. It is a year-round fishery, mainly targeting plaice, *Pleuronectes platessa*, and the more highly valued sole, *Solea solea*. The performance of six beam trawlers in 1995 was used to assess the basic uncertainty in the catch from day to day in the beam trawl fishery (Data provided by A. Rijnsdorp, RIVO IJmuiden).

The beam trawl fishery is highly intensive. About 60% of their time at sea the trawlers are towing their nets. Taking the performance of one of the six beam trawlers as an illustration: in 1995 this trawler made a total of 1326 hauls during 45 trips, *i.e.* about 30 hauls per trip and ca 7 per fishing day. The average haul duration was 2.24 hr. The duration of hauls recorded as lasting more than 3 hours must have been misreported (Rijnsdorp, personal communication). The variance in haul duration (CV = 0.18) was partly due to seasonality (Fig. 4.1, see also section 5.2). Hauls were made throughout the 24 hours with slightly higher catches of sole during the night, and of sole during the day (de Groot 1971).

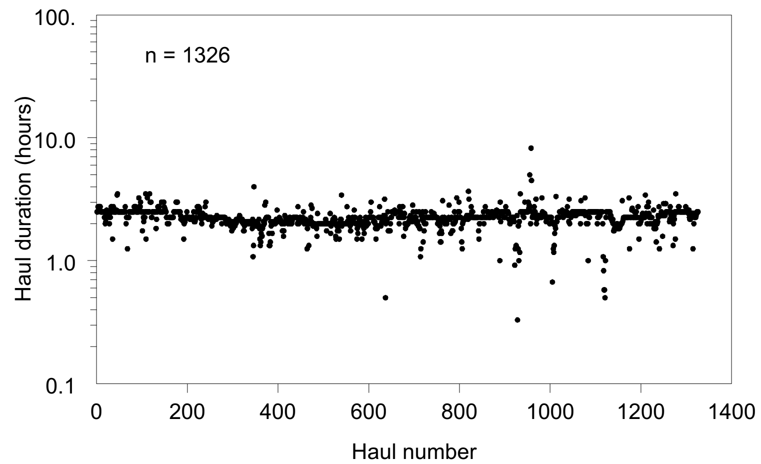


Fig. 4.1 Haul duration (hours) of trawler 2 (of Table 4.1) in the beam trawl fishery during 1995.

The six beam trawlers caught on average 100-180 kg of plaice and sole together per haul, but always more plaice than sole (Fig. 4.2, top). The proportion of 0-catches (δ) in this fishery is extremely low. Of its total of 1326 hauls, beam trawler 2 recorded 16 zero catches for plaice, of which 10 were in May, when the average catch of plaice was lowest (see also section 5.2), 2 for sole and 1 for both sole and plaice. The value per average haul and per beam trawler varied between 600 and 1000 guilders (1 guilder = 0.45 Euro). Although the average catch weight of sole was always smaller than that of plaice, the four times higher value per unit weight of sole made their contribution to the total value of the catch for each trawler, higher, from 76 to 93% per trawler (Fig. 4.2, bottom).

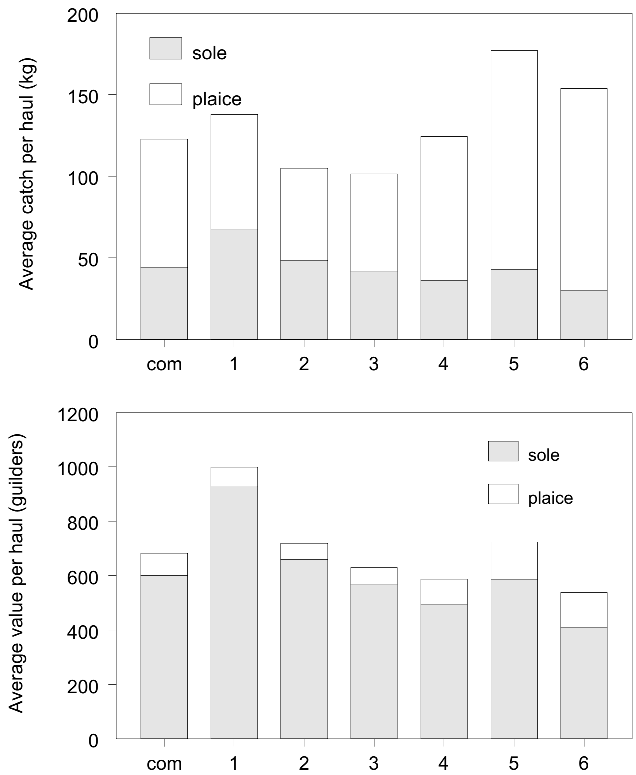


Fig. 4.2 Average catch per haul of six Dutch beam trawlers in the North Sea during 1995, combined (com) and per beam trawler (number). Beam trawlers sorted by decreasing proportion of sole in total catch weight. Top, weight (kg); bottom, mo ney value (1995 guilders).

Basic uncertainty in catch weight from haul to haul was first assessed via an ANOVA for the total variance in catch weight per haul (cf 3.5). The model structure, for which a SAS General Linear model procedure was applied, contained the individual trawler, the month and the fishing area in which the catch was made and an error term (ε):

$$^{10}\log C = trawler, month, area, \varepsilon$$

Fishing areas are officially indicated by standard 4000 km^2 quadrants as used by the International Council for the Exploration of the Seas (ICES). The variance in catch weight was larger for plaice than for sole due to stronger differences in plaice catches between vessels and between months, indicating stronger seasonality (see also section 5.2) (Table 4.1). Some beam trawlers concentrated their fishing activities in relatively small resource areas, like beam trawler 2 fishing north of the Dutch and German Wadden islands (Table 4.2).

The standard deviation in the residuals ($s^{10}\log C$), as a measure for haul to haul uncertainty, was 0.24 for both plaice and sole, corresponding with CV(s) = 0.60 (see 3.2). As these trawlers made 7 hauls per day on average, the basic uncertainty in the catch from day to day can be approximated from the variability after aggregation: CV = 0.60/√7 = 0.23. Per individual beam trawler this variability ranged between CV(s) = 0.17 to 0.25 for plaice, and between CV(s) = 0.14 and 0.29 for sole (Table 4.3). The variability in catch per fishing trip during which 30 hauls were made was CV = 0.60/√30 = 0.11.

Table 4.1 ANOVA-table for log-transformed catch weight (kg) of plaice and sole per haul. For further explanation see text.

ANOVA					
Source	Df	SS	MSS	F	$P_r > F$
Plaice					
Model	68	418	6.15	103	0.0001
Error	6716	399	0.0594		
Corrected total	6784	817			
Sole					
Model	65	166	2.55	46.07	0.0001
Error	6167	342	0.0555		
Corrected total	6232	508			
	R^2		√MSE		GM CpUE
Plaice	0.512		0.244		79.1
Sole	0.327		0.235		43.9
Variance explained					
Source	Df	Type I SS	MSS	F	$P_r > F$
Plaice					
Beam trawler	5	129	25.7	433	0.0001
Month	11	177	16.1	271	0.0001
ICES quadrant	52	113	2.17	36.5	0.0001
Sole					
Beam trawler	5	68.5	13.7	247	0.0001
Month	11	7.02	0.639	11.5	0.0001
ICES quadrant	49	90.5	1.85	33.3	0.0001

Table 4.2 Total number of hauls made and fishing areas frequented by the six beam trawlers in 1995. 1 ICES quadrant = circa 4000 km^2. The surface area of the North Sea is 500,000 km^2.

Beam trawler	Number of hauls	Number of ICES quadrants fished	Proportion of hauls in the three most frequently fished quadrants
1	1087	8	0.89
2	1326	10	0.94
3	1482	22	0.40
4	1386	16	0.83
5	1000	26	0.35
6	827	28	0.37
Total	7108	53	

Table 4.3 Variability in catch per day (7 hauls) based on the standard deviation in the residuals of the model for ^{10}logC per beam trawler and for the six beam trawlers combined, together with the proportion of total variance explained by the model.

Beam trawler	CV		R^2	
	Plaice	Sole	Plaice	Sole
1	0.23	0.17	0.478	0.386
2	0.20	0.18	0.597	0.283
3	0.25	0.21	0.451	0.253
4	0.20	0.18	0.483	0.382
5	0.17	0.29	0.432	0.602
6	0.17	0.14	0.659	0.497
Combined	0.23	0.22	0.512	0.327

The basic uncertainty in the size of the catch per haul could be considerably smaller than the CV = 0.60 calculated above, when focussing on a short series of hauls. This has to do with the spatial aggregation of plaice and sole and the responsive behaviour of the beam trawlers to such aggregations (see also Rijnsdorp *et al*. 2000a,b). This spatial aggregation is small relative to that of schooling pelagics but it could nevertheless induce serial correlation in series of successive catches per haul of either plaice or sole. Partial segregation of plaice and sole is also the reason why hauls in which catches of both plaice and sole are large, rarely occur (Fig. 4.3).

The relative stability in the catch per species and haul, and species in the short-term of a series of circa 3-10 hauls, is exemplified here with the records from a week of fishing by beam trawler 2. He made 35 hauls in 4 days in the week from 27 February to 3 March 1995; 33 hauls in ICES quadrant 37F7 and the last 2 hauls, on the way home, in ICES quadrant 37F6. Visual inspection of the catch per haul series, suggests that this beam trawler targeted sole during hauls 1 to 11, 16 to 18 and 30 to 35 (Fig. 4.4). The variability in the catch per haul during either plaice or sole fishing was considerably lower than that for the catch per haul for the 35 hauls combined (Table 4.4). By switching between target species, it seems this fisherman was able to stabilise his value per haul, species combined (CV = 0.16). Examining the complete records of the six trawlers it appeared, however, that stability as pronounced as in the example above was seldom realised.

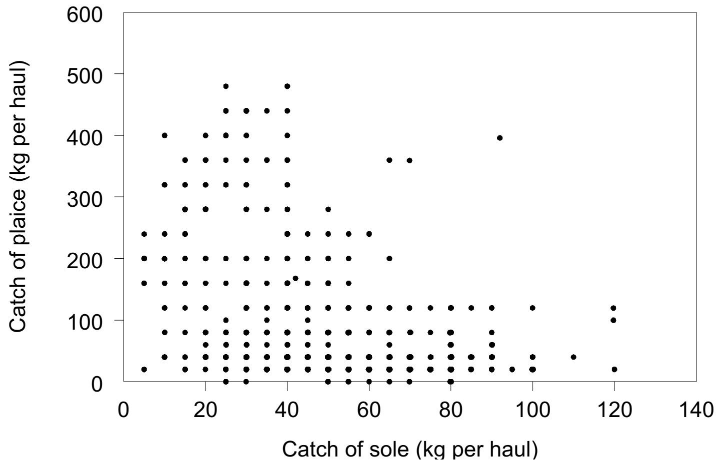


Fig. 4.3 CpUE of plaice plotted against CpUE of sole for individual hauls made by beam trawler 45 throughout 1995.

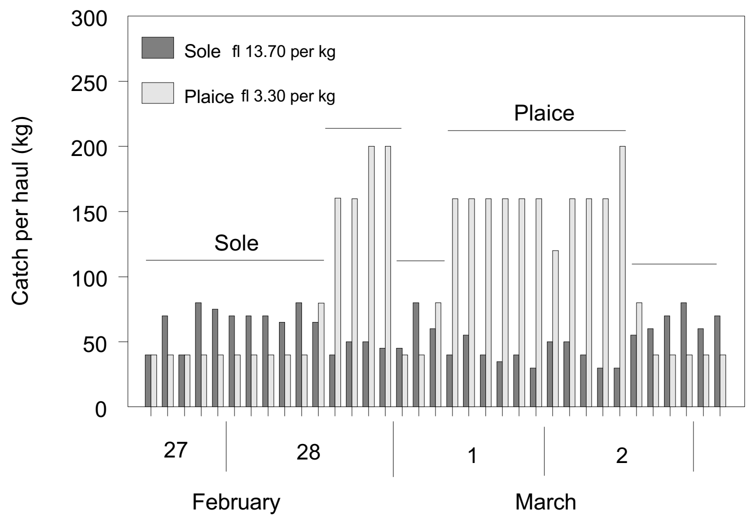


Fig. 4.4 CpUE of plaice and sole per sequential haul made by beam trawler 2 in the week 27/2 - 2/3 1995.

Table 4.4 Average catch per species and haul (CpUE) and variability in the catch per haul (CV) in periods when targeting for either plaice or sole. Based on data recorded by beam trawler 2 in the week 27-2 to 3-3-1995.

Target	Arithmetic mean CpUE (kg per haul)		CV		Number of hauls
	Plaice	Sole	Plaice	Sole	
Plaice	165	42	0.12	0.20	15
Sole	46	65	0.32	0.19	20
Combined	97	55	0.64	0.29	35

4.2.2 Trawling for pelagic herring in the Eastern Channel

In December-January the Dutch fleet of ca 15 large stern trawlers, each with a crew of, on average, 35 and with a storage capacity of 2-3000 tonnes, targets spawning concentrations of herring, *Clupea harengus*, in the southern North Sea and the Eastern Channel. The performance of eight of these stern trawlers in December 1993-1998 was analysed to assess basic uncertainty in catch weight from day to day (data provided by A. Eltink, RIVO IJmuiden).

The fishing trips of the stern trawlers lasted 3 to 4 weeks. Once in the fishing area they made on average 2.7 hauls per day (Fig. 4.5). The variability in the duration of these hauls was circa 3 times higher than those in the beam trawl fishery for flatfish (2.57 hours, CV = 0.52) (Fig 4.6). This higher variability is due to their fishing behaviour in response to the spatially strongly aggregated herring. That is to say, stern trawlers adjust haul duration to the total weight of herring already accumulated in the trawl codend, as indicated by the sensors recording increased tension in the ropes. Once they have caught enough - the reference seems to be around 50 tonnes and the technical limit is 200 tonnes - they haul in the net. This fishing behaviour results in the highly variable haul duration and explains why a relationship between catch weight and haul duration is lacking (Fig. 4.7).

The overall mean catch per stern trawler and haul was 49 tonnes of herring with a haul to haul variability of CV = 0.76 (Fig. 4.8). The average daily catch per trawler was 123 tonnes (CV = 0.63). Excluding the proportion of zero catches $\delta = 0.067$, the average catch per haul, from years and trawlers combined was 50 tonnes (CV = 0.69, GM = 38 tonnes). The 611 successful hauls were analysed for possible systematic differences between years and between trawlers in their catch per haul and in haul duration (Tables 4.5, 4.6).

$$^{10}\log C = year, trawler, \varepsilon$$

$$duration = year, trawler, \varepsilon$$

There were no significant differences between years and only 9% of total variance in catch per haul could be explained by differences between trawlers or by trawler*year combinations. The variability in the catch from haul to haul as inferred from the MSE was CV(s) = 1.01. Of the variance in haul duration, 32% was explained by differences between trawlers (21%), by combinations of trawler*year (8%) and by differences between years (2%). So differences between years do not play a role in the experience of these trawl fishermen, as far as catch rates or haul duration are concerned. Short-term trends in catch per haul within seasons are not experienced either, as the performance of trawler 3, executing as many as 170 hauls in December 1993 - 1996, shows (Fig. 4.9).

The variability in the catch from day to day is inferred from the 2.7 hauls made per fishing day on average and the haul to haul variability (CV(s) = 0.76) as CV = $0.76/\sqrt{2.7} = 0.46$. This is approximately twice as high as in the Dutch beam trawl fishery for flatfish. The variability in catch landed per trip, however, will be comparable, because of the longer trip duration of the herring trawlers. With an average catch per haul of about 50 tonnes, the storage capacity of

2500 tonnes on these stern trawlers is filled after about 50 hauls. Because 2.7 hauls per day were made on average, theoretically a trip could last at least 50/2.7 = 19 days.

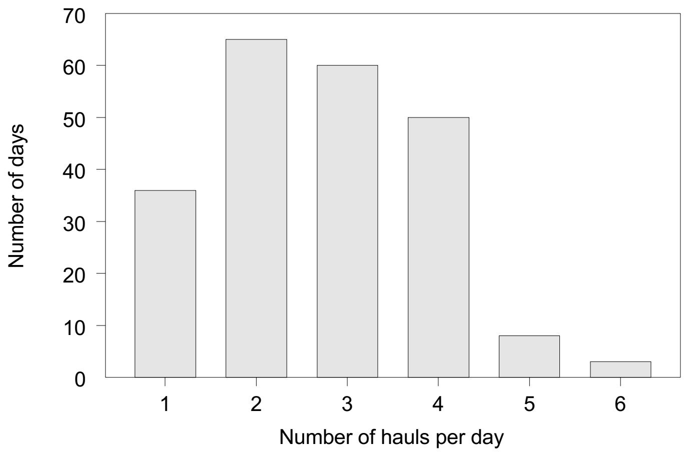


Fig. 4.5 Frequency of the number hauls made per fishing day in the Dutch herring fishery in the Eastern Channel during winters 1993-1998 (n = 212).

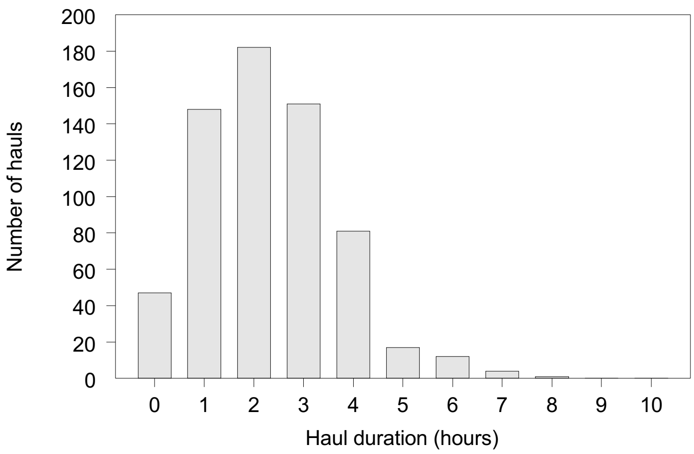


Fig. 4.6 Frequency of the number of hauls of variable duration (hours) in the Dutch herring fishery in the Eastern Channel during winters 1993-1998.

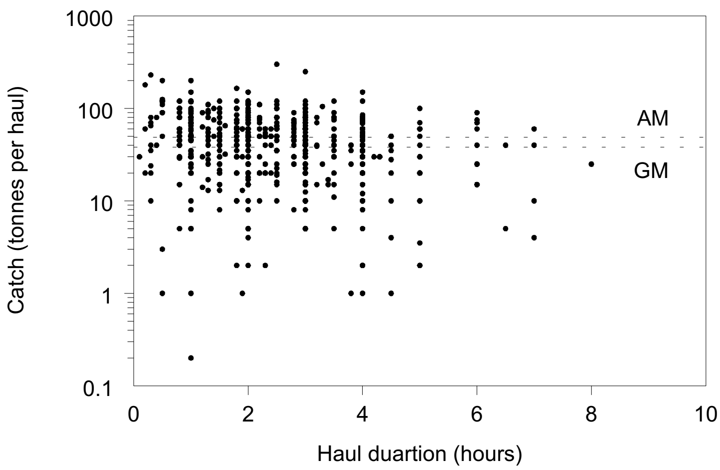


Fig. 4.7 Catch per haul (tonnes) plotted against haul duration (hours) in the herring fishery in the Eastern Channel 1993-1998. AM = 49 tonnes per haul, GM = 38 tonnes per haul.

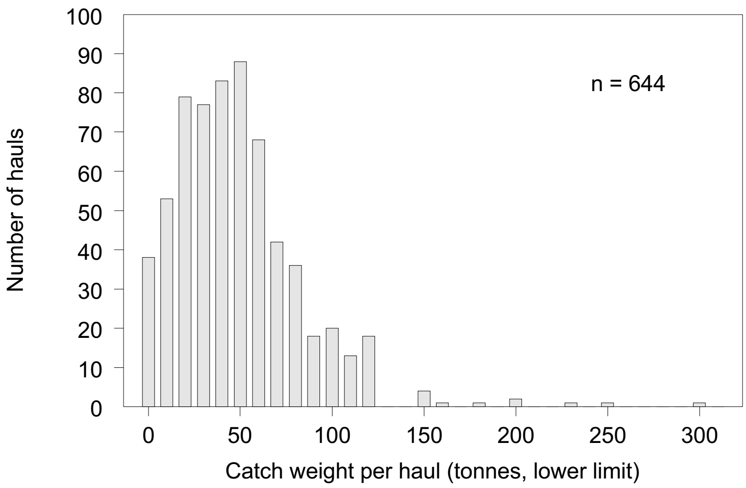


Fig. 4.8 The CpUE frequency distribution for all non-zero catches of herring made by nine stern trawlers in the Eastern Channel in December 1993 -1998. 0 = 1-10 tonnes, 10 = 11-20 tonnes etc.

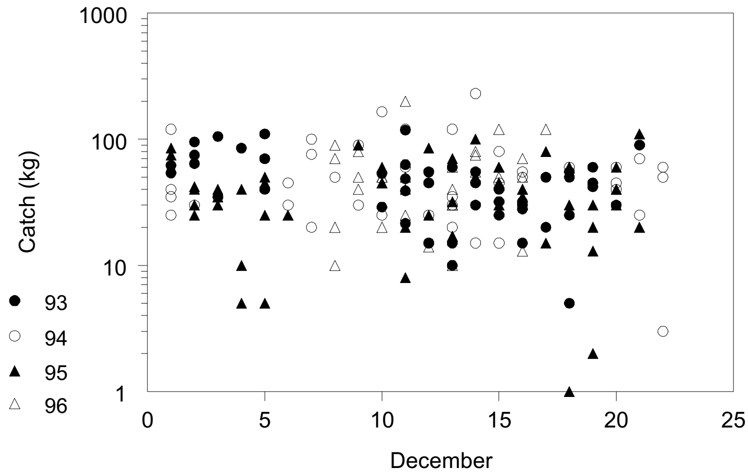


Fig. 4.9 Catching success (kg per haul) for trawler 3 in December, 1993 -1996.

Table 4.5 Analysis of variance of ^{10}logC for successful hauls in the Dutch herring fishery in the Eastern Channel, 1993-1998.

Source	Df	SS	MSS	F	$P_r > F$
Model	20	7.68	0.384	2.86	0.001
Error	590	79.16	0.134		
Corrected total	610	86.85			
	R^2		√MSE		GM
	0.0885		0.366		37.7
Variance explained	Df	SS	MSS	F	$P_r > F$
Vessel	7	2.344	0.335	2.50	0.0156
Vessel*year	13	5.340	0.411	3.06	0.0002

Table 4.6 Analysis of variance of haul duration (hours) for successful hauls in the Dutch herring fishery in the Eastern Channel.

Source	Df	SS	MSS	F	$P_r > F$
Model	20	346.18	17.309	14.00	0.001
Error	590	729.58	1.237		
Corrected total	610	1075.76			
	R^2		√MSE		Mean
	0.322		1.112		2.57
Variance explained	Df	SS	MSS	F	$P_r > F$
Vessel	7	231.94	33.13	26.80	0.0001
Year	5	23.44	4.69	3.79	0.0022
Vessel*year	8	90.79	11.35	9.18	0.0001

4.2.3 Trawling for semi-pelagic silver hake on the Scotian Shelf

Silver hake, *Merluccius bilenearis*, is a semi-demersal gadoid, from the Scotian shelf, east coast of Canada. It has traditionally been a valuable source of animal protein and export revenue for both Russia and Cuba. From April - November 1993 12 Russian and 12 Cuban trawlers of 80 - 110 m length (2300 - 3300 gross tonnage) were fishing in a restricted region, the "Silver hake box" (Gillis 1999). The overall variability in catch per haul (AM = 1413 kg, CV = 1.08) was larger than in the Dutch herring fishery. The variability in haul duration (2.24 hr per haul, CV = 0.37), however, was smaller than in the herring fishery, where haul duration was more adapted to the amount of herring already sensed in the trawl. Such adaptive behaviour is unlikely in the silver hake fishery, given the limited technology of this fleet (D. Gillis, personal communication).

Basic uncertainty in this fishery can be approximated after correction for as yet unexplained, short-term periodicity in catch rates, which was observed during events of concentrated fishing in particular sub-areas (Gillis 1999). Periodic cycles in catch rates of ca 6 days had a ratio of 3 between high and low CpUE, which corresponds with a variability in catch per haul of CV = 0.37 (see section 3.4.2). The residuals of this cyclical model revealed that differences in average CpUE (kg per hour) between trawlers were very small, but that variability in CpUE (kg per hour) as inferred from residual variance was large. The s^{10}logCpUE averaged for 9 stern trawlers, as read from Fig. 5 in Gillis (1999), was 0.42 corresponding with CV = 1.24. With 5.6 hauls per day (D. Gillis, personal communication), the basic uncertainty in the catch from day to day would have been CV = 1.24/√5.6 = 0.52.

4.2.4 Trawling for pelagics and demersals in the Red Sea, Eritrea

In the 1960s the Eritrea-based trawl fishery in the Red Sea mainly targeted pelagics, but this fishery ended in the 1970s. Eritrean fisheries in the Red Sea are now slowly recovering after a long period of civil war. Catch rates in the present, large-scale trawl fisheries and in the small-scale hook & line and gillnet fisheries are high because of the continued low fishing pressure. The operation of the newly installed Catch and Effort Data Recording System should ensure enough statistical power to inform the authorities when, with the gradual building up of fishing pressure, the most vulnerable catch categories start to disappear from the landings.

The data used here for assessing basic uncertainty in the daily catch in the trawl fishery originate from tables in Hartmann (1997), in which CpUE was standardised as kg per hour trawling. Standard deviations were inferred from standard errors, which were tabulated in combination with the number of hauls. Five 200-450 gross tonnage stern trawlers of the Saudi Fisheries Company (SFC) operated from March to July 1996 in three areas in the Red Sea (North, Central, South) located south and southeast of the harbour of Massawa. These trawlers fished around the clock for 24 hours and made circa 6 hauls of 2.5 hours per day (Hartmann, personal communication). The average catch per hour in the three areas was 352 (N), 309 (S) and 208 kg (C).

The overall variability in CpUE was lowest (CV = ca 1.5) for the dominant category of pelagic jacks and was well over CV = 3 for pelagic barracudas (Fig. 4.10). Part of the variance in the catch rates per species and haul, however, must be attributed to day-night differences in CpUE. Pelagic jacks, barracudas and mackerels were all caught in significantly smaller amounts during the night than during the day (Hartmann 1997). Catch rates of the abundant jacks, for instance, were approximately twice as low during the night than during the day, whereas catches of barracudas and mackerels were almost nil at night. These barracudas and mackerels were also the categories with the highest proportion (δ) of 0-catches recorded, in the central and southern areas especially (Fig. 4.10). In contrast, the CpUE for the demersal emperors was *ca* twice as high during the night as during the day. A factor of 2 difference between day and night catches already produces a variability within days of CV = 0.35 (see 3.4.2) due to such periodicity. Day to day variability, however, should be independent of this within day periodicity. With ca 6 hauls per day the variability in the daily catch, of the dominant pelagic jacks and the demersal emperors, must have been $1.5/\sqrt{6} = 0.61$ at the most. Correction for within day variability would scarcely lower this variability: CV = $\sqrt{(1.5^2 - 0.35^2)}/\sqrt{6} = 0.60$.

4.2.5 Scaling basic uncertainties in trawl fisheries

The range of basic uncertainty in the daily catch per target species for the trawl fisheries analysed here was CV = 0.23 – 0.60. Basic uncertainty seems to be smaller in trawl fisheries for demersals or bottom fish than in those for pelagics (Table 4.7). Although the Dutch fishery for pelagic herring is a large-scale, technically advanced fishery equipped with fish finding devices, the proportion of zero catches still amounts to δ = 0.07 and the basic uncertainty in the catch from day to day is large (CV = 0.40), compared to that in the beam trawl fishery. The mono-species trawl fishery for the semi-pelagic silverhake on the Scotian Shelf could not rely on more advanced techniques for the detection of fish concentrations and this may have contributed to its higher basic uncertainty (CV = 0.52). The basic uncertainty in daily catches was highest in the trawl fishery in the Red Sea, where pelagic jacks were the major category (CV = 0.60) of prey. In this multi-species fishery day to day variability in total catch weight for species combined would have been lower, more like the mono-species fisheries for herring and silver hake.

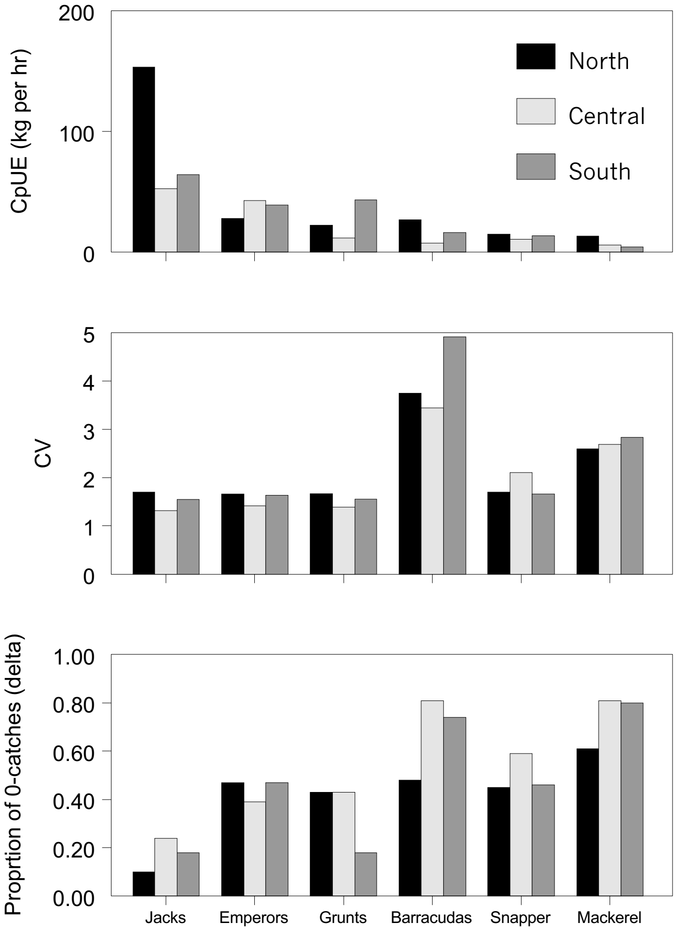


Fig. 4.10 CpUE (kg per hour), haul to haul variability and the proportion of zero catches (δ) for the six major categories of large- and medium-sized fish in the Eritrean trawl fishery in the Red Sea. P = pelagic; D = demersal. These six categories comprised 89% (C) to 96% (N) of the catch.

Table 4.7 Scaling of trawl fisheries by the basic uncertainty in the catch from day to day (CV).

Number	Trawl	Category	Type	Area	CV
1	Beam trawl	Plaice and sole	Bottom	North Sea	0.14
2	Beam trawl	Plaice or sole	Bottom	North Sea	0.23
3	Stern trawl	Herring	Pelagic	Eastern Channel	0.40
4	Stern trawl	Silver hake	Semi-pelagic	Scotian Shelf	0.52
5	Stern trawl	Jacks	Pelagic	Red Sea	0.60

4.3 Gillnet fisheries

4.3.1 Gillnetting for pikeperch in the Netherlands

Pikeperch, *Stizostedion lucioperca*, is a predatory percid with a Eurasian distribution, which thrives in eutrophic inland waters. Pikeperch spread throughout the Netherlands after its first appearance there in 1888 (Redeke 1941). In the second half of the 20th century it became a major target of professional gillnet fisheries and of sport fisheries in eutrophicating inland waters, especially Lake IJssel (200,000 ha). In late summer and autumn, professional fishermen set their gillnets (circa 100 mm stretched mesh) over night to catch 40-60 cm pikeperch and 20-30 cm perch, *Perca fluvialtilis*, a smaller percid, sometimes with large amounts of much less valued bream, *Abramis brama* (25-35 cm), a cyprinid. Nowadays, the stock of pikeperch in Lake IJssel shows severe signs of over-exploitation with instantaneous fishing mortality rates of well over F = 2 per year (Dekker 1991, Buyse 1992, Hartgers 1999, see also Chapter 6). Exploitation pressure is so high that only a small portion (circa 15%) of pikeperch recruiting to the autumn gillnet fishery at the age of three, survives this seasonal fishery of ca 3 months duration.

In the 1970s gillnet fisheries for pikeperch were banned in the smaller Dutch lakes because of a growing interest by sport fishermen in pikeperch angling (see also 4.5.1). Beulakerwijde (800 ha) was one of the few smaller lakes where a professional gillnet fishery for pikeperch was allowed to continue until catches fell sharply in the 1990s when this lake became much less productive due to the successful management of water quality. The performance of two professional fishermen in Beulakerwijde was closely monitored during the fishing seasons September - November 1983-1985 (unpublished results).

The numerical catch per fisherman and per day (CpUE) in their 1800 m gangs of 104 mm stretched mesh gillnets declined by almost an order of magnitude in every 3-months season, because of the, also here, high fishing mortality (Fig. 4.11, Table 4.8). There was a marked resemblance in CpUE between the two fishermen at the start of every season. The standard deviation (s^{10}logCpUE) in the residuals around the regression of the ^{10}log-transformed CpUE on day of the season, varied between 0.169 and 0.269, corresponding to basic uncertainties of CV(s) = 0.40 and 0.68 (Table 4.8). The CV of CpUE, in terms of kg per day fishing, must have been slightly larger due to the additional, although small, variance in the average weight of the daily catch of pikeperch. This measure for basic uncertainty must have been biased when 0-catches occurred at the end of the season.

Table 4.8 Regressions of CpUE (^{10}log-transformed numbers per fishing day) of pikeperch against day of the season, and the modal length (cm), of pikeperch caught by tw o fishermen in Beulakerwijde, the Netherlands.

	1983		1984		1985	
Fisherman	1	2	1	2	1	2
CpUE at Oct 1th	98.4	115.9	44.3	46.9	18.1	13.0
Trend (per day)	-0.0197	-0.0204	-0.0078	-0.0101	-0.0466	-0.0192
se trend	0.0025	0.0100	0.0036	0.0024	0.0085	0.0028
R^2	0.714	0.259	0.162	0.370	0.706	0.709
s^{10}logCpUE	0.169	0.176	0.188	0.244	0.202	0.269
CV (s)	0.41	0.42	0.46	0.61		
Number of settings	27	14	26	37	15	21
Modal length (cm)	47		44		44	

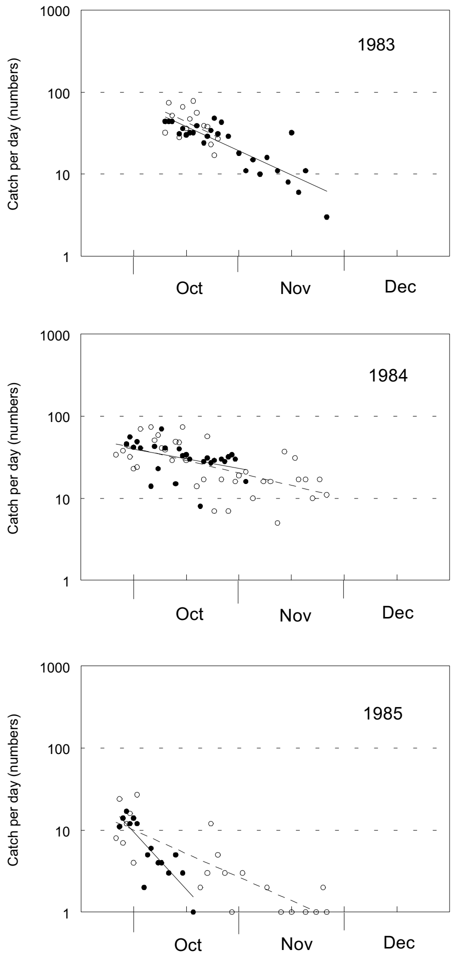


Fig. 4.11 CpUE (Numbers per fishing day) in the gillnet fishery for pikeperch of two individual fishermen in Beulakerwijde, the Netherlands, during three successive fishing seasons 1983 -1985.

4.3.2 Gillnetting for Nile perch in Lake Victoria, Tanzania

After its introduction in the 1950s the Nile perch, *Lates niloticus*, a centropomid, became a target species in the small-scale fisheries along the shores of Lake Victoria, first in Uganda and Kenya and, from the 1980s onwards, also in the southern, Tanzanian part of the lake. Projections of future developments in this fishery and in the stock of Nile perch are hard to make (Pitcher & Bundy 1995). To monitor future developments, the three riparian countries around the lake make a concerted effort to develop a standardised and informative CEDRS. For an estimate of the basic uncertainty in the gillnet fishery for Nile perch, data collected by Ligtvoet & Mkumbo (1991) along the southern shores of the lake, near Mwanza, Tanzania, were analysed.

The outcome of the Nile perch fishery at six sites distributed over ca 100 km of Tanzanian shoreline was monitored in 1987 and 1988 (Ligtvoet & Mkumbo 1991). Each month 5-10 boats were sampled randomly at each site. The Lake Victoria fishermen applied three fishing modes at that time: gillnetting with ca 190 mm (7 - 8") stretched mesh gillnets both inshore and offshore up to the 40 m depth contour, longlining and beach seining (Table 4.9). The mean length of Nile perch caught varied with the fishing mode applied. The average length of Nile perch in the catch of gillnets and longlines did not differ much between gears and years (64 - 71cm) and corresponded to the 69 cm optimum length for 190 mm (7.5”) gillnets (Witte & van Densen 1995, their Table 5.1). In the less size-selective beach seine fishery, significantly smaller Nile perch were caught (56 cm average length) (Table 4.10). The corresponding mean weights in the catch were circa 4 kg in the gillnet and hook and line fishery and circa 2 kg in the beach seine fishery.

The average catch rate varied between fishing modes from circa 30 kg per trip for an inshore gillnetter to more than 1000 kg per trip for a beach seiner (Table 4.10). Setting gillnets offshore was ca 3 times as rewarding in terms of catch weight per canoe as setting gillnets inshore, whereas the mean number of gillnets set per canoe in the offshore (40) was only 1.6 times as much as in the inshore (25). The length per individual gillnet mostly varied between 30 and 60 m, so the offshore gillnetters set ca 1800 m of netting and must have caught circa 1 individual Nile perch per 80 m of gillnet. When CpUE was expressed in kg per crew and day, the CpUE was more or less the same for offshore gillnetting, longlining and beach seining (ca 20-35 kg per person).

Since not seasonal patterns were observed in the catch rates (Ligtvoet & Mkumbo 1991), the variability in CpUE in the years 1987-1988 was assumed to be merely the consequence of the basic uncertainty in the catch from day to day. Only one zero catch was reported among the 208 catches recorded. The variability in the positively skewed CpUE frequency distribution varied between CV = 0.47 for offshore gillnetting to CV = 0.63 for longliners (Fig. 4.12).

Table 4.9 Characteristics of the Nile perch fishery in Southern Lake Victoria (from Ligtvoet & Mkumbo 1991).

	Gillnets	Longlines	Beach seines
Crew per fishing unit	3-5 persons per canoe	2-4 persons per boat	30-40 persons per 1-2 boats
Mesh size (stretched mesh)	178-203 mm		25-38 mm in codend

Table 4.10 CpUE of Nile perch (kg per canoe) and mean length in the catch in 1987 and 1988 (based on Table 31.2 in Ligtvoet & Mkumbo 1991).

Fishery	Fishing ground	Year	CpUE (kg per canoe per day)	CV CpUE	n	Mean length (cm)	CV length	n
Gillnet	Offshore	1987	107	0.51	41	70.5	0.10	1883
		1988	118	0.42	71	67.6	0.09	4662
	Inshore	1987	31	0.69	31	68.3	0.10	202
		1988	32	0.68	28	63.7	0.13	407
Longline	Inshore	1987	69	0.64	20	65.2	0.36	238
		1988	60	0.67	17	71.0	0.36	288
Beach seine	Inshore and open water	1987/ 1988	1140	0.51	12	56.2	0.25	6940

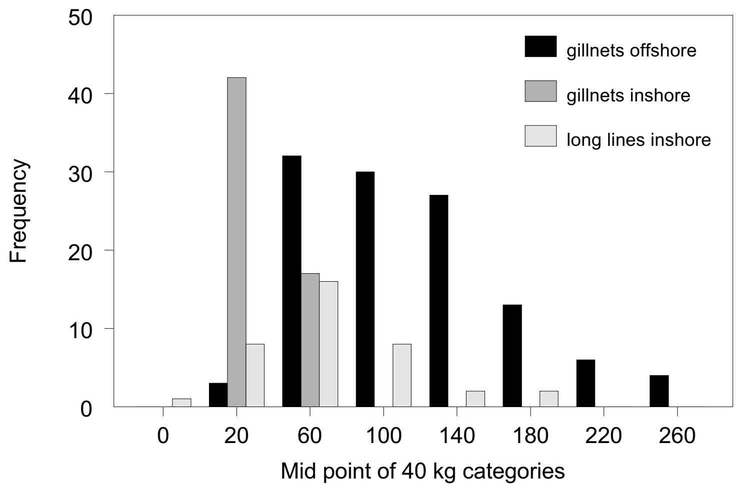


Fig. 4.12 Catch frequency distribution for offshore and inshore gillnet fishery and the fishery with long lines targeting Nile perch. Arithemetic means CpUE (kg per canoe and day) 117, 31.5 and 69.2 kg; variabilities 0.47, 0.58 and 0.63; number of catches 112, 59 and 37 (Data in Ligtvoet & Mkumbo 1991).

4.3.3 Gillnetting for tilapia in a Srilankan reservoir

There are hardly any natural lakes in Sri Lanka. There are many shallow dam reservoirs, sometimes 500 to 2000 years old and built for irrigation purposes, which cover a total freshwater area on this island of 100,000 ha. After the introduction of a tilapia species from Africa, *Oreochromis mossambicus*, in 1952, it became possible to crop the biological production of these reservoirs by gillnetting this deep-bodied herbivorous fish. Nowadays, catches also comprise two other tilapia species, the Nile tilapia, *O. niloticus*, and *Tilapia rendalii* (Pet 1995). During the monthly monitoring (4 days per month) of the fishery on Tissawewa Reservoir (circa 200 ha) from September 1991 through August 1992, 72% of the catch by weight comprised tilapia species (Pet *et al*. 1995). The rest were Indian carp species (21%), also introduced, and only 7% were endemic fish. The ca 11 fishermen on the reservoir set 400 m gillnets each, on average (CV = 0.17), with mesh sizes of 64-70 mm (2.5") stretched mesh. These gillnets are to a lesser extent used for seining and water beating as well. For religious reasons, the fishery is inactive during 2 days around full moon.

Catch rates varied between months and areas within the reservoir. The monthly average CpUE, excluding Indian carp, was 13.9 kg per night. Month was the only significant single factor in the analysis of variance of CpUE using a model with month, area and fishing method as explaining variables (Pet *et al*. 1995). The complete model explained 50% of overall variance, month explained 30%, the remaining 20% was explained by interaction terms. The variability in CpUE within months ranged from CV = 0.47 to 1.24 and was CV = 0.80 ± 0.24 on average (data in Pet *et al*. 1995). The significant interactions in the ANOVA had to do with the gradual re-allocation of fishing effort to the most productive areas in the reservoir, which changed through the year. The basic uncertainty in the catch from day to day, after correction for interaction terms, was CV = 0.71.

4.3.4 Gillnetting for tilapia, catfish and barbs in Lake Tana, Ethiopia

Lake Tana, the source of the White Nile, is a natural lake (316,000 ha) and the largest freshwater body in Ethiopia. Its fish community comprises tilapia, catfish and barbs, all exploited by a gillnet fishery. Development of the Lake Tana fishery is constrained by its poor market outlet. A viable market might be the capital city of Addis Ababa, but the city is 500 km away and this requires good transport facilities for fresh and frozen fish. Another aspect considered in developing the fishery, is that increasing fishing pressure on the fish community of the endemic *Barbus* species could impoverish the still high biodiversity of the lake ecosystem (Nagelkerke 1997). The challenge for local fisheries managers therefore, is how to balance the interests of exploitation and conservation. The data analysed here for the estimation of basic uncertainties in the gillnet fishery originate from a study of the fish stocks and the fishery in the Bahir Dar Gulf, the southern part of Lake Tana (Wudneh 1998).

The traditional subsistence fishery in the Bahir Dar Gulf (16,000 ha) is carried out by ca 110 reed boats, which cost 7 US$ and last 6 weeks. The reed boat fishermen practice various fishing modes, gillnetting with around 400 m 80 mm (stretched mesh) gillnets, water beating and hook & line fishing (Wudneh 1998). They target two species only, large Nile tilapia, *Oreochromis niloticus*, and barbel, *Barbus tsanensis*, in the inshore zones of the gulf. Their total catch, species combined, per one night fishing is 12 kg (Table 4.11). Since 1986 the total output of the fishery in the gulf has doubled because, supported by external funding, ca 20 motorised boats have come into operation. This enabled some fishermen to start the exploitation of the more offshore areas of the gulf. These fishermen set ca 1000 m of 110 mm (stretched mesh) gillnets. In other words, each sets circa 2.5 times as many metres of gillnet than the individual reed boat fishermen, but their total catch per night, species combined, was ca 15 times as large (170 kg) as that of the traditional reed boat fishermen (Table 4.11). The motorised boat fishermen not only target circa five *Barbus* species and the Nile tilapia, but also catfish, *Clarias gariepinus*.

The performance of both reed boat and motorised boat fishery were monitored on a monthly basis from January 1992 through October 1993. Important sources of variance in CpUE for the reed boat fishermen were differences in CpUE between locations and between months (Table 4.12). The fishery with motorised boats had additional variance because some boats performed consistently better than others. The ANOVA-model residuals for the total catch per boat, species combined, showed that basic uncertainty was more or less the same: CV = 0.63 for reed boat fishermen and CV = 0.66 for motorised boat fishermen. Unexpectedly, the basic uncertainty in the catch of tilapia was larger in the motorised boats than in the reed boat fishery. That the basic uncertainty in total catches was still more or less the same was probably due to the larger species diversity exploited by this fishery.

Table 4.11 CpUE (kg per trip) for the two types of fisheries in the Lake Tana per fish category and for total catches (from Kassa 1998).

	Reed boats			Motorised boats		
Fish category	CpUE (kg per trip)	CV	N trips	CpUE (kg per trip)	CV	N trips
Barbus	4	1.75	671	59	1.56	1491
Clarias				66	1.27	1490
Oreochromis	8	1.13	671	44	1.57	1492
Total	12	0.67	671	170	0.88	1490

Table 4.12 ANOVA-table for ^{10}logCpUE in the reed boats and the motorised boat fishery in the Bahir Dar Gulf, Lake Tana, Ethiopia (based on Kassa 1998 and Wudneh 1998).

		Reed boat		Motorised boat	
		Df	SS	Df	SS
Oreochromis	Boat			15	61.9
	Location	9	3.42	16	81.1
	Month	11	9.95	11	33.7
	Corrected total	20	46.21	1089	536.18
	R^2	0.290		0.330	
	s^{10}log CpUE (CV)	0.29 (0.75)		0.57 (2.15)	
Barbus	Boat			15	58.54
	Location	13	32.67	16	124.73
	Month	14	2.61	11	33.67
	Corrected total	339	73.29	1392	453.5
	R^2	0.480		0.478	
	s^{10}logCpUE (CV)	0.35 (0.96)		0.41 (1.20)	
Clarias	Boat			15	95.71
	Location			16	65.44
	Month			11	8.78
	Corrected total			1421	439.91
	R^2			0.386	
	s^{10}logCpUE (CV)			0.44 (1.34)	
Total	Boat	-	-	15	66.18
	Location	13	6.18	16	53.5
	Month	11	6.61	11	3.88
	Corrected total	640	50.74	1448	220.69
	R^2	0.250		0.560	
	s^{10}logCpUE (CV)	0.25 (0.63)		0.26 (0.66)	

4.3.5 Gillnetting for drums in the Nicoya Gulf, Costa Rica

The small-scale gillnet fishery in the Nicoya Gulf (150,000 ha), on the Pacific coast of Costa Rica, targets both fish and shrimps. To assess the variance in CpUE (kg per day trip) of drums, *Cynoscion* species, locally known as 'corvina', landing slips were gathered during six months, spread over three years 1984-1987 (Conquest *et al*. 1996). These slips were collected from a score of landing sites around the gulf and brought to a central location for processing by the Department of Fisheries.

Catch rates (CpUE), mainly of drums, differed between months by not more than a factor two, from 13 to 24 kg per trip, but the variability within months was very high, from CV = 1.90 to 3.99, excluding the extremely high variability in January 1987 (Table 4.13). The authors showed that log-transformations truly normalised the catch frequency distributions. It is however questionable whether the CVs reflect true basic uncertainty. It could be that fish is sold to collector boats or at landing sites before the aggregated catch is recorded on the landing slips. The explanation for this might be the larger economic importance of the shrimps, which are also caught in the gillnets and which could cause fish to be sold at sea or not targeted. This would not only explain the high variability and positive skewness in the catch frequency distributions, but also the unexpectedly high proportion of zero catches for a gillnet fishery (δ = 0.26 - 0.53).

Table 4.13 Characteristics of the frequency distributions in the gillnet fishery for corvinas in the Nicoya Gulf, Costa Rica (based on Conquest *et al*. 1996).

Month	CpUE (kg per trip)	CV	Skewness	Proportion of zero catches (δ)	CV excluding zero catches	N trips
Jan 84	23.9	3.63	28.41	0.31	2.96	2655
Oct 84	16.4	1.90	5.25	0.26	1.55	4792
Jan 85	19.0	2.01	6.09	0.27	1.64	1862
Jul 85	19.6	3.56	30.49	0.30	2.93	4878
Jan 87	13.7	11.28	71.50	0.36	9.00	7161
Jul 87	13.1	3.99	16.37	0.53	2.64	5687

4.3.6 Gillnetting and hook-and-line fishing in the Red Sea, Eritrea

After the civil war Eritrea started the careful monitoring of its small-scale fishery in the coastal area of the Red Sea (Hartmann 1998). At the end of the 1990s the species and size composition of the catch indicated that the fish community was still lightly exploited. Large specimens of highly valued demersals such as snappers, groupers, emperors and jobfish and a smaller proportion of pelagics, mainly mackerels, dominated the catch (Fig. 4.13). It is to be expected that an increase in fishing pressure exerted by a developing fishing fleet will quickly show a downward trend in CpUE for the largest, most vulnerable demersals. Estimates for variability (CV) in catch per trip were inferred from tables with 95% CLs and numbers of observations in Hartmann (1998), subsequently using disaggregation to obtain basic uncertainty in the catch from day to day.

The two types of vessel engaged in this small-scale fishery in Eritrean coastal waters differ in their sizes and motorisation (Table 4.14). Both types mainly use hook & line, but in the period 1995-1997 the smaller vessels especially started to use more and more gillnets as well. There is no particular seasonal pattern in this fishery, neither in fishing effort (number of trips) nor in the CpUE (kg per trip) (Hartmann 1998). The CpUE for the larger vessels was circa twice as high as for the small ones, but variability in CpUE per gear type and year varied only within a small range (Fig. 4.14). The variability for CpUE in the hook and line fishery ranged between CV = 0.28 and 0.31 (average 0.31) and for the gillnet fishery between CV = 0.31 and

0.40 (average 0.35). Assuming that this passive gear is set overnight during five nights per trip the basic uncertainty per night is approximated by disaggregation for hook and line CV = 0.31 * √5 = 0.69 and for gillnets CV = 0.35 * √5 = 0.78. If the two types of gear were operated alternately, the basic uncertainties would be smaller, CV = 0.31 * √2.5 = 0.49 and CV = 0.35 * √2.5 = 0.55 respectively. All basic uncertainties refer to the total catch, species combined, and are thus already reduced by a possible 'portfolio effect' (see section 3.6). Part of the variability in CpUE might also be attributed to differences in fishing power as related to vessel size, which varied considerably within the two categories (Table 4.14).

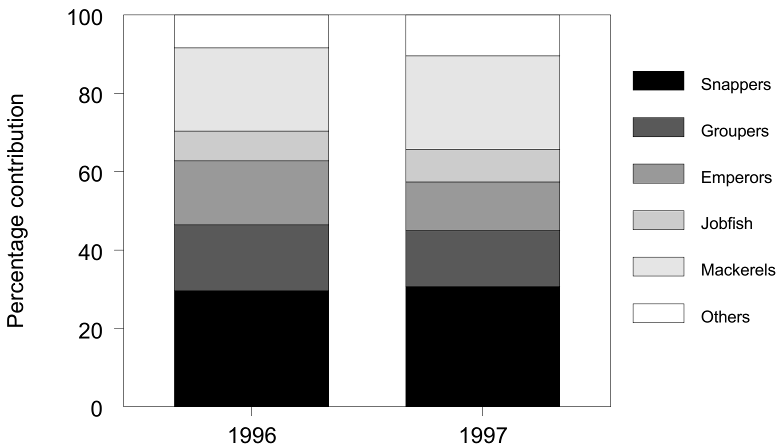


Fig. 4.13 Percentage contribution of major catch categories to the total weight of fish landed by the Eritrean gillnet and hook and line fisheries in the Red Sea in 1996 and 1997.

Table 4.14 Characteristics of the small-scale fishery in the Red Sea, based at Massawa, Eritrea.

Stern trawler type	Small (Houri)	Large (Sambukh)
Length (meters)	10.4 (CV = 0.28)	15.8 (CV = 0.22)
Motor	Outboard, petrol	Inboard, diesel
Crew members	5.4	6.8
Number of days per trip	5.0 – 7.5	6.3 – 8.7
Fishing grounds	50 – 150 km distance	> 105 km

4.3.7 Scaling basic uncertainties in gillnet fisheries

Although the gillnet fisheries examined varied greatly with respect to their target species and scale of operation, basic uncertainty ranged between relatively narrow limits, from CV = 0.5 up to 0.75 (Table 4.15). Theoretically, a gang of gillnets four times as long reduces basic uncertainty by a factor of 2 (= √4). Although the gillnetting for pikeperch and Nile perch are mono-species fisheries for relatively few, large specimens, the setting of more than 1000 m, or longer, gangs of gillnets seems to assure relative stability in day to day catches. The high basic uncertainty in the daily catch per species as experienced by the motorised boat fishermen of Lake Tana might be due to a selective type of fishing behaviour, which has evolved in a situation with surplus fish as the landings. Their high average catch of 170 kg per trip with a 1000 m gillnet led to the outlet of the fishery becoming saturated now and then. Thus, sometimes no more than five of the 20 motorised boats were in operation (M.A.M. Machiels,

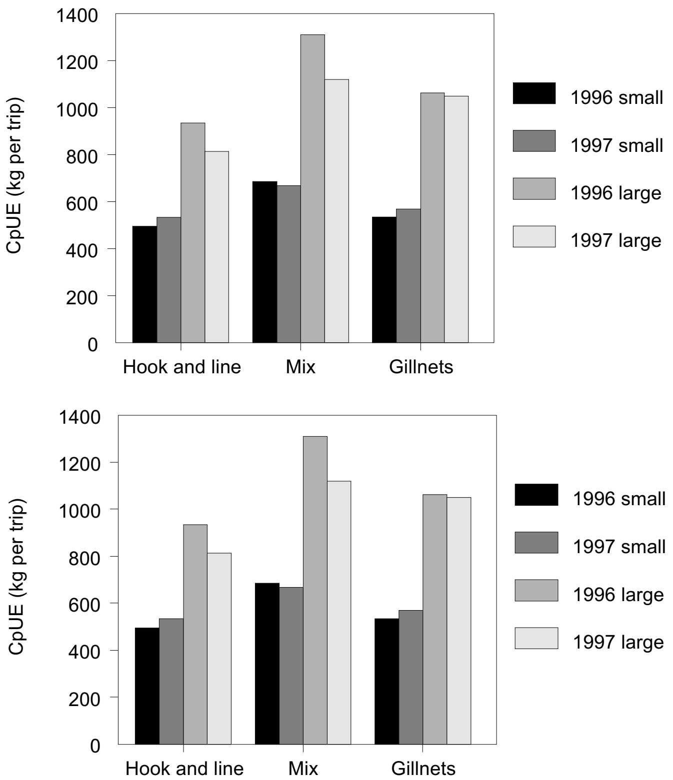


Fig. 4.14 Catch rates (CpUE, kg per trip) (top) and variability (CV) in catch per trip and gear category (bottom) for small and large vessels in 1996 (7.6 days per trip, CV trip du ration = 0.07) and 1997 (6.9 days per trip, CV trip duration = 0.12).

personal communication). These fishermen probably allocated their effort to sites with the highest probability of catching a particular species that was in highest demand. The very high basic uncertainty as estimated for the gillnet fishery for drums in the Nicoya Gulf, Costa Rica, must have been the consequence of very selective fishing interacting with the gillnetting for higher-valued shrimps.

Table. 4.15 Scaling of gillnet fisheri es by their basic uncertainty in their catch from day to day.

Number	Category	Area	Length Gillnets (m)	CV
1	Pikeperch	Beulakerwijde, the Netherlands	1800	0.47
2	Nile perch, offshore	Lake Victoria, Tanzania	1800	0.47
3	Nile perch, inshore	Lake Victoria, Tanzania	1125	0.58
4	Total catch, reed boats	Lake Tana, Ethiopia	400	0.63
5	Total catch, motorised boats	Lake Tana, Ethiopia	1000	0.66
6	Tilapia	Tissawewa Reservoir, Sri Lanka	400	0.71
7	Tilapia, reed boats	Lake Tana, Ethiopia	400	0.75
8	Total catch	Red Sea, Eritrea	-	0.55-0.86
9	Barbs, reed boats	Lake Tana, Ethiopia	400	0.96
10	Barbs, motorised boats	Lake Tana, Ethiopia	1000	1.20
11	Catfish, motorised boats	Lake Tana, Ethiopia	1000	1.34
12	Tilapia, motorised boats	Lake Tana, Ethiopia	1000	2.15

4.4 Light fisheries

4.4.1 Liftnetting, beach seining and scoop netting for a small pelagic in Lake Victoria, Tanzania

With its surface area of 68,000 km^2, Lake Victoria is the largest freshwater lake in the world (mean depth 20 m, max. depth 79 m). After the introduction of the Nile perch in the 1950s the Lake Victoria ecosystem has simplified and so has the resource base of its fishery (Ligtvoet & Witte 1991). Present day fisheries rely on only three fish species: the introduced Nile perch, *Lates niloticus*, the introduced Nile tilapia, *Oreochromis niloticus*, and the endemic small pelagic, *Rastrineobola argentea*, a cyprinid. During the 1980s the light fishery for the small pelagic, locally known as dagaa (Tanzania), expanded. It became the second most important fishery on Lake Victoria after the gillnet fishery for Nile perch. Fishermen in the Tanzanian waters of southern Lake Victoria catch dagaa, attracted by lights, with small-meshed beach seines and scoop nets in inshore waters, and with liftnets in more offshore waters (Mous 1991). The major part of these dagaa catches is sundried, resulting in a well-preserved product and it is therefore not surprising that a substantial part of the catch is exported (Wanink 1998). Wanink *et al*. (1999) advised the management to concentrate the fishery in offshore waters to prevent over-exploitation of juvenile stages residing in the more shallow inshore areas. The basic uncertainty in the daily catch per gear type was assessed during the monitoring of this fishery in two villages north of Mwanza, Igaragara and Igombe, from October 1988 through February 1989 (Mous *et al*. 1991).

Catch rates, but not the variability therein, differed greatly between gear types. Average catch of dagaa per night with both beach seines and scoop nets was around 80 kg, whereas liftnet catches were circa six times larger (Table 4.16). 0-catches were not observed in this fishery, probably due to a more homogenous spatial distribution of dagaa. Lamp-hour was evaluated as the most proper unit of effort and so CpUE estimates were converted into kg per lam-hour (Table 4.17) (Mous *et al*. 1991). The variability in CpUE estimated for the two sites and for two lunar months varied between CV = 0.48 and 1.38 with an unweighted mean of CV = 0.80.

Table 4.16 Characteristics of the fishing units and the CpUE per group and per lamp -hour in the fishery for dagaa, *Rastrineobola argentea*, in the Tanzanian part of Lake Victoria (based on tables in Mous *et al*. 1991).

	Beach seine		Scoop net		Lift net	
	Mean ± sd	n	Mean ± sd	n	Mean ± sd	N
Number of fishermen per group	4.4 ± 1.0	21	2.9 ± 0.6	7	4.0 ± 0.0	10
Number of lamps per group	3.8 ± 1.0	21	2.9 ± 0.5	7	2.9± 0.2	10
Mesh size (mm stretched mesh)	5-8		8		8	
Maximum distance from shore (km)	0.5		1		20	
Susceptibility to weather conditions	High		Moderate		Low	
CpUE (kg/group/night)	80	71	77	24	480	55
Maximum catch (kg/group/night)	360		640		1950	

Table 4.17 CpUE (kg/lamp-hour) for the fishing units in the fishery for dagaa, *Rastrineobola argentea*, in the Tanzanian part of Lake Victoria at two sites and in two succeeding lunar months (based on tables in Mous *et al*. 1991).

	Beach seine			Scoop net			Lift net		
	Mean	CV	n	Mean	CV	n	Mean	CV	n
Nov/Dec									
Igaragara	5.5	0.86	12	9.5	1.38	13	-	-	-
Igombe	7.8	1.02	7	-		-	44.1	0.70	14
Dec/Jan									
Igaragara	6.4	0.64	16	4.3	0.48	10	-	-	-
Igombe	3.6	0.54	6	-	-	-	6.7	0.78	10

4.4.2 Purse seining for clupeids and their predators in Lake Tanganyika, Burundi

In contrast to Lake Victoria, Lake Tanganyika is a narrow, deep rift valley lake (surface 33,000 km^2, mean depth = 570 m, max. depth = 1470 m). The fish community of Lake Tanganyika has two components: a less diverse pelagic community in the deep open water and a highly species diverse littoral community in the more shallow margins of the lake. Since 1954 the pelagic resources of northern Lake Tanganyika have been exploited by a fleet of ca 15 purse seiners, using Mediterranean light fishing techniques (van Zwieten *et al*. 2002). The purse seiners of 12-18 m length, with inboard diesel engines of 250 HP have a crew of about 30, an auxiliary barge carrying a purse seine of approximately 400 x 100 m, and 4-5 small light boats (Bellemans 1992). These purse seiners make ca 280 trips per year, i.e. ca 25 trips per month. They grade their catches by size: ‘small’ (ndagala), ‘medium’ (mukeke) and ‘large’ (sangala). Total catches are dominated by the category ‘small’, comprising two small clupeids *Stolothrissa tanganicae* and *Limnothrissa miodon*, supplemented with juveniles of the small piscivore *Lates stappersii* (Centropomidae). The second category of medium-sized fish comprises adult *L. stappersii* only. The more species-diverse, third category of large-sized fish, composed of the congeneric piscivores, *Lates angustifrons*, *L. mariae* and *L. microlepis*, has decreased markedly over the years and their contribution in the total catch has become negligible (section 6.2.4). The percentage contributions to the total catch over the period 1973-1992 was 71, 27 and 2% for ‘small’, ‘medium’ and ‘large’ fish respectively.

Traditionally, the purse seine skippers have been of Greek origin, but in the 1970s it became desirable to train African skippers as well. At that time, one wondered whether their training should include training in “fishing sense” or how to locate productive fishing sites (Chapman & Well 1975). The performance of an experienced Greek skipper was followed from day to day in March and April 1975 to assess whether there is such a thing as “fishing sense” and whether it contributed materially to the catch per vessel per night (Chapman & Well 1975). Catches of a total of 30 nights, 14 with sites as selected by the skipper and 16 nights with sites by random selection, were compared. The catch in these series was strongly dominated by medium-sized fish, i.e. adult *Lates stappersii*. The catch during the skipper nights was significantly higher (2079 kg per night) than during the nights with random selection (1165 kg per night) (Fig. 4..15). The variability in the two series, and in the series combined was, however, almost the same: CV = 0.93, 0.95 and 1.00 respectively. In the period July 1974 through February 1975 the skipper's performance was continuously monitored. Of the 105 nights recorded, he returned to the same site as in the preceding night during 37 nights. Overall this responsive behaviour was not significantly effective, except when only those combinations in which the catch in the preceding night exceeded 3000 kg were selected (Chapman & Well 1975). This is a weak indication of serial correlation in a series of daily catches that was probably due to more persistent local availability of a fish concentration.

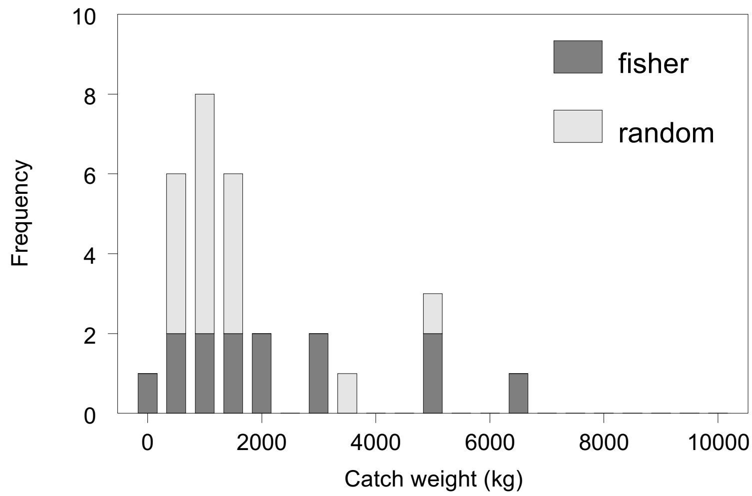


Fig. 4.15 Catch frequency distribution for nightly catches of *Lates stappersii* (500 kg categories) by one experienced skipper in the Lake Tanganyika purse seine light fishery in March and April 1975 (as based on Table I in Chapman & Well 1975). Fisher = sites selected by the fisherman; Random = sites selected randomly.

4.4.3 Purse seining for sardines around E-Java, Indonesia

Sardines and anchovies are small pelagics, whose share of the total landings of fish from Indonesian waters has steadily increased over the years. This is due to both the lesser resilience of non-pelagics, such as reef and demersal fish, under the steady increase in fishing pressure and the successive shift to pelagic fishing in more offshore waters. The tendency towards more pelagic fisheries progresses from western and central Indonesia towards the eastern part of the country. The national authorities have high expectations of the potential for further expansion of these pelagic fisheries and are keen on realistic estimates of the Maximum Sustainable Yield (MSY) for pelagics both small and large. The MSY is generally estimated with the surplus production model of Schaefer (1957). For that purpose CpUE (C/f) is plotted against fishing effort (f) and the MSY is inferred from the maximum in the product C/f * f. This requires continuous maintenance and improvement of the present Indonesian Catch and Effort Data Recording System (CEDRS), in order to produce unbiased estimates of CpUE and fishing effort in the most efficient manner. The following example refers to variabilities in catch rates (CpUE) and in fishing effort (f) as observed in a purse seine fishery with light attraction targeting pelagics in the coastal waters around Eastern Java (Pet *et al.* 1997a).

The purse seine fishery of E-Java is a medium-scale fishery, operated from a few, larger harbours which accounts for more than 50% of all sardines landed. In 1993 total landings of sardines, mostly *Sardinella longiceps* and *S. fimbriata*, in East Java was 56,000 tonnes. A purse seine fleet, with a variable size of 40 to 70 vessels, was sampled in Probolinggo harbour on the Madura Strait, during 4 to 6 days per month from March 1990 until March 1991. A typical purse seiner from this harbour is 13.5 m long, 3.5 m wide and 1.5 m deep, has a 30 hp inboard engine and uses a purse seine net 220 m long and 80 m deep. The mesh size of the net is 25 mm stretched mesh in the wings and 18 mm in the cod end. The purse seiners use floating rafts with six to eight kerosene lamps to attract fish during the night. The number of settings per nightly trip was 2.87 and hardly varied at all (CV = 0.10).

The Probolinggo-based purse seine light fishery has a characteristic periodicity in fishing effort and in catch rates as governed by the phases of the moon. Peak catches are landed around new moon. Around full moon, the fishery is inactive for a period of 10 days. Although medium-scale, the fishery has a high portion of 0-catches and a high variability in non-0 catches. The mean effort of the fleet operating from Probolinggo harbour was 36.1 trips per day, of which, on average, as many as 23.5 trips resulted in a 0-catch ($\delta = 0.65$). In total, 1807 trips were recorded of which 1201 did not yield any sardines. During the monitoring period the sardine landings were completely dominated by one species, *Sardinella longiceps*, locally known as 'tembang' (Pet *et al.* 1997b).The geometric mean CpUE of the non-zero catches was 404 kg of sardines per trip, but maximum individual catch recorded was more than 20 times higher (9000 kg), highlighting the positively skewed frequency distributions of the catches. When a purse seine is completely filled with sardines the weight can be more than the carrying capacity of the vessel. During the study, several vessels sank from overloading or had to cut the rope of their nets.

Part of the variance in the proportion of 0-catches (δ) and in the size of non-0 catches is explained by lunar periodicity and by month (season) (Pet *et al.* 1997a). To assess basic uncertainty in the catch per purse seiner from day to day, both types of periodicity have to be corrected for. Therefore, catch and effort data were first grouped into lunar periods of three successive lunar dates (Fig. 4.16). Further grouping was into three lunar phases: lunar phase 1, the non-fishing period, lasts from lunar day 11 to 20; lunar phase 2, half moon, from lunar day 6 to 10 and from day 21 to 25; phase 3, new moon, from lunar day 26 to 5. The proportion of successful trips and the weights of non-0 catches were high during new moon and towards the end of the year, after the dry season (Fig. 4.16). The size of the non-zero catches were also high during new moon and towards the end of the year, after the dry season (Fig. 4.16). The proportion of zero catches per monthly period varied between $\delta = 0.34$ and 0.85 (average 0.64). Per lunar period of three successive days it varied between $\delta = 0.55$ and 0.91 (average 0.68).

Not only was the proportion of zero catches high but also the variability in non-0 catches. The geometric mean CpUE of non-0 catches was ca 1.6 times as high around the new moon (lunar phase 3; 459 kg per trip) as during half moon (lunar phase 2, 291 kg per trip). The catch frequency distributions for non-zero catches were strongly positively skewed and became normal after log-transformation. The standard deviation in the ^{10}log-transformed catches for lunar phase 2 varied between $s\,{}^{10}\text{logCpUE} = 0.41$ and 0.88 (average s = 0.60, CV(s) = 2.40) and for lunar phase 3 between $s\,{}^{10}\text{logCpUE} = 0.54$ and 0.83 (average s = 0.68, CV(s) = 3.26). The basic uncertainty in the catch of sardines from day to day is inferred from the combination of the overall average for the proportion of zero catches ($\delta = 0.66$) and of the variability in non-zero catches for half moon and new moon combined (CV = 2.83). Basic uncertainty was then calculated as CV = 5.05 (see 3.4.1).

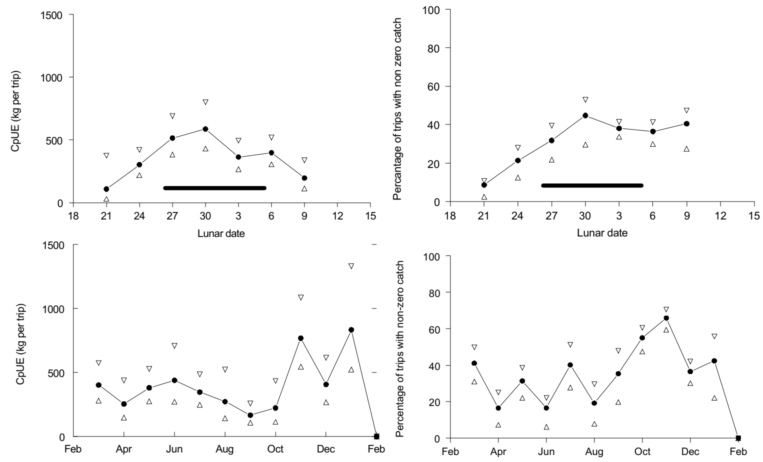


Fig. 4.16 Catch rates (CpUE as kg per trip, 95% CLs) per lunar period (top left) and per month (bottom left) and the percentage of non-zero catches (= (1 - δ) * 100%, 95% CLs) per lunar period (top right) and per month (bottom right). From Pet *et al*. (1997a).

4.4.4 Purse seineing, lift netting and beach seining for pelagics in Maluku, Indonesia

Because there is only a narrow fringe of shallow areas around Ambon and the two neighbouring Lease Islands, Haruku and Saparua, in the Central Moluccas, few demersal fish are caught and pelagics dominate the landings (Anonymous 1995). Major categories of pelagics in the landings are anchovies, sardines, scads, mackerels, halfbeaks, jacks and trevallies. They are caught with purse seines, liftnets and sometimes beach seines in well-defined coastal habitats such as bays, sea straits and other stretches of sheltered coastline. The fish are used for local consumption, but also as bait for the important pole and line fishery for skipkack, *Katsuwonis pelamis*, and other tunas, in offshore waters (Haskoning 1983, Hein 1993). It was expected that large, unexplained variances in catch rates for these pelagic fisheries constrain the fishermen's perception of spatial and temporal patterns in resource outcome. To test this hypothesis a study was made of spatial and temporal allocation of fishing effort and of CpUE in these waters (Jansen 1997, van Oostenbrugge 1999, van Oostenbrugge *et al*. 2001). Data from this study were used for the assessment of basic uncertainties in the daily catches with purse seines, liftnets and beach seines and all three used in combination, with light attraction.

The purse seiners are of comparable size to those from E-Java (see 4.4.3), 15 m long with nets of 275 m length and 60 m depth and with a minimum mesh size of 20 mm. These purse seiners catch mainly small tuna, *Auxis* spp. and some roundscads, *Decapterus* spp. (van Oostenbrugge *et al*. 2001a). The catch of lift nets and beach seines consists, on average, of smaller fish and is more species diverse, with beach seines catching some demersal fish as well. The mesh size of the lift nets is 5 mm, of the beach seines 7 mm. The beach seines measure 130 m and are 10 m deep.

The proportion of 0- catches, species combined, was high for both purse seiners (δ = 0.70) and liftnetters (δ = 0.68), and was comparable to the proportion of 0-catches in the E-Java purse seine fishery (δ = 0.66). In the more species-diverse beach seine fishery the proportion of zero catches was considerably lower (δ = 0.31). The geometric mean CpUE as kg per trip of non-0 catches, was several 100 kg for purse seiners, but ranged between 10 and 100 kg for both lift nets and beach seines (Fig. 4.26). The variability in non-zero catches did not differ systematically between the three fishing modes. The standard deviation in the catch frequency distributions of ^{10}log-transformed catches was on average s^{10}logCpUE = 0.45, 0.35 and 0.36 for purse seines, lift nets and beach seines respectively, corresponding with CV(s) = 1.39, 0.96 and 0.99. When zero catches are included, the basic uncertainties in day to day catches for the three fishing modes would be CV = 2.96, 2.24 and 1.37 respectively. The relatively low basic uncertainty in the total catch in the beach seine fishery is due to the 'portfolio effect' of a species diverse fishery, although the catch per haul was generally of exclusively one species. The beach seine groups made one, at the most two, hauls per night. These hauls were generally dominated by one species only (Jansen 1997).

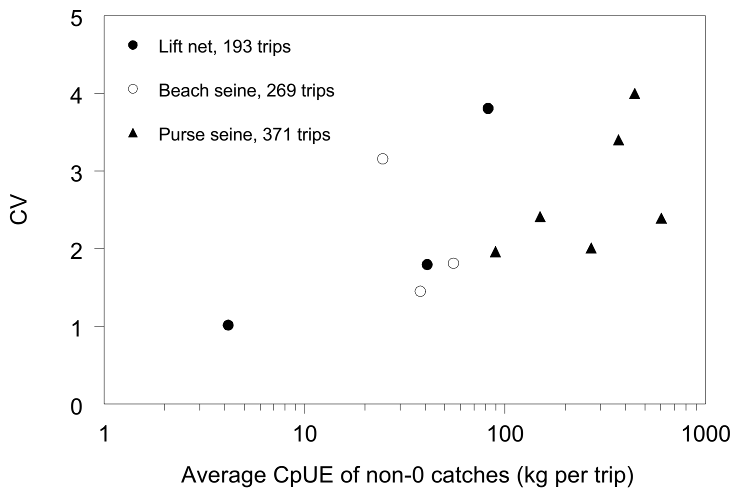


Fig. 4.17 Variability (CV) in daily catches (kg/trip) for three gear categories plotted against the geometric mean of non-0 catches. Variability is estimated from the standard deviation in ^{10}log-transformed non-0 catches and the proportion of zero catches. Each point represents a particular fishing unit (Data from tables 5.5 and 5.6 in van Oostenbrugge 1999).

4.4.5 Scaling basic uncertainties in the fishery with light attraction

Basic uncertainty in light fisheries ranged between CV = 0.8, with hardly any 0-catches in freshwaters, up to CV = 5 for mono-species light fisheries in marine coastal waters with a high proportion of 0-catches (Table 4.18). Fishering with light attraction, just as gillnetting and angling, is a passive fishing mode with catch rates affected by the spatial aggregation and the mobility of the fish it is desired to attract. Small pelagics are not necessarily strongly spatially aggregated as exemplified by the homogenous distribution of smelt, *Osmerus eperlanus*, a small pelagic, in lake IJssel, the Netherlands (Mous *et al*. 2000). It is possible that in the more transparent marine environment, where organisms occur in patchy distribution patterns at a relatively large spatial scale, the low rates at which a light trap encounters schools of pelagics induce the higher basic uncertainty in marine fisheries. This would also explain the higher proportion of 0-catches in these marine fisheries.

Table 4.18 Scaling of the fisheries with light attraction by their basic uncertainty (CV) in their catch per day with the proportion of zero catches.

Number	Category	Gear	Area	CV	δ
1	*Rastrineobola argentea*	Lift net, beach seine, scoop net	Lake Victoria, Tanzania	0.80	0
2	*Lates stappersii*	Purse seine	Lake Tanganyika, Burundi	1.00	0
3	Total catch	Beach seine	Maluku, Indonesia	1.37	0.31
4	Total catch	Lift net	Maluku, Indonesia	2.24	0.68
5	*Auxis* spp.	Purse seine	Maluku, Indonesia	2.96	0.70
6	*Sardinella longiceps*	Purse seine	E-Java, Indonesia	5.05	0.66

4.5 Sport fisheries

4.5.1 Pikeperch tournaments in Amsterdam

Day to day variability in sport fisheries is difficult to assess, but could possibly be approximated with the variability in catch rates between anglers fishing at the same site on the same day and with the same tackle. Tournaments offer a unique possibility for assessing this between-angler variability. The variability in catch rates between anglers during one particular tournament is mainly governed by mere chance and by angling skill, assuming that all anglers use the same tackle. Differences in angling skill are supposed to be large relative to that in fishing skill between professional fishermen (Hilborn 1985) but, only if differences in angling skill do contribute a large portion of between-angler variability does it become worthwhile to account for that in the design of creel surveys for which the statistical power is predefined. To weight the relative contributions of mere chance and of angling skill as the two major sources of variance, the performance of individual anglers should be followed through a series of tournaments, in order to assess possible systematic differences between anglers.

A most complete series of catches per individual angler and per tournament is the one for the 15 pikeperch tournaments held between 1992-1996 in two deep (35 m) Amsterdam town waters, Nieuwemeer (130 ha) and the less turbid Sloterplas (87 ha). Each tournament lasted 1 (7 hours) or 2 days (2 * 7 hours). Anglers (108-242 per tournament) fished in pairs from small open boats and were free to move around the lake. The organisers recorded numerical catches per angler as well as the individual size of each pikeperch caught, that had to be larger than 45 cm to be included. The average size of pikeperch caught was ca 53 cm (~ 1.3 kg). After recording, pikeperch were released back into the lake. The data were provided by Kovski and De Groot, who organised the 15 tournaments.

Catch rates, as number of pikeperch caught per angler, and standardised per 7 hr tournament, were low on average, but higher in Nieuwemeer (0.65, CV = 1.2 – 2.6 per tournament) than in Sloterplas (0.39, CV = 1.8 – 2.9). Higher average catch rates per tournament combined with a lower proportion of 0-catches (Fig. 4.18). The proportion of 0-

catches during any tournament was always more than $\delta = 0.4$. When average catch rates were really low, far below 1 pikeperch per 7 hr per tournament, most individual catches were either 0 or 1. Because, in a series with only 0-s and 1-s the variance equals the mean ($s^2 = \overline{C}$), catch frequency distributions mimic a random or Poisson distribution with $\delta = e^{-C}$ and CV = $C^{-½}$ (see 3.4.1). When average catch rates are higher, the individual catches are more unequally distributed among the anglers than according to the Poisson distribution and tends to a negative binomial with $k \rightarrow 1$ (Fig. 4.18). The Gini coefficient, another measure of the unequal distribution of catches between anglers, varied between G = 0.561 and 0.882 per tournament and, as expected, was highly correlated with the variability (CV) per tournament (Fig. 4.19).

A proper assessment of systematic differences in catching success between individual anglers requires that the same anglers participate repeatedly in the same pikeperch tournaments and so met the same conditions. Only 11 anglers participated in all 15 tournaments (Table 4.19). The ranking of these 11 anglers by their average catch rates agreed rather well with their ranking by their individual maximum catch. The differences between them, however, were hardly statistically significant due to the high variability per angler (Fig. 4.20). Anglers 3 through 11 could not be distinguished from each other on the basis of their individual catch rates, although number 3 caught 4 times as many pikeperch as number 11. Part of the variability per angler could be due to systematic differences in angling conditions between tournaments. But if these were true systematic differences, correction for between-tournament variability (CV = 0.64, or CV = 0.65 if averages per tournament were based on all anglers participating) would lower the random variability for the 11 anglers with only 0.64^2 = 0.41. If, in addition, the differences between anglers were true systematic differences, a conservative estimate of random variability per angler would be (see section 3.5 for equation):

$$CV^2_{random} = CV^2_{total} - CV^2_{angler} - CV^2_{tournament}$$

$$CV^2_{random} = 1.66^2 - 1.08^2 - 0.64^2$$

So CV_{random} = 1.08. This would imply that, per tournament, random variability is as large as variability due to angling skill, if the group of 11 anglers is thought representative of all anglers per tournament. Focussing on a small group of very skilled anglers would certainly reduce the variability per angling session, but would lower the number of observations as well, and this would strongly affect the statistical power. Simply enlarging the sampling size of anglers by a factor 2, would result into the same 'administrative gain' as far as variability reduction is concerned: $1.08^2 + 1.08^2 = 1.53^2$, and $1.53/1.08 = \sqrt{2}$. The organisational load of selecting and monitoring a group of highly skilled anglers is probably much more of a burden in comparison with doubling the number of anglers for which catches are recorded.

It may have been that the pikeperch anglers participating in the tournaments were more professional, and thus more homogenous in angling skill, than the population of pikeperch anglers throughout the country. This would imply that the results of country-wide surveys contain a larger portion of variability due to differences in angling skill.

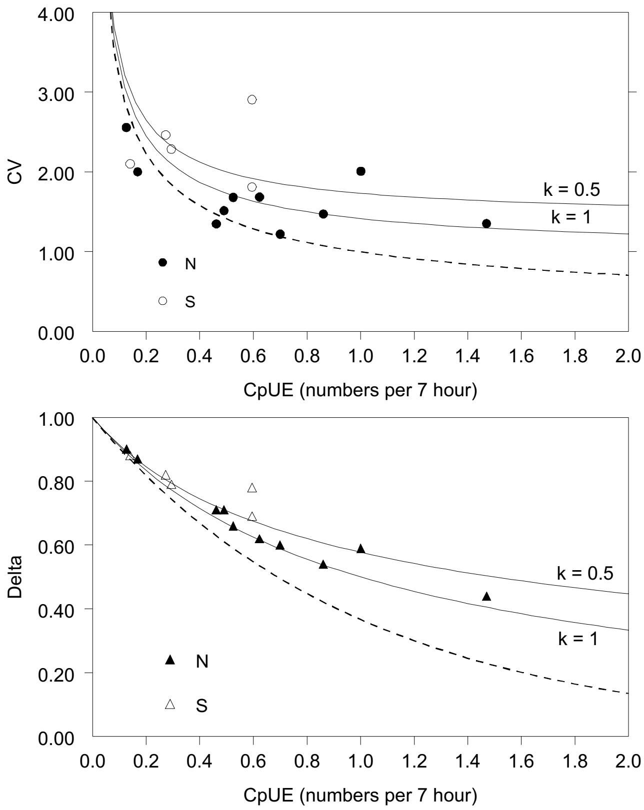


Fig. 4.18 Variability (CV) and the proportion (δ) of 0-catches plotted against average catch rate of pikeperch per angler during 15, 7 hr tournaments in two Amsterdam town waters. N= Nieuwemeer, S = Sloterplas. For 2*7 hr tournaments the proportion of 0 - catches was adjusted via $\delta_7 = 1/\sqrt{\delta_{14}}$. The dashed lines present relationships according to the Poisson distribution. The others according to the negative binomial with k = 0.5 and 1.0. Based on catches recorded by Kovski and De Groot.

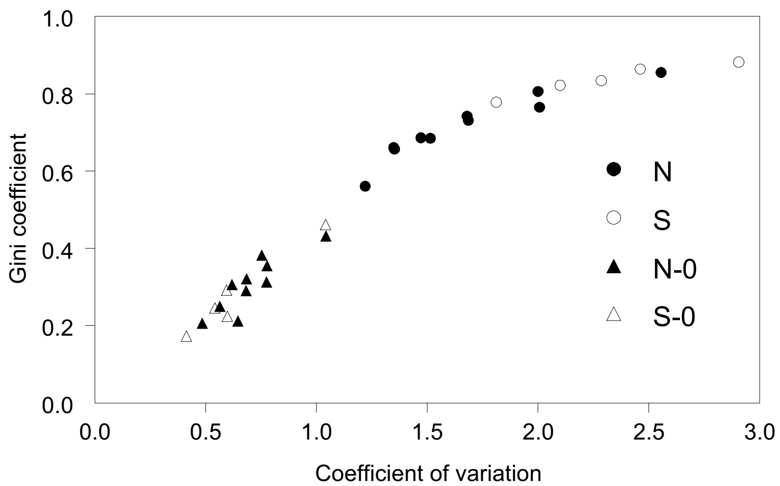


Fig. 4.19 The Gini coefficient for catch frequency distributions (with and without 0 -catches) per tournament as related to the CV in CpUE, including 0-catches. N = Nieuwemeer, S = Sloterplas (-0 means without 0-catches).

Table 4.19 Performance of 11 anglers participating in all 15 tournaments.

Angler	Proportion of 0-catches (δ)	CpUE (number per 7 hr tournament)	CV	Maximum catch
1	0.07	4.67	0.80	15
2	0.40	2.20	1.08	7
3	0.47	1.33	1.22	5
4	0.53	1.07	1.75	7
5	0.47	1.00	1.25	4
6	0.47	0.87	1.14	3
7	0.40	0.87	1.06	3
8	0.67	0.53	1.72	3
9	0.80	0.47	2.12	3
10	0.67	0.40	1.58	2
11	0.73	0.33	1.85	2
Combined		1.16	1.66	15

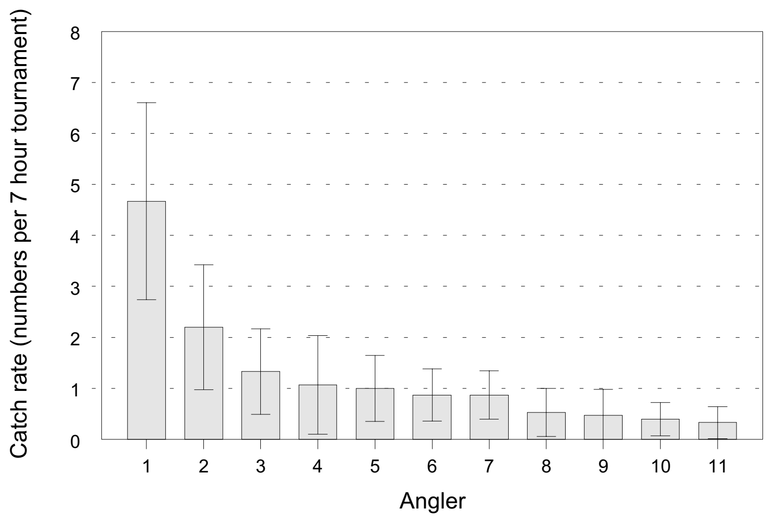


Fig. 4.20 Average catch rates (number of pikeperch per 7 hr tournament) with 95%CLs for pikeperch catches recorded for 11 anglers participating in all 15 tournaments.

4.5.2 Angling records for pikeperch in a national database

Catch rates during the pikeperch tournaments in the Amsterdam town waters were very low indeed, when compared to the catch rates for pikeperch as recorded for various waters throughout the Netherlands. Such recording at the national scale is organised by the Dutch Union of Anglers Federations (NVVS). This organisation supports 23 federations each with a multitude of angling clubs. The NVVS has set up a database of angler's catches for the purpose of evaluating angling quality and management per waterbody. Anglers report their catch and effort per angling trip on a voluntary basis to their own club, whose data are transferred to the NVVS.

In the period 1990-1995 altogether 48,148 trip records (ca 8000 per year), were stored in the NVVS database. Of this total only 1066 were identified as true pikeperch trips, made by

94 anglers fishing in 122 waterbodies (Lourens 1996). These anglers caught 2125 pikeperch in total, or 2.07 ± 2.46 pikeperch per trip (CV = 1.19); the average trip lasted 4 ± 1.5 hours (Fig. 4.21). This corresponds with circa 3.5 pikeperch per 7 hr angling session and nominal catch rates were thus at least 5 times as high as during the Amsterdam tournaments. The proportion of 0-catches in the total sample was $\delta = 0.30$, corresponding with a low $\delta = 0.12$ per 7 hr session.

Part of the total variance in catch rates is due to management-relevant differences between waterbodies and to time trends within waterbodies. However, given the high variability of angler catches, in combination with the small number of angling trips per waterbody (ca 9), the statistical power of the monitoring schemes is insufficient to detect these differences and trends as statistically significant. This statistical power will only improve if the monitoring is directed towards a selection of 'demonstration' waters, where much larger samples should be taken. It is because the NVVS took the initiative to set up the angler's database that such insights are gained and that future sampling efforts can be directed more efficiently.

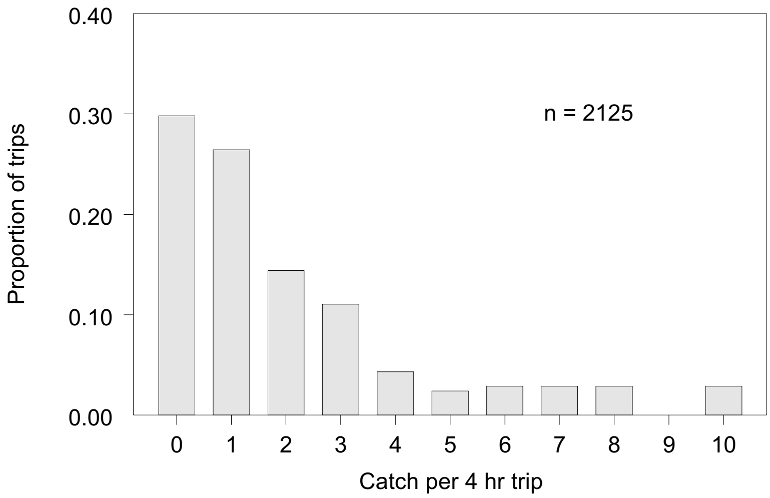


Fig.4.21 Catch frequency distribution as reported by pikeperch anglers and stored in the NVVS database (Fig. 6.6 in Lourens 1996).

4.5.3 British National Angling Championships

British National Angling Championships differ from the Amsterdam pikeperch tournaments by the way in which the trophy is measured and by the types of waterbodies. The trophy is measured in total weight instead of numbers, and for the total catch of species combined instead of the catch of one fish species only. The waterbodies are stretches of rivers and canals, instead of lakes as during the pikeperch tournaments in Amsterdam. Since 1972 there have been at least two championships a year with at least 936 anglers fishing per championship (O'Hara & Williams 1991). Anglers were usually spaced at a distance of 20 metres apart. So the effective total length fished in each competition was as least 18.7 km. Spatial patterns in fish abundance and environmental conditions along such large stretches could have contributed to the total variance in the individual catch per angler. However, when tested for spatial patterns in numerical catches during another type of tournament in the UK, in that case for bream, such patterns could not be detected (Kell 1991, his Fig. 18.5).

The questions formulated by O'Hara & Williams (1991) in their analysis of catch rates and variances from British National Angling Championships were very much in line with the key questions of the present study on the perception of time trends. Citing these authors:

- Are these catch data capable of giving some indication of fish community structure?
- On waters where several years' data are available are the patterns of catches consistent, or do they indicate trends that could be assessed in the light of known changes in species composition?
- Do anglers perceive different water bodies as better in competition angling terms than others?

O'Hara & Williams (1991) analysed catch data from 11 championships, of which eight were in the same river, River Trent, one in the River Ancholme and two in different canals (Fig. 4.22). Average catch rates varied from 0.3 to 1.3 kg, and the proportion of 0-catches was always low. The authors gave no standard deviations but they characterised the inequalities in the catch per angler with the Gini coefficient, which mostly varied between G = 0.4 and 0.6 (Fig. 4.22). According to Fig. 4.19 the corresponding variability would, by approximation, range between CV = 1.0 and 1.3. So even in a multi-species angling competition the variability in catch rates does not become much lower than CV = 1 for species combined.

O'Hara & Williams (1991) indicated the possibility that the structure of the fish community could have an effect on the variability in catch rates during the British National Angling Championships. They supposed that a community with many small fish causes lower variability for the same average catch, in terms of total weight, than a community with the same biomass but with lower numerical density.

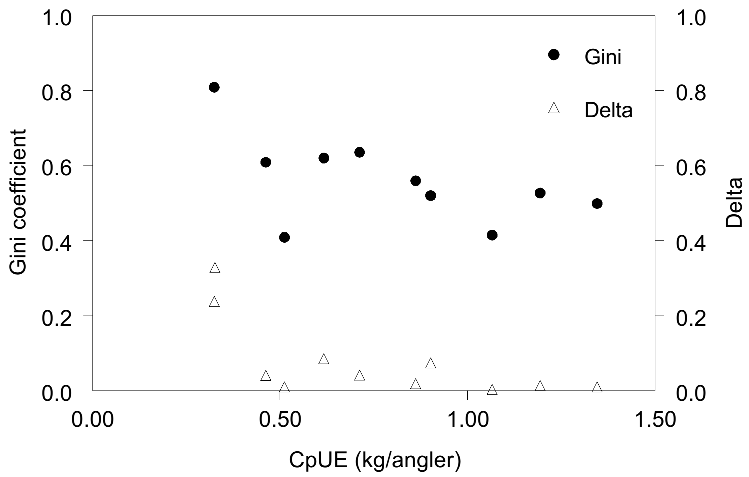


Fig. 4.22 Variability indicated with the Gini coefficient and proportion of 0-catches (δ) plotted against average catch rate (CpUE, kg per individual angler) for 11 British National Angling Championships (based on figures in O'Hara & Williams (1991)).

4.5.4 Angling surveys in the Netherlands

There are around 1 million anglers in the Netherlands, who mainly target cyprinids, roach and bream especially, in a multitude of small- and medium-sized waterbodies. Not only the national angling organisation (NVVS), but also the national authorities, took some responsibility for monitoring angler performance in these many waters on behalf of sport fisheries management. For years they evaluated the recreational value of angling waters in the

Netherlands as indexed with two performance measures of angling success: the proportion of successful trips (1 - δ) and the numerical catch per successful trip, both calculated per species (Steinmetz 1982, 1990; Steinmetz & Slothouwer 1982). An assessment of a relationship between these two measures, which could possibly vary per species, has not been tried, neither was variability in catch rates evaluated so as to assess the statistical power of the monitoring schemes.

Combining the data from various angling situations, it appears as if there is a general relationship between the proportion of 0-catches and the average catch rates (Fig. 4.23). When average catch rates are higher than 1 fish per 4 hour angling session, this relationship clearly departs from that according to a Poisson distribution characteristic for very low catch rates (see also 3.4.1). High catch rates combined with a relatively, still high, proportion of 0-catches, are more in line with a negative binomial with parameter k around 0.50. If the catch frequency distribution follows this negative binomial the overall catchability per survey would vary between CV = 1 and 2 for quite a large range in angling success (cf. Fig. 3.13). Part of such pronounced inequality in catch rates between anglers could be due to large systematic differences in angling skill between individuals. Those angling carp or grass carp are certainly all specialists. In the population of bream and roach anglers, however, there are possibly larger differences in angling skill, which explain the higher proportion of 0-catches, when average catch rates are relatively high. Another explanation would be a difference in the spatial aggregation of these fish categories.

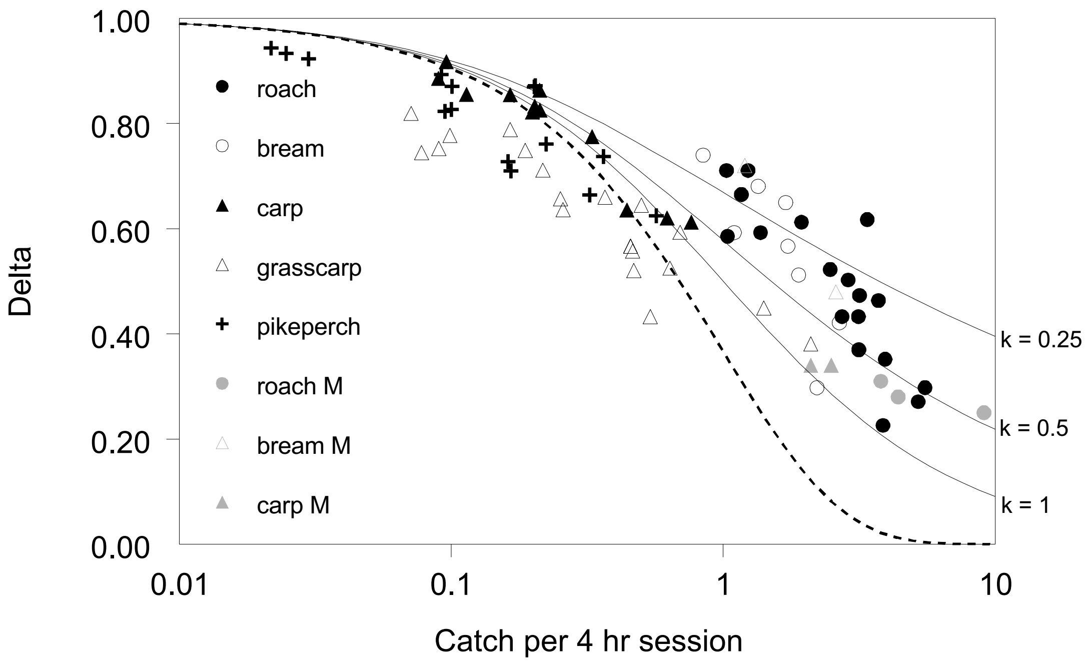


Fig. 4.23 Proportion of 0-catches (δ) plotted against CpUE (numbers per 4 hour angling session) for roach, bream, carp, grass carp and pikeperch. Data for roach and carp are both from the Twenthe canals (Steinmetz (1990, Table 2)) and the Philips recreational ponds, read from graphs in Steinmetz (1982, Figs 6 (p. 390) and 5 (p. 380)), for bream from the Twenthe canals (Steinmetz (1990, Table 2)), for grass carp from Achttienhoven in Steinmetz (1982, Fig. 7, p. 391) and for pikeperch from the tournaments discussed under 4.5.1. M refers to data in Muyres (1977). The proportion of 0 -catches is converted for trip duration of 4 hours. Dashed line – Poisson, Negative binomials with k = 0.25, 0.5 and 1.

4.5.5 Scaling basic uncertainties in sport fisheries

The examples from sport fisheries show that where catches are recorded in numbers and average catch rates are low, variability is not independent of the mean. When the average numerical catch is really low (<< 1), the series is mostly dominated by 1-s and 0-s and variability (CV), and the proportion of 0-catches, decreases with the average catch (C) according to the Poisson distribution. Both in the case of the pikeperch tournaments and in the national surveys, variability decreased less than according to the Poisson distribution. If the negative binomial with k = 0.5 is a proper description of the catch frequency distribution, variability in the catch per angler will hardly become less than CV = 1. Even during the British National Angling Championships, where the trophy is total weight irrespective of species caught, this seems to be a lower limit in the variability per angling session. Systematic differences between anglers will certainly contribute to the variability between anglers, but in terms of statistical power it hardly seems rewarding to organise a monitoring scheme for highly skilled anglers specifically. The statistical power for monitoring angling success in smaller waters is seriously constrained by the finite size of the population of anglers in combination with the inevitable high variability between anglers.

4.6 Day to day variability

The range in day to day variability is large, but there are some tendencies (Fig. 4.24). Trawling is a mobile and more large-scale fishing mode. Variability is therefore small, but once one targets more aggregated pelagics, variability enlarges. How variable daily catches then are merely depends on the scale at which concentrations fish occur relative to the area of operation. Large stern trawlers in Mauritanian waters targeting pelagics with advanced fish finding devices sometimes operate side by side and for days in succession to locate the highly mobile, large scale concentrations of *Sardinella* (A. Corten, personal communication). Also in fisheries with light attraction, which target for pelagics only, the spatial scale at which these pelagics aggregate will affect day to day variability, and this might explain why these fisheries have more variable outcomes in marine than in freshwater systems, where spatial aggregation is never very large.

In comparison, the variability in most gillnet fisheries ranges between narrow limits (CV 0.5 – 1). Only the catch per species by the motorised boats in Lake Tana, Ethiopia, is large (CV > 1), possibly due to lunar periodicity and other factors not captured in the factors for the ANOVA in Table 4.12. The basic uncertainty experienced by small-scale fishermen in the Spermonde Archipelago, Sulawesi, Indonesia, targeting with specific modes, a variety of both demersal and pelagic species, was never smaller than CV = 0.5 (Pet-Soede *et al*. 2000). The basic uncertainty in the light fisheries with lift nets and purse seines varied within the same higher ranges as depicted in Fig. 4.24.

Catches of sport fishermen vary in a different range (CV > 1) from those of most professional fishermen, which implies that any pattern in catch rates is more difficult to perceive for the angler than for the fisherman.

Day to day variability in catch rates is more or less random, and serial correlation was in any case not detected in the sample series. If it still exists, it is most probably explained by the slow moving around of large fish concentrations. Fishermen might respond to short-term persistence in the local availability of fish, by returning to the same site after a highly profitable catch on the previous day. During a study on the spatial allocation of fishing effort, in relation to the local catching success on the previous day, this kind of responsive behaviour was found, however, to be not very rewarding in a small-scale tropical fishery encompassing a variety of fishing gears (Pet-Soede *et al*. 2001). In the same study variability in daily catches per gear type and for species combined, was assessed and varied between CV = 0.9 and 2.2 (their Fig. 3). This high variability constrained the perception of spatial and temporal patterns in catch rates, and certainly that in catch rates per species.

Aggregating daily catches into monthly or annual totals reduces variability due to randomness by a factor of about 5 (month) or 15 (year). Indonesian light fishermen still experience a random variability in their monthly totals or averages of CV = 0.6 and 0.2 respectively. Also for sport fisheries, where high variability combines with low effort (days fishing per year), random variability in the annual series per angler will still be large. For most professional fisheries, however, there is very little of this variability left after aggregating or averaging for an annual figure.

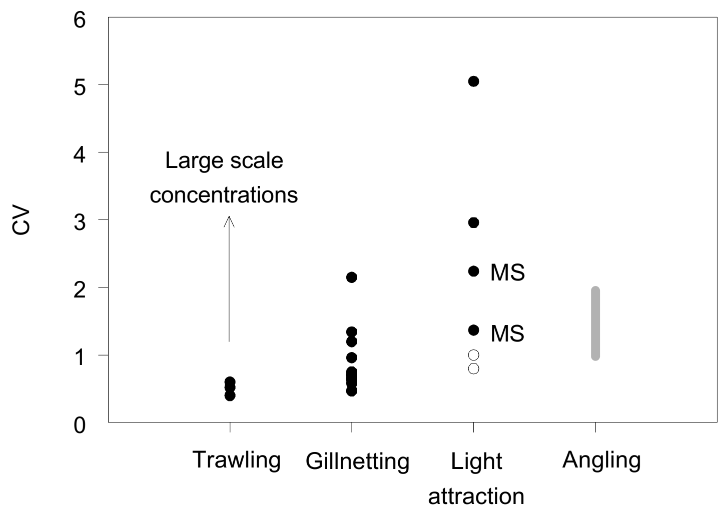


Fig. 4.24 Scaling basic uncertainties per fishing mode, based on Tables 4.7, 4.15, 4.29 and section 4.5.4. The open circles indicate freshwater fisheries with light attract ion. MS are multi-species fisheries.

4 Variability in daily catches - Conclusions

- Variability (CV) in daily catches - 'basic uncertainty' - ranges between wide limits, but there are more or less distinct ranges per fishing mode: trawls 0.25-0.50, gillnets 0.5-1.0, recreational angling 1 – 2, fisheries for pelagics with light attraction > 2.
- Its is the scale at which fish aggregate relative to the scale of operation that determines the variability in daily catches, and this shows most clearly in the large scale trawling for pelagics, which could still be highly uncertain on a day to day basis.
- Systematic differences in the catch rate between anglers explain only a small part of the overall variability in angler's catches. Monitoring the performance of a small, selected group of 'skilled' anglers is therefore no more efficient than random sampling of the whole angler population.

Chapter 5

Variability in monthly catches

In this chapter:

- Variability in monthly catches is related to seasonality as one of the periodic patterns within years which add to the total variability in catch rates experienced by a fisherman over the years. **5.1**
- It is shown how the seasonal pattern in catch rates in the Dutch beam trawl fishery in the North Sea changed over the years, as possibly affected by the management regime and the technical capacity of the fleet. **5.2**
- It is explained how in the gillnet fishery for pikeperch in Lake IJssel, the Netherlands, inter-annual changes in seasonality could be brought about by inter-annual differences in the size distribution of the new cohort entering the fishery each year. **5.3**
- The seasonality in catch rates from tropical lakes and reservoirs is discussed in relation to rainfall patterns, system morphology, the hydrological regime and the resultant fluctuations in habitat availability for fish. **5.4**
- It is discussed how in a situation with less predictable patterns in monthly catch rates, where seasonality only emerges from a series of monthly catches averaged over many years, this seasonality is hardly experienced as such by the individual fisherman, for whom it thus adds to the random variability already experienced on a day to day basis. **5.5**
- Conclusions are drawn on the ways in which seasonal patterns in catch rates, and the possible inconsistency therein, from one year to the next, might affect the perception of any long-term trend in resource outcome. **5.6**

5.1 Basic uncertainty and seasonality

Any periodicity adds to the total variance in catch rates as experienced by an individual fisherman. Periodicity occurs at various time scales: with the tides within a day, with the phases of the moon within a lunar cycle of 28 days and with the seasons within a year. Periodicity may arise both from changes in the local availability of the fish (biomass), e.g. of a migratory species, and from changes in the catchability (q) of the fish present, as with sardines which are difficult to catch in a light fishery during full moon. Fishermen are generally very aware of the periodicity in their catches. Where possible they respond on these periodicities via the differential allocation of their fishing effort in space and time. Where seasonality is very pronounced, they may change from part-time fishing to other activities in the off-season.

Seasonality implies predictability of monthly catch rates, but there is uncertainty involved as well, because seasonal cycles in catch rates do not always follow the same strict course in time. Seasonal cycles may be offset from a long-term average, and the high season may arrive earlier or later, or the ratio between the seasonal high and low in monthly catch rates may change from one year to the next. How clearly fishermen perceive seasonality in their catch rates depends on the extent to which the variance in catch rates is due to seasonality patterns, relative to the variance due to the basic uncertainty in the catch rates (van Oostenbrugge *et al*. 2001). As with trends and step trends also seasonality may be hard to perceive where variability is high.

A simple categorisation of seasonality in fisheries outcome as related to climatic and ecological parameters is hard to give. Although temperature fluctuations are certainly more pronounced in tropical than in temperate zone ecosystems, this does not preclude pronounced seasonality in tropical fisheries. But as important as temperature is the hydrological regime, which in fresh water systems determines habitat availability, spawning times, aquatic productivity and similar factors, as for instance, in floodplain fisheries (Lowe-McConnell 1979, Welcomme 1979, 1983).

In this chapter, seasonal patterns for fisheries examples are discussed with regard to their amplitude within the season, and with regard to their consistency from one year to the next, as possibly affected by a more erratic hydrological regime. Finally, an evaluation is made of how clearly seasonality is perceived, given the sometimes, high variability in day to day catches.

5.2 Beam trawling for plaice and sole – Shifting patterns and external conditions

Catch rates of plaice by Dutch beam trawlers in the North Sea are nowadays particularly high in the beginning of the year, decrease to less than half in the period April through August, and increase again towards the end of the year (CV_{month} = 0.35) (Fig. 5.1, Table 5.1). Catch rates of the four times more highly valued sole are much more stable (CV_{month} = 0.13). The seasonality in catch rates of plaice has always been pronounced with higher catch rates in the beginning of the year until the annual low around April-May when the quality and so the price of plaice is lowest (Fig. 5.1). Landings of sole seemed to have become more stable instead over the years (Fig. 5.1, Table 5.1). The explanation for the still high variability in monthly averages for plaice might partly lie in the availability of plaice and partly in the management regime and the increased scale of the beam trawl fishery (J-W. de Wilde, personal communication). The much stricter obedience to the EU quota system since 1995 could have meant that fishermen now fear to fish up their annual quotum for the highly-valued sole too early, and so under-utilize the economic potential of this species. Fishermen may therefore have chosen to direct at fishing their plaice early in the year, when this species is more available, and relatively easy to catch with today's larger trawlers under the harsher conditions at that time of the year.

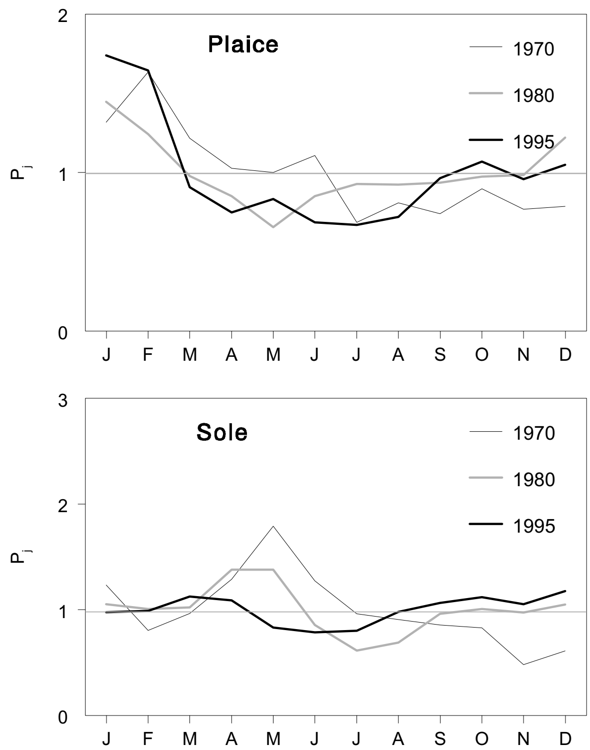


Fig. 5.1 Seasonality indicated with a multiplier (P_j) for the catch per day averaged per month of plaice (top) and sole (bottom) in 1970 (small vessels), 1980 (large vessels) and 1995 (Data from the annual reports of the Ministry of Agr iculture and Fisheries).

5.3 Gillnetting for pikeperch – Pattern affected by stock dynamics

The gillnet fishery for pikeperch in Lake IJssel, the Netherlands, is highly seasonal and is concentrated in autumn and winter with a closed season in spring (Fig. 5.2). At the end of summer (September), when eel catches fall with decreasing water temperature, gillnetting is intensified and continues throughout autumn and winter, until the closed season from 15 March until 1 July. Catch rates decline continuously and sharply at about 25% per month, from September until the end of the season, CV_{month} = 0.53. This sharp decline within the season is mainly due to a very high instantaneous fishing mortality rate of well over F = 2 per year (de Leeuw *et al*. 2000).

Table 5.1 Catch rates for plaice and sole by small and large vessels in the Dutch fishing fleet in 1970 and 1980 (Data from the annual reports of the Ministry of Agriculture and Fisheries) and in 1995 (Data from RIVO, IJmuiden). The data for 1995 are for 20 00 HP beam trawlers.

Year	Vessel type	Number of vessel days per month	Catch per Vessel day (kg)	CV between months	Value per kg landed (guilders)
Plaice					
1970	Small	6118	418	0.28	0.71
1970	Large	2404	411	0.53	0.71
1980	Small	2325	226	0.30	2.01
1980	Large	3664	646	0.21	2.01
1995	Total		1031	0.35	3.30
Sole					
1970	Small	6118	145	0.35	6.52
1970	Large	2404	131	0.45	6.52
1980	Small	2325	53	0.55	15.48
1980	Large	3664	225	0.23	15.48
1995	Total		481	0.13	13.70

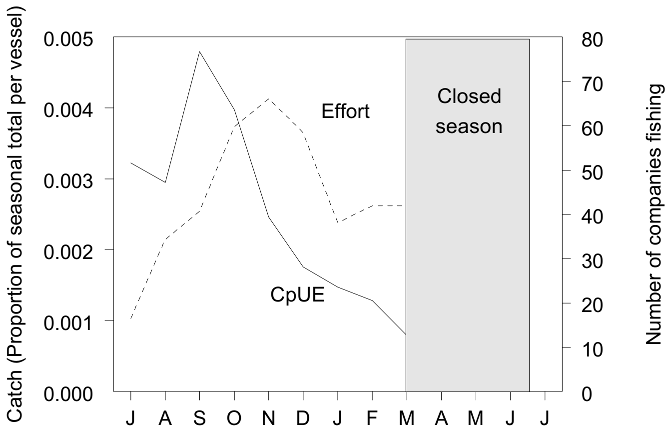


Fig. 5.2 Average monthly fishing effort (numbers of companies active in gillnetting) in the period 1969-1982 (from Buijse *et al*. 1992) and average monthly catch rate (proportion of seasonal total weight per vessel) as based on total landings per month for the seasons 1967 -1968 through 1982-1983 (Official catch statistics) and fishing effort.

The seasonal pattern in catch rates of pikeperch is not consistent, because of inter-annual differences in growth rate and recruitment. Cohorts of pikeperch generally recruit to the fishery after three summers, when their average size is 42 cm TL (Willemsen 1977). What portion of the new cohort recruits to the fishery depends on the growth of that particular cohort so far, on the variance in individual size within that cohort, and on the variance in the selectivity curve for the gillnets in use. Although the optimal selection length of the 101 mm stretched mesh gillnets is 48 cm (van Densen 1987), the variance in individual length within pikeperch cohorts (sd = 3 to 4 cm) and the variance in the selectivity curve of the 101 mm gillnets (sd = 3 to 4 cm) ensure that the largest individuals of the new cohort are already caught in the gillnets in mid-summer. A larger average length at the age of three implies a higher catchability (q) of these pikeperch in the 101 mm gillnets, and thus a sharper decline in the CpUE within the gillnet season. Superimposed on this uncertainty in seasonality due to inter-annual differences in growth rate, is uncertainty in seasonality arising from differences in annual recruitment. The recruitment variability translates into differences in the abundance ratio between three- and four-year old pikeperch, each with their own size-specific catchability and thus survival rates.

So Lake IJssel fishermen targeting pikeperch experience inconsistencies in the seasonal pattern of catch rates from one year to the next which are induced by inter-annual differences in growth rate and recruitment, both of which are strongly affected by summer temperature (van Densen *et al*. 1996, see also section 6.5).

5.4 Tropical lakes, rivers and reservoirs – Seasonality and the hydrological regime

Seasonality in the catches from tropical freshwater ecosystems is often related to the hydrological regime and thus to rainfall and thereby to river runoff and inundated shorelines. Spawning migrations of river fish are timed by these seasonal patterns in river runoff, which inundates spawning and nursery areas for fish in the river floodplains. In those river catchments, where periodicity in river runoff and flooding is more predictable, the migratory behaviour of fish is more pronounced (Bayley & Li 1992). How strongly the hydrological regime ultimately translates into seasonality of catch rates from tropical lakes and reservoirs is hard to generalize, but the behaviour of communities of lacustrine fish in large, deep lakes is expected to be more independent of the flood regime than that of riverine fish communities in small, shallow reservoirs.

Lake Victoria is the largest lake of Africa (68,800 km^2, max. depth 90m) and is situated on the equator with limited periodicity in ecosystem functioning that are driven by the hydrological regime and with small fluctuations in water temperature (van Densen & Witte 1995, Crul 1995). Although rainfall around the lake is clearly seasonal, being most pronounced in the south-eastern part of the lake around Mwanza, Tanzania (Crul 1995) (Fig. 5.3), intra-annual fluctuations in lake level are small (several 10cms), because of the large lake volume. Inter-annual variations in water level are as large or larger even than the intra-annual variations (Fig. 5.4) (van Densen & Witte 1995). Catch rates of Nile perch, now the major species in the lake's gillnet fishery, do not exhibit any clear seasonality (Fig. 5.5). Variability in catch rates (CpUE) of Nile perch with gillnets, averaged per month was CV = 0.25 for the offshore and CV = 0.28 for the inshore fishery, without any consistent development over time.

Lake Tanganyika is also large (33,000 km^2), but much deeper (max depth 1470m) than Lake Victoria. The rainfall pattern is very similar to that of Lake Victoria (Mwanza), with a period of almost complete dryness in June and July (Coulter & Spigel 1991). Catch rates averaged per month, of the purse seiners targeting pelagic fish in the northern part of the lake gradually change throughout the year, for total catch and for the three size categories separately (Fig. 5.6) (van Zwieten *et al*. 2002). The variability due to seasonality was CV = 0.22, 0.42, 0.23 and 0.15 for catch categories small, medium, large and for the total catch, respectively. Monthly catches of medium- and large-sized fish fluctuate antagonistically to the dominant category of small-sized fish and stabilize total catches as averaged per month.

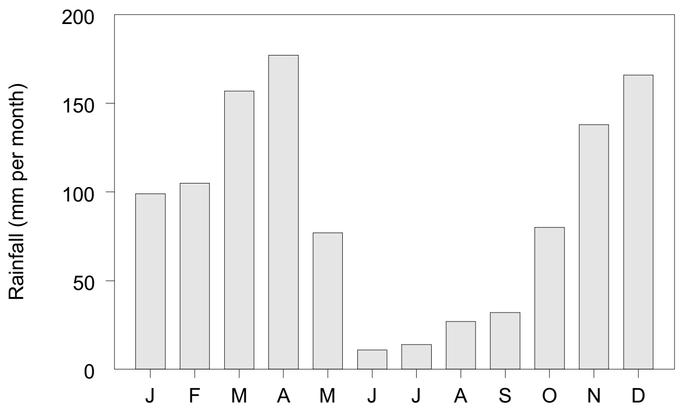


Fig. 5.3 Seasonal variation in rainfall (mm per month) in the Mwanza area of Lake Victoria (Tanzania) averaged for a 20 years period (source East African Meteorological Department, 1975).

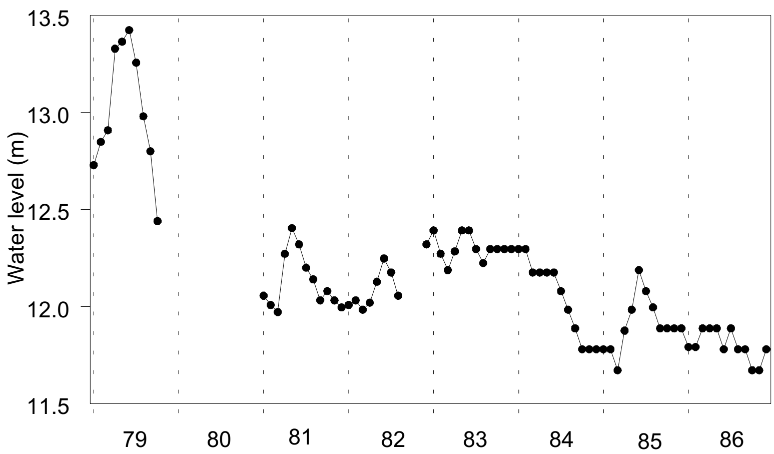


Fig. 5.4 Water level averaged per monthly intervals in the Nyanza Gulf (Kenya) over the years 1979-1986 (source: Ministry of Water Development, Kenya). From van Densen & Witte (1995, their Fig. 1.5).

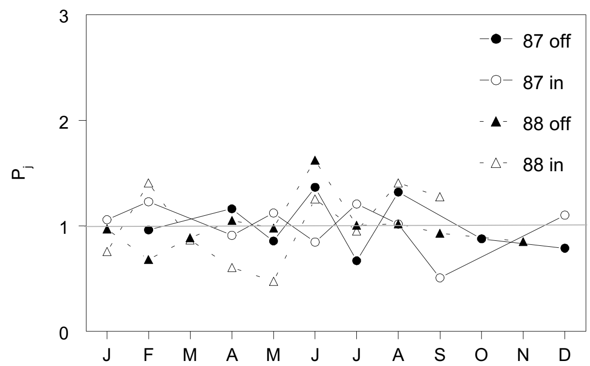


Fig. 5.5 Multiplier (P_j) for CpUE averaged per month for Nile perch caught with offshore gillnets (off) and inshore gillnets (in) in 1987 and 1988 (Data from Ligtvoet & Mkumbo 1991). P_j = ratio relative to the annual average.

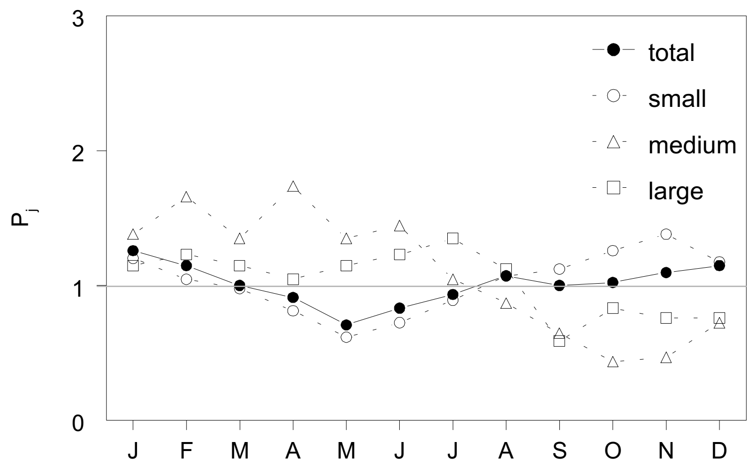


Fig. 5.6 Seasonality in CpUE averaged per month and relative to the annual mean for total catches and for the catch per size category in the Lake Tanganyika purse seine fishery over the years 1956-1992 (from van Zwieten *et al*. 2002).

Lake Tana, Ethiopia, is smaller (3200 km^2) and more shallow (max depth 9 m) than Lake Victoria and Lake Tanganyika. Rainfall around this shallow lake, shows marked seasonality, with heavy rains in the period May - October and almost complete dryness from November to April (Fig. 5.7). Rainfall peaks in July, after which the water level rises by 1.4 m over two months (Wudneh 1998). Masses of turbid water flowing from three large rivers into the lake cause a reduction in water transparency from circa 65 to 40 cm Secchi disc depth. Barbs, a major catch category, start upriver spawning migrations when river runoff increases, and catch rates increase because of the concentration of fish biomass in the resource area (Fig. 5.8). Tilapia moves inshore around that time and escape exploitation by the more open water gillnet fishery with motorised boats. The ratio between maximum and minimum catch rates averaged per month is as high as R = 5 for both barbs and tilapia. Catch rates of *Clarias*, the third species in importance, show no seasonality. Variability in the catch rates averaged per month as calculated for a full year's cycle (May 1992 - April 1993) was CV = 0.69 for barbs, CV = 0.47 for tilapia and CV = 0.29 *Clarias*. It is concluded that, in the experience of Lake Tana fishermen, seasonality in catch rates of two major categories in the fishery is clearly connected to the seasonality of the hydrological regime.

Fluctuations in water level and shoreline inundation of reservoirs are much affected by human interference with the hydrological regime. Changes in water level of large, deep reservoirs with steep margins, built primarily for power generation, are ecologically not that significant, because they do not translate into large fluctuations in habitat availability along the lake shores. Also, the fish communities in these reservoirs generally develop into more lacustrine ones for which the littoral zone is less important in their life cycle (Yap 1999).

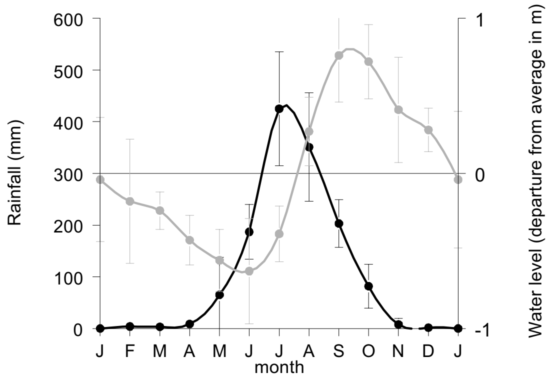


Fig. 5.7 Average monthly rainfall (mm) and water level (dotted line, meters around the overall mean = 1830 m above sea level) for Lake Tana, Ethiopia. Bars refer to standard deviations. Data averaged for the years 1990-1993 (From Wudneh 1998, his Fig. 2.1).

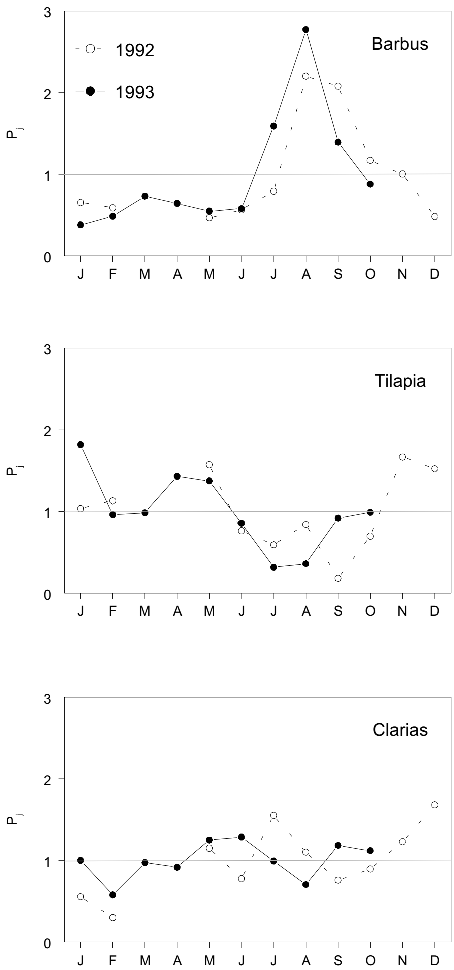


Fig. 5.8 Intra-annual patterns in average CpUE averaged per month for the three major categories of fish in the gillnet fishery of Lake Tana, Ethiopia, operated by fishermen with motorized boats in 1992 and 1993 (data from Wudneh 1998).

Kainji Reservoir is a large (1270 km^2), deep reservoir (maximum depth 60m, mean depth 11m) build in 1968 for power generation in the catchment of the River Niger, West Nigeria.

The reservoir is still highly productive with annual catches of 256, 301 and 226 kg per ha in 1995, 1996 and 1997 respectively (Ibeun & Mdaikli 1994, Anonymous 1997). Rainfall around the reservoir is as seasonal as around Lake Tana, Ethiopia, with heavy rains lasting from April until November and almost complete dryness in the period December - March (Fig. 5.9). Annual fluctuations in water level are large (6-7 m), certainly when compared with the average depth of the lake. Catch rates in the gillnet fishery (16-26% of total catches) may be seasonal with highest catches in May-June both in 1996 and 1997, when water levels are lowered to accommodate the large inflow during the rest of the rainy season. The pattern in monthly catch rates in the beach seine fishery (39-53% of total catches) certainly does not appear to be seasonal (Fig. 5.10). Overall, the variabilities in catch rates averaged per month were small, ranging from CV = 0.24-0.32 for gillnetters and CV = 0.28-0.36 for beach seiners. Catch rates are for species combined and this may have stabilised the monthly catch rates already. In conclusion, catch rates for species combined in the deep Kainji Reservoir fringed with steep margins, are hardly affected by the hydrological regime.

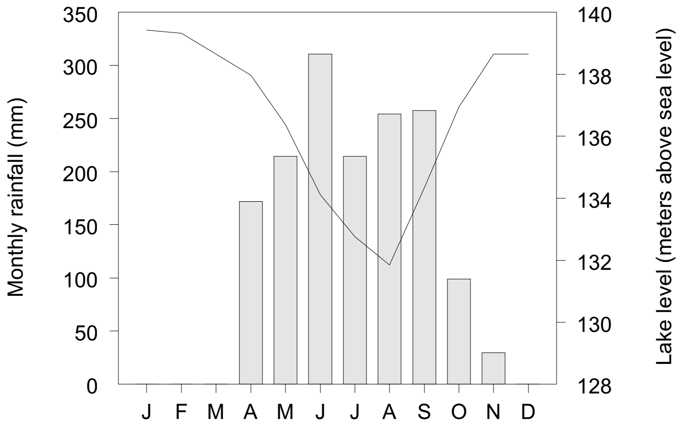


Fig. 5.9 Intra-annual pattern in rainfall and water level in Kainji Lake, N-Nigeria, in 1997. Bars represent rainfall; the line represents water level.

In contrast, in small shallow irrigation reservoirs, the impact of the hydrological regime on habitat availability and on ecosystem functioning must be large. Tissawewa Reservoir, Sri Lanka (ca 200 ha, mean depth 2.5 m) is such a small, shallow reservoir for which fluctuations in rainfall and river runoff translate directly in fluctuations in surface area (Fig. 5.11) (Pet *et al*. 1995). With the ca 1 m rise in water level, from the annual low of 2 m in September to the annual high of 3m in December, one month after the peak in rainfall, the surface area of the reservoir enlarges by 50% in 3 months time. Predictability of rainfall in the area is relatively low as is evident from the high inter-annual variability in monthly rainfall (Fig. 5.11, see also section 8.4), and so must be river runoff and the surface area of the reservoir. As the reservoir is used for irrigation purposes, inter- and intra-annual differences in surface area due to fluctuations in rainfall are amplified. Occasionally, the reservoir even dries up and the maturation of the reservoir ecosystem and its fish community then is completely reset (Piet 1996). So there is pronounced seasonality in rainfall, and with that, in water level and in reservoir area, but the predictability of the seasons is low and adds uncertainty to the variance caused by seasonality.

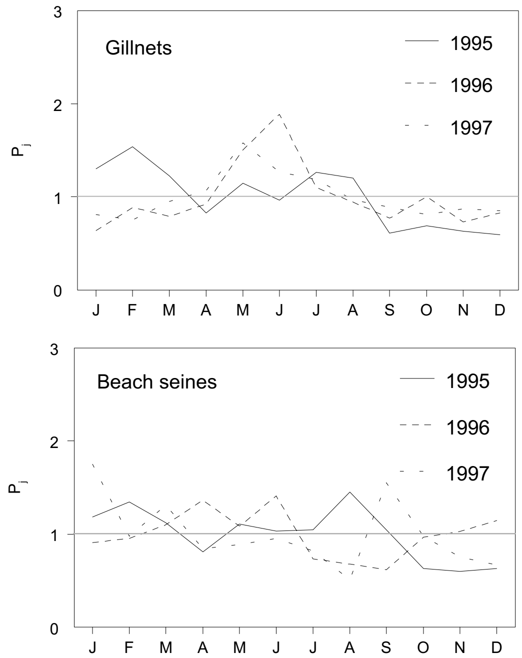


Fig. 5.10. CpUE (indexed with P_j as a multiplier for the year's average) averaged per month in the gillnet and beach seine fishery on Kainji Reservoir in the years 1995-1997.

Catch and effort in the gillnet fishery for tilapia in Tissawewa Reservoir were closely monitored for one full year, from September 1991 to August 1992 (Pet *et al*. 1995). Fishing effort in this fishery was lowest in August when the reservoir area was most contracted (Fig. 5.12). Catch rates also seem to vary with fluctuations in water level and were three to four times lower around May-June, in the middle of the dry season, than in the rainy season period September through March (Fig. 5.12). During the monitoring period, the variability in catch rates averaged per month was as high as CV = 0.42, and probably resulted from variability in both fish biomass and catchability. In conclusion, there is seasonality in rainfall, although most inconsistent, which translates into changes of as much as 50% in reservoir depth and area. The erratic pattern in the hydrological regime is amplified by the dam management in support of the rice culture in the area. The gillnet fishermen on the reservoir experience the impact of the erratic precipitation patterns and of the dam management on their resource outcome most directly. Seasonality as intra-annual periodicity in their catch rates will be hard for them to perceive.

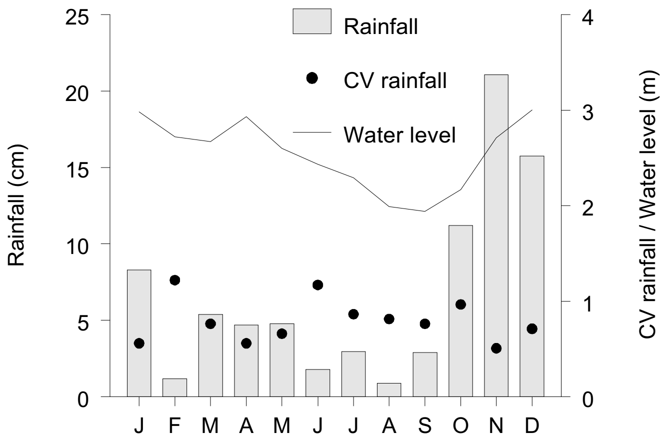


Fig. 5.11 Rainfall per month (cm), inter-annual variability in monthly rainfall (CV) and water level (m) of Tissawewa Reservoir, Sri Lanka, averaged per month in the period Jan 1987 to July 1993 (data from Helder 1995). Surface area (A, ha) is directly proportional t o water level (L, m) according to: A = 75*L (based on Fig. 3.2b in Pet 1995).

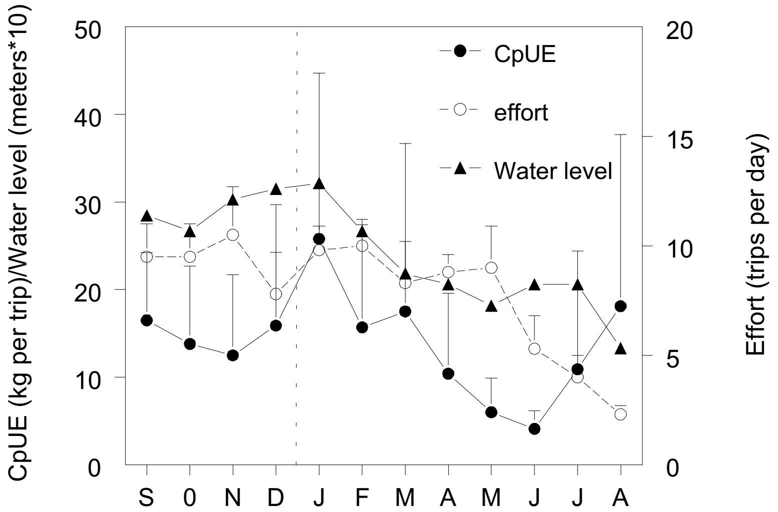


Fig. 5.12 CpUE ± SD (kg per trip) and fishing effort ± SD (trips per day) in the gillnet fishery in Tissawewa Reservoir, Sri Lanka, September 1991 - August 1992. Catch weight refers to three tilapia species and a minor quantity of endemics.

5.5 Between seasonality and randomness

If the seasonal pattern in catch rates is pronounced and very consistent from one year to the next, it will be more easy for the individual fisherman to account for such seasonality when evaluating catch rates in the longer term of successive years. Once monthly average catch rates contain a large amount of randomness or noise, the underlying seasonality becomes more difficult to perceive and to account for. Such randomness could arise from environmental uncertainty such as the erratic rainfall pattern around Tissawewa Reservoir or from high basic uncertainty in catch rates from day to day, which translates into randomness in the monthly averages when sample sizes are small.

There are few published series with monthly averages of angling success. One of them is a four year series with monthly catch rates for the sport fishery in the River Trent, UK (Fig.

5.13) (Cowx 1991). These monthly averages increased significantly over the years (18% per year, $R^2 = 0.18$, $n = 40$, $p < 0.01$). Most probably, an underlying decline in catch rates within each season is also present, but only for the first season is the decline statistically significant ($p = 0.00526$), and it explains no more than 50% of the variance in monthly catch rates in the other seasons. For the individual angler it will virtually be impossible to perceive the underlying seasonality in his highly variable catch rates. Variance due to seasonality her adds on to the unexplained variability as experienced by the individual angler. For the administration, it seems to be sufficiently informative to focus on the first four months, and to forget about the seasonality, when the objective is to evaluate for a possible long-term trend.

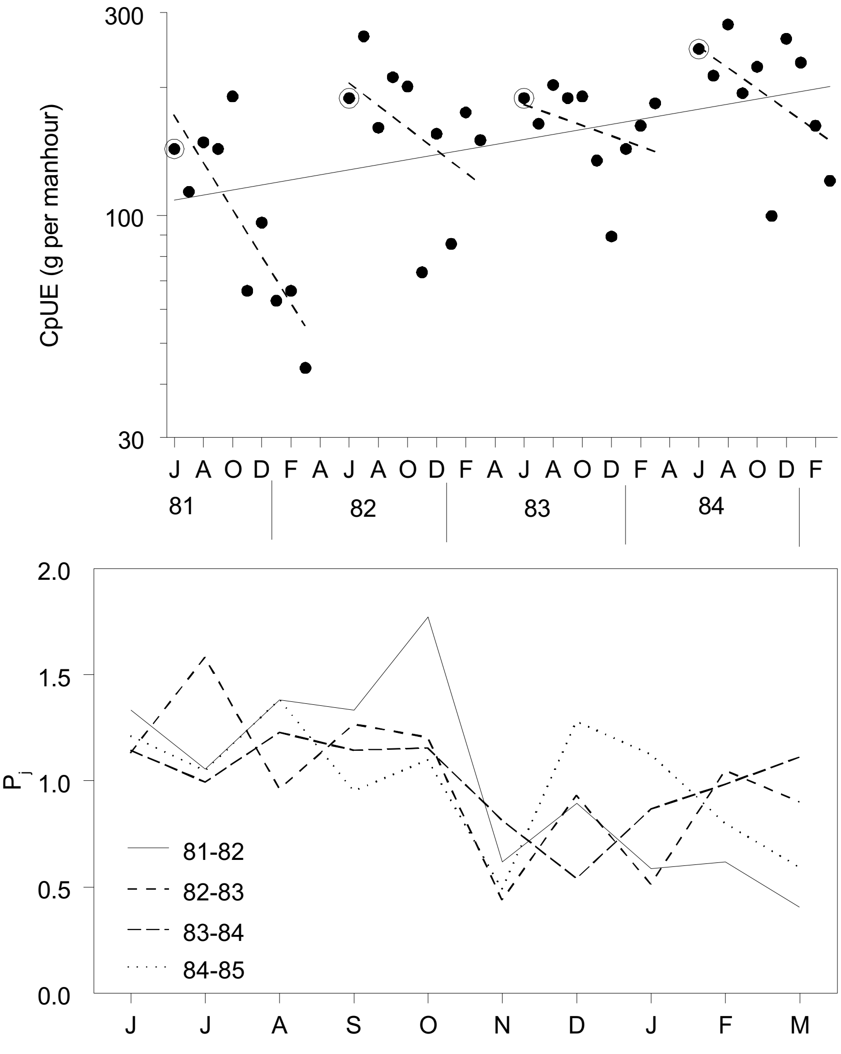


Fig. 5.13 Top: CpUE (g per manhour) in the River Trent per monthly interval. The encircled dots indicate the start of the angling season (June). The variability within seasons was CV = 0.45, 0.34, 0.21 and 0.29 (untransformed monthly averages). The percentage of variance explained by a short-term trend within the season is $R^2 = 0.80^{**}$, 0.46, 0.35 and 0.50; that by the long-term trend throughout all four seasons is $R^2 = 0.18$, Bottom: Monthly catch rates indexed with P_j (based on Fig. 15.4 in Cowx 1991).

5.6 Seasonality and the long-term trend

In theory, seasonality as intra-annual periodicity in catch rates should not obscure any long-term trend in catches rates the perception of the authorities, since it could be fully accounted for after assessing its contribution in total variance via an analysis of variance (ANOVA). But in the experience of an individual fisherman, seasonality as a recurring pattern in his catch rates at the least compounds his perception of a possible long-term trend, if it does not completely obscure such a trend for him, because of uncertainty or inconsistency attached to seasonality.

Uncertainty around the seasonal pattern arises mainly from two sources. First, there is basic uncertainty in daily catches, which translates into random variability in monthly averages as well, although generally 5 times smaller ($\sqrt{25}$ fishing days). Only when sample sizes are large enough and catch rates are averaged for the fleet as a whole, is this randomness in monthly averages virtually averaged out. Second, there is always inconsistency and thus uncertainty in the seasonal pattern from on year to the next. The inconsistency may arise from the erratic nature of environmental variables that have a direct impact on the timing of fish migration (e.g. temperature) or on the flooding of temporal fish habitats (rainfall). With large scale climatic fluctuations, as related for instance to the El Nino phenomenon, consistency in seasonality is low and because of that also the familiarity of fishermen with recurring patterns in resource outcome.

The example of the plaice fishery in the North Sea is a particular complex one. These beam trawlers seldom, if ever, catch either plaice or sole only, but with larger, more powerful trawlers their fishery can be more directed towards either one of these two flatfish species if management or market conditions require it. In addition these shifts in intra-annual patterns in catch rates will constrain the fisherman's perception of any long-term trend or in stock biomass of plaice.

5 Variability in monthly catches - Conclusions

- Variability in monthly catches reflects seasonality in resource availability and catchability, but the ultimate pattern depends on possible directed fishing in space and time as well.
- Seasonality in catch rates is less apparent in freshwater systems where the hydrological regime is driven by more erratic rainfall patterns and translates into largely unpredictable fluctuations in the availability of fish habitats.
- Where seasonal patterns are strong, they compound the perception of fishermen of possible long-term trends in catch rates. Where seasonality is inconsistent from one year to the next, and combines with large basic uncertainty, it merely adds to overall uncertainty about resource outcome.

Chapter 6

Variability in annual catches and the perception of trends

In this chapter:

- It is stressed that inter-annual variabilities, as calculated from the residuals around a long-term trend, generally contain short-term trends of short (blue noise) and of longer (red noise) duration, which become visible as such depending on the time window of the series. **6.1**
- Inter-annual variabilities are assessed from example series of annual catches from professional fisheries in the North Sea and in Dutch inland waters. **6.2**
- Inter-annual variabilities are also assessed for some of the rare series from sport fisheries. **6.3**
- The durations of short-term trends in annual series are compared, and the possible relationship between short-term trends of longer duration and red noise in environmental variability (temperature, rainfall) is discussed. **6.4**
- Inter-annual variabilities of annual catches and the coloured noise within these series is related to recruitment variability and stock structure. **6.5**
- On the basis of two case studies it is discussed to what extent inter-annual variability is reduced, when spatial aggregation per year takes place throughout a small ecospace, such as a lake, or throughout ever larger administrative spaces encompassing several distinct stocks or sub-stocks which vary independently from each other. **6.6**
- An attempt is made to explain the differences in inter-annual variability between the example series from an ecosystem and from a population perspective. Further, an assessment is made of trends and step trends that may be perceived in management-relevant time windows under boundary conditions for Type I and Type II errors. **6.7**

6.1 Time windows, trends, de-trending and the inspection of residuals

Variability due to a long-term trend over the years is the most relevant for fisheries management. The trend is the signal, with variability as the noise that contains both the basic uncertainty in the catch from day to day (Chapter 4) and the seasonality, with the possible inconsistency contained therein (Chapter 5). The smaller the time window for which catch data are evaluated, the less probable it is that the signal of a long-term trend in catch rates can be perceived. In smaller time windows there is relatively more noise, and thus a smaller proportion (R^2) of the total variance in catch rates is explained by the possible long–term trend. Small time windows emphasize short-term trends as induced by, for instance natural, fishery-independent variability in year-class strength. A long-term downward trend in catch rates, resulting from a monotonously increasing fishing effort, will in any case show more clearly in large time windows in which it is more easy to distinguish between long-term and short-term trends (coloured noise). In sections 6.2 and 6.3 example series from Dutch professional fisheries and from sport fisheries are used to assess inter-annual variability per species. The diversity of ecosystem types (sea, lake, river), species and exploitation pressure is expected to provide a full range of inter-annual variabilities.

Short-term trends or persistence leads to serial correlation (ρ) in the residuals around long-term trends. How long these short-term trends last, on average - 3-4 years, a decade or even longer – cannot be inferred from the serial correlation as auto-corrleation with a time lag of 1 year (section 3.2.1). A periodogram constructed on the basis of spectral analysis could show how important short-term trends of various absolute duration are (Bjornstad *et al*. 1999). Annual series for catches of fish are generally too short to grasp both high frequency (blue noise) and low frequency cycles (red noise) in these series. Nevertheless, visual inspection of the example series in section 6.4 gives some indication of the variable duration of short-term trends in different fisheries.

An ecological explanation for some of the short-term trends must be the dominance of a particular, strong year-class in the landings for some years in succession. How variability in year-class strength (CV_R), which in many cases appears to be stochastic (white noise), translates into the lower variability in annual landings (CV_C), is assessed and compared for a number of example series in section 6.5. More age groups in the population dampens the variability in annual landings that arises from the variation in recruitment.

Time series of catch and effort data are generated officially by the process of data aggregation through administrative spaces, from small to large, from the individual fisherman to the world at large (see Fig. 2.6). Ecospaces are scientifically defined areas, mostly with one unit stock. They do not necessarily coincide with an official, administrative space. Small administrative spaces, e.g. lake sections, could be comprising only parts of the lake's ecospace. At the higher end, large administrative spaces encompass several distinct ecospaces, such as when a number of freshwater lakes fit into a nation's administrative space for freshwater fisheries.

Aggregation of catch data through one small, clearly delineated ecospace, such as a lake, is expected to result in only small reductions of variability in annual averages, going from an individual fisherman, to a harbour and to the lake as a whole. Various levels in the administration would then experience almost the same inter-annual variability with strong co-variance, and would thus develop parallel views on developments in the resource and its outcome. This assumption is examined in section 6.6.1.

Aggregation of annual catch data through large administrative spaces, encompassing several ecospaces, is expected to lead to a steady reduction in inter-annual variability in more aggregated catch data. This reduction is explained from the 'portfolio effect', that occurs when summing or averaging catch data from administrative spaces the variation in which is largely independent, and thus perform no, or only weak, spatial correlation (see also section 3.6.3). In section 6.6.2 the annual landings from Indonesian fisheries, as recorded for administrative spaces of increasingly larger size, are evaluated for possible consistencies in variability reduction for ever more aggregated data.

Finally, in section 6.7, inter-annual variabilities are compared and trends and step trends that it is just possible to perceive, given modal variability, coloured noise and, in the case of step trends, also the time lag after measures are taken.

6.2 Inter-annual variabilities in some professional fisheries

Annual series for catch rates, as Catch per Unit Effort (C/f), are the most indicative for developments in stock biomass (see Box. 2.1). They are however, much less available than those for total catches (C_{tot}). The varariability in catch rates comes close to that in total catches, because developments in fishing effort are by nature more conservative. Most of the inter-annual variability in detrended series of total catches is then due to the variability in Catch per Unit Effort:

$$C_{tot} = \frac{C}{f} \cdot f_{tot}$$

$$\log C_{tot} = \log \frac{C}{f} + \log f$$

$$s^2_{\log C} = s^2_{\log \frac{C}{f}} + s^2_{\log f} + 2r \cdot s_{\log \frac{C}{f}} \cdot s_{\log f}$$

Now, where $s^2_{\log \frac{C}{f}} >> s^2_{\log f}$ and a relationship between C/f and f in detrended series is unlikely ($r \rightarrow 0$), variability in total catches approximates that in catch rates:

$$s_{\log \frac{C}{f}} \rightarrow s_{\log C}$$

Where instantaneous fishing mortality is regulated via a quota system and low stock biomass, and with that, low C/f dictates low fishing effort f, $r > 0$ and variability in catch rates could be significantly smaller than in total catches.

The same reasoning holds when inter-annual variability in total fishing effort (f_{tot}) is approximated with that in the instantaneous fishing mortality rate (F), assuming that the catchability coefficient (q) behaves more conservatively than f_{tot}, thus:

$F = f_{tot} \cdot q$, and

$^{10}\log F \rightarrow s\, ^{10}\log f_{tot}$

6.2.1 North Sea fisheries

Target species for human consumption in North Sea fisheries are flatfish, such as plaice and sole, pelagic herring and mackerel, *Scomber scombrus*, and demersal cod-like fish, mainly cod, *Gadus morhua*, haddock, *Melanogrammus aeglefinus*, and whiting, *Merlangius merlangus*. The economic performance of Dutch sea fisheries relies heavily on the exploitation of flatfish (J.W. de Wilde, personal communication).

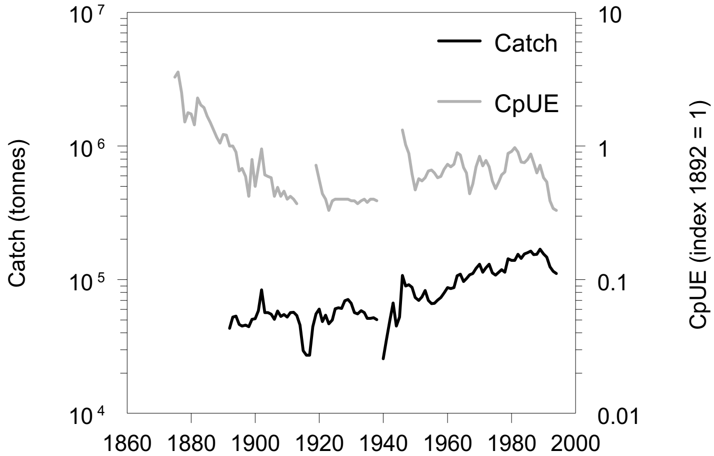


Fig. 6.1 Total catches (tonnes) and CpUE-index (1892 = 1) of plaice, *Pleuronectes platessa*, from the North Sea (data in Rijnsdorp & Milner 1996).

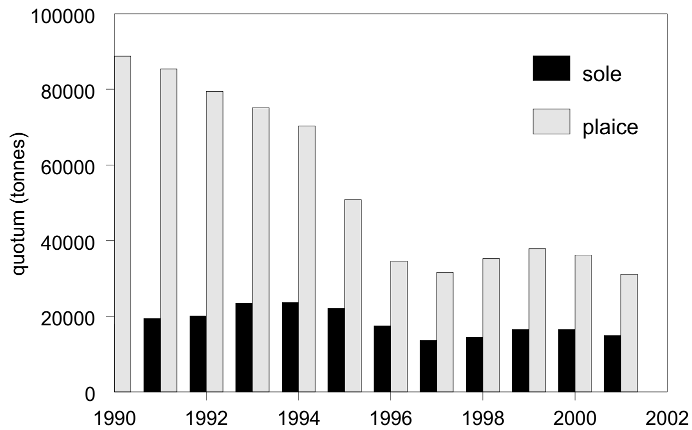


Fig. 6.2 Total allowable catch assigned to the Netherlands by the EU for plaice and sole in the North Sea fisheries 1990-2001.

Time series of total catches (C_{tot}) and of standardised CpUE for North Sea plaice date back to the late 19th century, and show that for almost a century total catches of plaice have increased from about 50.10^3 tonnes around 1890 up to 170.10^3 tonnes around 1990 (Rijnsdorp

& Milner 1996, website cpbnts1.bio.ic.ac.uk) (Fig. 6.1). Major setbacks were the wartime periods in the late 1910s and early 1940s. The overall increase ended by the early 1990s, when there was a dramatic decline in exploited stock biomass and the EU had to lower total allowable catches (Fig. 6.2). Such a dramatic decrease to comparable low levels was previously observed, when the fishery expanded in the late 19th century and stock size decreased by a factor 3 to a low in the 1920-1930s. Although fishing intensity has increased since then, the size of the exploitable stock had also increased and was ca 50% larger on average in the period 1945-1990 than in the 1930s. This increase in stock biomass is now attributed to the faster individual growth of medium-sized plaice, and so to the enhanced productivity of the stock (Rijnsdorp & van Leeuwen 1996). The faster growth can possibly be explained by man-induced changes in the ecosystem, either via eutrophication or, more probably, via intensified bottom trawling, which enhanced the productivity of the bottom fauna on which the plaice feed. Time series of annual landings as long as the one for North Sea plaice make it possible to distinguish trends of variable duration: a long-term trend due to ever increasing fishing pressure in the largest time window, a trend of shorter duration due to the increased productivity in more recent decades, and short-term trends due to the persistence of strong year-classes in the catch, in the smallest time window of only one decade.

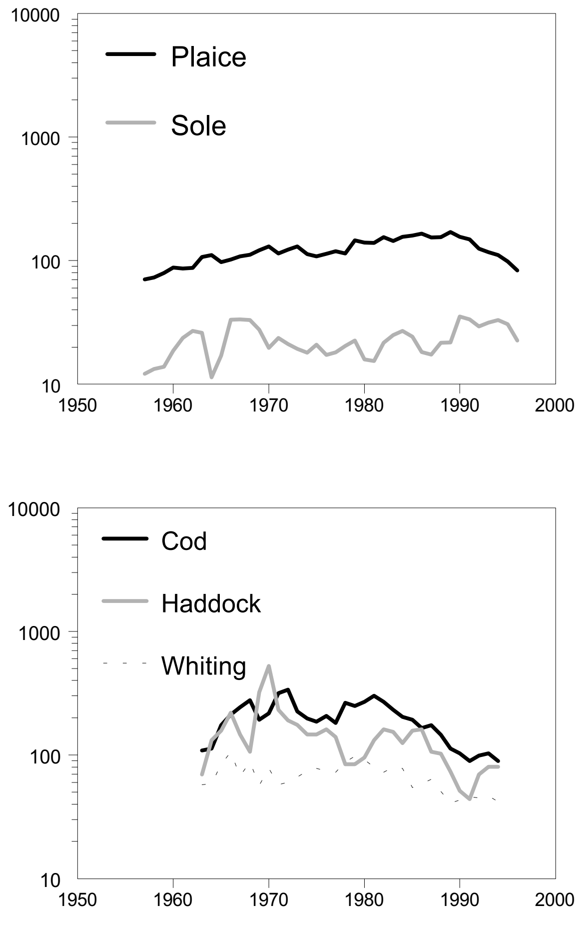


Fig. 6.3 Total landings from the North Sea for: a. plaice and sole in the period 1957-1996 (top) and b. cod, haddock and whiting in the period 1963 -1994 (bottom). (flatfish data A. Rijnsdorp, RIVO, cod - like fish Egner *et al*. 1996).

In the more recent past, of three to four decades, therefore still in a relatively large time window, total landings of plaice (1957 - 1990) and of sole (1957 – 1996) both increased steadily (Fig. 6.3, Table 6.1). The variability around these positive trends, was higher for sole (CV(s) = 0.27) than for plaice (CV(s) = 0.035). For assessing the short-term inter-annual variability in plaice landings, the period of sharply declining catches after 1990 was excluded. Serial correlation (ρ^2) in the detrended series for plaice explained 23% and for sole 30% of the residual variance.

Whereas, landings of plaice and sole increased at 1-2% per year since the 1950s, since the 1970s, those of cod-like fish, especially cod and haddock, have decreased at rates of circa 4-5% per year (Figs 6.3, Table 6.1). Inter-annual variability in the detrended series for total landings of cod-like species ranged from CV(s) = 0.20 for whiting up to CV(s) = 0.35 for haddock, all of which are much higher than the inter-annual variability for plaice and more comparable to that for sole (Table 6.1). Serial correlation (ρ^2) in the residuals around trends for the three cod-like species was always higher than for the two flatfish species and even explained up to 56% of the residual variance.

Table 6.1 Trend (b) in annual landings (^{10}log-transformed) from the North Sea, variance explai ned by the trend (R^2), variability around the trend (CV(s)) as calculated from the sd in the residuals (s = s^{10}logC), trend to noise ratio (b/s) and proportion (ρ^2) of residual variance explained by serial correlation. s = s^{10}logC, $^*p<0.05$, $^{**}p<0.01$.

	Flatfish		Cod-like fish		
	Plaice	Sole	Cod	Haddock	Whiting
Trend b	0.00976	0.00464	-0.0194	-0.0230	-0.0105
Period (n)	57-90 (34)	57-96 (40)	70-94 (25)	70-94 (25)	70-94 (25)
R^2 trend	0.871^{**}	0.177^{*}	0.653^{**}	0.568^{**}	0.458^{**}
CV(s)	0.086	0.27	0.24	0.35	0.20
Trend to noise b/s	0.261	0.0397	0.189	0.156	0.124
ρ^2	0.23^{**}	0.30^{**}	0.51^{**}	0.39^{**}	0.56^{**}

The fishing pressure on the relatively more highly valued plaice, sole and cod has doubled in the time window of 30-40 years between around 1960-1990 (Table 6.2, Fig. 6.4). In the 1960s the instantaneous fishing mortality (F) of sole increased sharply, but since 1970 it has developed more in line with that of plaice. The stocks of both plaice and sole now experience a fishing mortality of around F = 0.4 – 0.5 per year. The fishing mortality of cod, also doubled and has reached a value of around F = 1 per year. Fishing mortality for the less-valued haddock (F = 0.89 per year) and whiting (F = 0.77 per year) neither decreased nor increased significantly over time. So fishing mortality for the demersal cod-like species is circa twice as high as for the two flatfish species (Fig. 6.4, Table 6.2).

Inter-annual variability in fishing mortality was expected to be much smaller than that of the total catches (page 129-130). For sole, cod and haddock this expectation was confirmed (cf. Tables 6.1, 6.2). For plaice and whiting inter-annual variability in fishing mortality and in total landings was roughly the same, which suggests either very low variability in catch rates or a negative relationship between catch rates and fishing effort.

Table 6.2 Trends and variances in fishing mortality rates (F) (^{10}log-transformed) for five major fish species in the North Sea fisheries. To assess inter-annual variability in fishing mortality for sole the period 1970-1985 was selected, because of the non-linearity of the long-term trend. For explanation of symbols see Table 6.1.

	Flatfish		Cod-like fish		
	Plaice	Sole	Cod	Haddock	Whiting
Period (n)	57-93 (37)	70-85 (16)	63-94 (32)	63-94 (32)	63-94 (32)
b	0.00961	0.00730	0.00822	n.s.	n.s.
R^2	0.833	0.485	0.749	-	-
CV(s)	0.11	0.083	0.10	0.15	0.19
b/s	0.207	0.204	0.184		
ρ^2	0.26^{**}	0.023	0.064	0.055	0.00

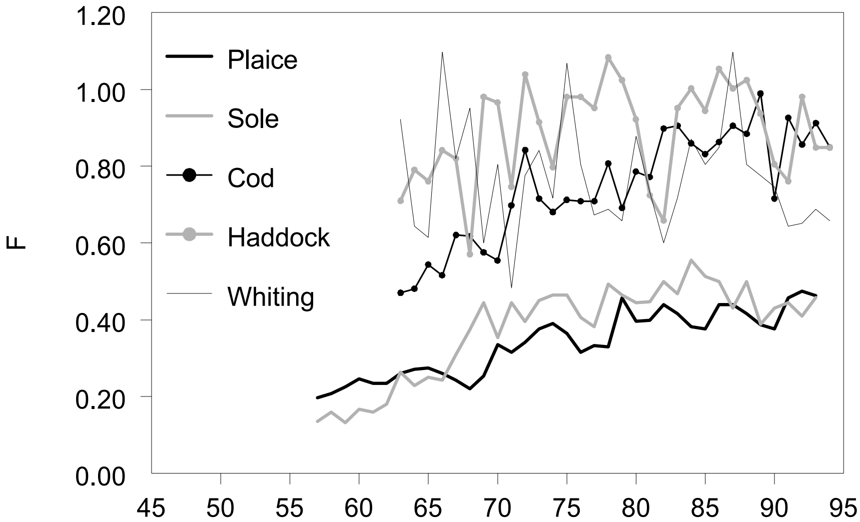


Fig. 6.4 Fishing mortality rates for five major fish species in the North Sea in the period 195 7-1994.

6.2.2 Zuiderzee, later Lake IJssel, fisheries, the Netherlands

The Zuiderzee was a shallow, brackish inland sea (300,000 ha) until its conversion to fresh water by the construction of a dam in 1932. In 1905 there were still 4653 permits issued to operate the multi-species, multi-gear fishery from the many small harbours bordering this inland sea. The fishery targeted especially pelagic herring, *Clupea harengus*, and anchovy, *Engraulis engraulis*, and in addition smelt, *Osmerus eperlanus*, eel, *Anguilla anguilla*, flounder, *Pleuronectes flesus*, and shrimp, *Crangon crangon*. Anchovy has always been the most desirable species to catch, because of its far and away highest value per unit weight. The availability of the resource was, however, most uncertain (Fig. 6.5). In the 74 year period 1857-1930 there was neither a significant trend nor serial correlation in the landings of anchovy, which averaged 888 tonnes per year. The inter-annual variability in annual landings was large ($s^{10}\log C$ = 0.63, CV(s) = 2.67, CV = 1.24) (Fig. 6.6). Fig. 6.6. shows that log-transformation of this time series is possibly too strong a transformation and CV-values, as calculated directly (CV) and as deduced from the standard deviation of log-transformed annual catches (CV(s)), thus diverge. The high inter-annual variability was due to the location of the Zuiderzee at the extreme northern boundary of the distribution area of this anchovy species. There was only very weak price elasticity and this did not stabilise the inter-annual variability in the monetary value of total landings (1857-1918 CV(s) = 2.31, CV = 1.20).

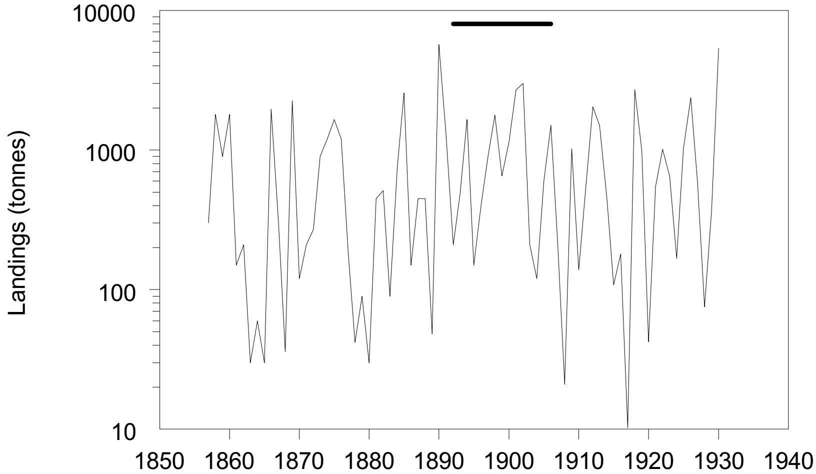


Fig. 6.5 Annual landings of anchovy from the Zuiderzee 1857 -1930. Until 1918 landings were recorded in anchors. One anchor of anchovy weighed ca 30 kg. The thick black lin e refers to the period 1892-1906 as in Fig. 6.7.

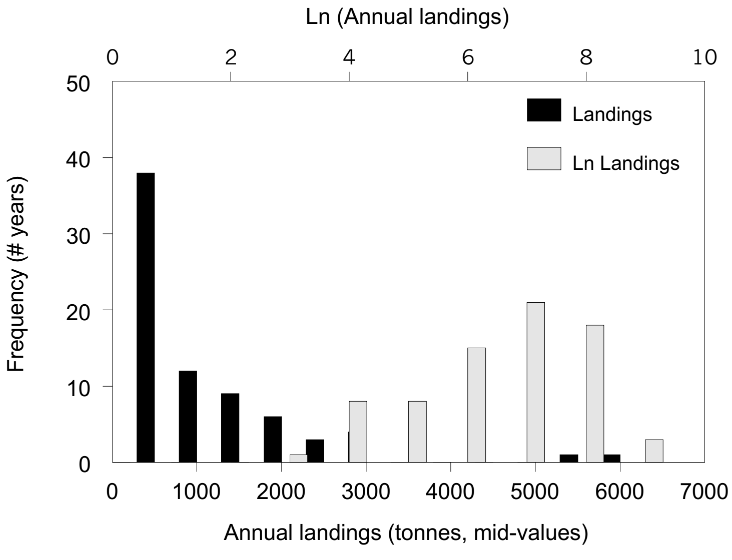


Fig. 6.6 Frequency distribution of the annual landings of anchovy in the period 1857 – 1930, before and after ^{e}log-tranformation.

To assess how large the impact was, of the uncertainty in the landings of anchovy, on the variable total outcome of the Zuiderzee fishery in terms of monetary value, the annual records for the 15 year period 1892-1906 were used (data in Redeke 1907). Annual landings of the six major species fluctuated most strongly for anchovy (CV = 0.88) and the least for flounder, a flatfish (CV = 0.24) (Table 6.3). Although herring dominated the landings by weight (CV = 0.26), it was the fluctuations in the amount of anchovy (CV = 0.88), which dominated the fluctuations in the money value of the total landings (CV = 0.40) (Fig. 6.7).

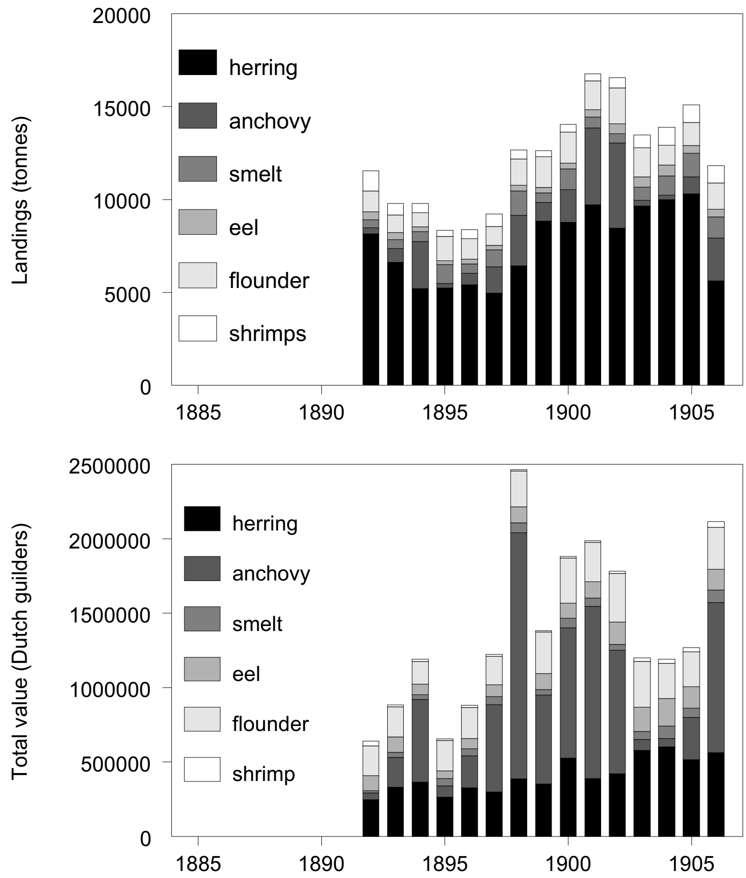


Fig. 6.7 Total annual landings (tonnes) (top) and total value (Dutch guilders) (bottom) of these landings per species category in the Zuiderzee fisheries in the period 1892 -1906 (Data from Redeke 1907).

Table 6.3 Variability (CV) in annual landings, in the value per unit weight and in the total value of fish landed in the Zuiderzee fisheries 1892 -1906 (Data from Redeke 1907).

	Catch weight	Value per unit weight	Total value
Herring	0.26	0.28	0.29
Anchovy	0.88	0.42	0.88
Smelt	0.40	0.23	0.35
Eel	0.31	0.12	0.34
Flounder	0.24	0.09	0.21
Shrimps	0.39	0.18	0.50
Total	0.23		0.40

In 1932 the Zuiderzee was turned into a 300,000 ha freshwater lake, Lake IJssel, through the construction of a 30 km long dam. Several land reclamation projects undertaken since then have reduced the lake surface to its present 180,000 ha. Within a few years the fishery turned from a pelagic, brackish water fishery for pelagic herring and anchovy into a mainly freshwater fishery, targeting demersals (Havinga 1954). The traditional fishery for eel, *Anguilla anguila*, continued, and is now operated in combination with a gillnet fishery for the predatory pikeperch, *Stizostedion lucioperca*, and perch, *Perca fluviatilis*. The fine-meshed eel trawls also caught large amounts of "trashfish", mainly smelt and ruffe, *Gymnocephalus cernuus*, which were sold to the fodder industry. After the trawl ban in 1970, eel fishermen turned to passive gear, such as fykenets and baited hook and lines.

Although total catch weight of fish species combined did not change much over the years, catch composition changed dramatically and recently turned back to pelagics again (Fig. 6.8). Total landings of eel initially increased, but since 1950 they have decreased down to an all-time low of 1.2 kg per ha in 1994 (Fig. 6.9). The decrease is explained from a combination of over-exploitation and, more recently, reduced immigration of glass eel into the lake (Dekker 1991, 1996). The inter-annual variability in detrended series of eel landings is low (CV(s) = 0.28) in comparison with that for pikeperch and perch (Table 6.4). Serial correlation (ρ^2 = 0.35) in the residuals is moderate and comparable to those for pikeperch and perch, but there are clear short-term trends of around 4-6 years duration to be perceived.

After the damming of the lake, landings of perch and pikeperch rose sharply, were interrupted during the wartime years (1940-1945) and developed differently after the war. Landings of perch increased, but at a slower pace. Those of pikeperch decreased with large inter-annual variability around the overall trend (CV(s) = 1.07). For pikeperch there are short-term trends of longer duration, 5-10 years, that can be perceived before and after the mid-1960s.

Annual landings of smelt for human consumption caught with fykenets, so excluding smelt caught with eel trawls and landed as trashfish, have increased since 1945 (Fig. 6.9). The variability around the long-term trend was as high as for pikeperch, but the residuals showed no short-term trends, as could be expected for this small pelagic with a life cycle of only 1-2 years, characteristic for land-locked smelt (Table 6.4). The total weight of the four target species combined, all landed for human consumption, increased until around 1950 and showed no trend thereafter (Fig. 6.9).

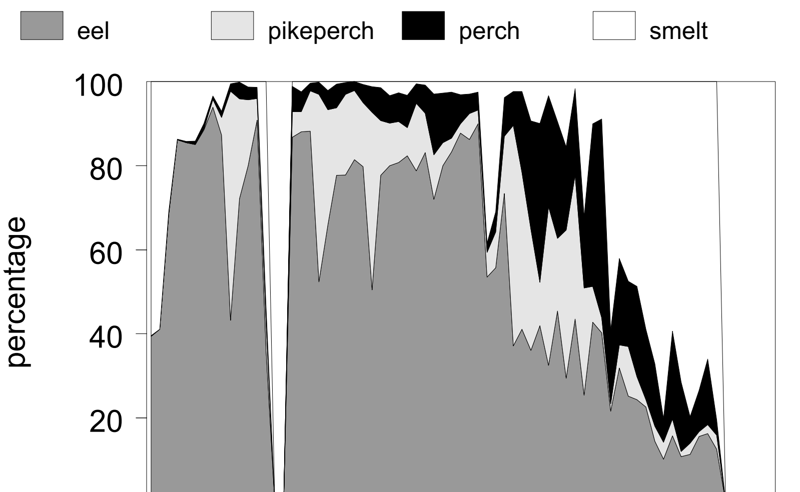
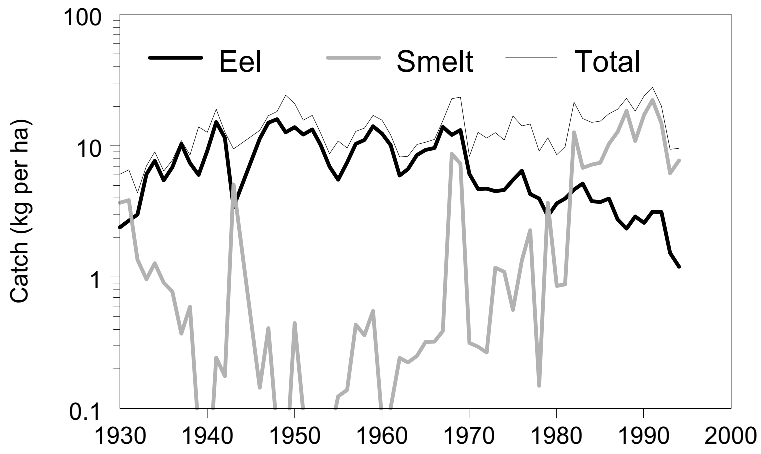


Fig. 6.8 Percentage composition of the total landings of four major species in the fishery in Lake IJssel since its creation in 1932.



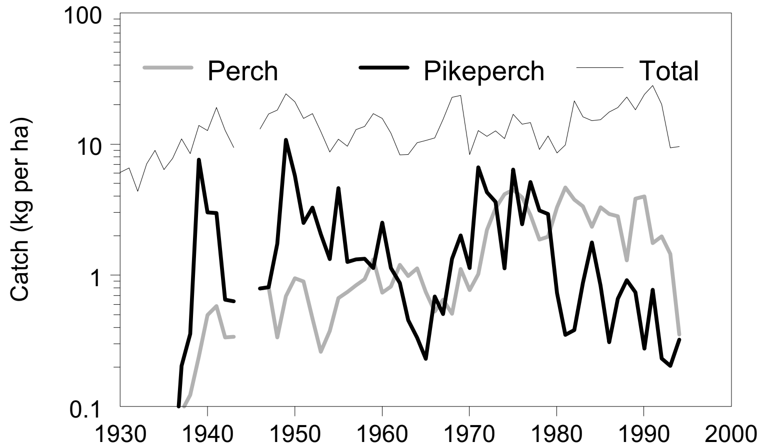


Fig. 6.9 Annual landings converted to catch per unit area (kg/ha) of four major fish species and for these species combined from Lake IJssel. Only smelt for human consumption is included.

Table 6.4 Trend (b, per year) in annual landings (^{10}log-transformed), proportion of total variance explained by the trend, variability around the trend, trend to noise ratio (b/s), and the proportion of residual variance explained by serial correlation (ρ^2) for three major species in the fishery on Lake IJssel in the period 1946-1994.

	Eel	Perch	Pikeperch	Smelt
b	-0.0227	0.0102	-0.0186	0.0525
R^2	0.878	0.251	0.330	0.707
S^{10}log C	0.121	0.251	0.378	0.483
CV(s)	0.28	0.63	1.07	1.56
b/s	0.188	0.0406	0.0492	0.109
ρ^2	0.35	0.38	0.28	0.07

The variability in resource outcome from Lake IJssel, in terms of value per unit area, has never been as variable as that of the Zuiderzee fishery. In the Lake IJssel fishery, eel has always been the species with the highest value per unit weight and this species dominated the total catch in weight until the 1980s. In 1999 the price per unit weight was 17.98, 9.35, 7.48 and 0.88 guilders per kg for eel, pikeperch, perch and smelt respectively (Productschap Vis 2000). Although smelt now dominates the total catch weight, it only marginally affects variability in the value of the total landings from the lake, because of its circa 20 times lower value per unit weight than eel.

6.2.3 Decline of river fisheries in the Netherlands

The River Rhine is the largest river in NW-Europe and flows through the Netherlands, before discharging into the North Sea. Until the turn of the 19th to 20th century three large riverine fish species were of great commercial interest for the fisheries in the Dutch section of the Rhine: sturgeon, *Acipenser sturgeo*, Atlantic salmon, *Salmo salar*, and Allis shad, *Alosa alosa*. All three disappeared from the landings, and from the river, at more or less the same relative rate (Fig. 6.11). In the short period from 1893-1915 landings of sturgeon decreased by a factor of almost 100. These dramatic declines are attributed to a combination of over-exploitation, river pollution and destruction of upriver spawning grounds (Grift 2001).

The downward trends for Allis shad and salmon stayed curvi-linear even after log-transformation. Therefore a parabolic function for ^{10}log-tranformed annual catches was used to describe these long-term trends and thus to assess inter-annual variability: CV(s) = 0.43 (1869-1911) and CV(s) = 0.67 (1871-1909) respectively. Only for Allis shad were the residuals significantly serially correlated ($\rho^2 = 0.41$). Numbers of sturgeon landed were always lower than those of salmon and much lower than Allis shad. After log-transformation the trend for sturgeon (1893-1915) is linear with the lowest variability around it of the three fish species: CV(s) = 0.35 ($s^{10}\log C = 0.147$). Serial correlation in the residuals was highly significant $\rho^2 = 0.649$.

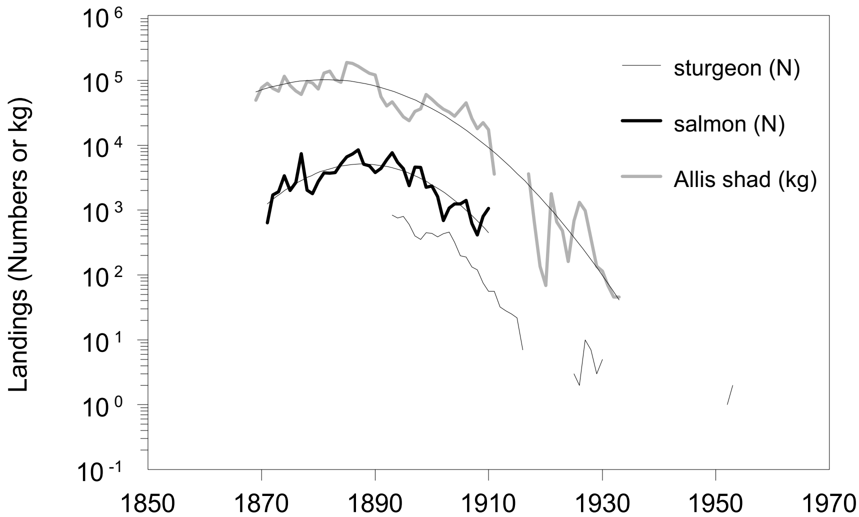


Fig. 6.11 Annual landings of sturgeon, salmon and Allis shad from the River Rhine in the Netherlands. Data for sturgeon and Allis shad from Verhey (1961) and for salmon from Aald erink (1911).

6.3 Inter-annual variabilities in some sport fisheries

Time series of annual catch data from sport fisheries are rare. There is generally no obligatory reporting of catch and effort by individual anglers within the framework of a nation-wide census programme. Exceptions are, for example, the reporting schemes for anglers targeting salmon in rivers for which a licence is needed (Churchward & Hickley 1991, Gardiner 1991).

In addition, in these records ultimate fishing effort is poorly standardised, only by the number of licences being recorded. In most cases it depends largely on the organisational capabilities of angling clubs and organisations whether there is even any standardised gathering of catch and effort data, let alone a systematic evaluation of such data. Nevertheless, there are some interesting examples.

There is a census on a Yorkshire river near Kirk Hammerton (UK), which lasts about 40 days each year, during which data are collected from about 600 anglers, including effort in terms of angling hours (Axford 1991). It would be expected that the random component in this annual data, due to basic uncertainty, is strongly reduced by the aggregation and averaging of the data. Time series over 24 years of numerical CpUE data (1966-1989) for five freshwater fish species, showed differences in trends and variances between species (Axford 1991, his Fig. 14.3). Catch rates were highest for small dace, *Leuciscus leuciscus*, and a large cyprinid, chub, *L. cephalus* (Fig. 6.11). Those of dace decreased significantly (p = 0.0233) over the years (slope = -0.0164 per year), but with strong inter-annual variability around the trend (s^{10}log CpUE = 0.223, CV(s) = 0.55) without significant serial correlation in the residuals (ρ^2 = 0.146, p = 0.0723). The absence of significant serial correlation in the residuals can be explained by the short life cycle of the dace. This small cyprinid recruits to the sport fishery at the age of only two. Catch rates for the larger and older chub showed no significant trend over time and the mean CpUE was only 0.115 per hour ± 0.025 (CV = 0.22, CV(s) = 0.22). Although they grow so much older, serial correlation was still not significant in the series (R^2 = 0.0820, p = 0.185).

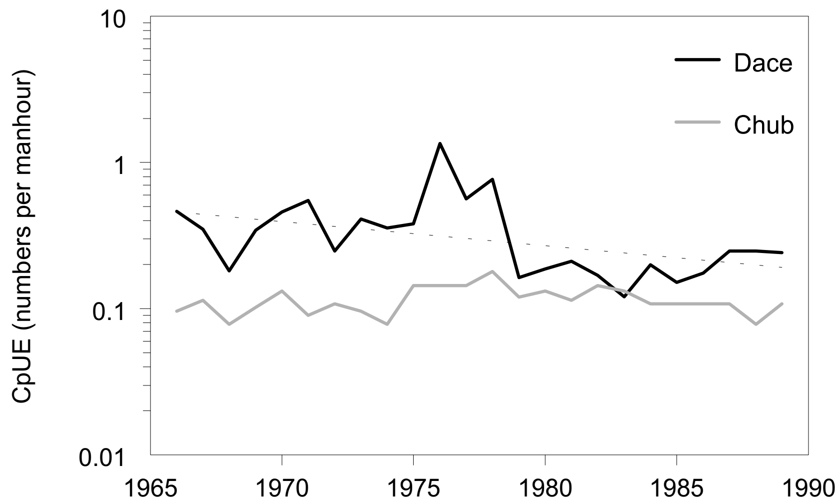


Fig. 6.11 CpUE of dace and chub (numbers per ma n-hour) in the sport fishery at Kirk Hammerton, Yorkshire, UK (based on Fig. 14.3 in Axford 1991).

It would be expected that when catch rates are expressed in total weight instead of numbers per angling hour, and for species combined instead of per species, the inter-annual variability in a detrended series would be smaller. Inter-annual variability in annual catch rates along the River Trent (UK), which are monitored as total weight per man-hour, was indeed low. The variability around the trend for the first series of catch data from the River Trent (1969-1983) was $s^{10}\log$CpUE = 0.118 (CV(s) = 0.28) (Fig. 6.12). For the second series (1979-1986) it was even lower ($s^{10}\log$CpUE = 0.0480, CV(s) = 0.11).

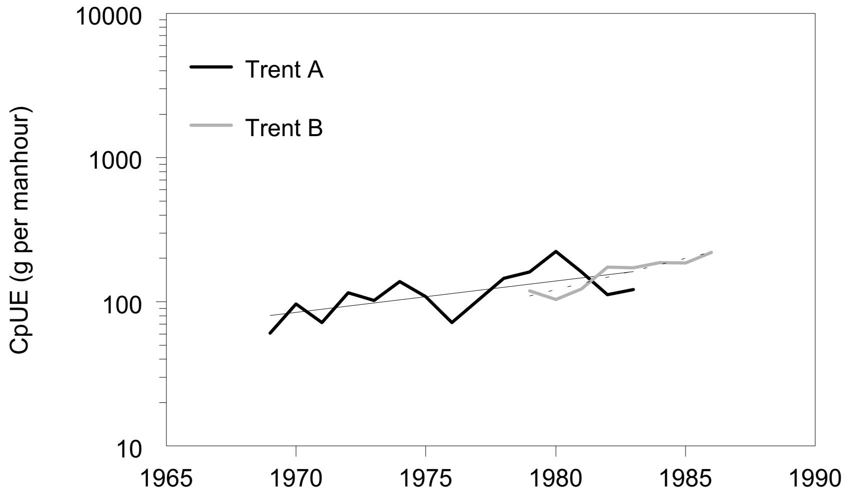


Fig. 6.12 CpUE (g per manhour) in the sport fishery on the River Trent (two series, A and B). Series A from Cowx & Broughton (1986); series B from Cowx (1991).

Angling clubs, such as the Lismore Angling Club on the eastern coast of Australia, have become aware that the management of their fishery requires information on trends and shifts in average catch rates, in order to identify problems with their resource and to evaluate the effectiveness of measures subsequently taken. Since 1956 this club has kept records of its competition results in total numbers, although irrespective of species, and since 1971 in numbers per species, together with the number of angling hours (Gartside *et al*. 1999). The major species caught are yellowfin bream, *Acanthopagrus australis*, and tailor, *Pomatomus saltatrix*. On average, circa 30-40 club members participated in the approximately 12 competitions per year, organised over an area with a radius as large as 160 km from Lismore. The CpUE, averaged for the full 38 year period, was 0.47 fish or 0.34 kg per angling hour. Catch rates were higher in the 1970s for reasons unknown to the authors (Fig. 6.13). Since 1976 CpUE for total catch and catch per species have declined. The rate of this decline in $^{10}\log$CpUE was $0.023.y^{-1}$ for bream and $0.055.y^{-1}$ for tailor during the 18 year period. The variability around the trend per species was $s^{10}\log$CpUE = 0.124 (CV(s) = 0.29) for bream and 0.321 (CV(s) = 0.85) for tailor. Serial correlation in the residuals around these trends was, ρ^2 = 0.09 and 0.07 respectively.

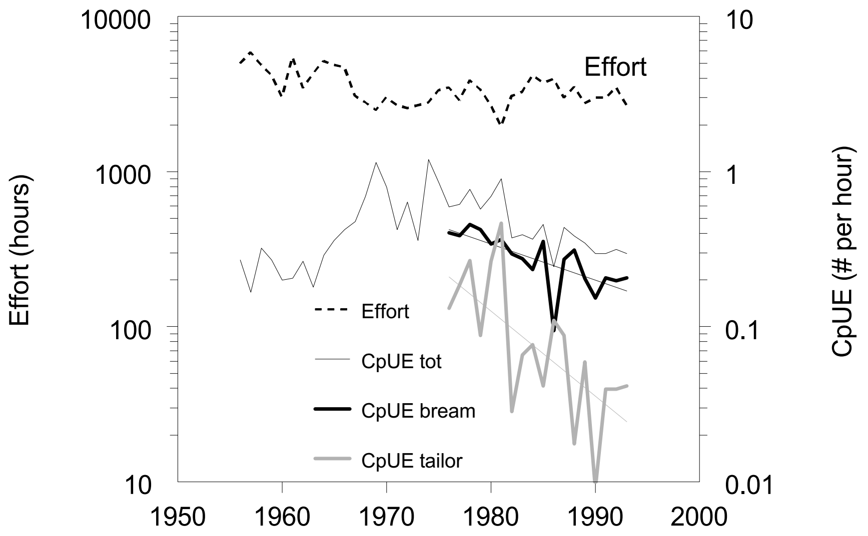


Fig. 6.13 Total effort and CpUE (Numbers per angling hour) for the Lismore Angling Club 1956 - 1993. Bream: yellowfin bream, *Acanthopagrus australis*, and tailor, *Pomatomus saltatrix*.

The more traditional angling for the highly valued salmon Atlantic salmon, *Salmo salar*, has produced the longest data series of catch and effort in sport fisheries. Total fishing effort, as the total number of licences, developed more conservatively over time than the annual catch rate, as the number of salmon caught per licence, on the 354 km River Severn in mid-Wales (Fig. 6.14) (Churchward & Hickley 1991). The initial 10-fold increase in the number of rod licences up to around 1960, was accompanied by a gradual decrease in catch rates, although with large inter-annual variability. In the 30 year period 1960-1989 there was neither a significant trend in effort (mean = 1479 licences per year, CV = 0.16, CV(s) = 0.16) nor in catch rates (mean = 0.63 salmon per licence and year, CV = 0.42, CV(s) = 0.45). Serial correlation in the effort series was $\rho^2 = 0.20$ ($p = 0.016$ for $\alpha = 0.05$) and $\rho^2 < 0.001$ in the catch rate series.

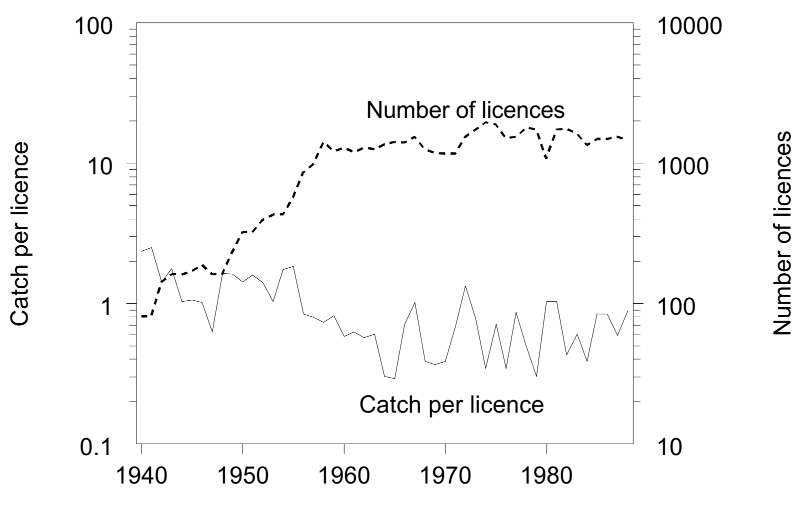


Fig. 6.14 Fishing effort (licences per year) and catch rates (numerical catch per licence) for the salmon fishery with rod and line on the River Severn in mid-Wales. Modified after Fig. 1.5 in Churchward & Hickley (1991).

6.4 Persistence in the residuals – Coloured noise

To be sure that the concept of a 'short-term trend' is comprehensible to both authorities and fishermen, and thus employable in fisheries management situations, it should not be based on its size relative to the time window of the full series available, but on an absolute measure in number of years. It is difficult to generalise on what duration of short-term trends to expect in what type of fishery. Theoretically, spectral analysis could indicate the frequency of peak years in detrended series and thus indirectly, and only by approximation, the duration of short-term trends. Time series of annual catches, however, are generally too short for spectral analysis. Therefore, estimates of variance and serial correlation in the residuals for a few example series are combined here with visual inspection of these series, in order to articulate the concept of a 'short-term trend' clearly.

All three example series show no long-term trend in the full time window depicted (Fig. 6.15, Table 6.5). The inter-annual variability ranges from a low CV = 0.09 for a fishery on Arctic char, a salmonid, in a Swedish lake up to CV = 0.65 for a fishery on lake whitefish, a coregonid, in Lake Michigan until 1950, when the ecosystem became disrupted because of the spread of the alewife, *Alosa pseudoharengus* (Miller 1957 in Wells 1977). After the recovery, inter-annual variability in the landings of lake whitefish was strongly reduced, as the series since 1970 shows. The serial correlations in the three example series differed strongly, from $\rho^2 = 0.18$ for lake whitefish after 1970 up to $\rho^2 = 0.73$ for the Arctic char (Table 6.5).

Visual inspection shows that where serial correlation is truly high, short-term trends last longer, 10-15 years in the series for lake whitefish up to 1950 and for arctic char. In the series for blue pike also the serial correlation is significant and apparent, but explains less of the overall variance. With almost the same variability as in the lake whitefish series the short-term trends are of shorter duration and therefore steep, so serial correlation is less. If these short-term trends of shorter duration indicate blue noise in the series, those of longer duration in the other low series suggest more reddish noise.

The short-term trends of 3 to 4 years could be due to the dominance of a very strong year-class in the landings for a consecutive number of years. But for a monotonic rise and fall in annual landings over 10-15 years, as in the other two fisheries, such an explanation seems unlikely, given the generally much shorter residence time of any year-class in the exploited stock (see section 6.3.2). These short-term trends of longer duration are more likely to be due to cyclical changes in the structure of the fish or aquatic community forced by gradual changes in environmental parameters or resulting from density-dependent processes in the fish stock or in the fish community as a whole, as described for freshwater and marine ecosystems (e.g. Holcik 1977, Bjørnstad *et al*. 1999).

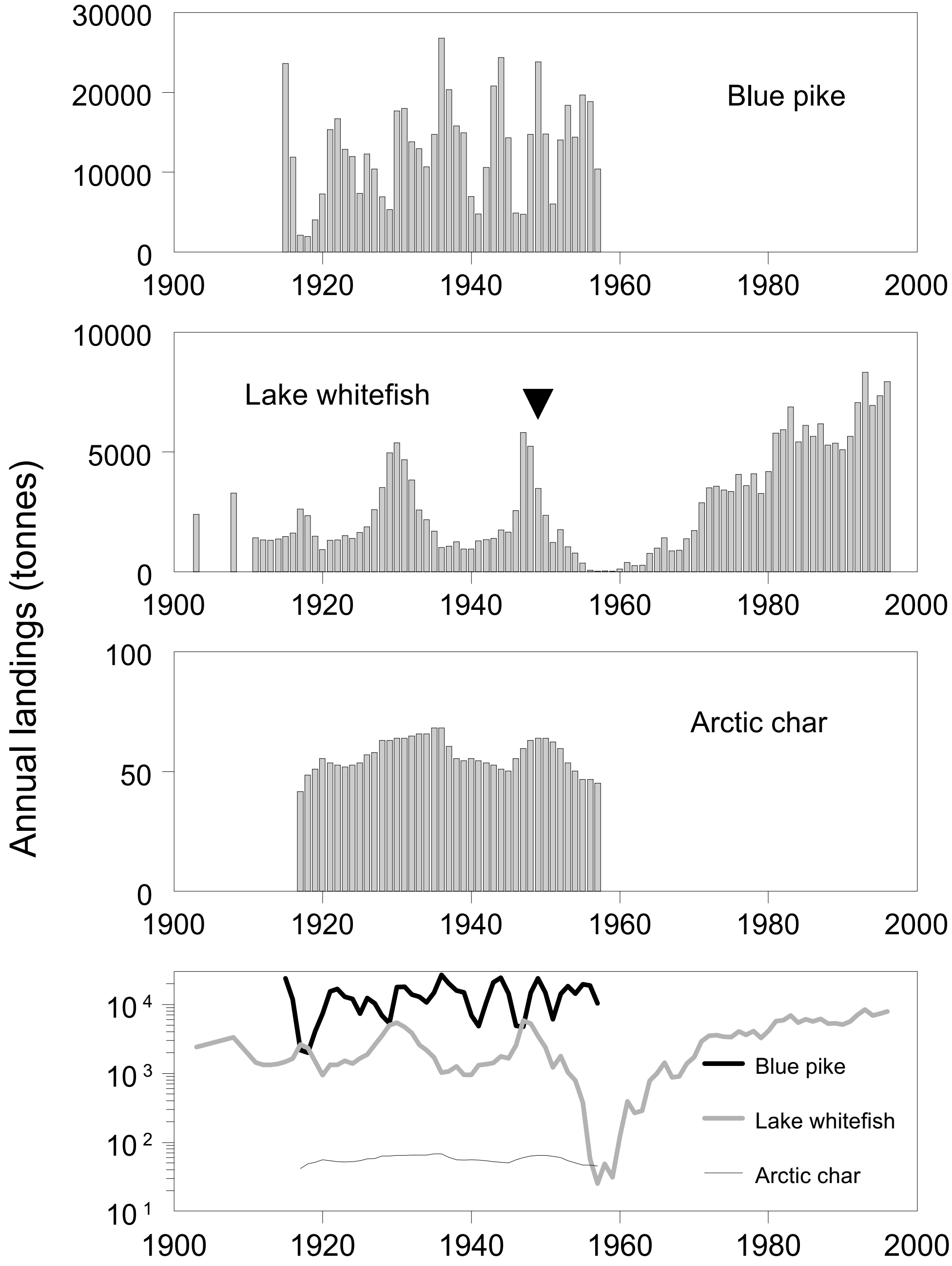


Fig. 6.15 Time series of annual landings of (1) blue pike, *Stizostedion vitreum glaucum,* Lake Erie; (2) lake whitefish, *Coregonus clupeiaformis*, Lake Michigan; (3) arctic char, *Salvelinus alpinus*, Lake Vättern, together with the series after log-transformation. Data for (1) and (2) from the website of the Greta Lakes Fisheries Commission (www.glfc.org), data for (3) from Grimas *et al*. (1972). The triangle in the second panel indicates the first appearance of the alewife in Lake Michigan.

Table 6.5 Characteristics of the time series for annual landings for three fisheries.

Fishery	1	2		3
	Blue pike Lake Erie	Lake whitefish Lake Michigan		Arctic char Lake Vattern
Years	1915-1957	1911-1950	1970-1996	1917-1957
CV	0.53	0.65	-	0.09
Trend	n.s.	n.s.	0.0176	n.s.
R^2	-	-	0.77	-
$s\,{}^{10}\log C$	0.260	0.254	0.077	0.0462
CV(s)	0.66	0.63	0.18	0.09
ρ^2	0.32^{**}	0.60^{**}	0.18^{*}	0.73^{**}

6.5 Inter-annual variability related to recruitment patterns and stock structure

Variability in annual recruitment (R) translates into smaller variability, but higher persistence, in the annual landings (C). The variability in annual recruitment or year-class strength is mostly stochastic (white noise), and is generally more strongly governed by climatic factors than by the conservative size of the spawning stock biomass. Most recruitment series perform no or only weak serial correlation (Power 1996).

Series with annual recruitment are the ‘in signal’, mostly considered as white noise from the unpredictable environment. The fish stock, characterised by its structure and dynamics, is then the ‘filter’ for this signal. The ‘out signal’, following this concept, is the series of annual landings, which fluctuate with the biomass of the exploited stock. This concept of environmental noise, mediated by a population, follows Roughgarden (1975) and Lundberg *et al*. (2000). The out signal will in any case show serial correlation due to the exploitation of more than one year-class at a time. To what extent variability reduces, and persistence in the ‘out signal’ increases, will depend on the structure of the stock and its dynamics, with their effects on growth and mortality rates, including fishing mortality. Only when the stock structure is simple by nature or has become simple because of very intensive exploitation, so that only one year-class is caught at a time, will persistence in the series of annual landings decline to insignificant levels.

The ‘in signal’, as annual recruitment, is not always the white noise around a long-term average, and sometimes shows long-term trends and even short-term persistence. Of the recruitment series for the commercially important species in the Dutch North Sea and Lake IJssel fisheries, that of cod significantly decreased (-47% in 30 years) and that of plaice increased (40% in 30 years) in the period from around 1960 – 1990 (Table 6.6). These trends explained only a small portion of the total variability, $R^2 = 0.11$ and 0.12 respectively. The recently lower recruitment of cod may be due to the higher temperature of the North Sea, as much as to the very low level of the spawning stock now (O'Brien *et al*. 2000). The recruitment of cod in 1997 and 1998, was the poorest on record. The overall very low variability in plaice recruitment is explained by the density-dependent mortality of their juveniles in coastal nursery areas (Bergman *et al*. 1988).

Inter-annual variability in recruitment is high (CV > 1), for haddock and for perch and pikeperch (Table 6.6). The highly variable recruitment of perch and pikeperch in Lake IJssel is positively linked to summer temperature (Buijse *et al*. 1992). Combined with the high fishing mortality, this ensures that annual landings are much affected by sometimes persistent changes in summer temperature (Fig. 6.16). Only for pikeperch has a recruitment mechanism been described, whereby higher temperature in early summer causes prey fish, mostly 0-group smelt, *Osmerus eperlanus*, to be more available for the gape-limited, fast growing piscivorous 0-group pikeperch (van Densen 1985, Buijse & Houthuijzen 1992, van Densen *et al*. 1996).

The CV(s) higher than the CV for perch suggest that a lognormal distribution is not the proper descriptor for the recruitment frequency distribution of this species. Power (1996) concluded from his analysis of recruitment for a 100 North Atlantic fish stocks, that the Weibull, or extreme value Type III distribution, is at least as good as the lognormal distribution in describing recruitment frequency distributions. The generic application of the lognormal distribution for recruitment frequency distributions may indeed be constrained, because with the increase in the shape parameter σ_0, extremely high values are assumed to occur, that seldom if ever occur in natural recruitment series.

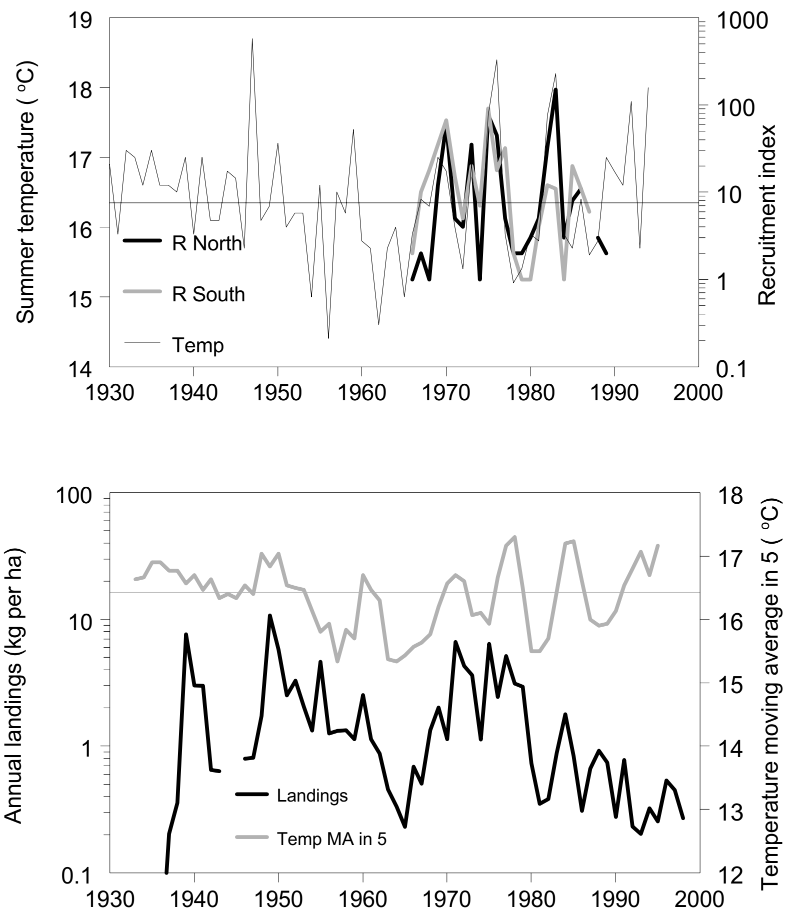


Fig. 6.16. Summer temperature (average 16.4 °C), recruitment and annual landings of pikeperch from Lake IJssel. Top: Recruitment is indexed by the number of 0 -group pikeperch per unit trawl haul in autumn. Bottom: Temperature as a moving average of 5 years of summer temperature shifted 3 years to the right. Pikeperch cohorts become vulnerable to the gillnet fishery after 3 years. Recruitment indices from Buijse *et al*. (1992).

When the inter-annual variabilities in recruitment of perch and pikeperch are compared for a series of combinations of species and location, the variability for perch in Lake IJssel is among the highest. The variability for pikeperch in the same lake is moderate within the broad range of recruitment variability (Fig. 6.17). Power (1996) has already stated that it is hard to talk about taxonomic-specificity in recruitment variability and that recruitment variability should be viewed as a stock specific attribute linked to life-history and local environmental conditions.

Part of the variance in inter-annual variability in recruitment could be due to the different ways in which recruitment indices are obtained. For example, indices based on trawl surveys at the end of the first summer may reveal consistently higher variability, than recruitment indices as reconstructed from the numerical representation of year-classes in the commercial catch (van Densen *et al*. 1996). Such reduction in inter-annual variability can possibly be explained by the stabilising feed-back mechanisms mentioned earlier, acting in the early life stages. Higher mortality rates of abundant, and therefore slow-growing 1-group perch, which remain vulnerable to predation for a longer time, is such a possible feed-back mechanism (Nielsen 1980).

It has always been hard to explain variability in recruitment from changes in the size of the spawning stock, via a so-called stock-recruitment relationship (Hilborn & Walters 1992). The size of a spawning stock composed of a number of year-classes, in which larger and older fish generally produce more eggs per unit weight, behaves conservatively, that is, its total biomass changes gradually over the years. Hence, any strong relationship between annual recruitment and spawning stock would be evident from significant serial correlation in recruitment indices. But recruitment of none of the five marine and two freshwater species in Table 6.6 showed serial correlation in a time window of 24-39 years.

Table 6.6 Variability in annual recruitment before (CV) and after log-transformation, with de-trending where necessary (CV(s)), for seven major species in the North Sea and Lake IJssel fisheries. The two figures for Perch and Pikeperch refer to estimates for the northern and southern basin of Lake IJssel respectively.

	Plaice	Sole	Cod	Haddock	Whiting	Perch	Pikeperch
CV	0.46	0.98	0.59	1.42	0.55	1.46-1.72	1.74-1.31
Slope	0.004897	n.s.	-0.00911	n.s.	n.s.	n.s	n.s
R^2	0.118	-	0.108	-	-	-	-
$s\,^{10}\log R$	0.153	0.352	0.245	0.454	0.226	0.794 - 0.811	0.586 - 0.521
CV(s)	0.36	0.96	0.61	1.41	0.56	5.24-5.66	2.28-1.79
N (years)	39 (57-95)	38 (57-94)	32 (63-94)	32 (63-94)	32 (63-94)	24 (66-89)	24 (66-89)

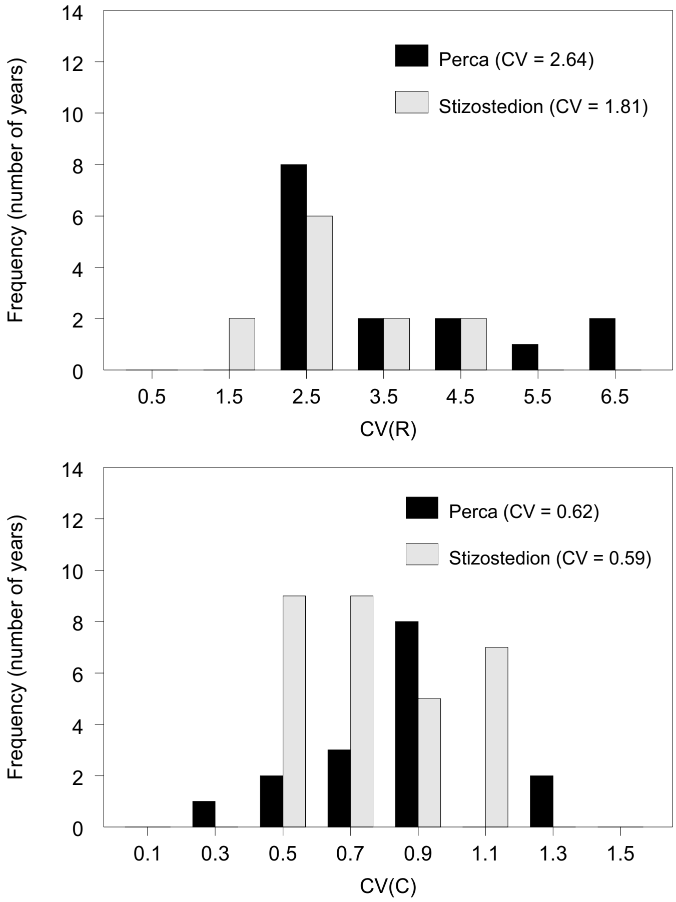


Fig. 6.17 Top: Inter-annual variabilities (mid-values) in recruitment (CV_R(s)) for a number of populations of *Perca* and *Stizostedion* species (based on data in Buijse *et al* 1992). Bottom: Inter-annual variabilities (mid-values) in annual landings as based on CV-values, obtained after fitting 2[nd] order polynomials (Buijse *et al*. 1991).

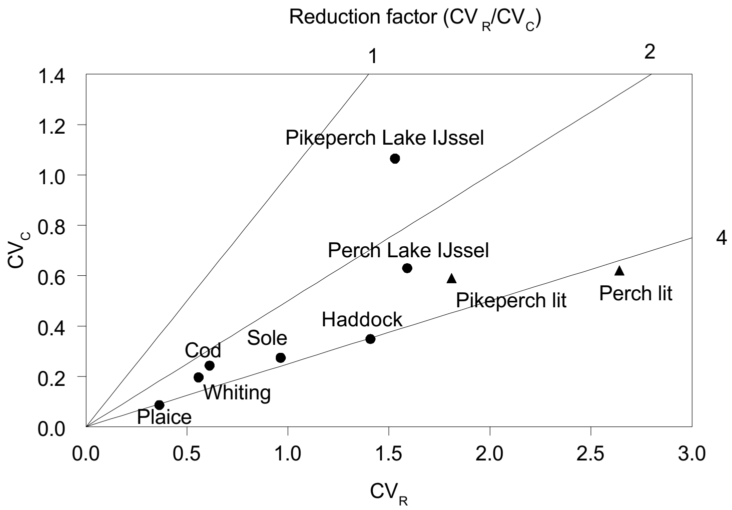


Fig. 6.18 Variability in annual landings (CV_C) plotted against variability in annual recruitment (CV_R) for de-trended time series for five fish species in the North Sea fishery and two fish species in the Lake IJssel fishery. CV-values were calculated from the sd in log-tranformed data (CV(s)), except the CV_R-values for pikeperch and perch which were calculated directly from untransformed values (Lake IJssel). The literature data are from Fig. 6.17.

Comparing variability in annual landings (CV_C) with variability in annual recruitment (CV_R) for the set of five marine and two freshwater species, shows that the reduction factor (CV_R/CV_C) is around 3 to 4 (Fig. 6.18). How a more simple population structure, as determined by growth and mortality rates, could enhance the reduction of variability (CV_R/CV_C), can be inferred from an analytical model of population structure and dynamics (Buijse *et al.* 1994). From this model it is evident that variability in annual landings (CV_C) is proportional to the variability in recruitment (CV_R) and modified by the number and relative contribution of all age groups in the catch.

$$CV_C = CV_R \frac{\sqrt{\sum_{i=a}^{A} \overline{C}_i^{\,2}}}{C} \qquad (6)$$

where C_i is the catch per age group and a denotes the youngest and A the oldest age group in the catch. The inter-annual variability is lower and annual landings are more stable, when the catch comprises more age groups and when the catch in terms of weight is more evenly distributed among the age groups. How many age groups are represented in the catch and how they contribute to total catch weight is determined by the annual rates of growth (K), natural (M) and fishing mortality (F). By using general relationships, as formulated for the Beverton & Holt (1957) analytical pool model, it can be inferred that variability in annual landings (CV_C) becomes less when growth (K), natural (M) and fishing mortality rates (F) and age of recruitment to the fishery (t_c) are all low (Fig. 6.16). The reduction factor is understandably low for intensively fished and fast-growing cod (F ~ 1 per year) and pikeperch (F > 2 per year), and high for slow growing, less intensively fished plaice (Fig. 6.19). The model does not account for possible density-dependent processes within and between the cohorts, which contribute to a further enhancement of variability reduction.

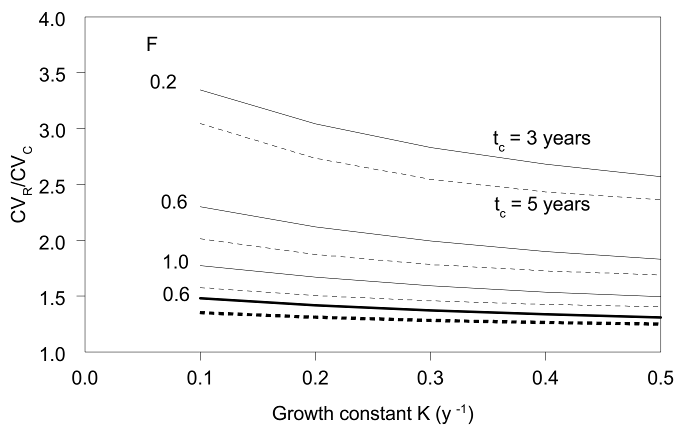


Fig 6.19 Reduction factor in inter-annual variability (CV_R/CV_C) as governed by population parameters for growth (K, X-axis), natural mortality (M = 0.2 per year, bold lines M = 1.0 per year) and fishing mortality (F = 0.2, 0.6, 1.0 per year) and by age of recruitment to the fishery (t_c = 3 years, dashed line 5 years). In fisheries with only 1 age group in the catch CV_R/CV_C would equal 1 (modified after Fig 6.5 in Buijse *et al.* (1994)). The upper limit for the age of the fish in the calculations was t_λ = 20 years. The value of the growth parameter K (per year) is: Plaice 0.3, Sole 0.4, Cod 0.3, Haddock 0.2, Whiting 0.4, Perch 0.14, Pikeperch 0.21 (data source for marine species, RIVO, IJmuiden; freshwater species, Buijse 1992).

6.6 Reduction of inter-annual variability after spatial aggregation

6.6.1 Data aggregation through one ecological space, Lake IJssel, the Netherlands

Lake IJssel is one clearly delineated ecological space of 200,000 ha and with small spatial differences in depth, bottom type and water transparency. Eel, pikeperch and perch are the target species in the fishery. Pikeperch and perch are piscivorous predators that rely heavily on the small pelagic smelt, *Osmerus eperlanus*. This forage fish is homogenously distributed at a smaller spatial scale, and shows only weak spatial differences in biomass density between three roughly equal lake areas (Mous 2000). Fishermen operate in large individual resource areas relative to the size of the lake. Gangs of gillnets more than 10 km long are not exceptional. These characteristics of the lake, the target species and the fishery make it likely that variability reduction, in series with annual landings per species, is weak when data are aggregated per fisherman, per harbour and for the lake as a whole and that there is strong proportionality between the series (see section 3.6). In non-parametric terms: when individual fishermen, harbour officials or the lake authorities try to rank years by the size of their annual catch, they would probably come up with more or less the same sequence of years. In management terms it suggests that variability around a possible long-term trend in resource outcome is the same for all the different actors at the three administrative levels in the lake fishery (fisherman – harbour – lake).

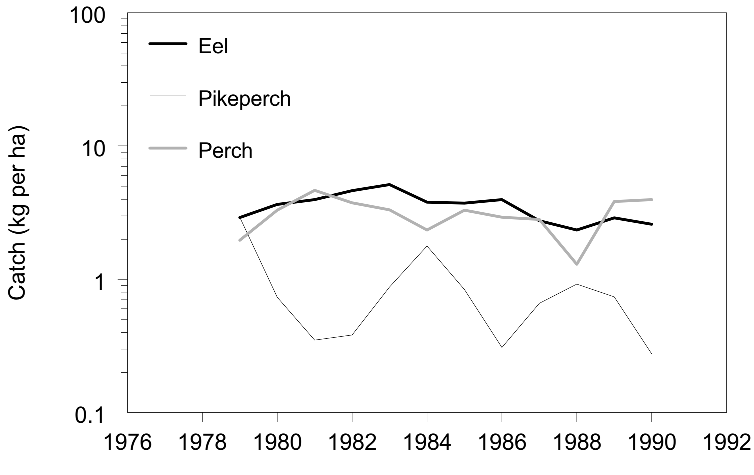


Fig. 6.20 Annual landings, converted to kg per ha, for the three target species in the Lake IJssel fishery: 1979-1990. Trends were not significant. Inter-annual variabilities CV = 0.24, 0.84, and 0.30 and CV(s) = 0.25, 0.80, and 0.36 for eel, pikeperch and perch respectively.

Eel are caught during summer with fykenets, baited traps, and with hook & line. Pikeperch and larger perch are caught in autumn and winter with 101 mm gillnets (stretched mesh). Smaller perch are caught in fykenets. At the end of the 1940s the lake's fishery was still practised by as much as 900 fishing units. This number has gone down over the years to the current 100 units, which operate from a number of small fishing harbours bordering the lake.

The outcome of the fishery is monitored and annual catches per species are officially reported as aggregated per harbour and for the lake as a whole. Time series of annual catches per individual fisherman are not recorded or processed by the fisheries administration, but were still available from six harbours around the lake for a small time window of 12 years (1979-1990) (data Willem Dekker, RIVO). This data source was also used to calculate totals per harbour. Some harbours around the lake are more specialised in their fishery by target species or gear type. In the period 1979-1990 most eel were landed in the harbour of Volendam, most pikeperch and perch in the harbour of Urk. Totals for the lake as a whole were taken from the official, annual reports on the lake's fishery (Fig. 6.20) (see also section 6.2.2).

Inter-annual variability in the annual series decreased only marginally from the lowest to the highest administrative level (Fig. 6.21). Further, most series per fisherman were significantly correlated with the series for the corresponding harbour total, and those harbour totals even more strongly with that for the lake total (Fig. 6.22). This suggests proportionality between time series of annual catches per fisherman, per harbour and for the lake as a whole, which is most clearly visible in the annual catches of pikeperch (Fig. 6.23). Most fishermen from the harbour at Urk targeting for pikeperch experienced changes in their annual catch which mirror those for the lake as a whole almost exactly. Gillnet fishermen from Urk operate throughout the whole of the lake as can be inferred from the mapping of the locations where nets were set by van Eerden *et al.* (1999, their Fig. 1). Moreover, time series of different harbour totals for pikeperch seem to mirror each other and the one for the lake total more than those for eel and perch (Fig. 6.24). So although long-term trends for this species will be more difficult to perceive due to the higher inter-annual variability, fishermen and authorities are able to develop parallel views on developments in the stock of pikeperch from one year to the next.

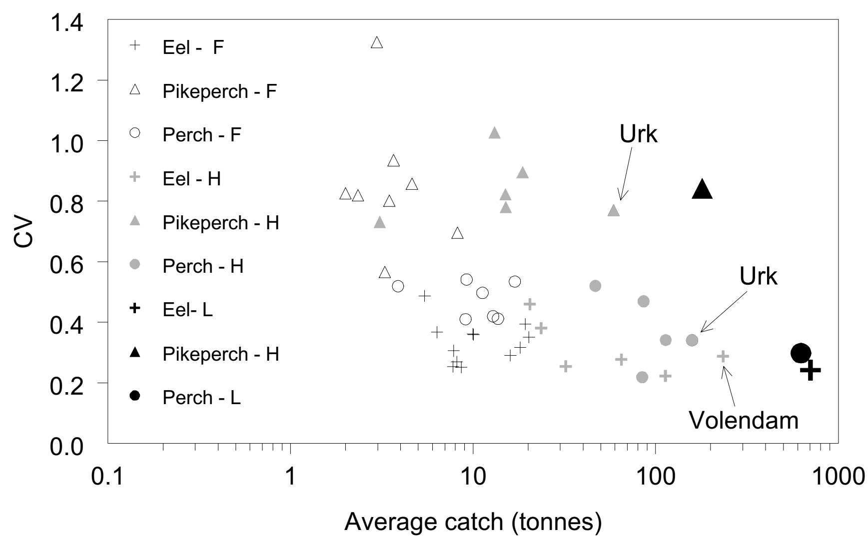


Fig. 6.21 Inter-annual variability in the annual landings per species from Lake IJssel (1979-1990) as aggregated at three administration levels: fisherman (F) – harbour (H) – lake (L). V = Volendam, U = Urk. Only those fishermen for which landings were reported in each year of the series were selected.

Possible reasons for less proportionality between series are inter-annual differences in fishing effort per fisherman and harbour, and the differential exploitation of segments of the same stock by individual fishermen or harbours. In the small time window of 1979-1990, probably only a small part of the inter-annual variability will be due to changes in total fishing effort applied per individual fisherman or per harbour. But in a larger time window comparisons should preferably be made on the basis of Catch per Unit Effort averaged per fisherman, harbour and the lake instead of on the basis of total catches. Developments in fishing effort are, however, poorly documented for the Lake IJssel fishery.

The lesser proportionality for eel and perch in the 1979-1990 series could also be due to the differential exploitation of these species by fishermen and harbours. Whereas pikeperch are only caught with gillnets, perch are caught with both gillnets (larger specimens) and fykenets (smaller specimens), and eel are caught with three types of gear: fykenets, baited traps and hook & line. Eel fishermen operating baited traps and hook & line catch the larger, more piscivorous eel. The proportions in which the various fishing modes are applied for catching eel differ per harbour, and so may the size- or type-selective utilisation of the eel stock in the lake. Such differentiation towards different parts of the stock, each with its own dynamics, may have brought about the smaller proportionality in eel catches as aggregated per harbour.

In conclusion, the assumption of a marginal reduction in inter-annual variability in more aggregated catch data for one relatively small and clearly delineated ecospace, with strong proportionality between the annual series for fishermen, harbours and the lake as a whole, is confirmed by the example of the Lake IJssel fishery. The lesser proportionality in the multi-gear fishery for eel is probably the consequence of harbour-related differential exploitation of the eel stock in the lake.

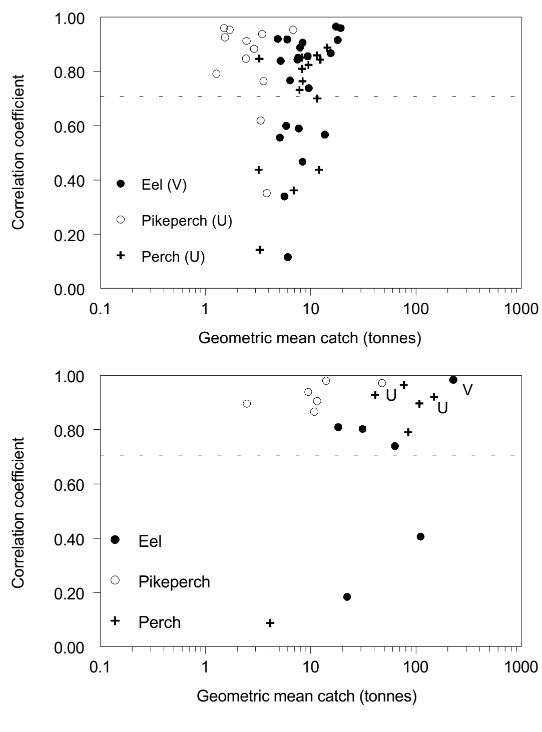


Fig. 6.22 (Top) Correlation between time series of annual catches per individual fisherman and time series of annual catches aggregated for the harbour from which this fisherman operates; (Bottom) Correlation between time series of annual catches per harbour and time series of annual catches aggregated for the lake as a whole. The dashed lines indicate that 50% of the variance is explained by the annual harbour (top) or lake's total (bottom).

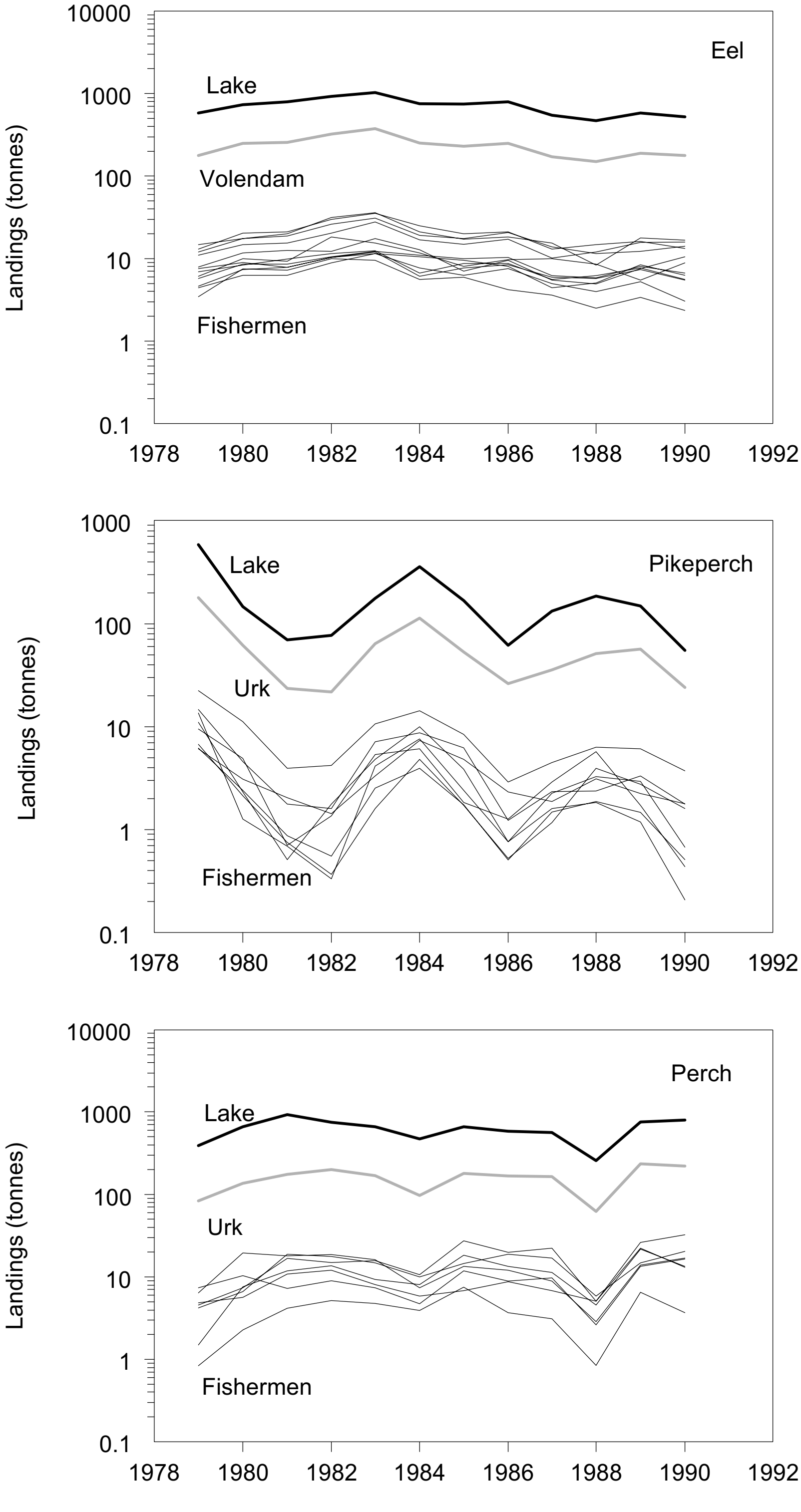


Fig. 6.23 Time series of annual catches (1979-1990) at three levels of aggregation. For each species the lake totals, the harbour totals and the catch per individual fisherman in these harbours are given. Only those series per fisherman are depicted for which the correlation with the harbour total is r > 0.80.

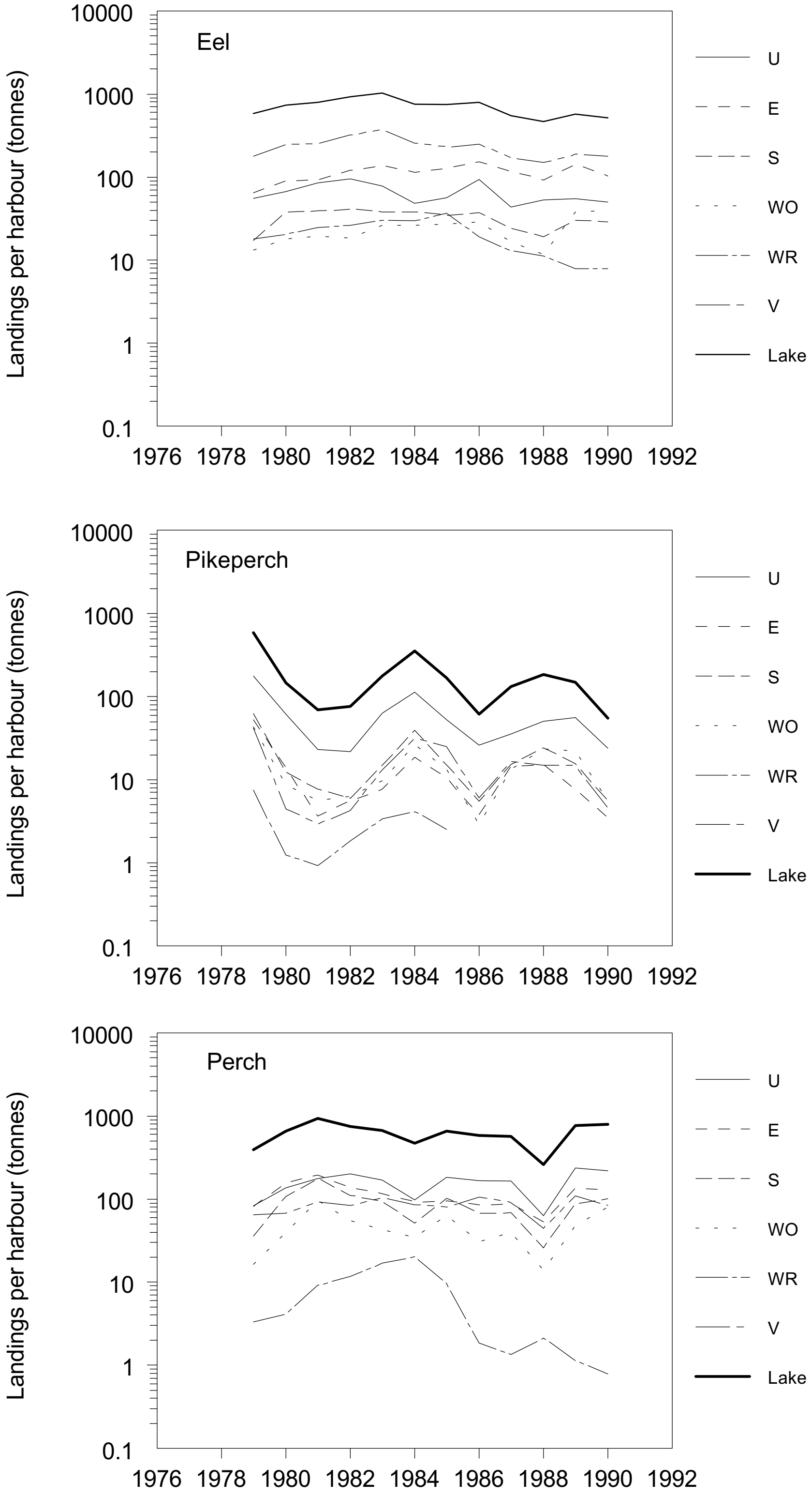


Fig. 6.24 Time series of annual catches (1979-1990) as aggregated per harbour and for the lake as a whole (U = Urk, E = Enkhuizen, S = Staveren, Wo = Wonseradeel, Wr = Wieringen, V = Volendam).

6.6.2 Data aggregation through increasingly larger administrative spaces in Indones ia

The expectation is that aggregation of catch data through ever larger administrative spaces, each encompassing several distinct eco-spaces, leads to pronounced reductions in inter-annual variability. To assess the extent of this, an evaluation was made of the variabilities in the official catch statistics from three statistical or administrative spaces in Indonesia, for which the resource areas differ by one or two orders of magnitude: the coastal shelf of Spermonde (SW-Sulawesi) (3.10^3 km^2), the province of SW-Sulawesi (45.10^3 km^2) and the FAO Fisheries Statistical Area 'Western Central Pacific' (4000.10^3 km^2), to which most of Indonesia belongs.

The nation-wide Catch and Effort Data Recording System of Indonesia was installed in 1976 and is organised according to the hierarchy of traditional administrative spaces: municipalities (kotamadya), districts (kabupaten), provinces and the nation as a whole. After aggregation through the smaller administrative spaces, each of the 27 provincial fisheries statistical bureaux sends its catch and effort data, aggregated for 45 official fish categories, 27 gear categories and 13 boat categories, to the capital for their aggregation into the totals for the annual country report. The 45 catch categories differ by taxonomic resolution (species, genus or family). As a member of the United Nations, Indonesia has to report its annual totals to the FAO for the annual reports on world fisheries statistics.

The 3.10^3 km^2 shelf area Spermonde, north-east of the city of Ujung Pandang (Sulawesi), reaches out some 40 km to the west, is bordered by four districts (kabupaten) situated along its 70 km coastline. Spermonde is the resource area for many small- and medium-scale fishermen, living on the islands in the archipelago and targeting pelagics, demersals and bottomfish (Pet-Soede 2000). Some fishermen target pelagics in the open sea of Spermonde with larger fishing units, but they still land their catch in one of the four coastal districts.

Time series of annual landings totalled for the four coastal districts and then totalled for the province of SW-Sulawesi have already been evaluated for possible long-term trends and for assessing inter-annual variability at the two administrative levels (Pet-Soede *et al*. 1999). The time window of these series was 19 years (1977-1995). The catch data for the Western Central Pacific for the 14 years period 1984–1997 (66 catch categories), were retrieved from the FAO-database Fishstat (www.faor.org), and processed similarly. After ^{10}log-transformation of annual catches per catch category, standard deviations (s^{10}logC) and coefficients of variation (CV(s)) were calculated, and where significant trends existed, standard deviations in the residuals were used.

The variability in annual landings per catch category decreased sharply with increasing size of the administrative space, but average size of the annual catch per category seems to be the most reasonable explanation for the overall variance in inter-annual variability (Figs 6.25). A 6-fold reduction in CV(s) went with a 100-fold increase in average catch size (C) which, in the almost exponential relationship CV(s) ~ $C^{-0.4}$, comes close to the theoretical maximum of variability reduction in a completely independent series (~$C^{-0.5}$) (Fig. 6.26). With decreasing variability, serial correlation in the series increased with increasing size of the administrative space. None of the 44 Spermonde series, only four of the 42 provincial series and 10 of the 66 slightly shorter series for the ‘Western Central Pacific’ showed significant serial correlation in annual catches or in the residuals after detrending.

Explanations for the lower variability with increasing size of the catch within administrative spaces might be that: (1) ecological categories (demersals, pelagics) differ in their characteristic variability ànd their presence in the catch, (2) larger catches are taxonomically broader, containing more species at one time, or (3) larger catches are reported from more sub-areas. First, within ecological groupings also the relationship with catch size is very strong, as the example from the province of SW-Sulawesi shows (Fig. 6.27). Second, there is indeed a slight tendency for the taxonomically broader categories to show, on average, lower variability (Fig. 6.28). Third, when catches from more productive catch categories are reported from more sub-areas, and thus from many distinct eco-spaces, inter-annual variability in the aggregated totals will then be low due to the 'portfolio effect' when summing independent series. Catch records for the less productive catch categories may, instead, regularly 'disappear in neighbouring broader categories', including 'others' or 'nei' (= not elsewhere indicated). This administrative bias, still to be assessed, may well cause additional variability in categories with, on average, the smallest, and stabilisation in categories with, on average, the highest catches.

The variability reduction in annual landings actually already starts with the catch recording in the smallest administrative space of an Indonesian municipality, where landings per species are already directly grouped into landings for taxonomically broad catch categories. Among the 44 official catch categories in the Spermonde series, there are only 13 species together with 25 genera and 6 families. This is different from many temperate zone situations, where a high taxonomic resolution in catch recording generally combines with low species diversity. For comparison, the landings in Lake IJssel, half the size of Spermonde, are all reported per species category of which there are around 10, and circa 90% of the Dutch landings from the North Sea are reported per species category (n = 18) (Annual Report, 1983). These examples stress that the administrative burden for the local fisheries officers in Indonesia, and in other tropical countries, to keep up with the taxonomic resolution in catch recording imposed by their species-diverse aquatic resources, is incomparably high.

In conclusion, variability in annual landings clearly decreases, and serial correlation in these landings increases, when catch data are aggregated through large administrative spaces. Further, hypothesis testing of factors governing inter-annual variability in aggregated data should focus on the spatial distribution of the fish in relation to the characteristics of the ecological area, and on the context within which biases in catch recording and administration occur.

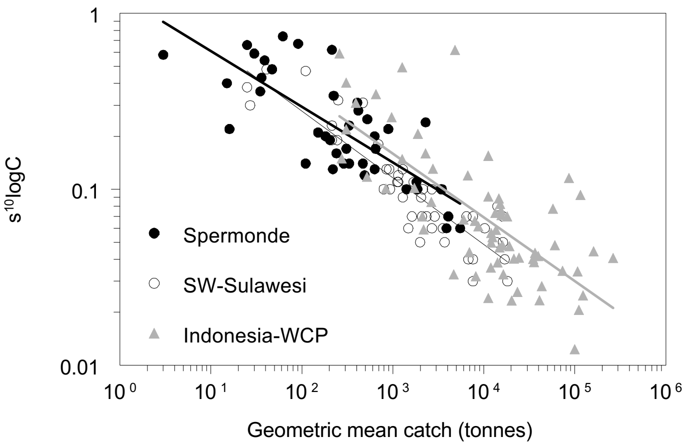


Fig. 6.25 Variability ($s^{10}logC$) in annual landings plotted against geometric mean catch (tonnes) in three statistical areas, Spermonde 1977-1995 (n = 44), province of SW-Sulawesi 1977-1995 (n = 42), Indonesia-WCP 1984-1997 (n = 66). Constants 0.103, 0.203 and 0.287, Regression coefficients –0.317, -0.380 and –0.362 with R^2 = 0.64, 0.81 and 0.53 respectively..

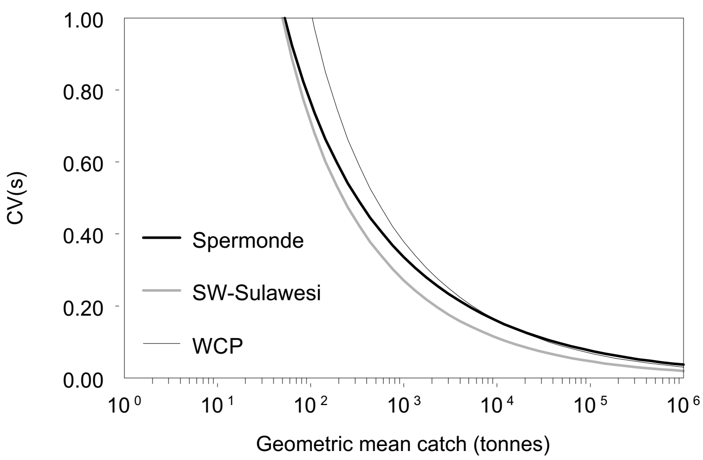


Fig. 6.26 Inter-annual variability (CV(s)) as a function of the geometric mean catch (tonnes) as inferred from the regression parameters in Fig. 6.25.

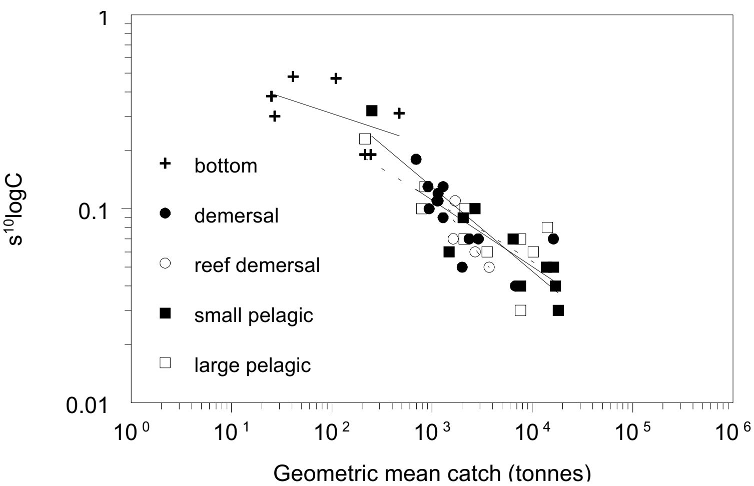


Fig. 6.27 Inter-annual variability ($s^{10}logC$) per catch category grouped per ecological grouping plotted against geometric mean catch per category for the Province of SW-Sulawesi in the period 1977-1995.

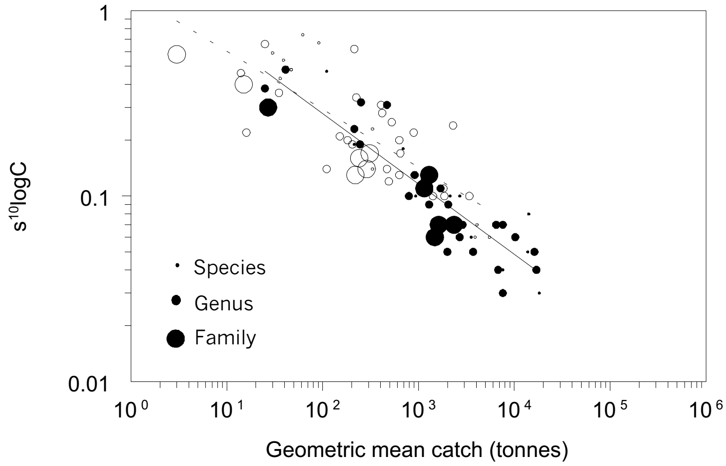


Fig. 6.28 Inter-annual variability (s^{10}logC) plotted against average catch per catch category, with categories differentiated by taxonomic grouping. Open symbols – Spermonde, Closed symbols – Provinec of SW-Sulawesi; small – species, medium – genus, large – family.

6.7 Inter-annual variability and the perception of trends

It is concluded from the example series that fishermen can be as uncertain about their next year catch as about their next day catch per target species. Inter-annual variability ranges from CV = 0.09 for plaice (95% confidence interval 0.07 – 0.11) from the North Sea until CV = 1.24 for anchovy (95% confidence interval 0.82 – 1.66) in the former Zuiderzee with modal variability around CV = 0.4 (Table 6.7). For comparison, the 95% confidence interval for sole from the North Sea is CV = 0.21 – 0.33. Variabilities for the annual landings of North Sea fish are relatively small (CV = 0.09 – 0.35). Because most fisheries are multi-species, the variability in the catch for species combined is less than that per target species because of the 'portfolio effect' when summing series that vary independently.

The overall range in Table 6.7 merges with that in two other studies on variability in annual landings and in catch rates. The inter-annual variability in CpUE per species category of small-scale trawlers in the Bay of Biscay, France, ranges between CV = 0.14 and 0.63, and was CV = 0.11 for species combined (Blanchard & Boucher 2001). For an earlier overview of inter-annual variability in total landings from freshwater fisheries, 118 annual series were retrieved from the literature, covering 51 species and 39 freshwater bodies (Buijse *et al.* 1991). The length of these series ranged between 8 and 88 years and half were 20-30 years long. The variability (CV) in annual landings for each of the 118 species-location combinations was calculated from the standard deviation in the residuals and the mean of the total series after fitting a 1st and a 2nd order polynomial to, in this case, untransformed annual landings. Applying 2nd order polynomials instead of a linear model reduced inter-annual variability only marginally, from an average variability of CV = 0.52 to CV = 0.45 (Fig. 6.29).

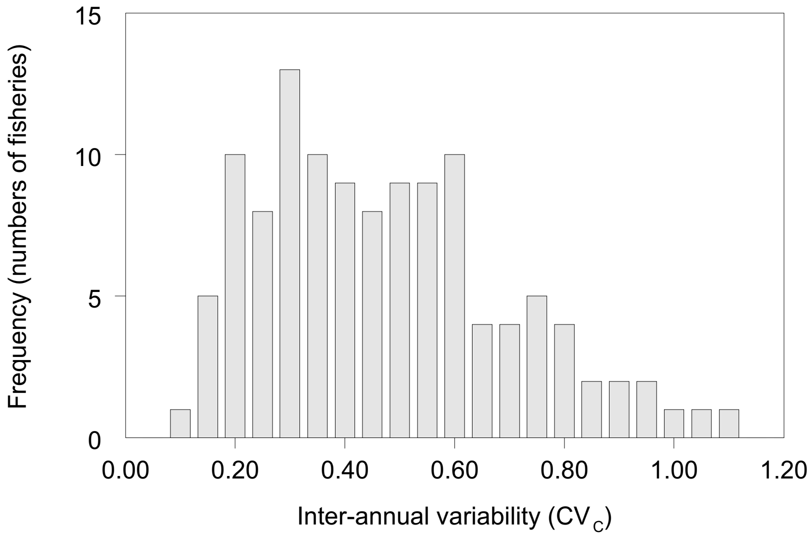


Fig. 6.29 Frequency distribution per 0.05 variability category (lower limits indicated) for 118 time series of annual landings per species and location and as assessed after fitting 2 nd order polynomials to untransformed annual landings (data from Buijse *et al*. 1991).

Differences in variability of the annual catch per target species are first and foremost explained by differences in annual recruitment and population structure (time). Next there is additional variability experienced by the individual fisherman, who operates throughout a large resource area such as the North Sea for example, where inter-annual changes in the spatial distribution of the fish biomass are more likely (space). The spatial distribution of whiting, for instance, is affected by, amongst other factors, differences in water temperature, and so by the unpredictable annual inflow of North Atlantic water (Zheng *et al*. 2001). In addition, changes in the spatial allocation of fishing effort from one year to the next add random variability that enlarges inter-annual variability in catch rates of the individual fishing unit. Such variability could certainly be expected for the highly mobile Dutch beam trawlers (Table 4.2) that fish in up to 28 ICES-quadrants of 4000 km^2 per year, thus covering a resource area more than three times the size of the Netherlands.

The larger and more dynamic the spatial structure of the resource area, the more probable it is that individual fishermen experience larger inter-annual variability than the authorities will find in the annual data aggregated for the area as a whole. In a smaller and clearly delineated eco-space, like Lake IJssel, the difference in variability experienced by individual fishermen and by the authorities can be quite small, as the example for pikeperch in Lake IJssel showed. Such small differences and the stronger co-variance contribute, in principle, to the development of parallel views on developments in the fish stock.

High variability in the annual catch of a target species can be accommodated within a multi-species fishery. The larger more stable catch of eel (CV = 0.28), with a higher price per unit weight, buffers the high inter-annual variability in pikeperch landings from Lake IJssel (CV = 1.07). This situation is quite different from that for fishermen in the same harbours a century earlier, when the extremely large variability in landings of the highly-valued anchovy (CV = 1.24), from the Zuiderzee, was poorly buffered and variability in total annual income for the individual fisherman was at least as large as CV = 0.40. Only after a year with a large catch of anchovy, could fishermen pay off their debts and repair their boats and gear (Bossaers 1987).

How much inter-annual variability affects the statistical power of recorders to perceive any trend or step trend can be inferred from Figs 3.6 and 3.9. With a modal value for inter-annual variability of CV = 0.4, a 70% reduction in a period of 10 years can just be perceived, under conditions $\alpha = \beta = 0.10$. A reduction by 50% would take around 15 years to be perceptible. With the same modal value, a step trend to an, on average, 50% higher annual catch might just be visible over 10 years, 5 years before and 5 years after the change. If the step trend within the 10 year series must prove the efficiency of management measures taken to enlarge the annual catch, it should actually be even larger, first because of an inevitable, uninformative lag phase and, second, because of inevitable coloured noise in the series.

The duration of a lag phase, as the transition period every fishery will go through when the management regime is changed, can be assessed from simulation modelling of the fishery on age-structured populations. For the gillnet fishery for short-lived tilapia in the Sri Lankan reservoir such a lag phase lasts only 1-2 years (Pet *et al*. 1996), whereas for the gillnet fishery for pikeperch and perch in Lake IJssel, it would certainly last 3-5 years (Buijse *et al*. 1992). If the management is impatient, and wishes to demonstrate as soon as possible that its decisions were wise in a time window smaller than 10 years, a lag phase of 3-5 years requires that the outcome of the fishery should at least double to assure this public success.

Thus, there is a kind of governance dilemma for the management. From the simulation modelling for the tropical and the temperate zone gillnet fishery, it seems that what are considered to be very sweeping measures would lead to much less than a doubling of total annual landings (Buijse *et al*. 1992, Pet *et al*. 1996). The management has thus to understand from the modelling that, in the long run of many years to come, management measures will prove to be efficient, but that in the short run, public proof of wise management will be weak. The situation will be better where inter-annual variability is less, as for the landings of plaice and cod from large resource areas like the North Sea. Here there is more scope for public proof of wise management, although for these stocks also one has to take account of a lag phase of several years.

What is not accounted for in the modelling referred to above, is the possible response to lower fishing pressure via a higher spawning stock biomass and possibly higher recruitment levels. Stock-recruitment relationships, however, are so strongly affected by environmental uncertainty that it is hardly worthwhile to take them into account when evaluations are made in a time window of 10 years.

Persistence in the annual series further constrains the perception of any long-term trend. Its presence is the rule rather than the exception. It is merely the consequence of exploiting a multi-aged resource the biomass of which is conservative by nature. If persistence is absent, it means that either the age structure is very simple, as in the case of anchovy in the former Zuiderzee, or that there is another, strong source of variance in addition to inter-annual changes in stock biomass. The shorter the series, the lower the serial correlation in the residuals that can be expected because the length of the series then comes close to the duration of a short-term trend. There is, in fact, a slight tendency towards higher serial correlation in shorter series (Fig. 6.30). On the one hand serial correlation lowers statistical power for perceiving any long-term trend, on the other hand the absence of serial correlation in longer series makes one suspicious as to the quality of the series as an index of developments in the size of the stocks.

With serial correlation seldom larger than $\rho^2 = 0.5$ Fig. 3.7 seems to show that it confuses the perception of long-term trends only marginally. However, the serial correlation due to short-term trends of longer duration (red noise), must be valued as relatively more confusing, as the series for lake whitefish from Lake Michigan until 1950 demonstrates. Reddish noise is unlikely to arise from the dominance of an incidental strong year-class in the exploited stock over a series of years, although this is believed to be the explanation for the circa 10 year fall and rise in the landings of lake whitefish from 1930 to 1950 (Wells & McLain 1973). The red noise could arise from gradual changes in stock structure governed by density-dependent processes, but it could be due to persistence in environmental variability as well. Annual rainfall in Niger, for instance, could be very persistent (Le Barbé & Lebel 1997), and this translates into short-term trends of longer duration in the outcome of river fisheries, which depend directly on river runoff and the flooding of the river margins (Fig. 6.31). Pikeperch recruitment, another example, very much depends on summer temperature. Summer temperature in the Netherlands is not truly stochastic, as shown by the fall and rise in summer temperature between 1950 and 1970 and the resultant fall and rise in annual recruitment, and so in landings, of pikeperch a few years later (Fig. 6.16). This reddish noise inevitably frustrates the fisheries management that tries to demonstrate over-fishing and to prove the effectiveness of measures taken, from the annual series.

Reduction of variability after spatial aggregation, and thus the resultant 'administrative gain', was very small in the gillnet fishery for pikeperch in Lake IJssel. The reduction becomes stronger, and so the gain larger, where data for one unit stock are aggregated through large resource areas such as the North Sea, where it becomes more likely that sub-units of the stock behave more independently. This is a gradual transition towards situations where annual series for distinct stocks of the same species are summed through a large administrative space, with in addition, ultimately the accumulation over taxonomically distinct catch categories. Variability reduction with increasing size of the total catch then depends on the developments in taxonomic diversity within catch categories and the independence between annual series. It is hard to generalise on the extent of variability reduction in this trajectory, but the reduction rate found for the Indonesian situation ($CV(s) \sim Catch^{-0..4}$) comes close to the theoretical maximum for many independent series. At the higher end, i.e. for the most aggregated series, it might be stimulating for the fisheries administration to perceive so clearly developments in the fishery at large. The problem, however, is at the lower end, at the more local level. From Fig. 6.26 it is evident that series with, on average, less than 1000 tonnes per year, like most of the Spermonde series, are highly variable ($CV > 0.4$), and trends are thus hard to perceive.

In conclusion, in a modal situation the fisheries management has to cope with a variability in annual catches of around $CV = 0.4$, combined with coloured noise in the series and time lags of about 3 years after a change in management. This indicates that, in a time window of 10 years, only downward trends resulting in at least a 5 fold reduction, and step trends resulting in at least a 2 fold increase in annual catch can be perceived. This implies a governance dilemma for the fisheries management: either to take sweeping measures to prove that management measures were wise and efficient, or take the more feasible measures which will inevitably have less clear effects. In the latter case the management has to communicate with the fishermen about the uncertainties attached to any measures to be taken. The situation looks better for less variable stocks such as those for plaice and cod in the North Sea. The vastness of resource areas like the North Sea, however, makes it probable that individual fishermen experience higher inter-annual variability in their catches (CV in time ánd space) than the central administration finds in the aggregated series for the fishery as a whole (CV in time). Here also transparent communication is required to overcome this inevitable disparity, but see section 7.6.

Table 6.7 Group-system combinations sorted by the variability in annual landings, together with serial correlation in the (detrended) series and the length of the time series. [s] indicates sport fisheries, [U] indicates CpUE instead of total catches, [*]CV between brackets. M = Marine, B = Brackish, F = Freshwater.

Group	System	Type	CV(s)	ρ^2	n (years)
Weight per species					
Plaice	North Sea	M	0.09	0.23	34
Arctic char	Lake Vättern	F	0.11	0.73	38
Lake whitefish	Lake Michigan 1970-1996	F	0.18	0.18	17
Whiting	North Sea	M	0.20	0.56	25
Flounder	Zuiderzee	B	0.21	0.30	15
Cod	North Sea	M	0.24	0.51	25
Sole	North Sea	M	0.27	0.30	40
Eel	Lake IJssel	F	0.28	0.35	53
Haddock	North Sea	M	0.35	0.39	25
Allis shad	River Rhine	F	0.43	0.41	42
Perch	Lake IJssel	F	0.63	0.38	53
Lake whitefish	Lake Michigan 1913-1950	F	0.64	0.60	38
Blue pike	Lake Erie	F	0.66	0.32	38
Pikeperch	Lake IJssel	F	1.07	0.28	53
Lates stappersii[U]	Lake Tanganyika	F	1.14(0.70)[*]	0.26	37
Anchovy	Zuiderzee	B	2.69(1.24)[*]	<0.001	74
Numbers per species					
Chub[s,U]	Kirk Hammerton	F	0.22	0.08	24
Bream[s,U]	Australia	M	0.29	0.09	18
Sturgeon	River Rhine	F	0.35	0.65	23
Salmon[s,U]	River Severn	F	0.45	0.001	30
Dace[s,U]	Kirk Hammerton	F	0.55	0.15	24
Salmon	River Rhine	F	0.67	0.07	39
Tailor[s,U]	Australia	M	0.85	0.07	18
Weight for species combined					
Total weight[s,U]	River Ouse	F	0.15	0.01	18
Total weight[s,U]	River Trent	F	0.28	0.005	14
Purse tot[U]	Lake Tanganyika	F	0.33	0.26	37
Purse small[U]	Lake Tanganyika	F	0.45	0.35	37
Purse large[U]	Lake Tanganyika	F	0.63	0.27	37

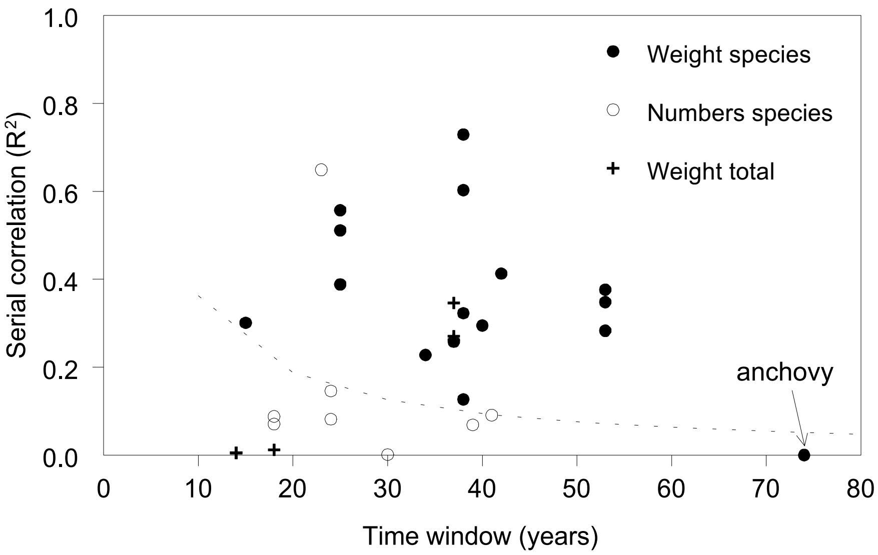


Fig. 6.30 Serial correlation (ρ^2) in detrended series of annual catches: a. per species and weight, b. per species and numbers, and c. per total weight species combined. The dashed line indicates 95% significance of serial correlation.

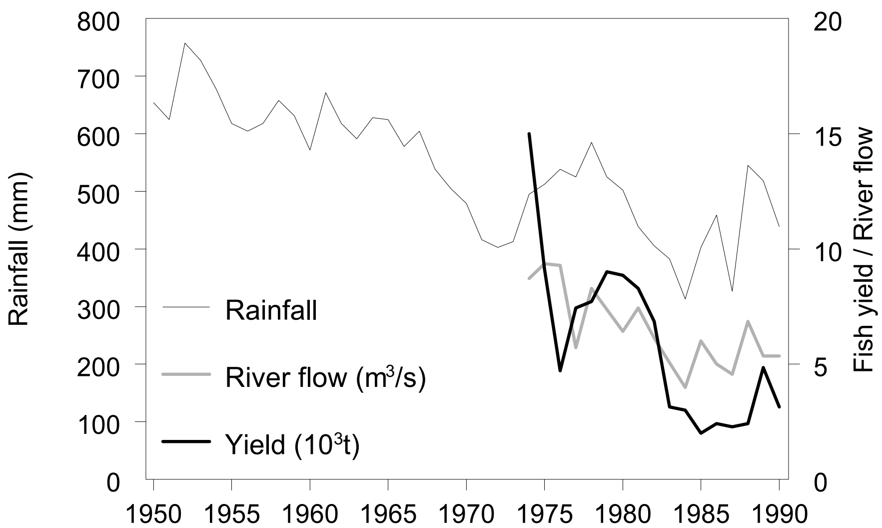


Fig. 6.31 Rainfall for the Sub-Sahel (rainfall index in Le Barbé & Lebel (1997) multiplied with average rainfall in Niamey, Niger, 545 mm (sd 121 mm) and river flow and fish yield for the River Niger, Niger (data in Brouwer & Mullié (1994)).

6 Variability in annual catches and the perception of trends - Conclusions

- Annual variability in the example series ranged between wide limits, from CV = 0.09 for plaice from the North Sea to CV > 1 for pikeperch from Lake IJssel. Systemisation is difficult but catches from more intensively exploited stocks are generally more variable. Catches from larger resource areas, like the North Sea, seem less variable, possibly due to a 'portfolio effect' of exploiting several, independent sub-units in the stock per species.
- With modal variability of CV = 0.4 an overall decrease of 70% or more can be perceived in a time window of 10 years, under boundary conditions for Type I and Type II errors $\alpha = \beta = 0.1$. With the same modal variability and in the same time window step trends with only a 40% increase in annual catches or larger can be perceived under the same boundary conditions. With variability as high as CV = 1 the increase should be 100% or more if it is to be perceived.
- The perception of any trend or step trend is further constrained by intermittent short-term trends (blue and red noise) and, in the case of step trends, by a lag phase of around 3 years before catches respond to a change in management. The blue noise is caused by strong year-classes that dominate the catch for a series of years.
- There is a 'governance dilemma', whereby the choice is between taking feasible, less sweeping measures with less significant effects or only costly, sweeping measures that will clearly be seen as effective in the foreseeable future.
- Inter-annual variability is reduced when the administrative space for which data are aggregated is enlarged. The reduction is marginal in small ecosystems where fishermen operate throughout the resource area, or where the spatial distribution of fish is consistent throughout the years. Once administrative spaces encompass several independent stocks per species, variability in aggregated series decreases sharply.

Chapter 7

Consequences for fisheries co-management

In this chapter:

- The greater capacity of authorities than of fishermen, i.e. the 'administrative gain', to perceive true trends is explained from differences in three variables: the number of observations or the time window for evaluation, the variability experienced around the trend and the critical value of α selected. **7.1**
- The time window in which fishermen could possibly evaluate their own series of annual catches is inferred from their years in the fishery. **7.2**
- The reduction in inter-annual variability after aggregating and averaging annual catches per fishing unit is related to the random component in the catch per fishing unit. **7.3**
- The selection of a higher critical value of α, i.e. the greater risk accepted by the authorities of making a Type I error by concluding that there is a trend where there is not, is explained by their concern for the economic efficiency and the ecological sustainability of the fishery in the long-term. Their choice of a higher critical value of α, as a measure of risk, contributes to a more 'Precautionary approach' in the fishery. **7.4**
- Just how difficult it can be to perceive and prove with time series data the efficiency of fishery measures taken on behalf of nature conservation is discussed using the example from a Dutch coastal fishery interacting with highly-valued bird species. In these situations, nature conservationists tend to focus on smaller time windows because they are used to the systematically lower inter-annual variability in bird numbers. **7.5**
- Recommendations are formulated on how to improve the capacity of fishermen to perceive trends in order to reach a more balanced conclusion in co-management situations, and also on how to make the administration better prepared for communication of catch and effort data to fishermen. **7.6**
- To what extent local knowledge of the resource and its management, as developed within fishermen's communities, relates to large-scale temporal patterns is discussed. **7.7**

7.1 Disparate perceptions of fishermen and authorities

Why and to what extent may the capacity of fishermen to perceive long-term trends in the outcome of the same fishery be weaker than that of the authorities, and how can we improve on the situation on behalf of fisheries co-management? In Chapter 3 the capacity to perceive a trend was formulated with the statistical power ($1 - \beta$) to detect a true trend (b) in total catches or in catch rates. Because the statistical power to perceive a particular trend (b) depends on the number of observations (n), on variance(s) around the trend, and on the acceptable risk (α) of concluding there is a trend where there is not, these three variables are compared in turn for fishermen and authorities (sections 7.2, 7.3 and 7.4).

Where fishermen, authorities and nature conservationists become involved in a discussion of the sustainability of a fishery, the interpretation of time series plays a prominent role. These are time series for fishing pressure and annual catch, and for the numbers of mammals and birds that are thought to be affected by the fishery, via a common aquatic resource base. As competitors, the interaction between the exploiters of the fish is mutual; the fishery could also be affected by strong population growth of the mammals or birds (Feunteun & Marion 1994, des Clers & Prime 1996). In section 7.5 the fishery for cockles in a Dutch coastal area, where fishermen share these bivalves, as an aquatic resource, with highly-valued bird species, is discussed as an example of such a complex management setting. In addition to the problems around causality and interaction strength, here also, as in fisheries (see section 6.10), the effectiveness of measures taken by the fishery should be evident from trends and step trends in the numbers of the indicator species, to prove the legitimacy of the nature conservation claims.

On the basis of the findings relating to the disparity in the capacity to perceive true trends which is to be discussed in sections 7.2, 7.3 and 7.4, suggestions are made in section 7.6 on how to improve the situation. Via feedback, training and outreach it should be possible to balance the skills in evaluating time series by fishermen, authorities and the fisheries administration at large. The same activities could make both sides more prepared for handling uncertainties in fisheries co-management. Local knowledge of the resource, as developed by fishermen themselves, should be given proper attention thereby, although such knowledge is generally more spatially oriented and is processed at smaller temporal scales (7.7).

7.2 Differences in the number of observations

The authorities collect and store catch records for the whole of the fishery. This provides them with many, largely independent, observations (n), which they evaluate in the largest time window possible, usually from the start of their systematic catch recording. In larger time windows, short-term trends are more easily distinguished from a possible long-term trend. So both the large number of observations and the, on average, larger size of the time window gives them 'administrative gain' in perceiving true trends, relative to the individual fishermen.

When older fishermen are approached regarding their own experience in the fishery, their time window may be as large as 50 years, but for the average fishermen in the fishery that time window is no more than 15-20 years. This is inferred from the age distribution of the population of fishermen. Most Dutch sea fishermen start fishing at the age of 20 and their number of years at sea must be around 15 years, no different from the situation some 65 years ago (Fig. 7.1). The number of years in the Lake IJssel fishery is longer (24 years), because fewer youngsters recruit to this fishery now in view of the deteriorating economic prospects (Taal & de Wilde 1997) (Fig. 7.2). The time window, as years, in the tropical fishery on Tissawewa Reservoir, Sri Lanka, was 19 years (n = 7, CV = 0.38) (based on data in Pet-Soede 1993).

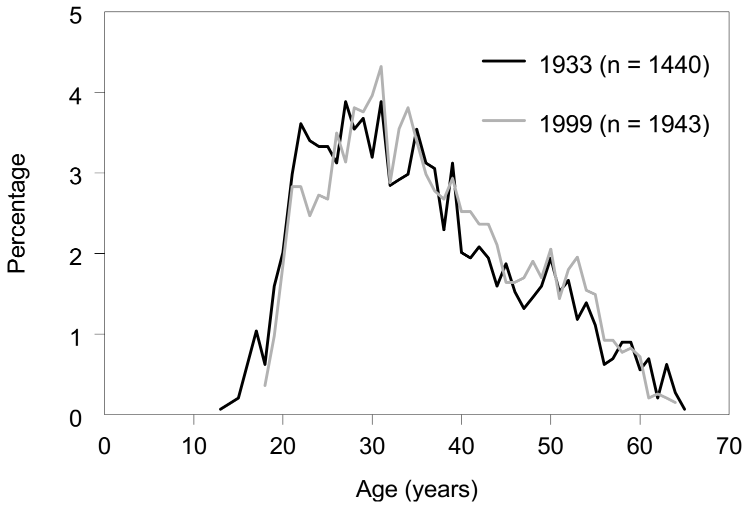


Fig. 7.1 Age distributions of the crews on board Dutch trawlers in the North Sea fishery. 1933: steam trawler fleet (15 years on board, on average) (Schouten 1942, his Graph 1); 1999: beam trawler fleet (15 years on board, on average) (data from Luns, Visserijcentrum Rijswijk).

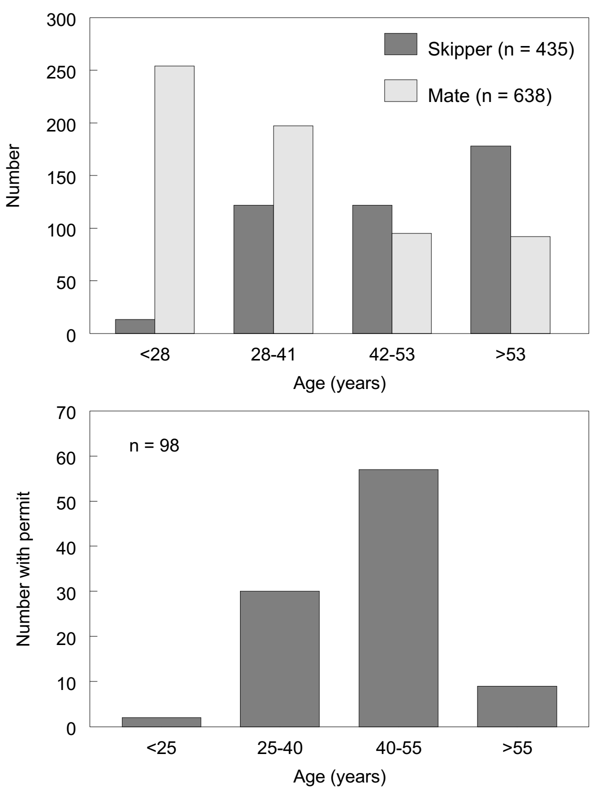


Fig. 7.2 Age distribution of fishermen in the Lake IJssel fishery. 1960: skipper (29 years on board, on average) and crew (16 years on board, on average) (Schaper 1962, Addendum 1); 1996: fishermen (24 years on board on average) (Taal & de Wilde 1997).

Whèther and hòw fishermen evaluate their catch rates in the complete time window of their years in the fishery might depend on the type of dispute. As entrepreneurs, they will be inclined to evaluate the outcome of their fishery in the smaller time window of the more recent past because they focus on the economic performance of their fishery, for which both external conditions (fuel and market prices) could change as rapidly as internal conditions (stock biomass). But, they might use a much larger time window when confronted with restrictions on effort and refer to earlier (short-term) downward trends that were followed by subsequent upward trends in the outcome of the fishery. In statistical terms, they doubt whether the conclusion that there is a long-term trend is correct, where persistence is high.

Whether the time window is so much larger for the authorities depends on the history and the way in which the Catch and Effort Data Recording System is set-up. The standardised monitoring of many fisheries started in the second half of the 20th century. With the growing length of the series they become progressively more informative as to the distinction between short- and long-term trends. Take for example, the length of the time series for annual recruitment (R), spawning stock biomass (SSB), annual catches (C) and fishing mortality (F), that the European Community published in their Green Paper (EC 2001). This paper is meant to stimulate discussions between fishermen, authorities, scientists and the general public on the formulation of a new Fisheries Policy in 2003 (EC Green Paper 2001). The 29 series span time windows of from 14 to 43 years (28 years on average). Insight into the nature of the variability in each of the four variables must have greatly improved since the formulation of the first EC Fisheries Policy in 1983. With the growing availability of longer series for annual landings, several authors have tried to categorise fisheries on the basis of trends and patterns perceived. Grainger & Garcia (1996) did so for 200 species-area combinations in global fisheries (45 years), Fiorentini *et al*. (1997) for 45 years of annual landings from the Mediterranean and Baisre (2000) for 60 years of annual landings from Cuban marine fisheries.

In conclusion, the large number of observations available to them guarantees an ‘administrative gain’ for the authorities in perceiving trends in resource outcome. The larger size of their time window is at least as important, not only because a larger window implies more annual observations, but also because longer series allow for the distinction between short- and long-term trends. For the individual fisherman with, on average, 15 years of experience in the fishery it is more difficult to distinguish between short-and long-term trends.

7.3 Differences in variabilities

Only where the variance in catch data contains a large random component will the authorities experience less variability in their aggregated data than individual fishermen will experience in the records of their own fishery. This difference in variability is the ‘administrative gain’. When variability in the catch from day to day is mainly random, the gain is large for a fisheries officer who aggregates independent daily catches into an average per harbour and per boat and gear category.

Variability in the catch from day to day, or basic uncertainty, increases from the relatively secure world of large-scale trawling for flatfish, as in the North Sea, through small-scale gillnetting and angling to the very insecure world of fishing with light attraction without fish finding devices as in Indonesia (Chapter 4). The small-scale gillnet fisherman sells his daily catches immediately and so experiences basic uncertainty most directly. Large-scale beam trawlers make weekly trips and experience lower variability in their daily catch and even lower variability in the size of the catch they land ($C_{day}/\sqrt{days}$). In essence it does not matter whether catch data are aggregated through space (e.g. fisheries officer) or time (e.g. weekly catch), as long as the daily catches are independent, variability in aggregated catches decreases in a predictable manner (Fig. 7.3).

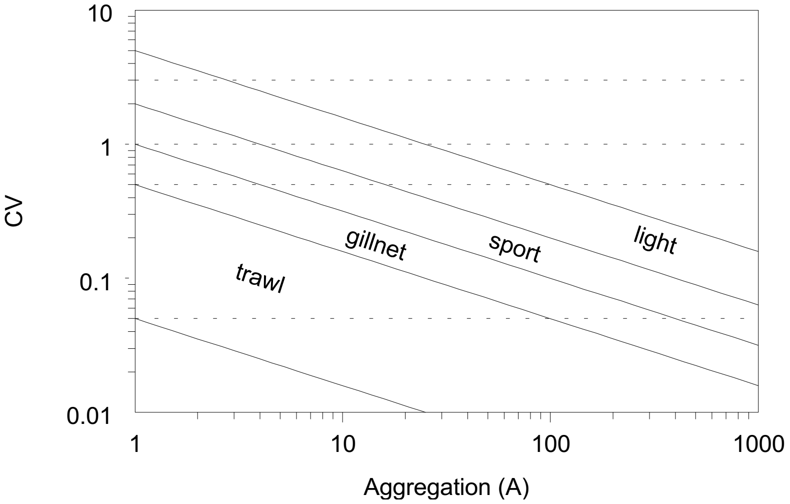


Fig. 7.3 Reduction of variability (CV) in the average catch per day as a function of the aggregation level A for four fishing modes. The starting values are the basic uncertainties in daily catch rates as assessed in Chapter 4: trawl (CV = 0.05 - 0.5), gillnet (CV = 0.5 - 1.0), sport (CV = 1.0 - 2.0), light (CV = 2.0 - 5).

Aggregation through space and time will reveal spatial and temporal patterns more clearly as long as the aggregation intervals merge with the underlying patterns, such as more or less productive fishing grounds or high and low seasons. However, it depends on the choice of the spatial and temporal entities (strata), whether the information on these patterns is preserved in the process of data aggregation. Where basic uncertainty is particularly large, as in light fisheries (CV = 3), the random variability in monthly totals or averages is still CV = $3/\sqrt{25}$ = 0.6. For these fishermen patterns in space and time are vague at best.

Seasonality, like any other periodicity in daily catches, adds to the total variance in daily catches and this variance is not reduced by aggregating through the resource area. A factor of from 2 to 4 difference in catch rates between high and low seasons corresponds to a variability of CV = 0.2 to 0.5. So for a trawl fishery such variability compares to their day to day variability and contributes equally to total variability in daily catches within a year. For a small-scale gillnet fishery with day to day variability of around CV = 0.75, a seasonal difference of a factor of 2, is marginally important in total variability. If means are equal then squared variabilities can be summed just as variances. The seasonality in the example would thus contribute only 0.2^2 (0.04) in an overall variability of $0.75^2 + 0.2^2 = 0.60$. Nevertheless, it will affect the perception of any long-term trend in catch rates over the years by the small-scale fisherman who lives by the day. He needs to compare his catch rates for the same period each year, separated by probably less indicative low seasons, if he is to evaluate his resource outcome in the longer term of years. For the authorities, seasons are more clearly perceived in their aggregated series, but this 'administrative gain' is difficult to value.

Where the variability in annual catches per fisherman, independent of the variability due to changes in stock size (CV_{time}), is large, the administration has much to gain in aggregating and averaging annual catches for the fleet as a whole. The additional variability for the individual fisherman, who operates locally, mainly arises from changes in the spatial distribution of fish biomass or fishing activities at the smaller (days) or larger (years) temporal scale. Light fishermen, because of the high variability in their catch rates from day to day, anglers, because of their moderate variability from day to day, combined with low numbers of fishing days per year, both still experience variability in annual catches as high as circa CV = 0.2 due to these small-scale temporal variabilities (cf. Fig. 7.3). At the larger temporal scale of years there is variability in the spatial distribution of fish, especially in large resource areas such as the North Sea, where environmental gradients like those in water temperature change positions over the years in an unpredictable manner (see section 6.5). Where there is possible independence in the dynamics of sub-units in the stock per species, the aggregation of catch data for the whole of the resource area could lead to a 'portfolio effect', and thus to smaller inter-annual variability in the area totals. Such fragmentation of the stocks is still hard to unravel (Holm *et al*. 1998, Begg *et al*. 1999).

Instead of a reduction in variability, data recording and aggregation could also lead to an increase in variability because of errors made in data recording and processing. Data handling inevitably generates bias and 'administrative noise', the extent of which is hard to assess but which should be valued when evaluating the statistical power of a fisheries administration. CEDRSs based on a sampling strategy will be more susceptible to such biases and are indeed criticised for the sometimes large bias and variances in the data due to the weak operation of sampling schemes and the poor handling of data (e.g. Dudley & Harris 1987). These authors estimate that incorrect sampling and data processing in the Indonesian CEDRS could lead to bias of 0.85 - 2.5 times true values. Administrative noise is harder to assess. Maus (1997) scored differences in catch data as stored in the databases of the various institutions monitoring the outcome of the marine fishery of Mauritania. The variability in annual catches between the institutions was assessed on the basis of his data (Fig. 7.4). As the catch records of the various institutions were not correlated, the variability of around CV = 0.1 – 0.2 must be random variability that is contained in the data series of every institution. This 'administrative noise' is negligible in comparison with the inter-annual variability as assessed for most fisheries in Chapter 6 (see Table 6.7).

In conclusion, authorities generally find lower variability in their aggregated series than individual fishermen experience in their own fishing practice. This 'administrative gain' is high where random variability per fishing unit is large relative to variability as due to inter-annual changes in fish stock biomass or in the outcome of the fishery at large.

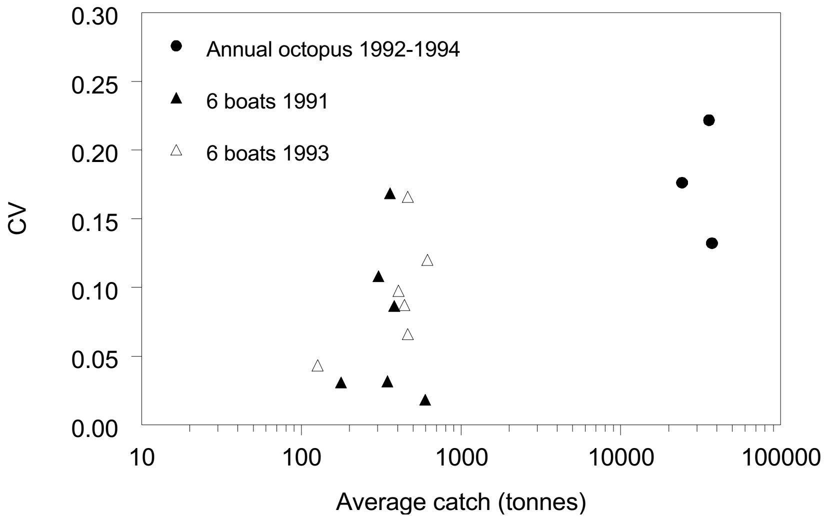


Fig. 7.4 Administrative variability (CV) in the annual landings of marine fish as recorded by different institutions in Mauritania plotted on the average catch per institution. Total landings of octopus (3 institutions) and total landings for six freezer boats combined (3 institutions) (based on figures in Maus (1997)).

7.4 Differences in the critical value α and the "Precautionary approach"

The higher the critical value α one accepts, the larger the statistical power (1 - β) to conclude that there is a trend where such a trend truly exists (cf. Fig. 3.4). At the same time, however, it becomes more probable that where no trend exists one erroneously concludes there is, and thus commits a Type I error. Those who want to reduce the probability of committing such an error at all costs, select a very low critical value of α, and thus increase the probability that they do not perceive a true trend (Type II error). It is a matter of how one balances the consequences of Type I and Type II errors, that determines how one selects critical values for error probabilities, and thus, for a ratio between the two (β/α). Fishermen and authorities balance these consequences differently. The authorities generally select a higher value for α and so enlarge their capacity to perceive true trends relative to that of the fishermen.

What possibly drives fishermen to select a low critical value of α, is that they take into consideration the economic efficiency of their enterprise (boats, gear) when effort restrictions are based on an erroneous conclusion that there is a downward trend, where there is not. They could criticise the conclusion of the authorities that there is a downward trend, referring to high inter-annual variability and to persistent short-term trends in the annual landings, which suggest that the application of a high α is indeed inappropriate. They will have seen earlier downward trends before, as well as the subsequent recovery, even without regulatory action being taken, because short-term trends are generally due to natural causes. So the discussion on what critical value of α to select is easily intermingled with the other parameters that affect the perception of true trends.

Nevertheless, the authorities fear economic inefficiency as much as do fishermen. The authorities, however, are as much concerned about economic inefficiency in the long- as in the short-term. Nót detecting a real downward trend in a fisheries resource can be very damaging in the long-term. It could take a long time before full recovery of the resource can be realised, at sometimes high economic and social costs (Hutchings 2000). The authorities therefore seek to minimise the probability of making a Type II error by enlarging their statistical power, either via more observations or a higher α. Where the collection of more observations is limited by technical or financial factors, accepting a higher α is one way to practice a precautionary approach based on a more long-term view.

The more long-term view in fisheries management is now supported by the widely accepted “Precautionary approach” in the management of natural resources. After being used in environmental treaties for the North Sea, the “Precautionary approach” was articulated in Principle 15 of the Rio Treaty 1993 as: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason, for postponing cost-effective measures to prevent environmental degradation". This approach was successively embedded in international agreements on fisheries management, such as the "UN Fish Stock Agreement 1995" and the "FAO Code of Conduct for Responsible Fisheries 1995". Always accounting for the ‘threats’ leads to Type I errors, always going for ‘full scientific certainty’ leads to Type II errors.

The question is, whether the "Precautionary approach" as formulated so far is of much help in local resource management, where fishermen and authorities are searching for transparent ways to balance the risks of Type I and Type II errors. There has actually been a fair amount of debate on the scientific basis for the application of the "Precautionary approach", via regulatory action on resource exploitation, and on environmental loading (Gray 1990, Stebbing 1992, Peterman & M'Gonigle 1992, Buhl-Mortensen 1996, Santillo *et al*. 1998). Peterman & M’Gonigle (1992) formulated a scientific basis for the application of the “Precautionary approach” and based this on power analysis, in combination with a decision rule for taking regulatory action, e.g. restriction of fishing effort. They distinguish between three outcomes of statistical tests, such as those for the significance of time trends (H_0 = no trend):

1. H_0 is rejected, regulatory action is recommended;
2. H_0 is not rejected, while the test had high statistical power (β low), no regulatory action recommended;
3. H_0 is not rejected, while the test had low statistical power (β high), thén regulatory action is recommended as a precautionary measure.

So by quantifying the statistical power ($1 - \beta$) required, it is formalised under which conditions the “Precautionary approach” will be applied. One way of enlarging statistical power is to accept a higher α, but the question should be asked, to what extent should scientific certainty be sacrificed? Buhl-Mortensen (1996) states that the fact that pure scientists minimise Type I errors, and so opt for a small α, provides no compelling reason for arguing that applied science, delivering premises for political decisions, ought to minimise these Type I errors. According to her, the two categories of scientists are governed by a different type of rationality. Decisions in pure science involve an epistemological rationality, whereas in applied science they require not only epistemological rationality but also ethical considerations. Fishermen and pure scientists focus on and anticipate more, the consequences of Type I errors and, although for possibly different reasons, both select a low critical value of

α. Fishery authorities and nature conservationists on the other hand, operating in the applied fields of resource use and conservation, place more weight on the consequences of Type II errors and select a high critical value of α.

Another, but less transparent, way of applying the "Precautionary approach" is to reverse the burden of evidence. That is, it is not those in defence of nature who should have to prove that a resource is likely to decline if exploitation continues or is intensified, but the resource users themselves should prove that the resource would maintain its present, or a defined minimum level, when they intend to continue or to intensify their resource use. In statistical terms: the Null hypothesis is no longer formulated as that the trend is nil (H_0: b = 0), but that the resource is already in danger, or on the decline, as a consequence of present resource use (H_0: b = b_0). The consequence is that now enough statistical power (1 - β) should be generated to reject the reversed H_0. The condition for this policy to be credible is that the conditions should not be too demanding and that one selects a value for b_0 which is not too close to 0, otherwise management becomes paralysed (Freestone & Hey 1996).

In conclusion, the authorities tend to select a higher critical value of α and this enlarges their capacity, relative to that of the fishermen, to detect true trends. This tendency is induced by their long-term interest in the economic efficiency of resource use. This long-term view has been stimulated over the last 20 years by the introduction of the "Precautionary approach" in natural resource management, which seeks to minimise the probability that costly damage is done to the resource. Local fisheries management would gain much from transparent procedures for balancing Type I and Type II errors.

7.5 Perception of the effectiveness of fishery measures on behalf of nature conservation

Fisheries management has to take into account the values of "Nature". Severe over-exploitation is not only irrational in terms of the economic viability of a fishery, but could also seriously affect nature values as a public good. Exactly which nature values are at risk is generally represented by the numerical presence of bird and mammal species of high nature value. These animals often share fish as a common aquatic resource with the fishery. Their populations are monitored with the same intention as in fisheries, namely to be warned in time about possible trends or step trends in the population sizes of these indicator species. One would prefer that the possible effect of an expanding fishery on these indicator populations was apparent directly, from a prompt and clear downward trend or step trend in their numbers; similarly for the effect of subsequent reductions in fishing effort.

Inevitably, the effect of restrictions in fishing effort will show up more clearly from developments in the aquatic resource itself than from time series for the ecologically more remote natural predators (Fig. 7.5). Further, this effect shows more clearly when natural variability in the aquatic resource, ànd in the predator population, is small and when the predator strongly relies on the shared aquatic resource. In these situations the statistical power of both fishermen and nature conservationists to detect trends, and to capture the result of effective fisheries management, is large. If the above conditions are not met, time series are less informative and the variability they contain could frustrate the discussion between fishermen, authorities and nature conservationists on causes, effects and which measures to take.

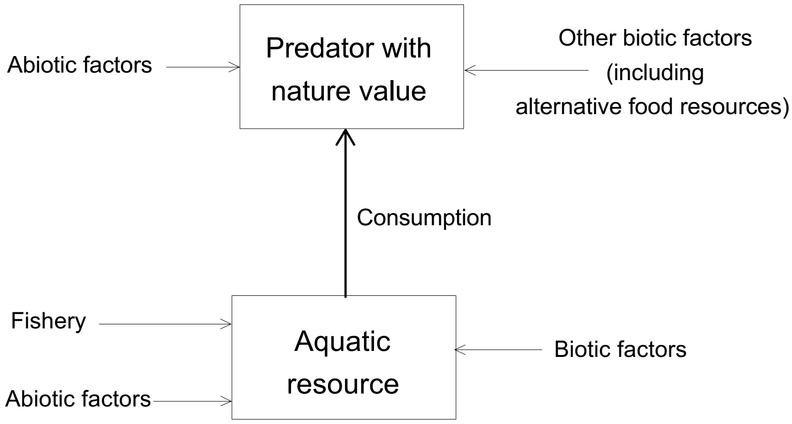


Fig. 7.5 Factors affecting inter-annual variability in the size of an aquatic resource and in the numbers of a predator with high nature value.

The Wadden Sea, a coastal area situated between the islands and the mainland in the North of the Netherlands, is such an ecosystem where a professional fishery exploits an aquatic resource which highly-valued bird species also rely on. The 270,000 ha Wadden Sea is a highly dynamic ecosystem because of the tides and is highly productive, with large amounts of benthic organisms, such as molluscs, shrimps and worms. Three separate professional fisheries target cockles, mussels and shrimps in the area.

The fishery for cockles (*Cerostoderma edule*, a bivalve), operated by 22 fishing units, yields around 7000 tonnes per year with an export value of around 50 million Dutch guilders. This fishery is now strictly regulated via permanently and temporarily closed areas. The fishery is completely forbidden in years when the total biomass of cockles, present in densities of more than $50.m^{-2}$, is below 7600 tonnes, the minimum food reserve until the year 2000 for highly-valued birds in the area (Policy Document on Coastal Fisheries 1993). Cockles are a target for the fishery as well as the forage base for eiderduck, *Somateria mollissima*, and oystercatcher, *Haematopus ostralegus*, which are highly-valued bird species that are abundant in the Wadden Sea area. In the 1950s and 1960s numbers of eiderduck rose sharply but seem to have stabilised thereafter (Fig. 7.6) (Ens 2001). The number averaged over the period since 1970 is 132,000 with an inter-annual variability of CV = 0.20. After a stressful situation in 1991, when cockle biomass was at an all time low, part of the population moved farther north into the North Sea, where now circa one-third of the population resides.

The development of cockle biomass over the years shows no trend whatsoever ($R^2 = 0.03$) and inter-annual variability (CV = 1.11, 1971-2001) is more than five times as high as in the number of eider ducks (Fig. 7.6). Although there were years with over 180,000 tonnes of cockle biomass, only once in every two years was cockle biomass over 30,000 tonnes (Fig. 7.7). Serial correlation in the series is negligible ($\rho^2 = 0.04$), but in the seven years 1981-1987 there was a significant and alarming downward trend (40% per year, $R^2 = 0.95$).

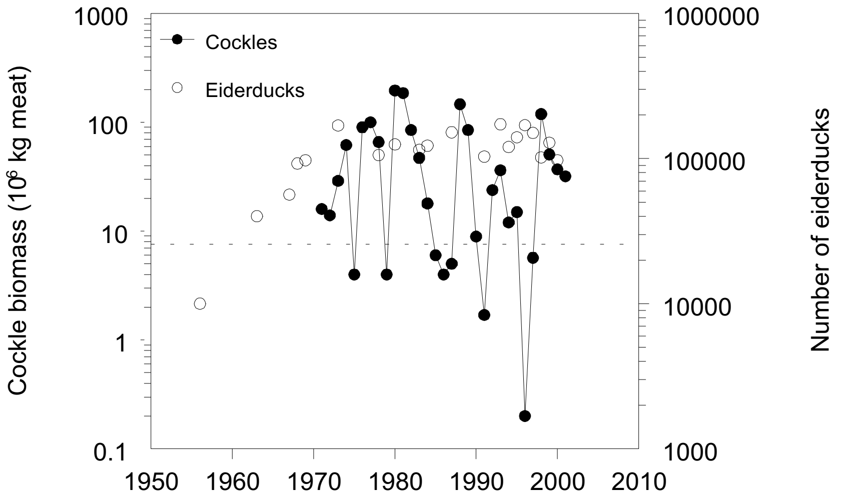


Fig. 7.6 Biomass of cockles present in densities of > 50 per m^2 and number of eiderducks from the Wadden Sea area (based on data in Stralen & Kesteloo -Hendrikse (1998), from T. Bult, RIVO, and in Ens (2001)). The broken line indicates the limit reference value o f 7,600 tonnes of cockles in densities of > $50.m^{-2}$ for closing the fishery.

From the high inter-annual variability in cockle biomass two conclusions can be drawn. First, step trends in cockle biomass of less than a factor of 2 are impossible to perceive in a time window of less than 10 years. Second, a fishery for cockles without alternative resources is only viable when fishermen stabilise their annual catch by taking larger proportions in years when cockle biomass is low. In ecological terms: as specialised predators they only survive with a Type II functional response to the changing biomass of their prey (Ivlev 1961). The Type II functional response by the fishery amplifies the inter-annual variability in cockle biomass. In the period 1985-1993 the highest proportion was taken in 1985 when the yield was 39% of the total biomass (Steins 1999, her Table 7.1). The food reservation policy has, however, softened the effect of the fishery on the cockle biomass so much that enhancement of inter-annual variability in this biomass by the fishery has become negligible.

Large mortalities of eiderducks in the winters 1990/1991 and 1991/1992, when cockle biomass was low, were indirect evidence of the dependence of these birds on cockles as their food resource. It made many, and certainly also cockle fishermen, aware of the possible negative effects of the fishery on nature values in the area, in years with low cockle biomass. The stressful situation in these two winters triggered the drafting of the management regime of 1993. Parts of the Wadden Sea (26%) became permanently closed to the cockle fishery, and in some years the fishery was closed completely (1996, 1997) or was allowed only a quota complimentary to the food reservation of 7600 tonnes.

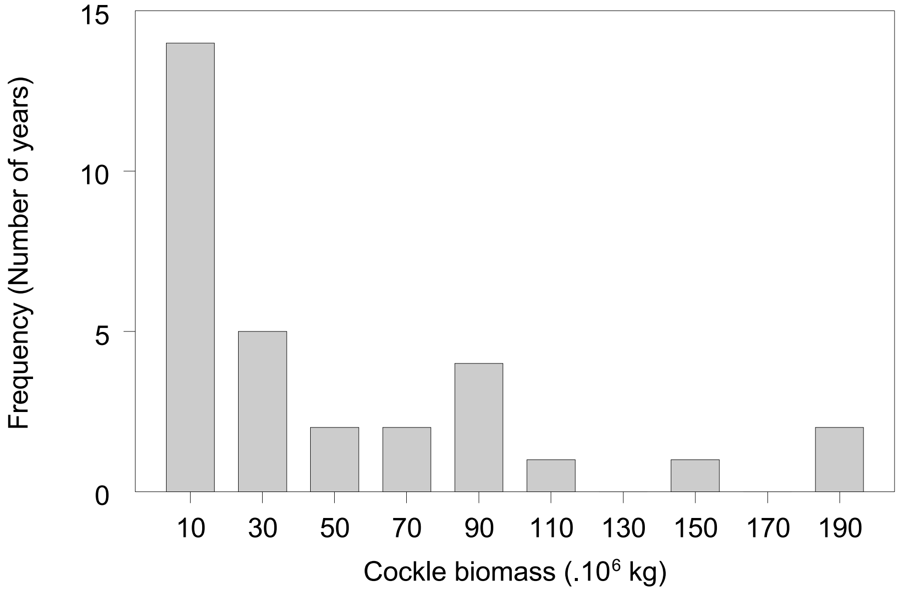


Fig. 7.7 Biomass frequency distribution for cockle biomass present in densities of > 50 per m ^{2} in the Wadden Sea 1971-2001 (based on figures in van Stralen & Kesteloo-Hendrikse (1998) and from T. Bult, RIVO).

Six years later, in a year with high cockle biomass, there was again a large mortality of eiderducks (21,000 in winter 1999/2000, 15% of the long-term average) (Camphuysen 2000). Based on ecological studies, the authorities attributed this mortality to the coincidental lower availability for eiderducks of both cockles (fewer young ones) and mussels (covered with acorn barnacles) in combination with low numbers of *Spisula*, a small mollusc, which is also exploited by a professional fishery. The dependence of eiderducks on cockles has thus become more ambiguous and forced the authorities to adjust the food reservation for eiderducks and oystercatchers to a total of 18,600 tonnes, whereby the three resources, cockles, mussels and *Spisula* became interchangeable (TRC 2000/10243).

Concluding so far, the effect of effort control on the cockle fishery on behalf of nature conservation in the Wadden Sea will be hard to perceive from long-term trends or step trends in either cockle biomass or in the number of eiderducks. Natural variability in cockle biomass is too high, the direct impact of the fishery has become marginal and the dependence of the eiderducks on cockles as an aquatic resource is not sufficiently unambiguous. So time series are a poor basis for assessing and, equally important, communicating the success of the fisheries management on behalf of the nature conservation in the area. Many stakeholders now focus on a small time window and on ecological details, which could explain the incidental more stressful situations. The strategic use of each new bit of ecological information by both fishermen and nature conservationists for their own sake, made a scientist in the field plead for more balanced discussions, by which he probably meant that they should take a longer view (Ens 2000). Still, there is a very promising development towards co-management of the cockle fishery by the fishermen and the authorities, and with the involvement of nature conservationists (Steins 1999). It is even considered as an example of policy-oriented learning in natural resource management (Verbeeten 1999).

It is hard to generalise, from the above example, on a systematic difference in the capacity to perceive trends of fishermen and nature conservationists, each with respect to their own target species. Inter-annual variability in cockle biomass is high and comparable to that in the outcome of highly uncertain fisheries (Table 6.7). Inter-annual variability in the number of eiderducks is small (CV = 0.20) and one could wonder whether this is a common trait for birds used as indicator species. If so, nature conservationists would be alarmed earlier than fishermen are, by trends of comparable size in the stock of their target species.

To assess the range of inter-annual variability in the numbers of birds per species in the Netherlands, in fact one large administrative space, the results of monitoring schemes as displayed on the website www.sovon.nl of the national organisation for bird studies in the Netherlands (Sovon Vogelonderzoek Nederland) were used. These counts in the Netherlands apply to either breeding birds or wintering birds, each with their own monitoring scheme and both schemes with the involvement of many volunteers. The monitoring scheme for breeding birds uses fixed plots. Observation uncertainty is strongly reduced here, because methodological shortcomings due to, for instance, spatial clustering of the birds is accounted for as much as possible. The monitoring scheme for wintering birds may suffer from a larger portion of observation uncertainty, as counting is done only once in the last two weeks of the year on various routes of 20 km, along which 20 observation sites are more or less evenly spaced.

The time series referred to 132 different bird species, of which 68 are counted both as breeding and as wintering birds (Table 7.1). After ^{10}log-transformation of the numerical indices 67% of the series of breeding birds and 54% of the series of wintering birds showed a significant linear trend (Table 7.1). Applying quadratic (x^2) or polynomial functions (x, x^2) only marginally enlarged the explained variance in the series. Inter-annual variability was calculated as CV(s).

Table 7.1 Data sets of annual bird counts in the Netherlands as displayed on the website www.sovon.nl. Between brackets the additional number of time series when only linear trends are tested for significance.

Category	Period	Number of years	Number of species	Tested for trends		
				Linear	Quadratic or polynomial	Non significant
Breeding	1984-1997	14	105	42 (59)	28	35 (46)
Wintering	1980-1997	18	95	34 (51)	23	38 (44)

As is generally acknowledged, inter-annual variability is larger for wintering birds than for breeding birds, and the serial correlation in the residuals, although rarely significant, was more positive than negative (Fig. 7.8). The lower variability for breeding birds may partly be due to their sedentary behaviour during summer when building their nests and when breeding, than during winter when they are searching for scarcer food and some of them show migratory behaviour. Over all, inter-annual variability in detrended series of breeding birds in the Netherlands is systematically low and seldom larger than CV(s) = 0.2. This contrasts with the variability in populations of North-American bird species, where modal variability is as high as around CV = 0.4 (Box 7.1). In any case, the statistical power of the Dutch national bird monitoring programmes for perceiving true trends in the national totals, must on average be large. The volunteer who participates in the national monitoring schemes might experience higher inter-annual variability in numbers per bird species than is left after compilation into national totals. But when she regularly consults the national database for evaluation, she develops another sense for environmental variability than when focusing only on her own field observations.

In all, where fishermen meet nature conservationists on integrated ecosystem management, there is in general an asymmetry in the uncertainty they experience in their target variables and in their balancing of Type I and Type II errors. Fishermen are confronted with nature conservationists who have generally less doubt about trends and step trends in their target species, and are less hesitant to conclude that there is a trend, where there is not (high α). The two groups possibly differ less in their focus on smaller time windows. It is not always in the interest of nature conservationists, strong in defence of threatened species and habitats, to refer to the larger window in which recent downward trends possibly compare to earlier natural fluctuations. Either way, it seems rewarding to account for disparities in trend perception between fishermen and nature conservationists as well, when organising co-management discussions.

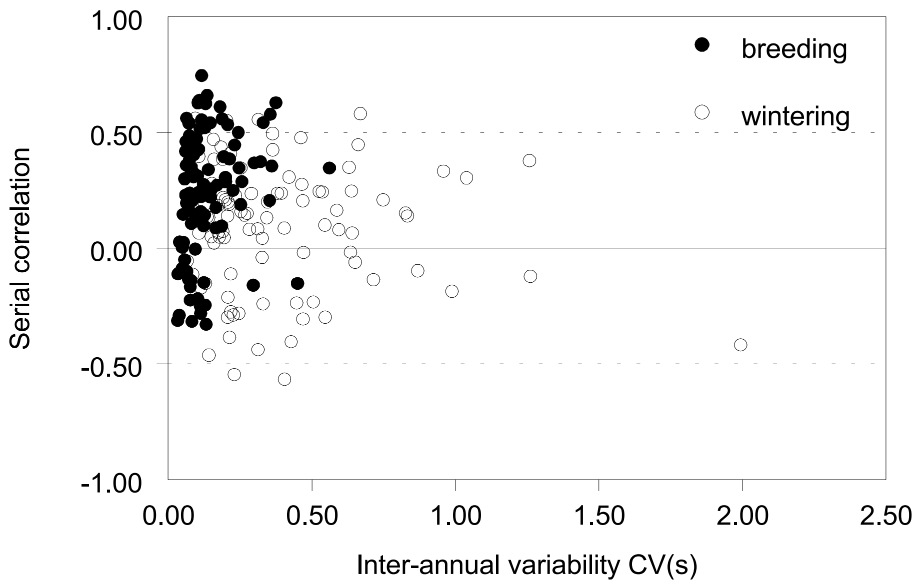


Fig. 7.8 Serial correlation in the residuals plotted on inter-annual variability (CV(s)) around linear trends of ^{10}log-transformed indices for annual bird counts in the Netherlands. Index in first year of the series = 100. Beyond the dashed lines serial correlation is significant.

7.6 Improving the capacity for trend perception

The challenge for those managing information in the fisheries sector is as much in bridging the gap between fishermen and authorities as in improving the evaluative capacity throughout the fisheries administration. Efforts applied in these directions contribute directly to fisheries co-management, because they will balance the skills for handling catch and effort data and make both sides better prepared for discussions in co-management situations.

Fishermen lag behind in their capacity for perceiving long-term trends in catch and effort data because of their smaller time window (n), larger variability experienced (CV) and greater hesitation to conclude there is a downward trend where there might not be one (α). Of course fishermen will not, and authorities will not that frequently, evaluate time series in the analytical and quantified way as presented here. But, every actor in a fishery evaluates temporal and spatial patterns in resource outcome. Whatever decision rule they apply, formal or non-formal, documented or not documented, the evaluation will always be affected by the size of the trend, the number of observations, the variance around the trend and the risk one is willing to take that the conclusion turns out to be wrong after all. The statistical decision rule used here (equation 3.3), is just one of the possible constructions to account for all four factors simultaneously. It is certainly more difficult to compare between fishermen and authorities using the instant availability of data and the skill and technical facilities they possess to process these data.

There is another difference between fishermen and authorities that is even more difficult to quantify, but that certainly affects the evaluation of possible trends in resource outcome. That is, fishermen will find it more difficult in a management setting to focus only on highly aggregated data, because they experience resource use and outcome on a day to day basis in their own, local resource area with its own patterns, variabilities and complexities. Complexity is particularly great where fishermen, such as the Indonesian light fishermen, operate in periodic environments with not only seasonal, but also pronounced tidal and lunar cycles in their catch rates. In a discussion on time series of annual catches they will be inclined to refer to occasional and local experiences as well. Authorities, on the other hand, have less of a problem with taking a more distanced position. They will find it easy to focus on highly aggregated data such as a series of annual catches, excluding underlying seasonality, spatial patterns or their interaction, when evaluating time series with annual catches. This aspect of evaluative capacity should also be taken into account in the communication of fisheries information.

Improvement of the evaluative capacity of individual fishermen should start with the outcome of their own, individual fishery. There are fishermen, certainly also small-scale fishermen, who keep records of their catches on their own initiative. They not only keep records for the monitoring of their economic performance, but also because they are keen on any information that might emerge from the listing of these data. There are also examples of individual anglers, who store data on size, time and location of their catches in an electronic database. Fishermen and anglers who keep records on their own initiative, however, generally lack guidance in turning their data into information and in evaluating such information.

Such stimulation and guidance on data storage and processing by professional fishermen now comes, although very basically, from those who develop tools for community-based resource monitoring and management (Maine *et al*. 1996, IIRR 1998). They, for example, give instructions on how to do fish catch monitoring and how to construct and communicate a trend line (IIRR 1998). From the very basic formats suggested, it shows how limited trend analysis is worked out, as yet, as a tool for community-based management, but that these formats will certainly act as an incentive for awareness building in the community on quantitative and dynamic aspects of resource outcome (Table 7.2).

Table 7.2 Approach for possible trend analysis by coastal communities as schematised in IIRR (1998, Vol. 2, p. 179-180)

- Organize one to three groups with three to six members
- Use a sample graph to explain the concept of trends and trend lines
- Ask the group to draw the trends of some of the most important changes in the community. You may make suggestions on how they can do it but encourage them to come with their own style.
- Use stones, seashells, art paper or other available materials to show trends.
- Let each group present their graph to the rest of the group.
- Probe for explanations of the changes. This helps identify underlying problems. Find out what solutions have been tried, its advantages and disadvantages and reasons for success or failure.
- Formulate preliminary recommendations to address the problem.

Thus, what is needed is thorough guidance in the evaluation of times series for catch and effort. The following suggestions are based on the various constraints in trend perception and analysis identified in sections 7.2 through 7.4. First, fishermen should be made aware that the effect of ever growing fishing pressure mostly shows up from annual catches in the long-term, in, say, a time window of at least 15 years. Such longer experience is, on average, gained by at the most half of the fishermen. In the smaller time window of a younger fishermen most of the variance in annual catches is due to randomness and to short-term trends of circa 3-5 years rather than to a possible long-term trend. So developments in the last 5 to 10 years are framed differently for younger than for older fishermen in the community.

Second, catch data can be highly variable, and fishermen should be made aware of whether and when this matters. This can be exemplified with their own data. Simply scoring daily catches for a one year period is enough to learn that basic uncertainty has already 'vanished' after data aggregation into monthly intervals. What is possibly left is seasonality, that can be perceived much more clearly and then makes them aware that basic uncertainty and seasonality do not matter when it comes to the evaluation of long-term trends. Light and sport fisheries are particular cases for which aggregation through time, ànd through the population of anglers or light fishermen, is necessary to show up temporal and spatial patterns as clear and significant. Here evaluation of one's own series of catch data is hardly instructive, but combining catch data from all fishermen in the community or anglers in the club could help.

Two aspects of inter-annual variability, both highly important in evaluating developments in a fishery, are hard to exemplify and compare with catch data as obtained by individual fishermen. This is variability due to short-term trends, which is only visible in larger time windows, and variability reduction after aggregation through larger ecospaces. To demonstrate the importance of both, it is necessary that the fisheries administration provides fishermen with longer time series of annual catches aggregated through these larger ecospaces. These series should preferably be standardised in terms of catch per unit effort, so as to enable fishermen to see for themselves how their individual performance corresponds with that for the fishery as a whole. This exercise should make them aware that the time series with the most aggregated data and with lowest variability is not just óne of the many series, but ultimately the móst representative and instructive one.

Third, fishermen should be made aware of the strategic use of selecting a high critical value of α and with that to enlarge their capacity for perceiving true trends. What could be instructive is to let them formulate, document and compare what financial risk they take by nót concluding there is a downward trend, where such trend truly exists (no regulatory action), and what risk they take by concluding there is a trend, where there is not. It would make the discussions on what conclusion to draw and what decision to take more transparent, as discussions on the amount of data, on the variability in the data and on the risks of making errors (β/α) are then less intermingled.

Next comes the evaluative capacity within the fisheries administration itself and their skill to communicate time series for catch and effort data. First, administrators should assess and learn to understand how uncertain and complex the environment is in which fishermen operate and reflect on their resource outcome. For example, this means that the administration has to obtain series with daily, monthly and annual catches of individual fishermen per community. Next they should evaluate such time series before and after aggregation through time and through the fishermen community, in order to grasp a sense of the patterns and variabilities experienced at the various temporal and administrative scales. As Neis *et al*. (1999) put it, fishermen develop a detailed small-scale understanding of the resource, while fisheries scientists typically aim at a larger scale. Fishermen would therefore not easily agree with statements on the state of the stocks that conflict with their own experience, except when the large-scale understandings are compared with localised observations throughout the area (Neis *et al*. 1999).

Second, there is skill needed on what format to use when communicating information on developments over time between fishermen and authorities. A graph or bar diagram is certainly more appropriate than a table with figures. But full comprehension and inference of conclusions from such a graph should not be assumed to be something easy to learn. In the western world graphs were not used even at the end of the 18th century and it took until the beginning of the 20th century before graphs were used to value resource outcome in every day life (Tufte 1983, Neeleman & Verhage 1999). Also, until this very day one worries about the proper format for presenting quantified information to be used for decision-making by even a trained public (Tufte 1983, Hilborn & Peterman 1996). Comprehension of information contained in a graph at the very least requires practice in reading graphs. When the administration supports fishermen in acquiring such practice, the best starting point will be to present data and graphs in a neutral way without adding evaluations or interpretations as already made by themselves or by scientists. So advice is better given in response to the initial evaluations made by the fishermen themselves.

Third, the evaluative capacity of the various layers in the administration should be improved. For that purpose one should be aware that time series are mainly evaluated at the higher levels in the administration where data become available already highly aggregated, and thus without high temporal or spatial resolution (Fig. 7.9). It is necessary then to build greater confidence among lower levels in the administration in their capacity, and in the legitimacy, for evaluating catch and effort data. Many in those levels are hesitant to draw any conclusion regarding trends or patterns in annual series and are inclined to await the outcome of detailed ecological or fisheries studies before making any interpretation. Sometimes the emphasis is so much on generating tabulated totals, as for example in the traditional fisheries information system of Vietnam, that one hardly comes across any graphed information there (van Zwieten *et al*. 2002). This is not merely a consequence of lack of computer facilities, but it is the lack of appointments of staff concerned with the frequency, organisation and formats for standardised evaluation procedures and of the questions being asked. Thus it is more of an organisational problem, than lack of understanding. Feedback and training within the organisation could build their capacity to evaluate time series. Once again, developing a skill for evaluating graphed time series requires experience.

So both fishermen and authorities should prepare themselves for discussions, in a co-management setting, on trends and variances in resource outcome. Common participation in role plays which serve that purpose but for which virtual data are generated may be very instructive for both sides. Such role plays could demonstrate how economic interests and individual catch histories of fishermen on one side, and commitments to a general fisheries policy of the authorities on the other side, affect perceptions of developments in the resource and the risks that each is prepared to take in its management (van Densen & van Zwieten 2001).

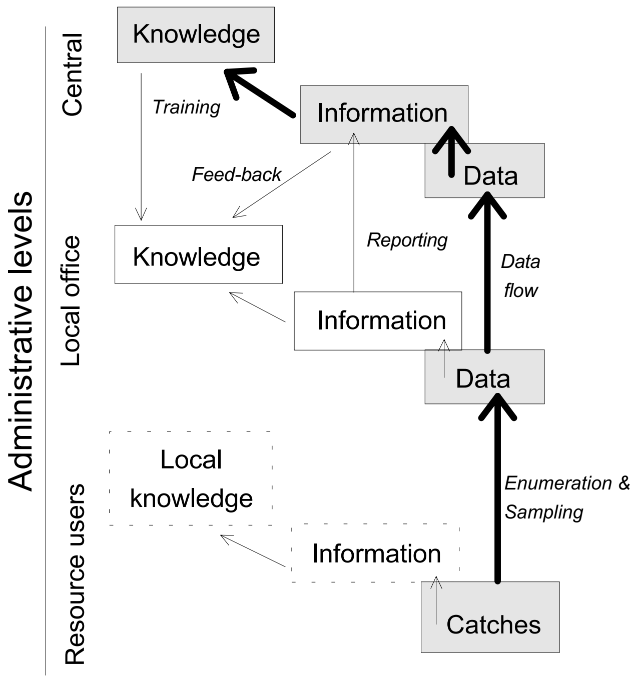


Fig. 7.9 Generation and transfer of fisheries data, information and knowledge within the fisheries administration. Bold arrows indicate currently dominant pathways. Other arrows indicate data and information flows that should be stimulated.

In conclusion, fishermen could enhance their evaluative capacity by trying to assess trends and variances in their own individual series and in those for the fishery as a whole, and by comparing the consequences for their fishery of concluding there is a trend where there is not, and vice versa. Authorities could enhance such capacity by stimulating the evaluation of time series with catch and effort data at the various levels in their administration. Further, authorities could prepare themselves for discussions on resource outcome in co-management settings by evaluating time series per individual fishermen.

7.7 Local knowledge and long-term trends

Local knowledge of fishermen of spatio-temporal aspects of a resource has not been mentioned in the above suggestions for enhancing evaluative capacity on both sides, although many consider it a highly valuable resource of information. Article 6.4 of the "FAO Code of Conduct for Responsible Fisheries" states for instance that: “Conservation and management decisions for fisheries should be based on the best scientific evidence available, also taking into account traditional knowledge of the resources and their habitat, as well as environmental, economic and social factors”. Thus, it demands the integration of scientific and local knowledge of the resource. But how much effort in this direction will pay, where large-scale temporal patterns matter? And what are the reference points in such an information strategy?

Local knowledge as it is now documented, seems to refer mostly to spatial patterns and to small-scale temporal patterns in the resource and its outcome, such as periodicity in fish reproduction and in catch rates as related to lunar phases and seasons (Johannes 1993, 1994a,b, Benneker 1996, Sverdrup Jensen & Raakjar Nielsen 1998). So it is also probable that fishermen use local knowledge to manage their fishery more with regard to spatial patterns and in smaller time windows. There are examples of how knowledge of spatio-temporal patterns in fish biomass is used to assign fishing locations within a community so as to reach equity in resource access (Berkes 1992). Fishermen in the inner delta of the River Niger use their local knowledge of small-scale temporal patterns and causality to adapt their fishing pressure to the variable amount of fish in the seasonally inundated floodplains, so as to assure stable catches throughout the rest of the season (Sissoko *et al*. 1986, Malvestuto & Meredith 1989, Meredith & Malvestuto 1990, Laë 1994, 1995).

For the local community, developments in resource outcome at a larger spatial scale, and thus short- and long-term trends over the years, are more difficult to perceive and to distinguish from each other. Also, the causes for these trends are less easy to understand, and therefore local knowledge of large scale patterns is less easy to develop. Throughout this study arguments have been given which support this general finding. Referring to statistical power for trend perception, it would be very informative to assess how clear a causal relationship there is still between fishing intensity and resource outcome when derived from annual series for catch and effort in a local fishery. This could tell us in which ecosystems and fisheries local knowledge with respect to time trends and their causality develop more easily.

Where local knowledge certainly contributes to a better perception of long-term trends in the resource, is in adjusting serious observation bias in official monitoring schemes, as was clearly demonstrated for the stocks of Newfoundland cod (Finlayson & McCay 1998) and bowhead whales in the western arctic (Huntington 2000). A kind of local knowledge that is as yet too rarely acknowledged, is the capacity of fishermen to trace developments in total stock size from shifts in species and size composition in their catch. The concept and use of such integrative parameters has only recently been given more attention in fisheries science and environmental monitoring (Welcomme 1999, CIW 1999, Pauly *et al*. 2001). Until now information on species composition contained in the data series of official Catch and Effort Data Recording Systems has seldom been utilised for monitoring purposes, although the data processing could easily be geared to the generation of such information (Gascuel & Ménard 1997).

In conclusion, local knowledge of long-term trends in resource outcome is generally weakly developed. Spatial knowledge of fishermen could contribute much to the optimisation of less unbiased monitoring schemes. As trends in the species and size composition in the catch are less ambiguous, local knowledge as developed on the basis of these parameters is a promising input to the design of more integrative monitoring schemes and their use in co-management settings.

7 Consequences for co-management - Conclusions

- Authorities have a larger capacity – ‘administrative gain’ – to perceive true trends and step trends compared to individual fishermen, because of their larger time window, smaller variability in their aggregated data and their more ‘precautionary approach’ by which they accept a higher probability, α of concluding that there is a trend where there is not.
- On behalf of fisheries co-management, fishermen should be encouraged to evaluate developments in their own catches and in the fleet’s average. Authorities should realise that fishermen experience variability in resource outcome at smaller temporal (days, months) and spatial scales (individual resource area), and should imagine how this affects their perceptions of developments in the resource.
- Nature conservationists are used to small variabilities ($CV < 0.2$) in annual bird numbers. This narrows their time window for evaluation. Where nature conservationists, fishermen and authorities sit together to discuss fishery-bird interactions, they should be aware of the variabilities in annual series that each of them is accustomed to.

Box 7.1 - Inter-annual variability and the statistical power of wildlife monitoring programmes

The US Government, through its Patuxent Wildlife Research Center, published a listing of 450 studies involving species counts over time (www.mp1-pwrc.usgs.gov). This listing includes, in addition to species name, the length of the series (number of years), the mean of the series and the Coefficient of Variation. Only published studies with consecutive counts of local populations over 5 or more years were tallied. The purpose of the compilation of inter-annual variabilities per species was to use these variabilities in the assessment of statistical power necessary for the monitoring of plant and animal populations. The website gives information on statistical methods, design of monitoring programmes, software and references in the field of power analysis.

Only inter-annual variabilities per species for birds, fish and mammals were retrieved from the listings, in order to evaluate them here for systematic differences between major animal categories. On average large mammals and birds show the lowest, and non-salmonid fish the highest, inter-annual variability (Fig. B7.1). As the authors stressed, the data combine natural population variation with variation associated with study design, observer effects, and methodology. But in some series trends or step trends must have increased the variability as well. Also, because of these possible trends, the variabilities listed are considered to be maximum estimates of inter-annual variability.

Reference on the website: Eagle, P.C., Gibbs, J.P. and Droege, S. Power analysis of wildlife monitoring programs: exploring the trade-offs between survey design variables and sample size requirements.

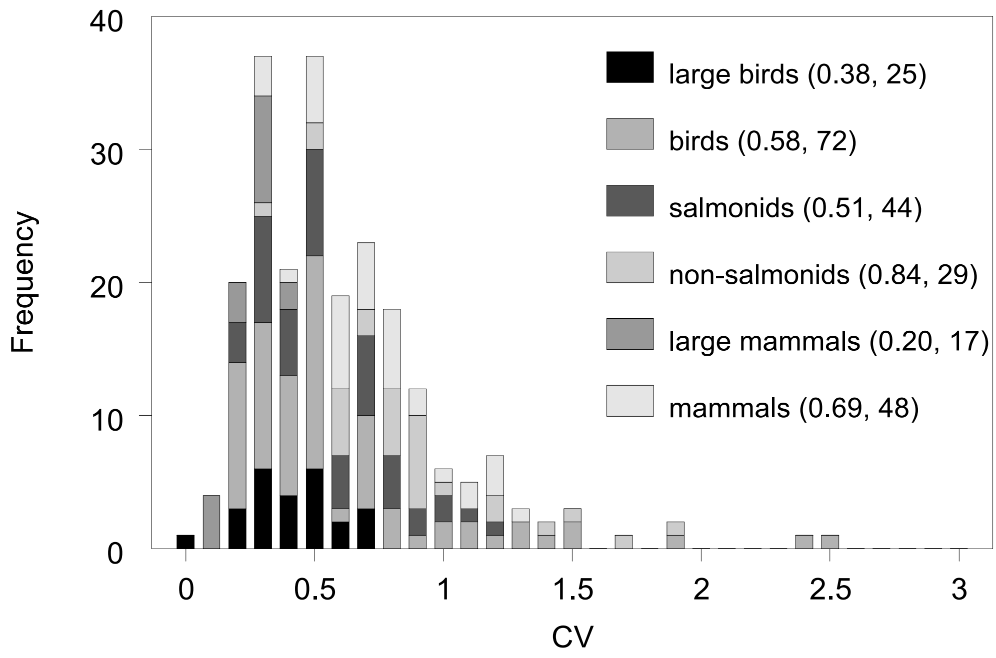


Fig. B7.1 Inter-annual variabilities per vertebrate species (CV) grouped into major animal categories as listed on the website www.mp1-pwrc.usgs.gov. The categories 'birds' and 'mammals' do not include 'large birds' and 'large mammals'. Between brackets: CV, number of series.

Chapter 8

Variabilities and the perception of trends in agriculture

In this chapter:

- Similarities and differences between crop agriculture, nomadism and fisheries are discussed in relation to modes of exploitation, property rights and access to the resources. **8.1**
- Inter-annual variabilities in the yield of some major crops are compared at various spatial scales, from the sub-field level up to the global scale . **8.2**
- Spatial variabilities in crop yields are also compared at various spatial scales, and an assessment is attempted of the proportion of unexplained variability therein. **8.3**
- An assessment is made of the extent to which inter-annual variability in rainfall translates into variability in crop and forage production, depending on the type of agri-ecosystem. **8.4**
- Inter-annual variabilities in milk production by nomadic herds in Eastern Africa are related to inter-annual variability in rainfall and forage growth; the management practices used by the nomads to cope with these variabilities are discussed, as is their capacity to track ecosystem changes in the short and the long term. **8.5**
- Inter-annual variabilities in crop agriculture are used to assess which trends and step trends are perceived, how these variabilities compare to those in fisheries, and how they might make farmers and fishermen feel insecure about their resources. **8.6**

8.1 Crop agriculture, nomadism and fisheries

Fishermen harvest from their aquatic resource base every day and thus experience variability in daily, monthly and annual catches. Crop farmers, in contrast, harvest their crops mostly once a year, and so experience inter-annual variability only in annual totals. The question is, do crop farmers experience inter-annual variabilities in resource outcome in the same range as do fishermen? And is their capacity to observe trends and step trends therefore as variable as amongst fishermen? Downward trends in crop agriculture could be due to soil degradation, whereas step trends to higher yields would be expected from a change in farm management.

Soil degradation caused by erosion, nutrient depletion and structural decline of the soil has become a problem world-wide. Soil structural quality is a kind of natural resource comparable to fish stocks, but whose resilience is much less. About 38% of the world's agricultural land is now affected by human-induced soil degradation, and recovery rates are expected to be slow (Bouma & Batjes 2000). When farmers have to be made aware of the ongoing process of soil degradation and of the effectiveness of measures suggested to improve soil quality, they should be able to perceive trends and step trends in land quality from their resource outcome. The ratio of actual to potential crop production is now propagated as an indicator of land quality (Bouma & Droogers 1998), but the stability of such indicators, and their use in monitoring programmes for soil quality greatly depends on the variability in annual crop production, just as in fisheries the variability in annual catches determines the perception of trends and step trends in the aquatic resource (Chapter 6).

Inter-annual variability in crop production will be large in dryland areas where there is less control over water as a limiting factor. So it will be large in the rain-fed production of cereals such as millet and sorghum in sub-Sahelian Africa. For the same reason also, there will be large variability in the production of forage on which nomadic herds graze in these dryland areas, and in the milk production by these herds.

Just as in fisheries, there will be an 'administrative gain' for the authorities that aggregate data on crop yields over larger administrative spaces because of the resultant reduction in inter-annual variability. This reduction will be stronger where there is more random variability in the spatial distribution of resource productivity within years. And just as in fisheries, authorities or scientists who communicate research findings on agricultural practices to farmers, should therefore account for the higher variability in crop yields as experienced by the individual farmer. Such anticipation of the farmer's greater uncertainty of his annual crop yield becomes particularly relevant where farmers are engaged in agricultural research programmes (Riley 1998, Riley & Fielding 2001).

Resource use by nomads differs from that of crop farmers as much as from that of fishermen. Their cattle are private property, just as a farmer's field, but nomads graze their cattle on common pastures without any direct control over the forage production on these pastures. Nomads and fishermen are similar in that they both tap their resource every day; nomads milking their cows and fishermen setting and hauling nets. Also, both nomads and fishermen share large common resource areas, nomads their extensive pastures and fishermen their village fishing grounds. Nomads, just as fishermen, thus experience variability in their daily, monthly and annual totals in resource outcome and both are capable of responding to these variabilities via their mobility, continuously searching for better areas in which to graze their cattle or for locations with higher catch per unit effort.

In this chapter, inter-annual variabilities in the production of some major crops, (wheat, rice and sorghum) are first compared at various spatial scales, from the sub-field level, to that of the farmer's field, to national and finally to global scales (8.2). Secondly, spatial variability in crop yields between fields is discussed, as is the unexplained variability therein (8.3). Then inter-annual variability in crop and forage production is related to variability in rainfall (8.4), as is the variability in milk production by nomadic herds (8.5). The effectiveness of the nomads' mobility, and other strategies for stabilising resource outcome, is discussed. Finally, it is estimated, as it was for fisheries in section 6.5, which trends and step trends can be perceived and by whom (i.e. level of data aggregation), given inter-annual variabilities at the various spatial scales (8.6).

8.2 Variability in crop yields at various spatial scales

In the literature on crop agriculture inter-annual variabilities in crop production are seldom if ever captured in one and the same framework. Such an approach would tell us by approximation how large an inter-annual variability to expect for what type of crop, under which environmental conditions, and at what spatial scale, should such data be aggregated. The following is an attempt to develop such an approach.

At the largest spatial scale (global) and for the broadest crop category (cereals) the variability in annual production is as low as CV = 0.028 - 0.034 (Table 8.1) (Hazell 1989). Amongst these cereals, wheat is the major crop in the world in terms of total production, followed by maize and rice. Inter-annual variability in crop production, calculated after detrending without prior log-transformation, is low for maize (CV = 0.039) and rice (CV = 0.039) but high for millet (CV = 0.078), a typical crop from arid areas (Table 8.1). Overall, inter-annual variability slightly increased in the period 1960-1982, which is partially due to the increased use of high-yielding varieties, which are more vulnerable to environmental fluctuations (Hazell 1989).

Table 8.1 World cereal production (10^6 tonnes), excluding China, and the inter-annual variability (CV) therein, sorted by this CV as averaged for both periods, per crop category and after detrending. The years refer to the periods 1960/61-1970/71 and 1971/72-1982/83 (based on data in Table 2.2 in Hazell (1989)).

Crop	Production		CV		
	1960-1970	1971-1982	1960-1970	1971-1982	Average
Maize	210	317	0.033	0.044	0.039
Rice	120	155	0.039	0.038	0.039
Wheat	253	353	0.054	0.048	0.051
Sorghums	40	53	0.052	0.057	0.054
Barley	95	150	0.048	0.075	0.057
Other cereals	41	35	0.046	0.093	0.070
Millets	20	21	0.079	0.077	0.078
Oats	49	48	0.113	0.054	0.084
Total cereals	829	1134	0.028	0.034	0.029

On a national scale, the inter-annual variability in the yield (production per unit area) of cereals was well above CV = 0.10 for South-Africa, Australia and the USSR, where annual yields were lower than the world average of 1.65 tonnes per ha (Fig. 8.1). In Indonesia and Bangladesh with, by approximation, the same relatively low yields, inter-annual variability was still about four times as low as in the three countries mentioned above. Countries with the highest yields experience inter-annual variability in the production of cereals of around CV = 0.06 - 0.09.

It was expected that the lowest variabilities would coincide with the highest yields, assuming that such high yields were obtained under more controlled conditions. But inter-annual variability in the yield of three major cereals, namely wheat, sorghum and rice, varied independently of the yield averaged per country (Fig. 8.2). When these yields are as low as 1 - 2 tonnes per ha there is quite a range in their inter-annual variability per country. This variability was highest (CV > 0.2), in Australia and Brazil, where yields were only around 1 ton per ha. Yields of wheat were highest in European countries: UK, followed by W-Germany and France, all with yields of more than 4.5 tonnes per ha and with inter-annual variability between CV = 0.05 and 0.1.

Inter-annual variability in the yield of sorghum was slightly higher on average than that in the yield of wheat. High yields of sorghum (more than 4 tonnes per ha) were recorded for Southern European countries; Spain, followed by Italy and France, and also here inter-annual variability was around CV = 0.1 or less (Fig. 8.2). Variability in sorghum yield was highest in Thailand, more than CV = 0.35, where the average yield was at least three times lower than in Southern Europe. In addition to the estimates for the inter-annual variability in sorghum yields given by Hazell (1989), such estimates, averaged for the whole of the country, were also made for four Sub-Sahelian countries in the 20 year period 1980-1999, when variability ranged between CV(s) = 0.11 for Burkina Faso (average yield 0.74 tonnes per ha) and CV(s) = 0.27 for Niger (average yield 0.25 tonnes per ha) (Fig. 8.3). Niger had the lowest average yield, the highest inter-annual variability and the trend to noise ratio (b/s) was 0.16.

Although the variability in the annual yield of rice averaged per country also caried strongly, it was particularly low (CV < 0.05) for some countries where annual yields of rice were as low as 1 - 2 tonnes per ha. When excluding the countries numbered 1 to 4 in Fig. 8.2, average variability per country was lowest for rice (CV = 0.075), but was not that much higher for wheat (CV = 0.088) and sorghum (CV = 0.10).

With the significant increase in total yield due to the use of new varieties, fertiliser, irrigation etc., inter-annual variability in the average yield for the whole of a country has decreased only marginally. Moreover, the annual yield of wheat in the UK has increased continuously from the Middle Ages until the present by more than an order of magnitude, but the inter-annual variability therein has not decreased any further for more than a century (Fig. 8.4). Around 1300 annual yield was only 0.3-0.5 tonnes per ha. It increased to 1.0 ton per ha around 1750, when seed drills came into use. Around 1920 it had become 2.1 tonnes per ha, when fertilisers and new wheat varieties were applied. By 1980 it had reached levels as high as 6.5 tonnes per ha, when more N-fertiliser, short-straw varieties and fungicides were applied as well (Austin & Arnold 1989, their Table 7.1). Nevertheless, in the whole period since 1845 inter-annual variability for the whole of the country has fluctuated around CV = 0.10, whereas in the same period resource output has increased by a factor of 4 (Fig. 8.4). So it is probable

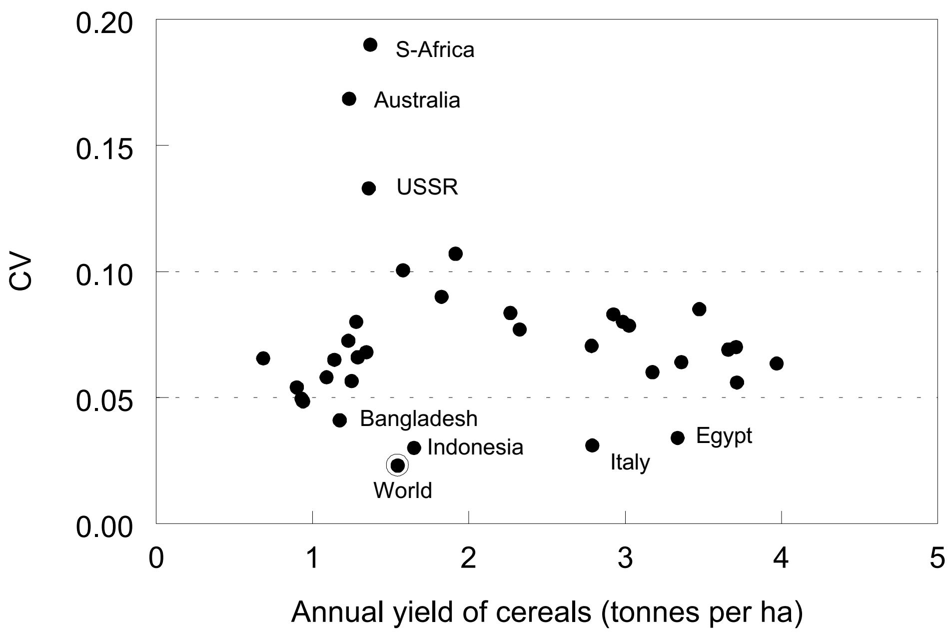


Fig. 8.1 Inter-annual variability (CV) in detrended series for the yield of cereals per country plotted on the series average for annual yield (tonnes per ha). CVs and yields were calculated by averaging the values for the two successive periods 1960/61-1970/71 and 1971/72-1982/83 listed in Table 2.3 in Hazell (1989). The dashed line (CV = 0.10) is a reference depicted in Figs 8.2,4,5, 7 and 10 also.

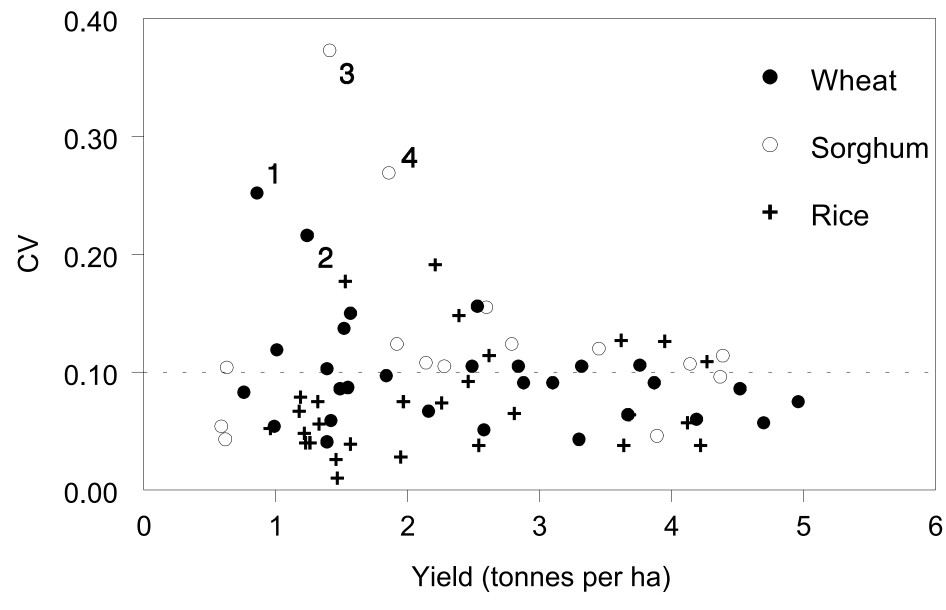


Fig. 8.2 Variability (CV) in the in the annual yield (tonnes per ha) of wheat, sorghum and rice (tonnes per ha) averaged per country in the period 1971/72-1982/83. 1 = Brazil, 2 = Australia, 3 = Thailand, 4 = South-Africa. (Data from Table 2.4 in Hazell (1989)).

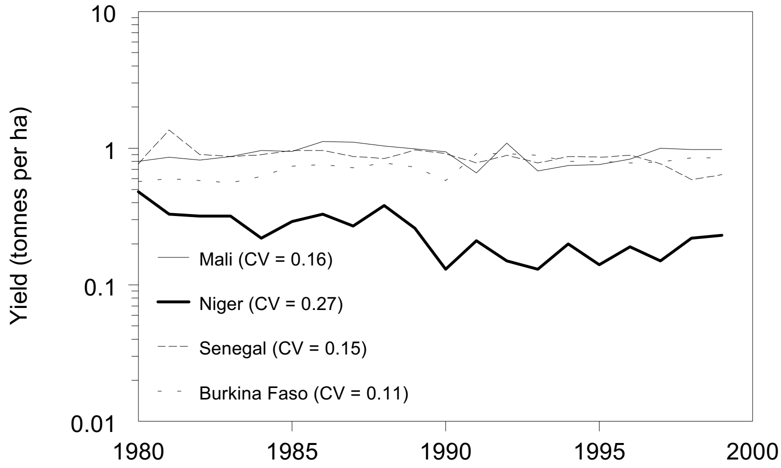


Fig. 8.3 Annual yields (tonnes per ha) of sorghum as country averages for four Sub -Sahelian countries together with inter-annual variabilities (CV(s)) in detrended seri es (data from www. fao.org).

that in the coming decades also one will have to account for such inter-annual variability in resource output at the country level, which variability is probably hard to reduce any further.

The next step is to analyse inter-annual variability at the field scale and also the inter-annual variability experienced by an individual farmer. The inter-annual variability in the yield of wheat per farmer's field in the UK has decreased with increasing resource output, but, as with the national average, not significantly more since the mid 19th century (Fig. 8.4). It was CV = 0.3 and more in the Middle Ages and has decreased to around CV = 0.10 - 0.15 at present, with lower variability in fields where inorganic fertilisers are applied instead of manure.

When evaluating inter-annual variability at the field level for other crop types also, using time series from long-term agronomic experiments, a general tendency emerges towards lower variability at higher yield levels (Figs 8.5, 8.6). To assess these inter-annual variabilities, annual yields were not log-transformed first, but the standard deviation in the residuals around the linear regression of yield on year was divided by the series average yield, to obtain an estimate for inter-annual variability (CV). This seems common practice in agronomy (Hazell 1989). Inter-annual variabilities in yields of wheat from experimental stations in Australia, Chile and Argentina were high relative to those in the UK for the same annual yield (Fig. 8.4). This difference is possibly due to harsher and more variable conditions under which wheat has to be grown in these countries. Inter-annual variabilities in yields of rice were as low as those in intensive wheat production. Lowest inter-annual variability was estimated in time series for double-cropped rice production in China. Inter-annual variability was highest for yields of rain-fed sorghum at an experimental station in Burkina-Faso (Figs 8.5, 8.6).

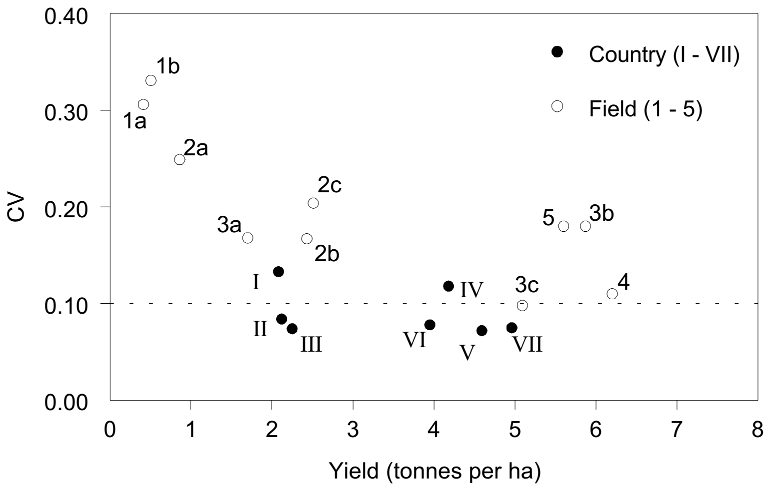


Fig. 8.4 Inter-annual variability (CV) in the yield of wheat in the UK as averaged for the whole of the country (closed symbols) and per field (open symbols). Data for country averages are from Austin & Arnold (1989, their Table 7.2, I - V) and from Hazell (1989, his Table 2.4, VI and VII). Data for variabilities per field stem from Austin & Arnold (1989, their Table 7.3).

Country		Field	
I	1832-1859	1a	1225-1349
II	1880-1917	1b	1211-1349
III	1918-1945	2a	1852-1918, no manure of fertilizer
IV	1948-1984	2b	1852-1918, only manure
V	1961-1983	2c	1970-1978, inorganic fertilisers
VI	1960-1970	3a	1970-1978, no manure or fertilizer
VII	1971-1982	3b	1952-1971, manure only
		3c	1967-1978, complete inorganic fertiliser, 144 kg N per ha
		4	1952-1971
		5	1967-1978

Thus, inter-annual variability in crop yield decreases with the increase in the spatial scale for which yield data are averaged, and with increased production level. The large range in inter-annual variability at field level for the same crop must be due to environmental variability the impact of which is not reduced via more controlled farming practices.

Just as with crop yields, inter-annual variability in forage production on rangelands in arid areas, where nomads graze their cattle, tends to be lower where forage production is high (Fig. 8.7). So when production is as high as 5 tonnes dry matter per ha, variability is CV = 0.2. When production is low variability per area ranges between wide limits and around an average of circa CV = 0.6. As Houérou *et al.* (1988) make no reference to the total surface area for which variability was estimated, nor to a correction for any area effect on these variabilities, the range of variabilities is possibly less than as depicted in Fig. 8.7. If the sizes of the areas correspond with the rangeland through which a nomadic herd completes its annual migration, these variabilities anyway correspond to those experienced by nomads as individual resource users, just as the variability per field is experienced by the individual farmer.

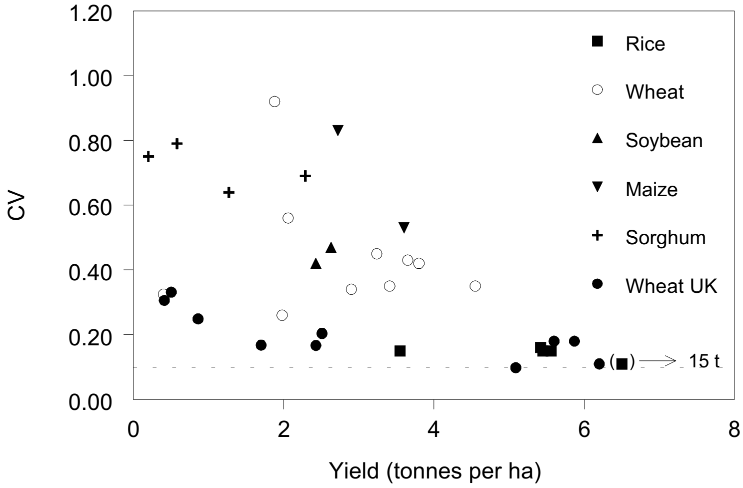


Fig. 8.5 Inter-annual variability (CV) in the yield of five types of crop grown at experimental stations (based on data in Pichot *et al.* (1981) and Steiner & Herdt (1993)). Sorghum: Burkina-Faso; Wheat: Australia, Chile, Argentina; Maize: Argentina; Soybean: Argentina; Rice: Indones ia, China. The data points for wheat in the UK are similar to those in Fig. 8.4.

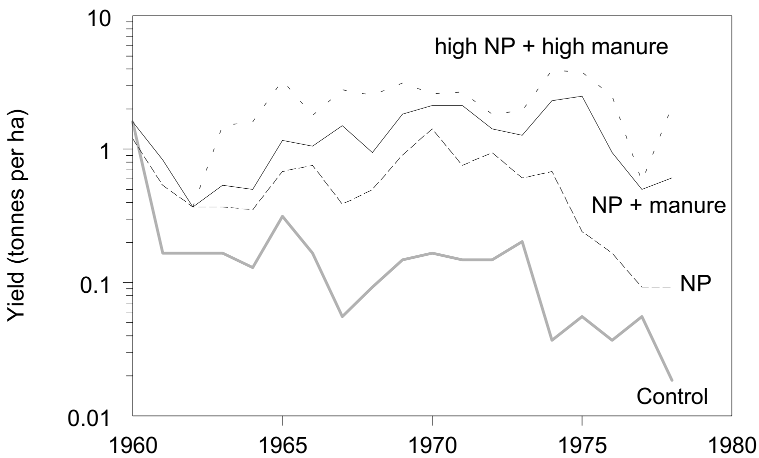


Fig. 8.6 Annual yield of sorghum at the SARIA experimental station, Burkina -Faso, with three treatment and one control series. CV(s) = 0.76, 0.79, 0.64 and 0.69 for the fou r series (data from Fig. 1 in Pichot *et al*. 1981).

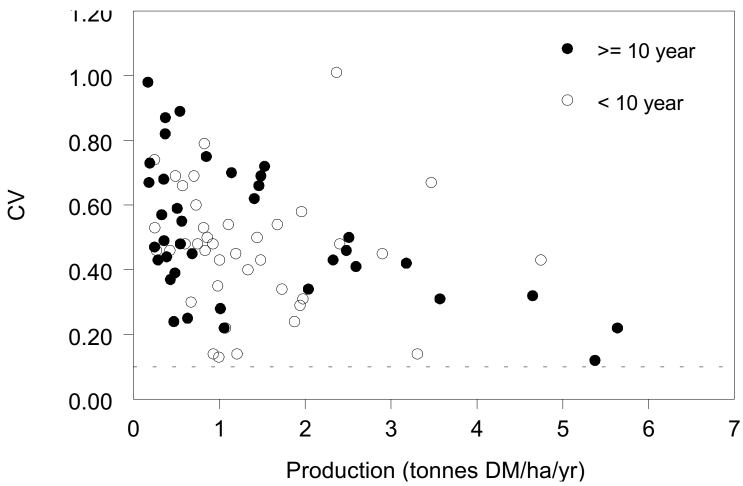


Fig. 8.7 Inter-annual variability (CV) in forage production plotted against forage production (tonnes dry matter per ha) for arid areas as listed in Table 1 of Houérou *et al.* (1988).

In conclusion, there is a steady decrease in inter-annual variability of crop yield over larger administrative spaces, from as high as CV = 0.8 in the yield of sorghum at field scale in dryland agriculture, down to CV = 0.04 in global average rice yields. More controlled production systems in the temperate zone have reduced variability at field scale down to nearly CV = 0.10.

8.3 Spatial variability and its causes

The reduction in inter-annual variability in crop yield, averaged for ever larger administrative areas, is the consequence of changes in the spatial distribution of crop production from one year to the next. Such changes that are most easily explained, are those in rainfed crop production in dryland areas where rainfall is patchy and erratic (Graef & Haigis 2001). At the smallest spatial scale, within a farmer's field, changes in the spatial distribution of crop production in response to the amount of rainfall contribute to lower inter-annual variability in crop yield for the field as a whole, as is demonstrated in rainfed agriculture (Brouwer *et al.* 1993).

To start at the smallest spatial scale, with increasing production level not only does inter-annual variability for the field as a whole decrease (Figs 8.4, 8.5), but spatial variability within fields as well (Figs 8.8, 8.9, Box 8.1) (McBartney *et al.* 1997). In other words, fields become more homogenous in their production per unit area. One way of demonstrating this is to calculate a CV for crop yield per plot within fields (Fig. 8.8). Where production is lower and spatial variability higher, the frequency distribution for the number of plots per production category becomes more positively skewed with increased occurrence of bare plots with zero production (Fig. 8.9) (Gandah 1999). Aerial surveys in SW Niger in 1988 showed that as much as 14% of each pearl millet field was non-productive (Manu *et al.* 1990 in Brouwer *et al.* 1993). The frequency distribution for the intensively managed stands of silage maize in the Netherlands has a tail to the left, but this was probably due to plots that stayed extremely wet during winter and so produced less maize (Fig. 8.9, H. Booltink personal communication).

Where these spatial patterns in crop yield within a farmer's field change in opposite ways from one year to the next, this contributes to a reduction in inter-annual variability per field (Brouwer *et al.* 1993, Brouwer & Bouma 1997). The explanation is that differences in soil and bottom elevation bring about spatially differentiated responses to rainfall within fields. The differences in soil characteristics at short distances of meters within fields is brought about by differential wind and water erosion and deposition, by growth of trees and shrubs before clearing, by trees left standing such as acacia, by uneven application of manure, by differential leaching and even by termite activity. These more heterogeneous fields can show combinations of relatively high, dry and fertile areas and more wet and leached depressions (Brouwer *et al.* 1993). In wet years the total yield from these fields is nutrient-limited. In dry years the depressions capture the scarce water and ensure a minimum yield, in this way stabilising the variability in crop production for the subsistence farmer (Box 8.2). It should be

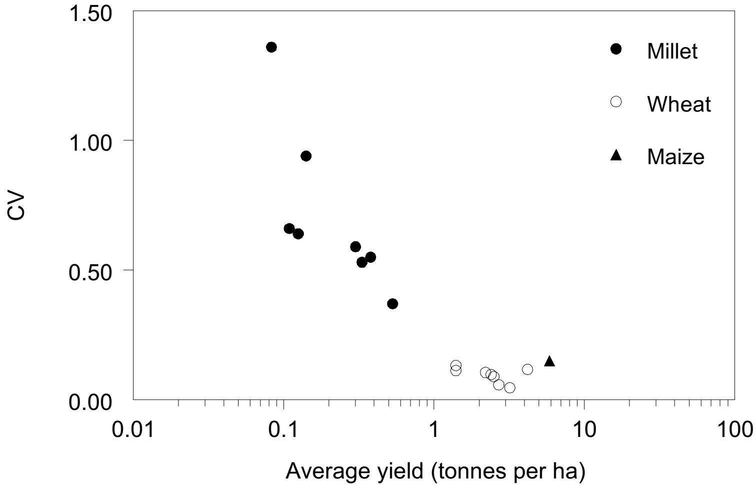


Fig. 8.8 Spatial variability (CV) in the production per plot within fields plotted on yield (tonnes per ha) of millet, wheat and maize averaged for that field. The data for millet are from Gandah (1999, his Table 3.2), studying 25 m^2 plots in 0.675 ha fields in Niger (1995-1996). The data for wheat are from a range of widely dispersed locations as listed in Table 1 in McBratney *et al*. (1997), and for maize from H. Booltink (Department of Soil Science and Geology, Wageningen University) for a 16 ha field with 15 m^2 plots in the Netherlands (see also Fig. 8.9). Maize was silage maize. For reasons of comparison yield of maize as recorded was halved. The CVs for wheat were scaled to the same plot size as used for sorghum in Niger by multiplying the CV with $(a/25)^b$, where a = plot size for wheat in square meters and b is the exponent given in McBratney *et al*. (1997) or assumed b = 0.5 for maize (Netherlands).

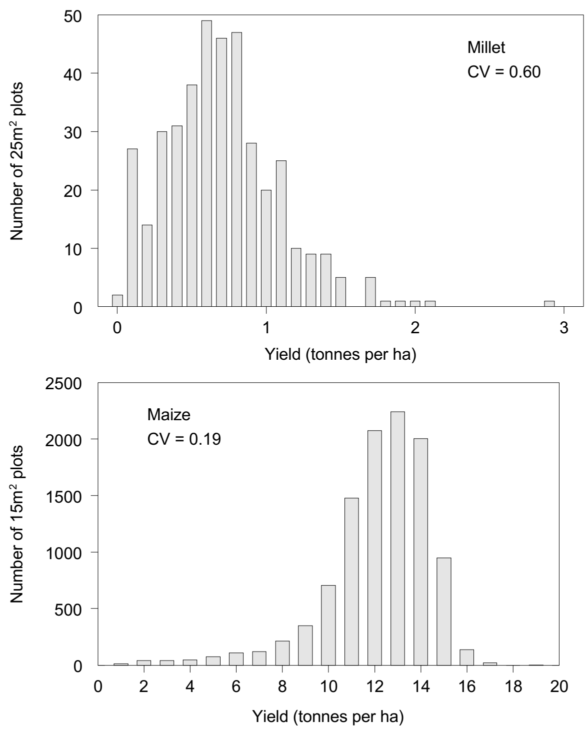


Fig. 8.9 Within-field variability in the yield per plot (converted to tonnes per ha) for (top) millet in Niger (1ha, 25 m^2 plots, Y = 649 kg/ha) and (bottom) maize in the Netherlands (16 ha, 15 m^2 plots, Y = 11743 kg/ha). Data for millet from Stein *et al.* (1997) and for maize from H. Booltink (Department of Soil Science and Geology, Wageningen University).

considered whether farming practices aimed at homogenising these fields would even lead to an undesirably higher frequency of poor harvest years (Brouwer *et al.* 1993). Also, due to the micro-variability in soil fertility, development stages of the crop vary and in this way spread the sensitivity of the crop to drought stress. In addition to this 'passive' stabilisation via spatial heterogeneity, farmers actively apply a type of risk management per individual field by inter-cropping early and late varieties of millet (Brouwer *et al.* 1993).

Not only the variability in crop yield within but also between nearby fields tends to be higher in marginal dry land agriculture than in productive temperate zone agriculture. The within-year variability in yields of millet between individual fields within an area of 20-30 km^2 in Mali is as high as CV = 0.45 - 0.98 (van Dijk 1997) (Table 8.2). For comparison, the within-year variability in the yield of wheat between fields in the UK (244,000 km^2) did not change throughout the period 1830-1980 and has always been relatively small (CV = 0.14 - 0.19), when yields of wheat increased by a factor of 4, from circa 2 to 7 tonnes per ha (Table 8.3).

Few agronomic studies have yet tried to explain in a quantitative way the differences in crop yield between farmer's fields from all possible farm-related characteristics. In one of these studies it was shown that as much as 60 to 71% of the variability between individual fields, in the yield of rain-fed sorghum, within one village in the Far North Province of Cameroon, could be explained by a combination of field characteristics and management styles of individual farmers (Table 8.4) (de Steenhuijsen Piters 1995). The yield of not very productive dry-season sorghum, grown on residual moisture, varies less between fields. Notwithstanding the large proportion (R^2) explained, the amount of inter-annual variability that is still left and that might contain a considerable portion of randomness, is high, although rather constant (CV_{res} = 0.25-0.31) (Table 8.4). This residual variability in the yield of sorghum (CV_{res}) between fields is inferred here from the proportion of unexplained variability (1 - R^2) and the overall CV via $CV_{res} = (1 - R^2)^{1/2}$. Part of the residual variability may have arisen from spatial differences in rainfall within the study area. Especially early in the season, small local differences in rainfall may affect the farmer's decision to sow (30 mm) or not (15mm) (J. Brouwer, personal communication). Such differences could occur over a distance of even a few kilometres (Graef & Haigis 2001).

Table 8.2 Mean yield of millet (kg/ha) and variability (CV) between fields at various locations, all within an area of 20-30 km^2 in Mali (data in van Dijk 1997).

Location	Year	Yield (kg/ha)	CV	Field size (ha)	N fields
Tiile	1990	281	0.98	1.52	16
	1991	402	0.49	0.99	16
	1990/91	341	0.74	1.25	32
Debere	1990/91	381	0.49	2.55	9
Yaraama	1990/91	377	0.45	0.89	7
Wiinde	1991	656	0.57	0.38	5

Table 8.3 Variability (CV) in yields of wheat between fields in th e UK (From Table 7.4 in Austin & Arnold (1989)). The authors mention that inter -annual variation is largely eliminated here.

Period	Yield (tonnes per ha)	CV
1830-1859	1.93	0.17
1934-1938	3.40	0.14
1967-1978	5.70	0.16
1971-1978	5.44	0.14
1980	7.37	0.19

Table 8.4 Mean annual yield (kg/ha) of rain -fed and dry-season sorghum, variability in yield between fields (CV) and proportion of the variance explained (R^2) by field characteristics and cultivation practices, for one village in northern Cameroon (dat a in Steenhuijsen Piters 1995). Toupouri and Moundang are two ethnic groups. Average annual rainfall in the area is between 600 and 700 mm.

Crop	Category	Year	Yield (kg/ha)	CV	R^2	CV_{res}	Field size (ha)	N fields
Rain-fed sorghum	Total	1991	1950	0.52	0.66	0.30		52
		1992	2500	0.51	0.63	0.31	0.5	51
		1993	1610	0.47	0.60	0.30		47
	Toupouri	1992	3110	0.36	0.69	0.20	0.6	36
	Moundang	1992	2150	0.56	0.71	0.30		90
Dry-season sorghum		1991/1992	1000	0.31	0.36	0.25		31
		1992/1993	800	0.34	0.32	0.28		34

Summarising, the experiences of crop farmers in Sub-Sahelian Africa and in intensive temperate zone agriculture are very different. Not only because there is about 5 times lower crop yield in the Sub-Sahel, but also because there is much larger temporal and spatial variability, both within and between fields, as experienced by the subsistence farmer in Sub-Sahalian Africa. In temperate zone agriculture, inter-annual variability per field has now become almost as low as CV = 0.1, with a similarly small variability throughout space, both within fields (ca 20 m^2 plots) and between fields. In contrast, in Sub-Sahelian Africa, inter-annual variability as well as variability between and within fields is 5 times as high. Although unexplained variability between fields in a farmer's village can be as high as CV = 0.35, the administrative gain in perceiving long-term trends in annual yield to be expected from aggregating yields throughout the village, is limited because of the much higher inter-annual variability. If inter-annual variability for an individual field with sorghum is CV = 0.7, and spatial variability is CV = 0.3, variability would be reduced after aggregation to, at most, CV $= (0.7^2 - 0.3^2)^{1/2} = 0.63$.

8.4 Variability in rainfall and in crop and forage producti on

Variability in annual rainfall is highest, within any latitude belt, where mean annual rainfall is lowest, and vice versa (Riehl 1979) (Fig. 8.10). It is high, up to CV = 0.80, in the dry parts of Pakistan with annual rainfall of only around 100 mm. It is as low as CV = 0.20 in the wet parts of Sri Lanka, where mean annual rainfall is mostly well above 1000 mm. Regions with really low inter-annual variability (CV < 0.15) are mainly restricted to the equatorial tropics: Congo Basin, the Amazon Basin, and parts of Indonesia (Riehl 1979).

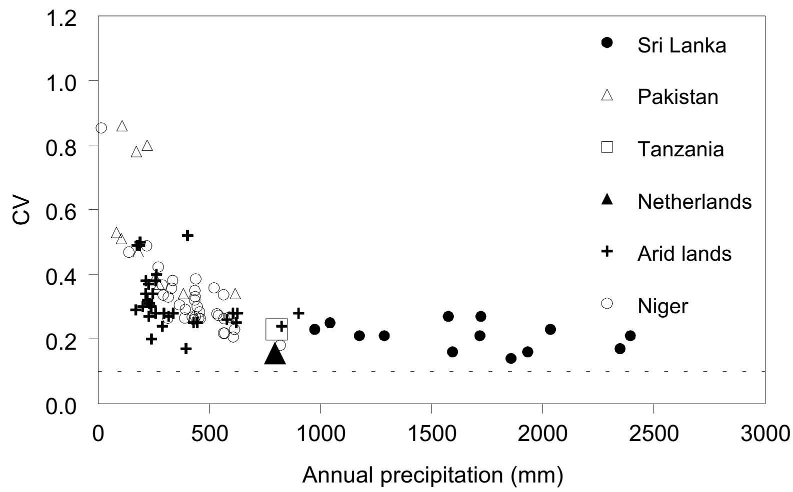


Fig. 8.10 Variability (CV) in annual rainfall plotted against the amount of rainfall (mm per year). The Sri Lanka data refer to time series of annual rainfall at 14 sites in Sri Lanka during a 34 year period (1960-1993) (Domroes 1997). The Pakistan data refer to observations at 10 stations during periods varying from 42 to 133 years per station (Schaefer 1997). The observation for Tanzania refers to Musoma station over the 'nominal period' 1931-1960 (Green 1988). The observation for the Netherlands stems from the rainfall at Zwanenburg, adjusted to Hoofddorp, over the 'nominal period' of 30 years 1949-1978 (Buisman 1978). The data for arid lands from Houérou *et al.* (1988) are a selection from their Table 1 of time series of 10 years and longer, which mainly refers to arid lands in USA and Canada. The Niger data are based on observations at 35 stations in the period 1950-1989 (Le Barbé & Lebel 1997).

Inter-annual variabilities in rainfall are marginally affected by long-term trends. But to account for the recognised variation in climate in the longer term, the World Meteorological Organisation recommends a minimum 30-year data sequence, a nominal period, for 'reliable' means and thus also variabilities to be established. Most series used for constructing Fig. 8.10 span a period of around, or exactly, 30 years.

Seasonality in rainfall is generally higher in tropical areas with distinct dry and wet seasons. Although Tanzania and the Netherlands have around the same annual precipitation, the seasonality is much weaker in the Netherlands (Fig. 8.11). Inter-annual variability in rainfall during the dry months is expected to be higher than that for the wet months, especially where seasonality is more pronounced. In Tanzania inter-annual variability for the dry month of June, for instance, is as high as CV = 1.74 (1931-1960) (annual CV = 0.23), whereas inter-annual variability for the driest month in the Netherlands (May) is only CV = 0.50 (annual CV = 0.16).

In fact, it is necessary to focus on inter-annual variability in rainfall for time intervals shorter than a year in order to understand how rainfall affects inter-annual variability in crop production. In tropical areas with pronounced seasonality the crop-growing period can be as short as 100 days (Biswas 1997). But in areas where rainfall is highly erratic in intensity and amount, both in time and space, it might even be necessary to use time intervals as short as a week or ten days over which rainfall data should be aggregated. The shorter the time interval (season, month, week), the larger the inter-annual variability and the stronger the positive skewness in rainfall frequency distributions. For dry areas it would be wise to infer the probability of rainfall from these skewed frequency distributions for weekly intervals even (Biswas 1997). Monthly rainfall data would not suffice here, because during the monsoon season, daily rainfall varies immensely and a month's rainfall may come in only a few days. Such irregular distribution of rainfall may cause irreparable damage in the early stage of a crop's life cycle.

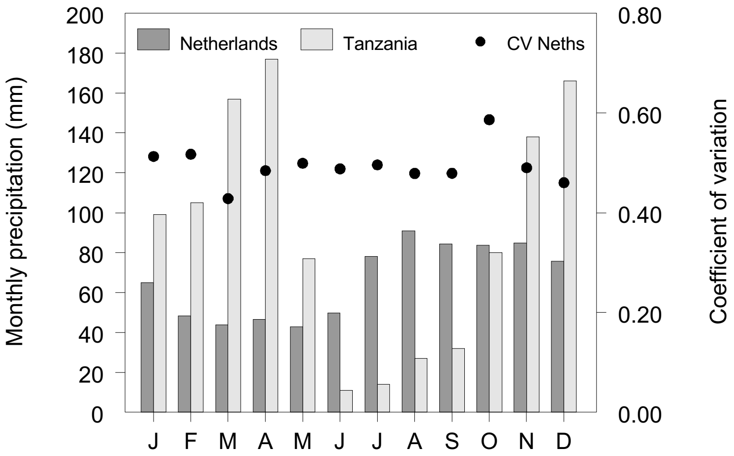


Fig. 8.11 Mean (AM) monthly precipitation at Zwanenburg, the Netherlands, adjusted to Hoofddorp for the 30-year nominal period 1949-1978, and at Mwanza, Lake Victoria, Tanzania for a 20-year period, together with the inter-annual variability (CV) in monthly rainfall (basic data for the Netherlands from Buisman 1978, for Tanzania from Crul 1995).

In many dry and poor areas farmers have to rely on rainfed crop production in the absence of proper irrigation facilities. This certainly holds for the dry areas in sub-Sahelian West Africa, where millet and sorghum are major crops. In those areas where the average length of the rainy season, being the period in which precipitation exceeds evaporation, becomes less than 50 days, millet and sorghum then occupy about 80% of total cultivated area (Elston 1983). Here, inter-annual variability in rainfall is certainly expected to translate most directly into inter-annual variability in crop production. In Nigeria for instance, inter-annual variability in rainfall explains more than 50% of the variability (CV = 0.08) in the yield of sorghum averaged for the whole of the country during the 13-year period 1966-1978 (Fig. 8.12) (Elston 1983).

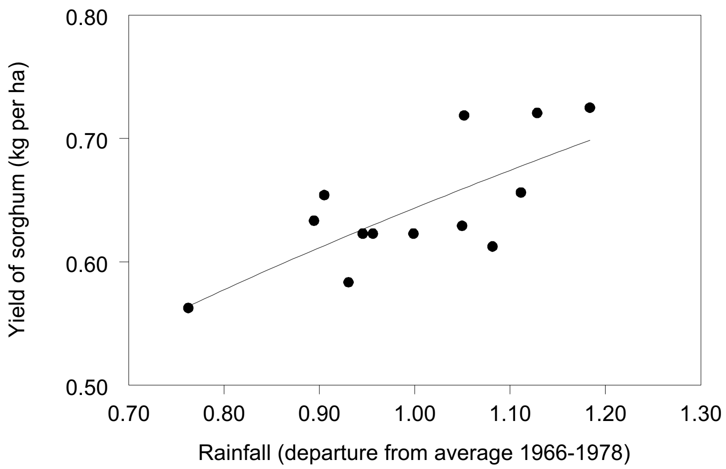


Fig. 8.12 The relationship between annual yields of sorghum averaged for the whole of Nigeria (Y, tonnes per ha) and rainfall indexed with the departure (multiplier) from the average of the May to October rainfall (R), 1966-1978. $^{10}\log Y = -0.191 + 0.487\,^{10}\log R$ ($R^2 = 0.55$, $p < 0.01$). Data from Elston (1983).

The more intensively managed crop production in temperate zone agriculture is much less affected by inter-annual variability in rainfall. Few studies, however, have quantified the smaller, but still present, impact of environmental variability. The proportion of total variance in annual crop production explained by the variability in rainfall has become small relative to that explained by the steep trend in crop yield from an ever more productive agriculture. For example, in Kalamazoo county, Southwest Michigan, USA, the increased use of fertiliser, improved crop varieties, herbicides and pesticides all contributed to an increase in the yield of maize by a factor of 2 – 3 over a 40-year period, from about 1.8 tonnes per ha in 1945 to about 4.8 tonnes per ha in 1985 (Crum *et al.* 1990). Inter-annual variability in the yield of maize, after detrending and averaged for this county, was CV = 0.16. After correcting for the long-term trend, Crum *et al.* found only very weak correlations between yield of maize and annual rainfall in Kalamazoo county (1945-1985, average 855 mm per year). Even when reducing the time interval to the most critical two-month period (July-August), rainfall explained only 5% of the residual variance in detrended annual yield figures. So in comparison with dryland agriculture, the effect of rainfall on crop yields in western, temperate zone agriculture is hardly detectable. In western agriculture only years which are extremely dry or wet might cause apparent crop damage, if no additional efforts are made to manage water supply.

As with crops, forage production in dryland areas is greatly influenced by inter-annual variability in rainfall. Comparing forage production at semi-arid and arid sites, 79% of inter-annual variability in rangeland production within the Mediterranean, and 80% within the Sahelian-Sudanian region, could be explained by variability in annual rainfall (Fig. 8.13) (Le Houérou & Hoste 1977). For the same geometric mean rainfall of around 300 mm per year, rangeland production was, according to the relationships established here, 1.28 times as high in the Mediterranean (166 FU/ha) as in the Sahelian-Sudanian region (130 FU/ha). The higher efficiency in the Mediterranean is explained by the lower evaporation in this more northern area (Le Houérou & Hoste 1977). For another series, from 77 sites in arid and semi-arid rangelands, the relationship between primary production and annual rainfall was less strict with only 34% of variance in primary production explained by variability in rainfall (Fig. 8.14). The greater range in production for the same rainfall category in these series may be due to the incorporation of more temperate zone sites from the USA and Canada into the second series, where evaporation is lower even than in the Mediterranean.

How variability in annual rainfall (CV_R) translates into variability in forage production (CV_P) depends on the shape of the relationship between production and rainfall. Le Houérou *et al.* (1988) named the ratio between the two variabilities the Production to Rain Variability Ratio (CV_P/CV_R) and calculated this for a series of rangelands in arid and semi-arid areas. If the relationship is linear and production is simply proportional to rainfall, this ratio approaches unity (1:1). But for many rangelands the ratio is larger, up to 2:1 and more (Fig. 8.15). This implies that that there is an upward curvature in the relationship between production and rainfall.

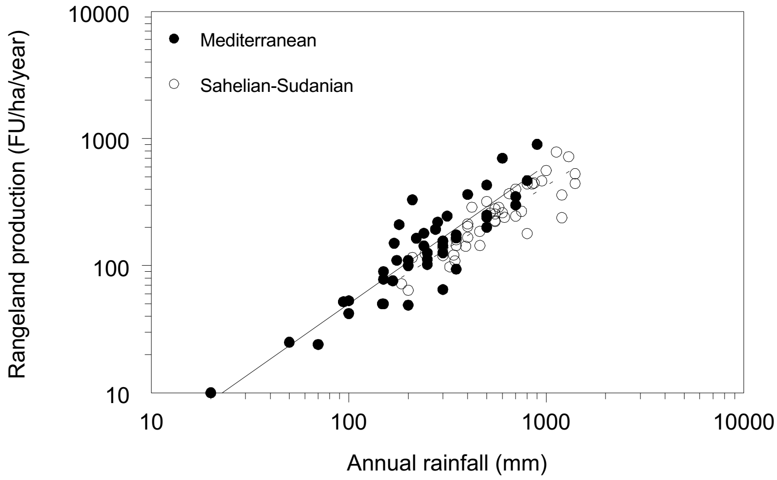


Fig. 8.13 Annual production of rangeland (FU/ha) plotted against annual rainfall (mm) for 45 sites in the Mediterranean and 43 sites in the Sahelian-Sudanian region (Data from Table 1 in Le Houérou & Hoste (1977)). 1 FU corresponds to 1 kg of barley and to 1650 Kcal for adult ruminants consuming roughage. Mediterranean: -0.484 + 1.092 $^{10}\log R$ ($R^2 = 0.79$); Sahelian-Sudanian, excluding the outlier of North Sanam, Nigeria: -0.321 + 0.983 $^{10}\log R$ ($R^2 = 0.80$).

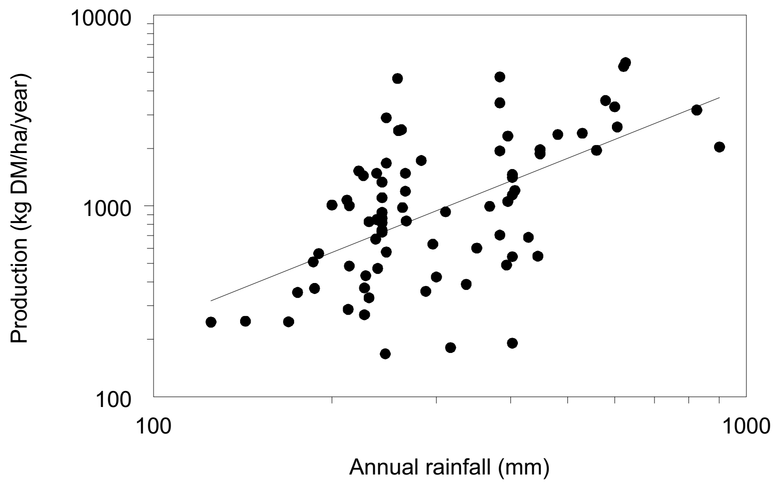


Fig. 8.14 Primary production (P, kg DM per ha per year) of rangeland plotted against annual rainfall (R, mm) per site for the series in Table 1 in Le Houérou *et al.* (1988). $^{10}\log P = -0.0986 + 1.241\ ^{10}\log R$ ($R^2 = 0.32$, n = 77).

In the driest areas, with rainfall down to 200 mm per year, variability in rainfall is around $CV_R = 0.3$ (Fig. 8.15). Nomads will thus experience at least this variability in their forage base.

In conclusion, inter-annual variability in forage production in rangelands is at least as large as in rainfall. Nomads in these areas will thus experience inter-annual variability in the carrying capacity of their rangelands between CV = 0.3 and 0.6 at least.

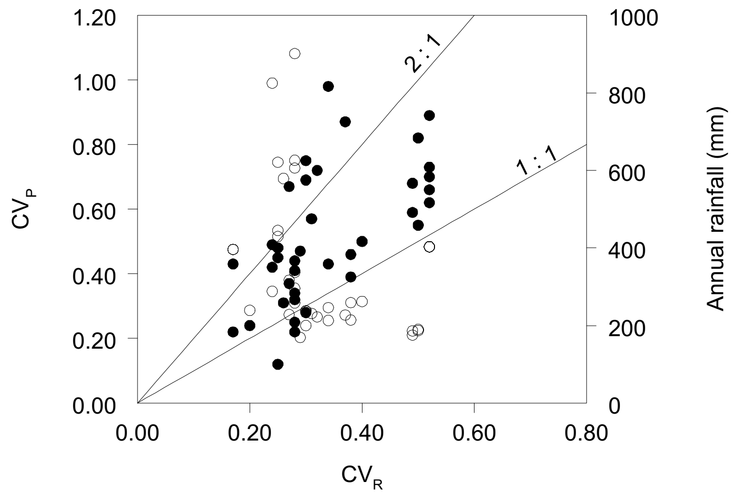


Fig. 8.15 Inter-annual variability in forage production (CV_P, closed symbols) and annual rainfall (mm per year, open symbols) plotted against variability in rainfall per rangeland (CV_R) as listed in Table 1 in Le Houérou *et al.* (1988). Only sites with time series of 10 years and more were selected.

8.5 Rainfall, nomadism and tracking ecosystem changes

Just as are crop farmers, nomads in the arid and semi-arid areas of Africa are greatly dependent on rainfall for the productivity of their resource base. Nomads, however, are supposed to be able to cope with drier, more stressful periods by their movements through large areas. The situation to be described and elaborated on here, in order to assess inter-annual variabilities in resource outcome as experienced and reacted to by nomads, is that of the Maasai in eastern Kajiado, Kenya (Bekure *et al.* 1991).

The nomadic Maasai live in an area with low annual rainfall (550 mm per year), which according to Fig. 8.10 would correspond with an inter-annual variability in rainfall of circa CV = 0.3. The duration of the annual growing season, which was actually a summation of two distinct rainy seasons per year, was calculated from rainfall data (1935-1984). This duration was almost normally distributed around an average of 2.9 months (CV = 0.39) (Fig. 8.16). Annual forage production was estimated from the duration of the growing season via model relationships (Potter 1985, de Lee & Nyambaka 1988, both in Bekure *et al.* 1991) (Fig 8.16). The relationship between forage production and length of the growing season shows as a weakly S-shaped curve, and was almost proportional. Inter-annual variability in forage production (average 1.93 tDM/ha/yr) during the 30 year period was CV = 0.51. This variability is similar to the variability in forage production in dry areas world-wide of around CV = 0.5 (see Fig. 8.7). Years were subsequently categorised on the basis of their forage production (t DM/ha/yr) as: "very low" < 1, "low" 1.0 - 2.0, "medium" 2.1 - 3.4, and "high" > 3.4.

Nomads crop the forage production via their cattle, whose milk is a much more important resource outcome than beef. Inter-annual variability in forage and in milk production per cow is roughly proportional to that in the length of the growing season (Fig. 8.16, Table 8.5). Total resource outcome as litres of milk per herd, however, may vary more, because cow mortality was higher in the drier years. This mortality could be as high as 40% when forage production was less than 1 ton per ha and forage conditions were "very low". Under "low" conditions mortality was 9%, and under 'medium' and "high" conditions only 5%.

The consequences of the stressful, very dry years were larger for nomads with smaller herds (30 head of cattle), because these nomads had proportionally more cows and calves in their herds and these classes of stock are more likely to die during drought. One traditional drought-adaptation strategy is that of keeping large numbers of animals, yielding less milk per cow. It increases the probability of a quick regeneration of the herd after a drought. Rich nomads herd 300 head of cattle.

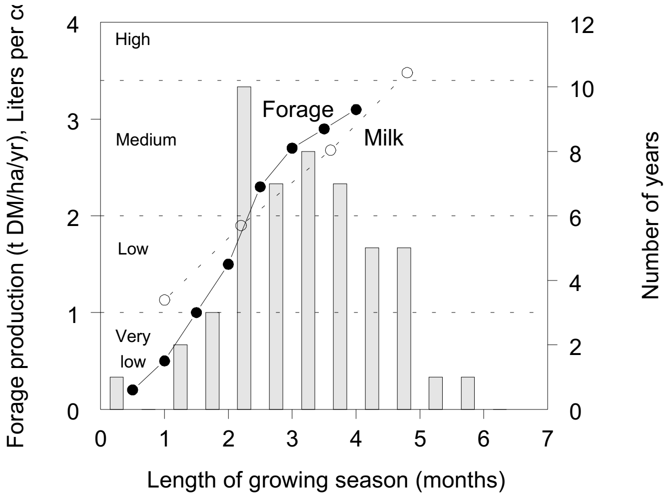


Fig. 8.16 Annual forage (tonnes DM per ha) and milk production (liters per cow with calf) as related to the length of the growing season (months) (left Y-axis) and the frequency, as number of years per duration category, of growing season (1.25 = 1 - 1.5 etc) (right Y-axis). Based on data presented in Figs 10.1, 10.4 and 10.5 in Bekure *et al.* (1991).

Table 8.5 Rainfall, length of growing season, forage production, milk production and cow mortality for year types grouped by resource class (see text for criteria for grouping) (based on data in Tables 10.4 and 10.5 in Bekure *et al.* 1991).

Year type grouped by resource class	Rainfall ($mm.yr^{-1}$)	Length of growing season (months)	Forage production ($t DM.ha^{-1}.yr^{-1}$)	Milk production per cow with calf ($litres.y^{-1}$)	Mortality of cows (%)
Very low	307	1.0	0.4	113	40.0
Low	404	2.2	1.4	190	9.1
Medium	664	3.6	2.8	268	5.2
High	830	4.8	3.9	348	5.4
Mean	550	3.0	2.3	234	10.3

Inter-annual variability in actual herd size (CV = 0.14) was circa 2.5 times as low as in permissible herd size, based on the variable carrying capacity of the resource area (Fig. 8.17). Based on forage production, the average capacity for a 10,000 ha group range was estimated as able to carry 6026 TLU (CV = 0.36), so circa 0.6 TLU per ha, where 1 TLU (Tropical Livestock Unit) = 1 standard animal of 250 kg. This theoretical average hardly differed from the actual average herd size observed (5595 TLU). Since over the full range, milk production per cow seems only slightly less variable than the length of the growing season (Fig. 8.16), and average herd size is larger in years with a longer growing season, inter-annual variability in actual milk production totalled for the whole of the area will still be close to that in the length of the growing season (CV = 0.51). This variability is many times larger than that in actual herd size (CV = 0.14).

So although nomads use mobility and herd size as stabilising strategies, inter-annual variability in resource outcome for a 10,000 ha group range is still as high as that experienced by a subsistence farmer growing millet or sorghum in Sub-Sahelian Africa. According to Gilles & Jamtgaard (1981) Maasai herders in East Africa must therefore have access to between 120,000 and 200,000 hectares of rangeland to really cope with this situation of high temporal and spatial variability.

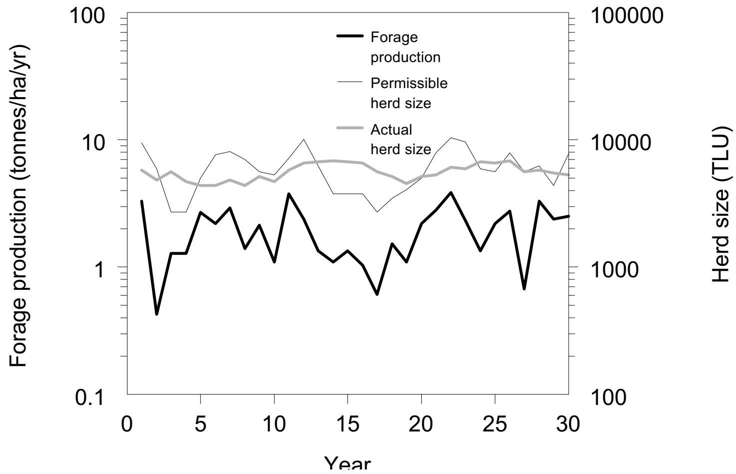


Fig. 8.17 Fluctuations in forage production and in permissible and actual herd size for a 10,000 ha group range over a 30-year period (based on Fig. 10.4 and 10.7 in Bekure *et al.* 1991). 1 head of cattle = 0.7 TLU, 1 goat or sheep = 0.1 TLU, 1 camel = 1.0 T LU.

Besides mobility, control over water or dry season pasture has always been a major component of traditional African range management strategies (Gilles & Jamtgaard 1981). While pastures are typically held in common, water points may be attached to groups of families who have "rights" to their use. By controlling access to certain wells, these family groups could protect adjacent pastures from overgrazing in periods of low rainfall. These territorial organisations and controls on range use were disrupted when, in the 1970s, African governments with the aid of foreign donors launched massive water development programmes to expand the amount of pastureland that could be grazed in the dry season. It decreased mobility of livestock and lead to environmental problems, particularly soil degradation (Gilles & Jamtgaard 1981). Restoration is a slow process because of hysteresis in the trajectory back to recovery of the vegetation cover (Rietkerk 1998). This hysteresis thus prolongs the time window in which the effects of measures taken can be perceived.

Given the large inter-annual variability in resource outcome, it is difficult to separate the enduring effects of livestock impact on environmental quality from climatic fluctuations without proper long-term monitoring data (Niamir-Fuller 1998). This author expresses the same worry about the capacity for trend detection, as articulated in Chapters 2 and 3 of this study, which comes down to the limited capacity of resource users to distinguish the human impact on resource dynamics from the effect of environmental variability.

Niamir-Fuller (1998) points out the need for proper monitoring of the arid zones of Africa with indicators that are sensitive to ecosystem variability, productivity and resilience, while at the same time lending themselves to easy and rapid monitoring. Such monitoring the author suggests could build on existing indigenous knowledge of spatial and temporal variability in the livestock and forage base, as organised around categories of nomenclature, descriptive knowledge, classification, and analytical knowledge of interactions and causality. Spatial knowledge of nomads is organised around the classification of ecological patches, such as different pastures and key sites. Temporal knowledge of each of the patches and key sites indicates how productivity and value of the site change with time. Most nomadic groups do not impose strict time limits on the grazing of a particular pasture, but will move when specific indices show high grazing pressure. This implies that short-term evaluations of ecosystem quality can be made on the basis of monitoring tracking indicators (Table 8.6) (Niamir-Fuller 1998).

Whether long-term trends are perceived as clearly is unlikely given the intra-annual variability in resource outcome as estimated above (CV = 0.5). Moreover, Ferandez-Gimenez (2000) concludes from her study of the ecological knowledge of Mongolian pastoralists, that they have great understanding of spatial patterns and of small-scale temporal patterns, for which they also have the social mechanisms to react (see her Table 2), but that they hardly recognize a connection between recent changes in land use patterns and future pasture degradation. For them, degradation is either an inevitable process of earthly aging or a temporary and reversible phenomenon.

Table 8.6 How pastoralists track time variable ecosystem processes, where a distinction is made between temporal environmental variability (noise) and environmental degradation (signal, trend) (selection from Table 10.1 in Niamir-Fuller 1998, for references see there).

Tracking ecological processes	Variables	Indicators
Temporal environmental variability	• Describe changes with drought and other rainfall variation in plant community • Predict future changes • Morphology and phenology of plants that allow resistance to stress and adaptation to drought	• Vegetation diversity • Specific indicator plants • Vegetation cover • Livestock behaviour • Preceding season's meteorological conditions
Environmental degradation	• Classify type of degradation • Classify stages of degradation • Causes	• Specific indicator plants • Plant composition • Soil cover and compaction • Grazing pressure (trampling, faeces) • Livestock behaviour (especially milk yield)

There are enough examples, other than that of pastoralism in Africa, which also demonstrate that monitoring and evaluation of ecosystem quality on a short-term basis is incorporated into the management of common pastures. In Peru, for example, dry season grasslands (*bofedales*) are common pastures, which are located above 3600 metres and the use of which is controlled by groups of families. The wool production of animals pastured on the *bofedales* is closely monitored and stocking rates are adjusted when declines in productivity occur (Flores-Ochoa 1968, Palacios Rios 1977, both in Gilles & Jamtgaard 1981). In Switzerland common grounds are generally limited to seasonal pastures (*alps*) with low and/or variable yields of forage. A few villagers care for all the animals, which graze on *alps*. Weekly milk and cheese production is closely monitored so that any decline in the quality or quantity of grass is easily observed. Overgrazing is largely prevented here by community regulation that limits the number of animals that may be placed on the commons to those that can be fed through the winter on hay produced in village hay meadows (Netting 1972, 1976 in Gilles & Jamtgaard 1981).

In conclusion, nomads are able to rationalise their resource use in the short-term within years via the most integrative way in which they value the state of the ecosystem from a number of directly observable indicators. This instant census of the terrestrial environment has no equivalence in fisheries, where signals from the aquatic environment must be captured more indirectly, mainly from developments in catch rates. Whether and how nomads track ecosystem changes and developments in their resource outcome in the long-term of many years, and whether and how they evaluate and react to these developments is still difficult to tell. Large variability and hysteresis in the trajectory back to recovery, in any case make it hard to perceive a step trend in resource outcome after a change in management.

8.6 Variabilities, trends and the feeling of insecurity

In agriculture, as in fisheries, there appears to be a broad range in inter-annual variability in resource outcome as experienced by individual farmers (Fig. 8.18). It ranges from small variability in the yield of wheat as experienced by a crop farmer in the UK (CV = 0.14) to a variability as large as CV = 0.70 in the yield of millet and sorghum as experienced by the crop farmer in the arid areas of Sub-Sahelian Africa. Although the highly controlled production modes in temperate zone crop farming have greatly reduced inter-annual variability, the application of more homogenous production material has brought about some increase in inter-annual variability more recently (Hazell 1989). Just like crop farmers, the nomads of arid areas experience high variability in resource outcome, in their case in the annual milk production by their herds (circa CV = 0.5). Variabilities are lower for larger administrative units, but for some crops and countries, variability at the village level remains high, such as for sorghum in Africa and wheat in Australia and the former USSR.

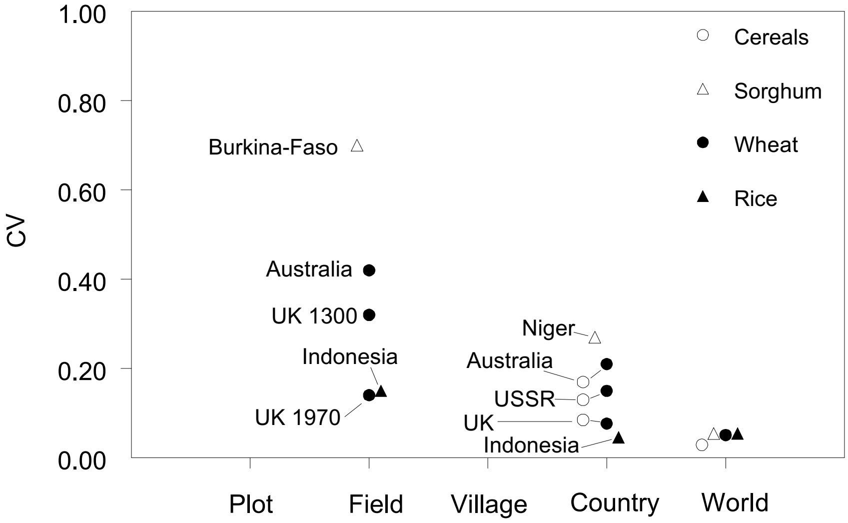


Fig. 8.18 Inter-annual variability in crop yield at three spatial scales (field, country, world). For cereals, variability is based on the residuals in detrended series for total production. Data are from Hazell (1989), except for field level sorghum in Burkina-Faso (Fig. 8.6), wheat in Australia (Fig. 8.5) and the UK (Austin & Arnold 1989) and rice in Indonesia (Fig. 8.5), and for country level sorghum in Niger (Fig. 8.3).

Because of the low inter-annual variability in crop yield (CV = 0.1) that they experience, western crop farmers are alert to relatively small trends and step trends in their annual yield. Also, in contrast to a fishery, there is no lag phase, except for improvements in soil quality, and the response to a change in management is direct. In a time window of 10 years, with 5 years before and after the change in management, the low variability of CV = 0.1 already enables the perception of yield improvements of 10-20%. See section 6.5 for references to fisheries under the same standard conditions for trend detection ($\alpha = \beta = 0.1$). The high variability (CV = 0.5 – 0.7) in resource outcome in dryland areas on the other hand, both for crops and for nomadic herds, implies that only improvements by at least a factor of 3 can be perceived here in a time window of 10 years. Long-term downward trends due to soil degradation will also be difficult to perceive and so is, given the histeresis in the trajectory to recovery (Rietkerk 1998), the effectiveness of management measures taken. No wonder that perceptions about long-term trends for the same area could differ so strongly (Pearce 2001).

Given the high inter-annual variability in resource outcome, it is no wonder that crop farmers and nomads in dry land areas look for all sorts of ways to stabilise their income. They cannot easily tap different resources simultaneously to obtain a kind of ‘portfolio effect’, from their independent fluctuations, unlike many fishermen who target a number of fish species at the same time. Crop farmers spread their risks more through space and time. Some of them till several fields spaced at a distance of several kilometres to average out some of the variability in crop yield due to the very patchy patterns in rainfall (Graef & Haigis 2001). In a series of drier years the extent of such an area could become out of reach of their individual mobility, when the number of rain events is reduced instead of the amount of rainfall per event (Le Barbé & Lebel 1997). By inter-cropping early and late varieties of millet risk is spread over time (Brouwer *et al.* 1993).

Short-term trends of several years (blue noise), so well-known from fisheries as confusing the perception of any long-term trend, will be less common in dryland agriculture, because annual rainfall is supposed to fluctuate in a random manner in most situations (white noise). Unfortunately, it is just in arid areas with already high inter-annual variability in rainfall, that persistence is more pronounced (Le Barbé & Lebel 1997). Short-term trends in annual rainfall in these dry areas of around 5-10 years (red noise) not only translate into persistent changes in crop production but also into river runoff and therefore in fish yield, as, for example, along the River Niger in Niger, sub-Sahelian Africa (see Fig. 6.31). These short-term trends will possibly obscure the long-term downward trend in rainfall predicted for the Sahel over the next 30-60 years, on the basis of Global Circulation Models (Brouwer & Outtara 1995). People now respond rather instantly to periods of above average rainfall and migrate to normally drier and less populated areas, as was observed in the Tahoua District in Niger (DDE-Tahoua (1993) in Brouwer & Outtara (1995)). These migrants remain in these areas even when rainfall drops, thus increasing the pressure on wetlands which are the scarce natural resources with lower production risks (Brouwer & Mullié 1996).

Where environmental variability is large, it not only obscures possible long-term trends and step trends, but also provides the resource user with a feeling of insecurity. Although fishermen might be very uncertain about their next day's catch, it is no indication whatsoever of the variability in their annual totals. The uncertainty for a crop farmer, however, is concentrated in his annual yield, which in dry land agriculture very much depends on the size and arrival of the rains. The sorghum farmer in the Sub-Sahel has to see whether enough rain, whose distribution in this area is so patchy in space and time, falls on hís crop at the ríght time of the season. His feeling of insecurity must have grown even during the persistent series of dry years in the Sub-Sahel since 1970, since it was the number of rain events that decreased, not the length of the wet season or the amount of rainfall per event (Le Barbé & Lebel 1997). The average time interval between two rains must thus have become longer. In combination with the unpredictability of the time of arrival of these rains, this makes for a most uncertain world to live in.

The strong feeling of insecurity of Sub-Sahelian farmers might be reduced to some extent if they could be informed about rainfall forecasts for their area. It has indeed become possible to forecast seasonal rainfall for the Sub-Sahel one year ahead on the basis of oceanic sea surface temperature anomalies, but only in three categories as yet: wet, normal, dry. Institutional analysis has shown that even remote farmer communities could be reached to disseminate this particular information in time (Kirshen & Flitcroft 2000). But the patchiness in rainfall at the smaller spatial scale and the randomness in the arrival of the rains will always leave a major feeling of insecurity for the individual farmers. This cannot be overcome, because modelling and forecasting rainfall with high spatial and temporal resolution is still out of reach for many years to come.

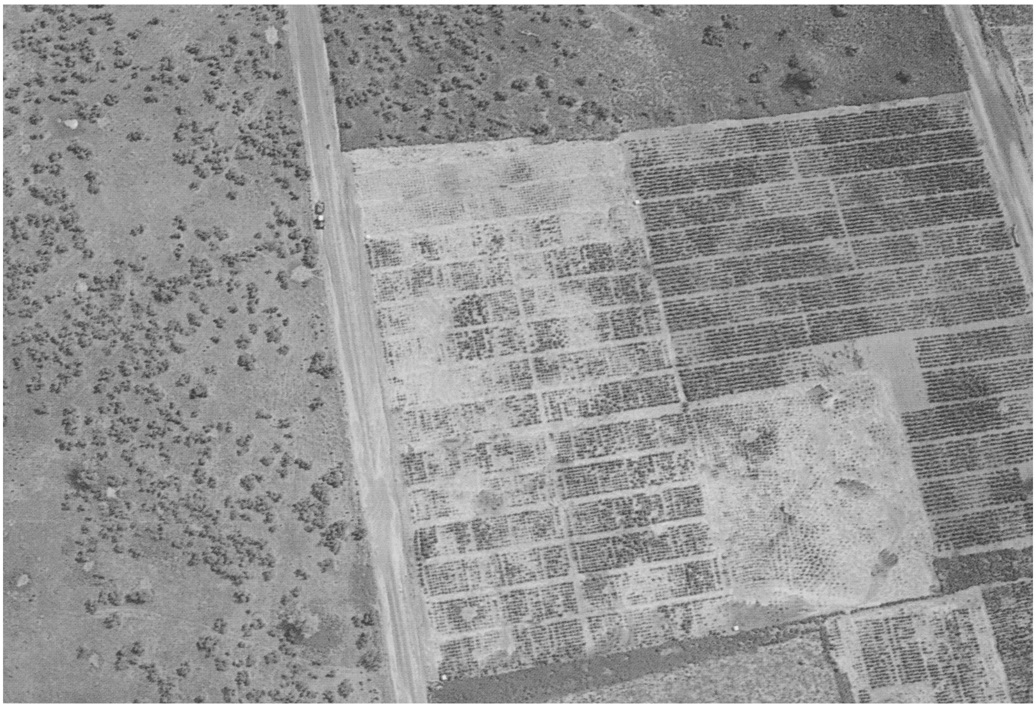
Nomads must also have a strong feeling of insecurity. In the smallest time window of one year, or one season, they are certainly capable of responding quickly to environmental changes, as can be seen from their subtle use of the type of vegetation as environmental indicators (Niamir-Fuller 1998, Table 8.6, Fernandez-Gimenez 2000 her Table 2). But, at the larger time scale of many years, such local knowledge seems of little direct value in their resource management (Fernandez-Gimenez 2000). It does not guide them towards greater security. In their study of the Jallube, a clan of the nomadic Fulani of West-Africa, de Bruijn & van Dijk (1995, pages 10-11) described how these nomads share an attitude of dealing with insecurity in the short-term, not wanting to foresee but to hope for the best in their unpredictable future. These nomads even feel depressed and anxious and define past and future securities in terms derived from religious and customary ideologies.

Finally, the individual crop farmer in dryland areas of the Sub-Sahel and the fisherman operating a fishery with a highly uncertain annual outcome must also differ in their perception of causal relationships between their resource outcome and the environmental variability. The crop farmer can attribute the variability in his crop yield to the amount of annual rainfall and its distribution over the year. The fisherman, however, is not able to relate the variability in his annual catch to one environmental variable, that he might observe independently of his catch. The, mostly subtle, mechanisms behind the formation of year-classes are beyond his observational and cognitive capabilities. Only the river fisherman who catches fish in the floodplains of rivers with largely unpredictable runoff, could learn by experience how the size of his annual catch relates to total river runoff. Just like the crop farmer, he awaits the rains, and then knows some time in advance to what extent the floodplains will be inundated and fish will become available. One example is that of the floodplains of the River Mahakam, Kalimantan, Indonesia, where more than 80% of the variance in annual catches is explained by the number of days in the previous year when the height of the river was at more than a particular level (Christensen 1993).

8 Variabilities and the perception of trends in agriculture - Conclusions

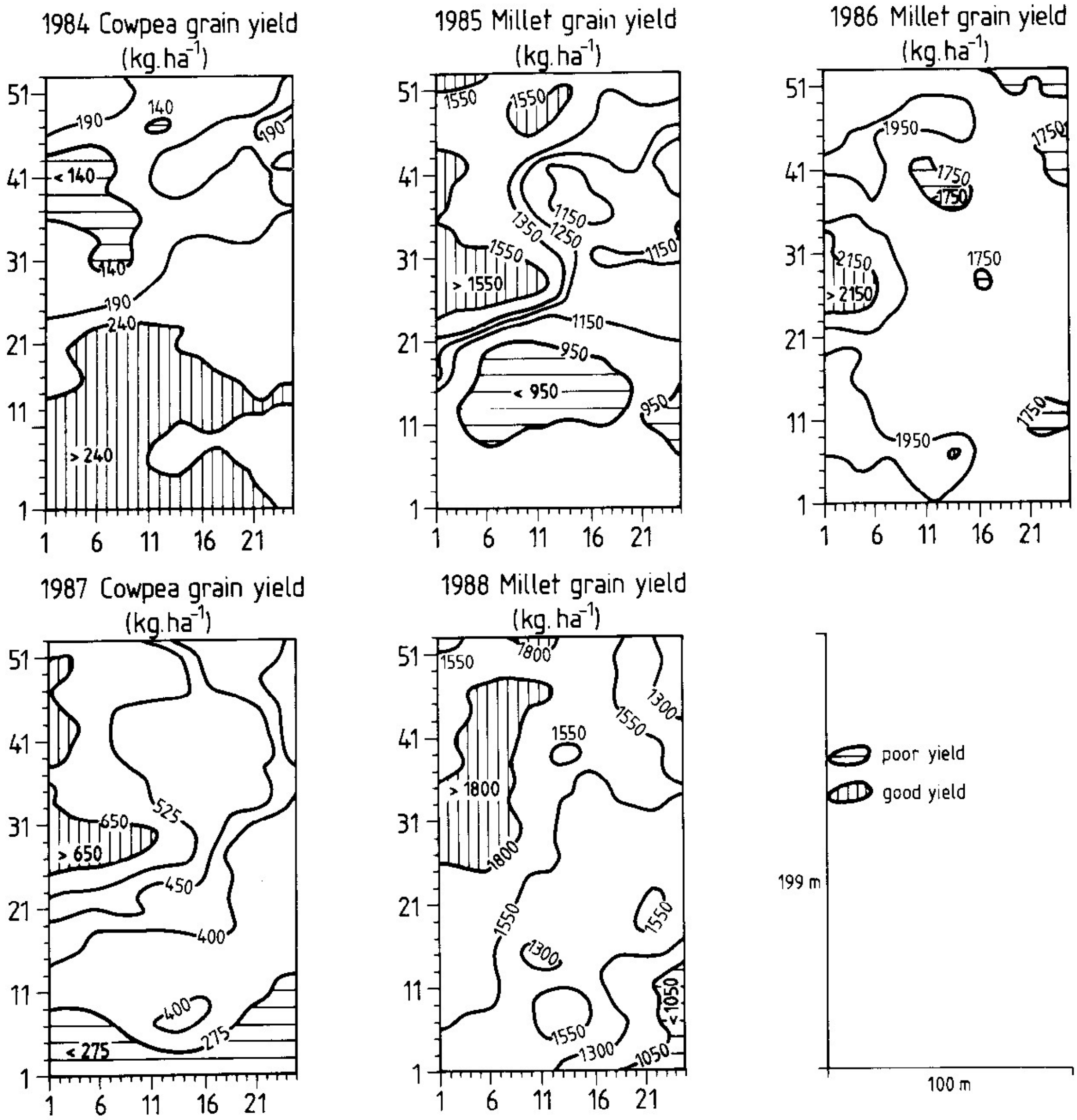
- Inter-annual variability in crop yield per farmer's field ranges between CV = 0.1 in highly productive, intensively managed agriculture up to CV = 0.7 in marginal, rainfed agriculture. Nomads in dryland areas experience inter-annual variability in resource outcome - milk production of their herds – almost as that high as in rainfed agriculture, CV = 0.5.
- Variability is reduced when the yield is averaged for larger administrative spaces, but for some countries inter-annual variability per crop type could still be as high as CV = 0.2 or more.
- Farmers in rainfed crop agriculture look for all kinds of ways to stabilise their production, amongst others by tilling several fields spread through the area, thus reducing the variability that also arises from spatially, erratic rainfall patterns. Variability in terrain structure within one field is another mechanism by which yields are stabilised, because local, although less fertile, depressions in a farmer's field guarantee some crop production in dry years.
- Downward trends due to soil degradation and step trends after a change in farm management are most difficult to perceive in rainfed agriculture, because of high variability and of 'red noise' in annual rainfall. Further, as in fisheries, there is a lag phase before the annual yield responds to a measure taken to improve soil quality.
- With inter-annual variability in rainfed crop production higher than CV = 0.5, only step trends of more than 50% can be perceived in a time window of 10 years under boundary conditions $\alpha = \beta = 0.1$. Agricultural extension programmes should account for the farmer's weak perceptions through time, but in contrast to fisheries, the effectiveness of a change in farm management is easily seen from fields at an experimental station (space).

Box 8.1 - Spatial patterns in crop production within a farmer's field



Top: Millet growth in experimental fields in Niger; left natural soil variability, to the right variability has been reduced by blanket application of phosphorus (Fig. 8 in Brouwer & Bouma 1997). Bottom: Field with wheat in Groningen, the Netherlands.

Box 8.2- Space-time variability in crop growth within fields



Year-to-year variability in the spatial distribution of pearl millet and cowpea in a field at ICRISAT Sahelian Centre, Niger, during 1994-1998 (Fig. 2 in Brouwer *et al.* (1993)).

Chapter 9

Variabilities and the perception of time trends in Dutch whaling in the 17th and 18th century

In this chapter:

- The Dutch whaling industry in the 17th and 18th century, targeting bowhead whales between Spitsbergen and Greenland and in Davis Strait, is described as the most well documented exploitation of a natural resource in Dutch history. **9.2**
- Variability in annual catch rates between whalers and within years is characterised, as is the effect on the catch frequency distribution of the fact that some whalers lingered in the whaling grounds, hesitant to return home with zero catch. **9.3**
- Catch records of individual commanders are compared to test for possible significant differences in whaling success. **9.4**
- Long-term trends in annual catch rates are assessed as are variances and persistence in the residuals around such trends. **9.5**
- The 19th century whaling for bowheads is described as the last stage of a once important fishery, in order to assess how inter-annual variability possibly increased once catch rates and fleet size decreased. **9.6**
- Capacities of individual commanders to perceive a long-term trend from their own catch record, and of administrators from the averages for the fleet, are assessed on the basis of statistical power analysis. Trends in the size of whales caught, indexed with the number of casks of blubber obtained per whale, are also evaluated. **9.7**
- The consequences of the, on average, low but highly variable profitability of the whale fishery for the investment strategies are discussed, as is the displeasure of some that information about the low overall profitability would become widely available. **9.8**
- It is discussed how methodological constraints in data processing and evaluation of the 17th and 18th century could have hindered the full use of data available for rational exploitation of the resource in biological and economic terms. **9.9**

9.1 Introduction

Downward trends in the catch rates of large whales during the 20th century, up to the 1983 worldwide ban on whaling are now evidently clear and dramatic (Box 9.1). The exploitation of the large whales was far from sustainable, but whaling effort was not, or very little reduced in view of these downward trends. Various factors will have contributed to the reckless stock depletion of the blue and fin whales successively. One factor must have been the poor perception of developments in resource outcome by those operating at a more local scale, with larger inter-annual variability in their catch rates than in the annual series averaged for the world as a whole. Further, clear graphical display of these series as, for instance, constructed by Payne (1968) may not have been available in time.

Moreover lessons on sustainable exploitation of whale populations did not necessarily have to be learned from the developments in 20th century whaling. The stocks of deep-bodied baleen whales - the northern and southern right whale and the bowhead whale - had already been depleted earlier. Their large size, slow, and fairly predictable movements, coastal distribution, and the fact that they floated when dead, made them the prime target of early European whalers (Perry *et al.* 1999).

Already, around 1100, the Basques had started whaling for the northern right whale from small open boats in the Gulf of Biscay. Later they moved to the shores of Labrador and Newfoundland to chase the stock of northern right whales in the north-western Atlantic, when the stock in the eastern Atlantic became depleted. Their whaling activities ended when, at the end of the 17th century, the stock in the north-western Atlantic also became depleted, after they had caught 25 – 40,000 northern right whales within an 80-year period, circa 300 – 500 per year on average (Perry *et al.* 1999). Meanwhile, northern right whales were also hunted more to the south, off the Eastern United States. Reeves *et al.* (1999) estimate that as many as 4607 northern right whales could have been caught there in the 38-year period from 1696 – 1734, circa 120 per year. By the end of the 18th century, however, this fishery also collapsed (Reeves *et al.* 1999). Therefore the French and later the English, started to search for southern right whales in the South Atlantic. In the North Pacific the Japanese had already started whaling for the northern right whale at the end of the 16th century (Perry *et al.* 1999). Due to intensive whaling after 1820, the stocks of the northern right whale in the Pacific had become depleted by the end of the 19th century. At present only a few 100 northern right whales remain in both the North Atlantic and the North Pacific (Perry *et al.* 1999, Aron *et al.* 2000).

The whaling for the bowhead whale, *Balaena mystecetus*, and especially the exploitation of the stock near Spitsbergen is a mainly Dutch story. At the beginning of the 17th century the Dutch started exploitation of the bowhead whale in the Eastern Arctic between Spitsbergen and Greenland. They hired Basques as crew to advise them on the hunting of this slow-moving baleen whale with the most northern distribution. The Dutch fleet of around 150 whalers dominated whaling for bowheads for almost two centuries. From 1719 onwards they also started exploiting on a distinct stock of bowheads in Davis Strait between Greenland and Canada. The Dutch dominance lasted until the end of the 18th century, when their position as a whaling nation was taken over in both areas by the English in the Eastern Arctic, and when the Americans started bowhead whaling in the Western Arctic.

The stock of bowheads near Spitsbergen is believed to be almost extinct now (Jonsgård 1981). At the beginning of the 20th century the last whalers headed for the Arctic to catch bowheads. By that time the number of bowheads was reduced to such an extent that in the Eastern Arctic only 1 bowhead was caught per voyage on average. These last bowheads were caught with steam-powered catcher boats and with the cannon-fired, explosive-head harpoon that was invented by Svend Foyn in 1864. Halfway through the 17th century, i.e. circa two-and-a-half centuries earlier, catch rates near Spitsbergen had been as high as 5 to 10 bowheads per voyage. These bowheads, were however at that time still caught with hand–held harpoons thrown from small rowing boats. This simple technique endured for almost two centuries. So the catchability (q) of the bowheads per voyage as one unit of effort must have been considerably lower then. The relative difference in stock size is thus not easily inferred from the number of bowheads caught per voyage during both eras. The size of the stock near Spitsbergen before exploitation is now estimated at circa 25,000 individuals; the one in Davis Strait and Hudson Bay at 12,000 (Woody & Botkin 1993).

The Dutch whaling for bowheads in the 17th and 18th century is a long story in a large time window as compared to the short stories of around 20 years in which the stocks of blue and fin whales very completely depleted. Catches were meticulously recorded and average annual catch rates were calculated as Catch per Unit Effort (number of whales per vessel and voyage) from 1669 onwards. From 1719 onwards everybody could obtain lists printed each spring, naming the vessels which had just left for the Arctic, and with an open space left to fill in the number of whales caught and the number of casks of blubber brought home by the whaling vessels returning in late summer. Two major publications on Dutch whaling both list average annual catch rates per vessel (Zorgdrager 1729, van Sante 1771), and van Sante 1771 even contains a complete overview of individual catch rates per commander, the captain of the whaling vessel. So data were readily available, in aggregated and non-aggregated format, for everybody interested in developments in resource outcome.

Concluding so far, the 17th and 18th century whaling for bowheads in the Eastern Arctic was for one particular stock and operated by one nation mainly, with a large fleet of circa 150 whalers, based in harbours all concentrated in the north-western part of the Netherlands, and with a, for that time, very well documented resource outcome as numbers of whales and casks of blubber yielded per voyage. The economic importance of this natural resource and its well-documented exploitation challenged many historians to publish on the social, economic, biological and even climatological aspects of this historical whale fishery (Wätjen 1919, van der Woude 1972, Bruyn & Davids 1975, de Jong 1972, Hacquebord 1984, 1999, Leinenga 1995).

The questions to which answers are sought here are related to the capacity of individual commanders and of whaling companies, who had access to time series of annual catches as averaged for the fleet as a whole, to perceive time trends in resource outcome:

1. How large was the intra-annual variability in catch rates between commanders? What part of it was due to randomness in the catch per commander, and how large was the inter-annual variability in catch rates averaged for the fleet as a whole?
2. Could a long-term trend in catch rates, as a signal of stock depletion, already be perceived by an individual commander in his life time career in the whaling industry, or were

variabilities so large that stock depletion could only be perceived from long series of annual averages for the fleet as a whole ('administrative gain')?

To answer these questions, first the development of Dutch whaling in arctic waters, concentrated in the summer months June-August, is outlined (section 9.2). Using the annual catch per individual whaler as retrieved from the 18th century lists for the harbours of Amsterdam and Rotterdam, catch frequency distributions were constructed to assess the variability between whalers (section 9.3). To check for any consistent difference in the catch rate per commander, which may reflect a difference in whaling skill, the individual catch records of 59 commanders with a career of 20 years or more in whaling were selected from van Sante (1771), to assess whether some commanders performed better than others (section 9.4). Successively the developments in total effort (fleet size) and in Catch per Unit Effort (whales per vessel and year) are then evaluated for possible long- and short-term trends in the 17th and 18th century (section 9.5). Also, developments in annual catch rates in the 19th century are evaluated for inter-annual variability in order to compare the capacity to perceive trends throughout the full history of bowhead whaling (section 9.6).

To answer the second question, the time window (years) needed to detect that the short- and long-term trends were true trends is assessed for individual commanders evaluating their own series of annual catches, and for administrators who evaluated fleet averages (section 9.7). In addition to catch rate (number of whale per voyage), the average size of bowheads caught, which translates into the number of casks of blubber obtained per whale, is evaluated as a possible indicator of exploitation pressure. Trends in returns on effort in terms of train oil and in terms of money value per voyage are evaluated, in order to see whether long-term trends in these economic indicators could possibly have been perceived more clearly. Because of large variabilities between vessels and between years, small-scale investment in the whaling industry of the 18th century was a lottery for many (e.g. de Jong 1978). In section 9.8. it is assessed what change there was on which return on investment made. Finally, it is discussed how the, at that time, still very limited capacity to process data into information could have constrained evaluation of the time series of catch data (section 9.9). In the 18th century nobody had any idea of what graphed time series or probability frequency distributions were, let alone that they could be of help in managing the whaling industry.

9.2 Two centuries of Dutch whaling in Arctic waters

In 1612 two Dutch vessels started the whaling for bowheads, *Balaena mystecetus* (Linnaeus, 1758), in the arctic waters near Spitsbergen. This fishery would last more or less continuously until the end of the 18th century, when Dutch activities overseas were halted by French occupation. Efforts to rebuild a Dutch whaling industry in the 19th century were unsuccessful and ended in 1863 when the whaler "Dirkje Adema" from Harlingen made its last voyage to the Arctic. English, Scottish and American whalers carried on after that and continued until the almost complete extermination of the stock of bowhead whales in the waters between Spitsbergen and Greenland at the beginning of the 20th century.

At the start of the whaling near Spitsbergen the Dutch competed with English whalers in the western bays of Spitsbergen, where they could easily chase the slow-moving bowheads. These large mammals, which filter plankton in more productive coastal areas between 55°N and 80°N, were sought there mainly for two products: train oil and baleen. Train oil was needed as lighting fuel, as a lubricant for machinery, or as an expedient to make cheap textiles waterproof (Leinenga 1995). The train oil was rendered from blubber by boiling, first at land stations on the west and north-west coasts of Spitsbergen, and after 1650, in the Netherlands to which the blubber was transported in casks. Whalebone was used for hoop skirts and as busk in corsets, but its commercial importance diminished in the second half of the 18th century, when hoop skirts became less fashionable and corsets were considered unhealthy.

After two years of whaling as a free enterprise in 1612 and 1613, Dutch whaling activities were controlled by a chartered company, the "Noordsche Compagnie" (1614-1642). The other chartered company controlling the whale fishery near Spitsbergen was the English "Muscovy Company". The two companies kept fishing effort low in order to control price levels and, as they intended, to maintain the resource exploitation sustainable. De Jong (1972, note 341) refers to a discussion on sustainability by the Muscovy Company with British "interlopers" in 1654. The Muscovy Company referred to drastic reductions in catch rates when these interlopers joined the fleet, although these interlopers operated outside the bays. Shortly thereafter the English would leave the whale fishery in this area for about a century. From 1642 onwards Dutch whaling became a free enterprise again and functioned as such until the end of the 18th century.

Fig. 9.1 The two whaling grounds for the Dutch fleet targeting bowheads in the Eastern Arctic. The dashed line indicates the frontier of the pack ice during summer.

At the beginning of the 18th century Dutch vessel-owners started to look for new hunting areas, and the more ice-free Davis Strait, west of Greenland, was thought promising, because the whales from Davis Strait were bigger and thus yielded more blubber (Leinenga 1995) (Fig. 9.1). From 1719 onwards a regular Dutch whale fishery developed in Davis Strait. Because of a short period with increasing catches near Spitsbergen after ca 1730, the enthusiasm for the Davis Strait fishery declined. Also, the total effort, which had to be made to catch whales in Davis Strait, was greater because of the longer journey. The whalers had to leave for Davis Strait by the end of February or beginning of March, whereas those heading for Spitsbergen could leave as late as April. The start of the whaling season in Davis Strait was generally around late April, early May (Leinenga 1995). As early as the end of May, whales moved out of there in a northerly or westerly direction and by June they became more difficult to catch. The hunting season in Davis Strait thus lasted ca 6 weeks, whereas around Spitsbergen the fishery could be operated for at least twice as long. The time at which the whalers returned to the Netherlands varied greatly between years and ranged from late July until October-November. The ones that waited too long could be wrecked or get locked up in the ice. One of them, the whaler "Frankendaal", was lucky and even survived through the winter, returning to Amsterdam on 28 February 1787 (Mooy 1942).

9.3 Back home after half a year with zero catch

Catch data from the first 50 years of the whale fishery are scarce, alas. The number of whales caught per vessel up to 1669 can only be reconstructed, although incompletely, from freight contracts (Bruyn & Davids 1975), logbooks and incidental catch numbers (Hacquebord 1988). The total number of vessels heading for arctic waters, total number of vessels wrecked and total number of whales caught after 1669 were reported in a complete overview of the whaling fishery published nearly a century after the fishery started (Zorgdrager 1729) (Fig. 9.2).

Catch recording and data availability improved further when, in 1719, Karel van Ryschooten started to publish his list: "Lyst der Groenlands-vaarders, van Holland, Hamburg en Bremen, als meede de Straad-Davids vaarders. In den jaare 1719 uytgevaaren". This list, already printed before the arrival of the whaling fleet from the arctic grounds, contained columns in which the results of each voyage could later be entered by shipping agents, company clerks, or other interested persons (Ross 1979) (Fig. 9.3). The list, sorted by Dutch and German harbour, contained the printed names for each vessel owner, vessel and vessel commander and with blank columns to be filled in later with the number of whales caught, number of casks of blubber and the return date of each vessel. The number of whales recorded per vessel was not necessarily an integer. According to some this could be explained by co-operative fishing but others, such as de Jong, found the explanation of Beaujon (1888 in de Jong 1978, p. 289) that whalers during flensing could lose parts of the whale due to bad weather, ice conditions or privateers more plausible.

After 1720 two separate lists were published annually, one for Greenland (Spitsbergen) and one for Davis Strait. The most complete collection of these annual whaling summaries known as the "Amsterdam lists" is archived in the Municipal Archives of Amsterdam. Ross (1979) points out the differences between the various lists, which he checked for consistencies

302 Bloeijende Opkomst der Aloude, en

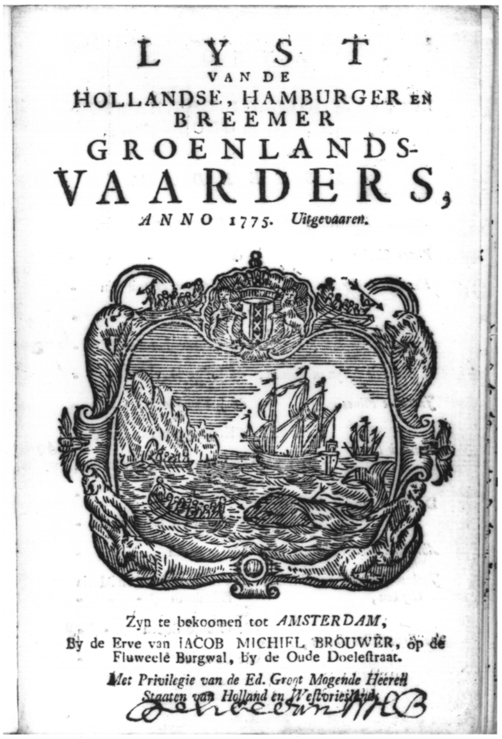
Naaukeurige LYST van de Hollandtsche

Sedert den Jaare 1669. tot

Jaaren	Schepen uitgevaren.	In 't Ys gebleeven en verongelukt.	Visschen gevangen.	Quardeelen Spek.	Door elkander gereekent, Visschen.	Door elkander gereekent, Quard. Spek.
1669	138	- - -	822	- -	-	- -
1670	148	4	792	- -	-	- -
1671	155	6	$309\frac{1}{2}$	- -	-	- -
1672, 1673, 1674	Om de Troubel Tyden verbod op de Groenlandsche Visschery geweest.					
1675	148	14	$881\frac{1}{2}$	- -	-	- -
1676	145	7	$808\frac{2}{3}$	- -	-	- -
1677	149	3	686	30050	$4\frac{90}{149}$	$201\frac{101}{194}$
1678	110	18	$1118\frac{3}{4}$	- -	-	- -
1679	126	3	831	39857	$6\frac{25}{42}$	$316\frac{41}{126}$
1680	148	12	1373	52406	$9\frac{41}{148}$	$354\frac{7}{74}$
1681	172	6	889	30306	$5\frac{29}{172}$	$176\frac{17}{86}$
1682	186	9	1470	62960	$7\frac{28}{31}$	$338\frac{46}{93}$
1683	242	11	1343	43540	$5\frac{133}{242}$	$179\frac{111}{121}$
1684	246	om de Oost blyven zitten. 11; en Gebleeven. 14	1185	44730	$4\frac{201}{246}$	$181\frac{34}{41}$
1685	212	23	$1383\frac{1}{4}$	55960	$6\frac{445}{848}$	$263\frac{51}{53}$
1686	189	11	639	29543	$3\frac{8}{21}$	$156\frac{59}{189}$
1687	194	16	617	23211	$3\frac{35}{194}$	$119\frac{125}{194}$
1688	214	7	345	14600	$1\frac{131}{214}$	$68\frac{24}{107}$
1689	163	11	243	10120	$1\frac{80}{163}$	$62\frac{14}{163}$
1690	117	5	$818\frac{1}{2}$	34960	$6\frac{116}{117}$	$298\frac{94}{117}$
1691	- 2	Van Hamburg en Bremen uitgevaaren, en hier verboden.		- - -	-	- -
1692	32	- - -	62	2748	$1\frac{15}{16}$	87
1693	89	8	175	8480	$1\frac{86}{89}$	$95\frac{25}{89}$
1694	62	- - -	$156\frac{1}{4}$	7562	$2\frac{129}{248}$	$121\frac{30}{31}$
1695	96	- - -	201	9106	$2\frac{3}{32}$	$94\frac{41}{48}$
1696	100	6	380	14975	$3\frac{4}{5}$	$149\frac{3}{4}$
1697	111	8	$1274\frac{1}{2}$	42281	$11\frac{107}{222}$	$380\frac{101}{111}$

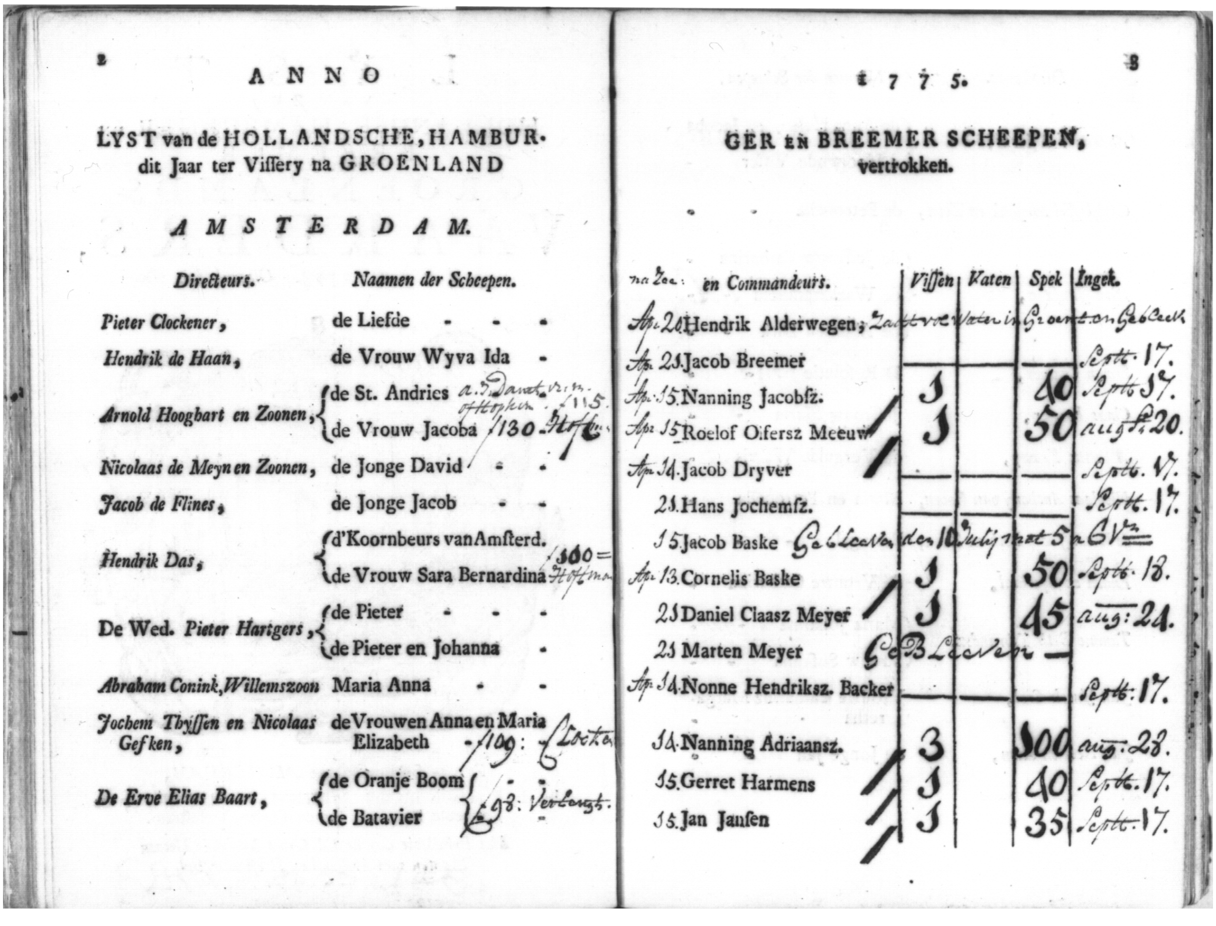
jaaren

Fig. 9.2. List of whaling effort and catch by the Dutch fleet near Spitsbergen (Zorgdrager 1729, p. 302). Column 1: Year, 2: Total number of vessels heading for arctic waters, 3: Total number of vessels stuck in the ice and wrecked, 4: Total number of whales caught, 5: Total amount of blubber in quarteels (1 quarteel = 233 liter), 6: Whales per vessel, 7: Quarteels per vessel.



LYST
VAN DE
HOLLANDSE, HAMBURGER EN
BREEMER
GROENLANDS-
VAARDERS,
ANNO 1775. Uitgevaaren.

Zyn te bekoomen tot AMSTERDAM,
By de Erve van JACOB MICHIEL BROUWER, op de Fluweele Burgwal, by de Oude Doelestraat.
Met Privilegie van de Ed. Groot Mogende Heeren Staaten van Holland en Westvriesland.



2 ANNO 1775. 3

LYST van de HOLLANDSCHE, HAMBURGER en BREEMER SCHEEPEN, dit Jaar ter Vissery na GROENLAND vertrokken.

AMSTERDAM.

Directeurs.	Naamen der Scheepen.	en Commandeurs.	Vissen	Vaten	Spek	Ingek.
Pieter Clockener,	de Liefde	21 Hendrik Alderwegen,				
Hendrik de Haan,	de Vrouw Wyva Ida	21 Jacob Breemer				Septb. 17.
Arnold Hoogbart en Zoonen,	de St. Andries	15 Nanning Jacobsz.	1		40	Septb. 17.
	de Vrouw Jacoba	15 Roelof Oifersz Meeuw	1		50	aug. 20.
Nicolaas de Meyn en Zoonen,	de Jonge David	14 Jacob Dryver				Septb. 17.
Jacob de Flines,	de Jonge Jacob	21 Hans Jochemsz.				Septb. 17.
Hendrik Das,	d'Koornbeurs van Amsterd.	15 Jacob Baske				
	de Vrouw Sara Bernardina	13 Cornelis Baske	1		50	Septb. 18.
De Wed. Pieter Hartgers,	de Pieter	21 Daniel Claasz Meyer	1		45	aug. 24.
	de Pieter en Johanna	21 Marten Meyer				
Abraham Conink, Willemszoon	Maria Anna	14 Nonne Hendriksz. Backer				Septb. 17.
Jochem Thyssen en Nicolaas Gefken,	de Vrouwen Anna en Maria Elizabeth	14 Nanning Adriaansz.	3		100	aug. 23.
De Erve Elias Baart,	de Oranje Boom	15 Gerret Harmens	1		40	Septb. 17.
	de Batavier	15 Jan Jansen	1		35	Septb. 17.

Fig. 9.3 a) Front page of one the Amsterdam lists for vessels heading for Spitsbergen in 1775, b) First two pages of the list of vessels sailed from Amsterdam to Spitsbergen in 1775.

in catch records. But the example he gave just confirmed the very small "administrative variance" contained in the various lists (Table 9.1). Also van der Woude (1972) gave examples of these administrative differences between these archived records, which were mostly no more than 2-3%.

Table 9.1 Total catch of Dutch whalers returning from Davis Strait in 1770 as found in three different sources (based on figures in Ross 1979).

Source	Number of vessels	Number of whales	Number of casks with blubber
Amsterdam Municipal Archive	45	84½	3839
Rotterdam Maritime Museum	45	85½	3847
Van Sante 1770[*)]	46	84½	3815

Table 9.2 Characteristics of the catch frequency distributions for whaling vessels sailing from Rotterdam to Greenland and from Amsterdam to Greenland and to Davis Strait (data from the "Amsterdam lists"). SD = standard deviation, CV = coefficient of variation, N = total number of vessels, N_0 = number of vessels with zero catch.

Year	Mean number of Whales/vessel	SD	CV	Skewness	N	N_0	δ	Number of companies	Number vessels/company
Rotterdam to Greenland									
1723	1.43	2.01	1.42	1.99	24	9	0.38	16	1.50
1724	2.14	2.63	1.24	1.95	20	4	0.20	14	1.43
1725	1.56	1.25	0.81	0.39	20	4	0.20	15	1.33
1726	1.81	2.06	1.14	1.44	13	4	0.30	10	1.30
1727	2.77	1.74	0.63	1.32	13	0	0	10	1.30
Amsterdam to Greenland									
1771	0.98	1.18	1.20	2.19	58	18	0.31	-	-
1772	5.74	3.36	0.59	0.67	47	0	0	-	-
1773	1.99	1.45	0.73	0.93	42	3	0.07	-	-
1774	3.15	2.30	0.73	0.62	42	4	0.10	-	-
1775	0.95	1.19	1.25	2.08	40	14	0.35	-	-
Amsterdam to Davis Strait									
1730	3.12	2.41	0.77	0.31	45	9	0.20	29	1.55
1731	2.53	2.07	0.82	0.65	57	12	0.22	37	1.54
1732	1.50	1.55	1.03	0.93	80	28	0.35	48	1.67
1734	2.84	2.22	0.78	0.61	59	10	0.17	37	1.59
1735	2.36	1.99	0.84	1.00	67	14	0.22	38	1.76

Variabilities in catch rates per individual whaler comprise variances within and between years. The intra-annual variability between whalers may have been due to the size of the vessel, to fishing in groups or not, to time spent in the area, to the professional skill of the commander and, of course, to a portion of mere chance.

To first assess the intra-annual variability, a sample of catch records from the "Amsterdam lists" was taken. Average catch, proportion of zero catches (δ) and variance and skewness in catch frequency distributions were calculated for vessels sailing from Rotterdam and Amsterdam to Greenland and to Davis Strait during three 5-year periods halfway through the 18th century (Table 9.2). There was no particular selection made, except that two major harbours and both whaling areas were included in the series. In most of these years the average catch per harbour ranged between 1 and 3 whales per vessel. The variability in catch rates between vessels varied between CV = 0.5 and 1.5, and was smaller in years with on average larger catch rates and smaller proportion δ of zero catches (Fig. 9.4). Catch frequency distributions per year, harbour and destination were all positively skewed (Table 9.2, Fig. 9.5). There were no apparent systematic differences between harbours, years or whaling areas.

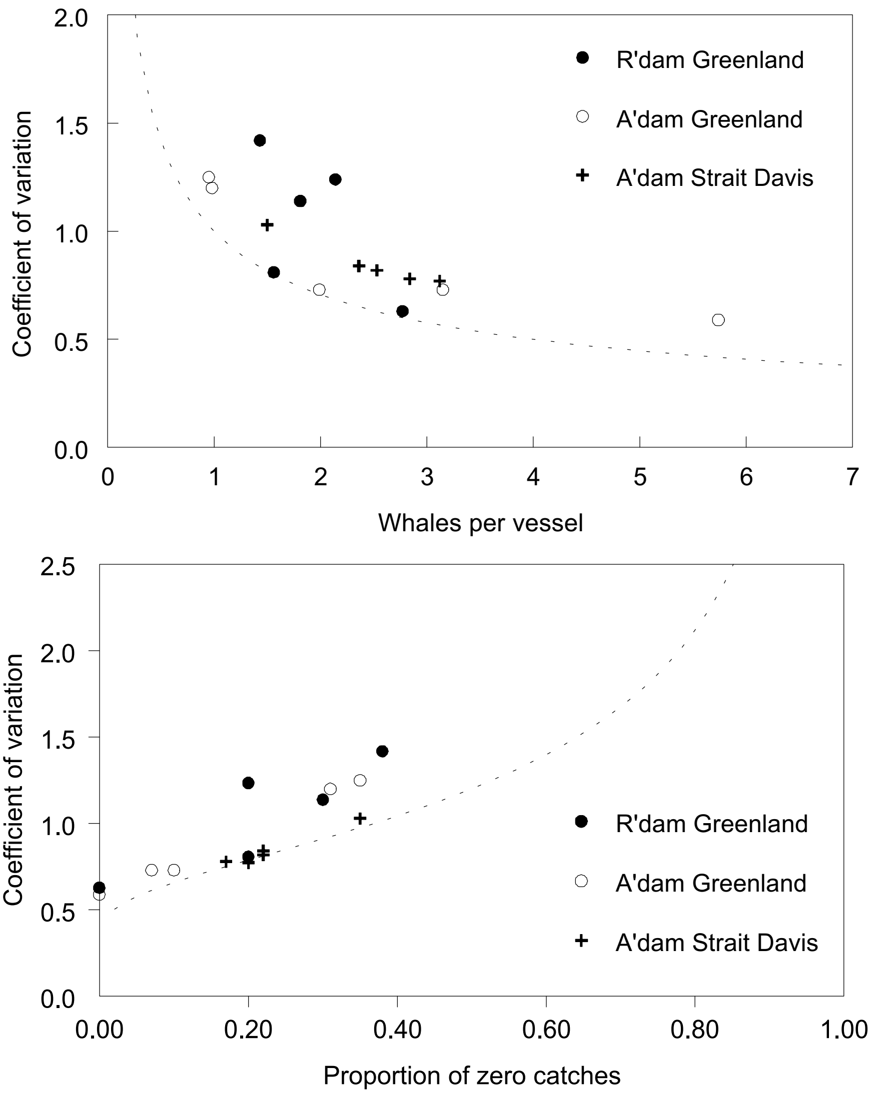


Fig. 9.4 Top: Variability (CV) in numerical catch rates (number of whales per vessel) within year and harbour plotted against the average catch per vessel for whalers sailing from Rotterdam and Amsterdam to Greenland and Davis Strait halfway thro ugh the 18th century. The dashed line represents the relationship according to the random or Poisson distribution ($CV = 1/\sqrt{x}$). Bottom: Variability (CV) in catch per vessel plotted against the proportion (δ) of zero catches for the same harbour-area combinations. The dashed line represents the relationship according to the Poisson distribution ($CV = 1/((\ln(1/\delta))^{\wedge}½)$). Data from the "Amsterdam lists" (Table 9.2). See Chapter 3 for the relationships between variability and the mean and the proportion of zeros in Poisson distributions.

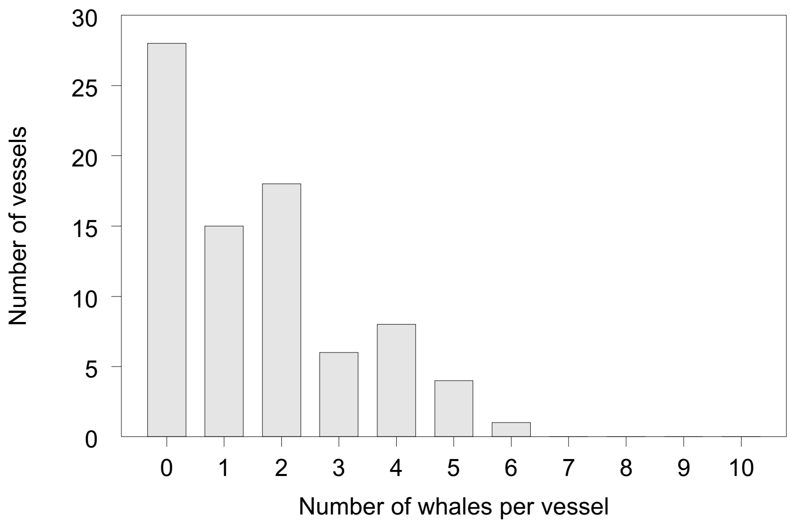


Fig. 9.5 Catch frequency distribution for vessels which sailed from Amsterdam and headed for Davis Strait in 1732 (Mean = 1.5 whale per vessel, CV = 1.03, $\delta = 0.35$).

Those who returned without having caught any whales, sometimes still brought casks of blubber. They transported these casks for the more successful ones, whose storage capacity was insufficient. This explains why in a plot of number of casks of blubber against number of whales caught per vessel the relationship does not show appear very proportional near the origin (Fig. 9.6). From this same plot it can be seen that significantly more casks were rendered per whale from Davis Strait than from Spitsbergen. This means that the sizes of bowheads in Davis Strait were larger than near Spitsbergen in the same period. One cask contained one Dutch quarteel (233 liter) of blubber. With circa 50 casks of blubber flensed per whale, one whale must have yielded 12,000 liters of blubber.

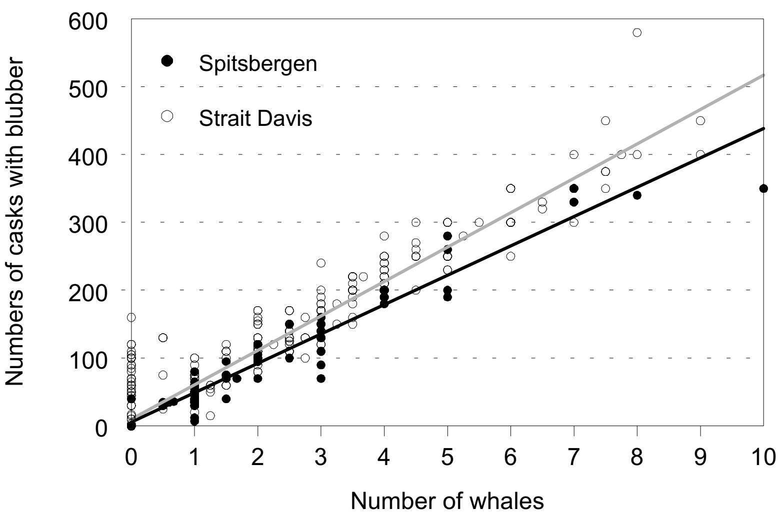


Fig. 9.6 Number of casks with blubber transported per vessel plotted against the number of whales caught by that vessel. Based on catch records from the samples in the "Amsterdam lists" in Table 9.2 (Rotterdam to Greenland, Amsterdam to Davis Strait). The regression lines were calculated excluding vessels with zero catch.

The variance in catch rates between vessels could possibly have been explained from the size of the vessels, but sizes of individual vessels were not recorded in the annual lists. The vessels were 30-36 m long, 8-9 m wide and 3.5-3.8 m deep and had a crew of 28-50 persons (de Jong 1972). Each vessel had 4-7 whale boats, 6 m long, on board from which the whales were chased by ca 6 persons, equipped with harpoons, lances and lines of up to 300-400 m length (Palm 1946). When, in the first half of the 17th century, whalers still operated in the bays of Spitsbergen and boiled the blubber at the land stations, a few vessels ("kapitaalschip") had a crew of 60-80, which then included 12 sailors, 4*6 men for chasing the whales and 24-36 working at the land stations (Hacquebord, personal communication). The other vessels at that time ("fluitschip") had only sailors and the crew for the whaling boats on board.

Another explanation for variability between vessels could be the increased chance of catching whales when operating in a company fleet. Most companies, were however small and owned or hired just one whaling vessel. It seems that being organised was no advantage. In any case, catch rates were not systematically higher for vessels organised into company fleets and sailing from Amsterdam to Davis Strait in 1732 (Fig. 9.7).

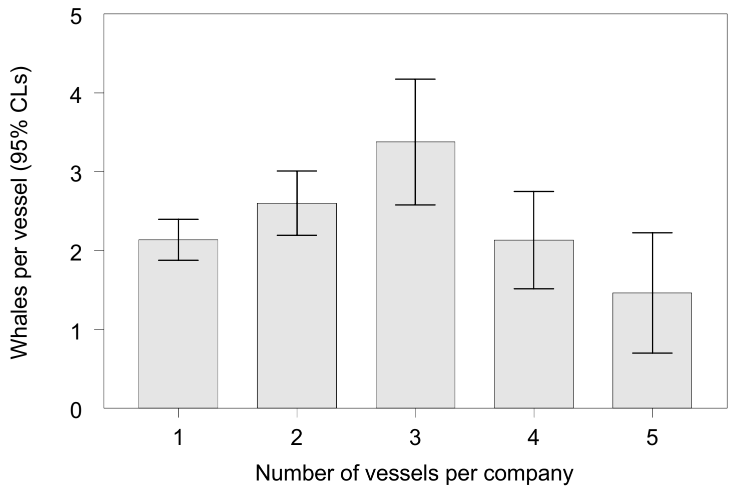


Fig. 9.7 Average CpUE (whales per vessel) ± 95% CLs for all vessels sailing from Amsterdam to Davis Strait in 1732 belonging to a total of 48 companies grouped by company size (number of vessels per company). The average number of vessels per company was 1.67 (see Table 9.2).

Fishing effort, as time spent in the area, varied greatly between vessels. Most vessels left the Netherlands during a short period of ca 2 weeks around April. The voyage took around one month (Zorgdrager 1729). So they arrived at the whaling grounds at the end of May or beginning of June. By that time the whales had also arrived in the area from their wintering grounds south of Greenland. Males and immature females came first, followed later by females with their young who had stayed longer at the calving area near Jan Mayen Island (Hacquebord & Leinenga 1994, Hacquebord 1999).

The time of which the whalers returned varied greatly. Returning as soon as possible, after having caught a number of whales, made the blubber less rancid and guaranteed a better quality of the train oil and thus higher price (Hacquebord 1984). Some returned as soon the end of July, some as late as October, occasionally as late as November. Catch rates of vessels returning from Spitsbergen to Amsterdam in the years 1771-1775 (Table 9.2) were evaluated

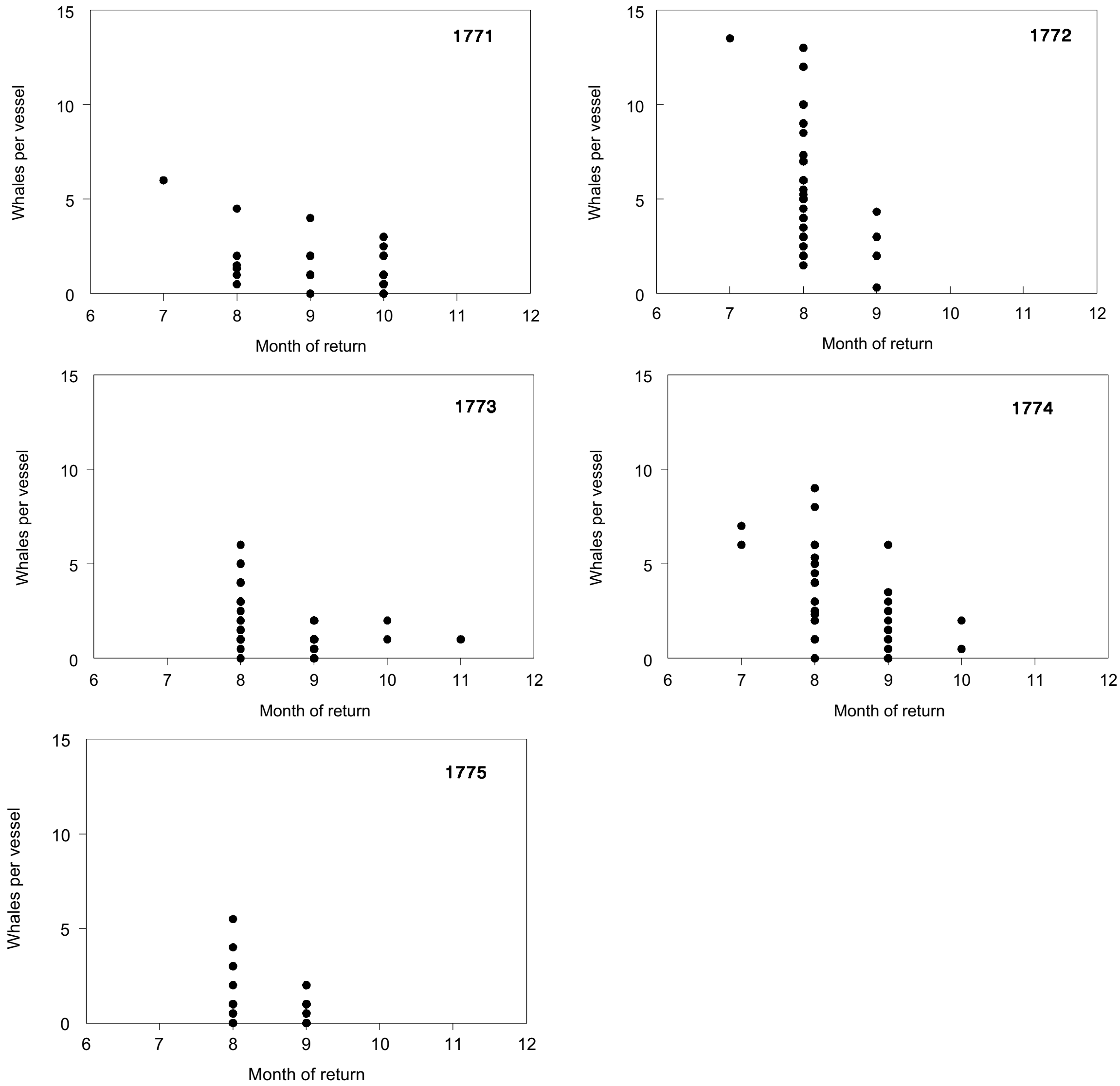


Fig. 9.8 Catch per individual vessel per 'year' and 'month of return' for vessels sailing from Amsterdam to Spitsbergen 1771-1775

in relation to time spent in the area. Those spending more time in the Arctic did not necessarily catch more whales. It seems that instead catch rates were lower for those staying longer. The group returning after August had a systematically smaller average catch (Fig. 9.8). In a bad year, with disappointing catch rates already at the start of the season, a larger part of the fleet remained in the area to keep on trying (e.g. 1771). Lingering at the whaling ground much longer was not, however, very profitable. There wàs a chance of catching a whale, although, as it seems, an ever smaller chance and under ever colder and harsher conditions. The least successful commanders possibly did not dare to return to the Netherlands after six months with zero catch. So the shape of the catch frequency distributions for the whole of the season must have been affected by fishing success in June and by the responsive behaviour of the whalers in terms of time spent in the area in relation to catching success and timing of the season. The proportion δ of zero catches in the catch frequency distribution may have been decreased by the lingering of the initially less successful whalers. For them to say goodbye to those already returning home certainly made them sad as the following poem shows (translated from Mooy (1942), p. 25):

Sadly they looked
How it sailed away
Their last neighbour ship
A dot,
Slowly disappearing to the horizon

9.4 Few commanders were significantly more successful

If size of the vessel, fishing in company, or time spent in the area do not explain the variability in catch rates between vessels then differences in whaling skill per commander still may do so. Professional skill in whaling was initially hired from the Basques, who helped with the whaling strategy in the early 17th century. As the Dutch gained experience over the years the position of the vessel commander as the one who applied the fishing strategy, also became stronger. Independent information on the whaling skill of individual commanders is hard to retrieve and quantify, i.e. the best that could be done was to search for possible significant differences in whaling success between individual commanders, and to assess the importance of this variability relative to the overall variability between vessels.

In his most complete record of the Dutch whaling van Sante (1771) included catch histories per individual commander as the number of whales they caught annually during their career as vessel commander. This data set enabled a test of whether catch rates were significantly different between individual commanders, and whether commanders with longer experience did significantly better. Only commanders whaling near Spitsbergen and with a record of 20 years or more since 1700 were selected, from Ary Breet up to Jacob de Leeuw, totalling 59 commanders. This was approximately half of all commanders listed in alphabetical order (first name) with such a long record.

The data set thus obtained consisted of 1484 annual records covering 70 years altogether, from 1700 until 1769. Of this total 18 annual records referred to vessels being wrecked or damaged and 4 vessels were privateered. Being wrecked certainly did not always mean the end of the commander's career, because several were rescued and returned on board other whalers. The proportion of zero catches in the 1462 records remaining, was relatively small ($n = 183$, $\delta = 0.12$). The 1279 non-zero catches were ^{10}log-transformed for processing in an ANOVA with ‘calendar year’, ‘commander’ and ‘number of years in service’ as explanatory factors. These three factors together, explained only 46% of the total variance in catch rates (Table 9.3). The uncertainty as quantified with the square root of the mean square errors was $s\,{}^{10}\log CpUE = 0.278$, corresponding to $CV(s) = 0.70$.

Most of the total variance in catch rates was due to significant differences between years (Table 9.3, Fig. 9.9.A). For the commanders selected, whaling was particularly profitable at the beginning of the 18th century, although with large variability from one year to the next in this period, and around 1745. In some years the average catch rate was well above 5 per voyage. Catch rates were very low around 1730 and around 1765 when, on average, not more than 1 or 2 whales were caught.

Table 9.3 Analysis of variance in ^{10}logCpUE (CpUE = # whales per voyage), in a sample of 1279 records from 59 commanders whaling near Spitsbergen in the period 1700 -1769. Sum of squares refer to Type I SS. Type III SS showed the stability of the analysis: SS_{III} Calendar year 60.49, SS_{III} Commander 12.64, SS_{III} Number of years in service 1.33.

Source	Df	SS	MS	F-value	Pr > F
Model	128	74.65	0.583	7.56	0.0001
Calendar year	69	61.89	0.897	11.63	0.0001
Commander	58	11.43	0.197	2.55	0.0001
Number of years in service	1	1.33	1.331	17.26	0.0001
Error	1151	88.79	0.0771		
Corrected Total	1279	163.442			
R^2 = 0.457; Geometric mean = 3.56 whales per voyage					

Of the within year variance, only around 11% was due to systematic differences between commanders. The differences in catch rate per vessel commander were relatively small. Of 59 commanders, only 5 did significantly better and 7 worse than average (Fig. 9.9.B). The variability between commanders, as averaged for their career of 20 years or more, and corrected for the year's average was CV = 0.22. Once again, it can not be concluded from these results that it was superior whaling skill which determined that some commanders outperformed others. Their better performance could be due to a larger vessel, better equipment, and so on, all kinds of vessel characteristics for which information, if at all available, will be very hard to retrieve. Experience do not seem to have enhanced the commander's individual whaling skill, because only a small part of the total variance in catch rates was explained by the commander's years in service, with on average slightly lower catches even for those longer in service (Table 9.3, Fig. 9.9.C).

How variable a commander's individual record could be, is evident from the catch histories of the commander with the poorest and of the commander with the best record (Fig 9.10). Although being the poorest performer, Gijsbert Jacobsz Pille also had two good years in his series from 1700 to 1720 during which years he caught 15 whales. In the same period the best performer, Jan Dirksz van de Velden, did at least as well in these two years and caught more whales than Pille in most other years. Sadly for Pille he was wrecked in a year (1714) when the fleet did particularly well with an average of more than 10 whales per vessel (Fig. 9.9.A., 9.10).

In conclusion, in the 18th century most of the variability between vessels and within years, which, depending on the year's average, varied between CV = 0.6 and 1.4, is unexplained. After aggregating and averaging for the fleet as a whole, a considerable portion of this variability will disappear from the series ('administrative gain').

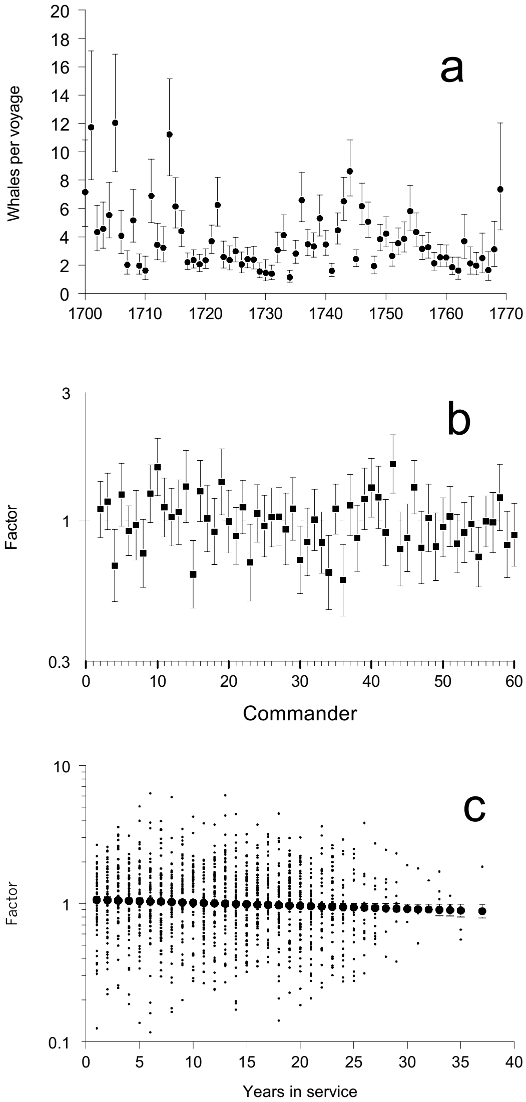


Fig. 9.9 Comparisons of catch rates of 59 commanders with a career in whaling of 20 years or more in the period 1700-1769. a. Per calendar year (average number of whales per year), b. Per individual commander (after correction for annual average), c. Per year in the fishery (after correction for annual averages and of individual performance).

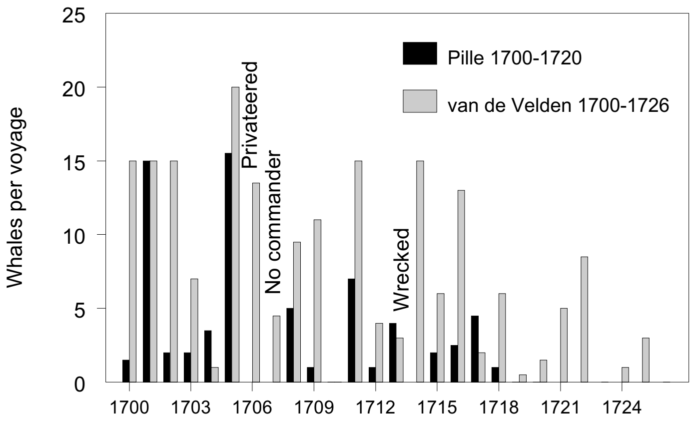
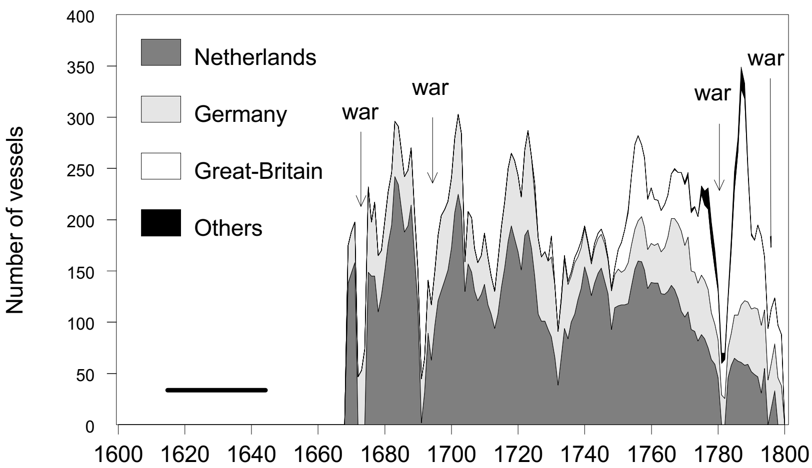


Fig. 9.10 Individual catch records of two commanders whaling near Spitsbergen (data from van Sante (1771)). Pille was privateered in 1706, was not a commander in the following year and was wrecked in 1714.

9.5 Developments in fleet size and whaling and whaling success

The Dutch whaling near Spitsbergen started in 1612 with two vessels. In the following decades, when whaling was still controlled by chartered companies from the Netherlands and England, fleet size was around 30-50 vessels (Hacquebord 1999). Once whaling became a free enterprise halfway through the 17th century, fleet size expanded strongly to 200-300 vessels by the end of the 17th century. This was the era with the largest total catch of bowheads ever (see below). Total fleet size remained at around 200-300 vessels throughout the whole of the 18th century, but fluctuated strongly, partly due to wartime activities. Until halfway through the 18th century the fleet was almost completely dominated by Dutch whalers, accompanied by a minor but stable number of whalers from Germany (Fig. 9.11). Halfway through the 18th century whalers from England joined the whaling near Spitsbergen again, after being absent for almost a century.



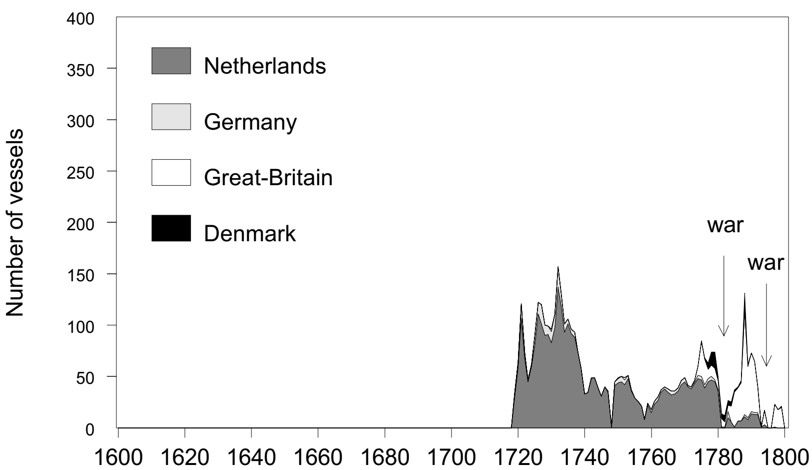


Fig. 9.11 Size and nationality of the fleet heading for Spitsbergen (top) and for Davis Strait (bottom) . Wartime periods were 1672-1674, 1691 and 1781-1782 (Data from Leinenga (1995)). The bold line in the upper figure refers to the period 1612-1642, for which no official records exist but for which Hacquebord (1999) reconstructed developments in fleet size from various sources.

The Dutch fleet, whaling in Davis Strait since 1719, was initially as large as the fleet heading for Spitsbergen but after 1740 not more than 50 vessels on average tried their luck in Davis Strait. Thus until at least halfway the 18th century Dutch whalers dominated the fleet in both areas. Towards the end of the 18th century English whalers took over this dominant position from the Dutch, but they finally gradually retreated from the whale fishery due to the wars in Europe, after their whaling activities peaked around 1787-1788.

It seems logical to suggest that it was the unrelenting whaling industry of the 17th and 18th century that decimated the population of bowhead whales near Spitsbergen, but the destructive impact does not clearly show up from a long-term downward trend in the catch rates which are available (1669 - 1800). In almost one and a half centuries of meticulously recorded annual catches this trend is weak (Fig. 9.12, Table 9.4). Catch rates were indeed initially high, but from circa 1670 onwards downward trends of 20-25 years (1669-1690, 1700-1725, 1740-1765) were followed by periods of recovery and this persistence together, with the overall high inter-annual variability (CV = 0.9) obscured the perception of any possible long-term downward trend. When the initial decrease (1669-1690) is excluded, there is no long-term trend whatsoever for more than a century. During that period the average catch rate was 2.97 (arithmetic mean) or 2.28 whales per year (geometric mean).

Table 9.4 Slope (b) of the regression of ^{10}log-transformed average annual catch rates on year, the standard deviation in the residuals (s ^{10}logCpUE), the trend to noise ratio (b/s) and the serial correlation for a time lag of 1 year. [a)] As only 1 vessel went to Davis Strait in 1748, not having caught a whale, the series 1719-1779 was interrupted due to log-transformation and serial correlation was tested for the first 29 years only. $^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

Area	Period	Years	b	R^2	s^{10}logCpUE	b/s	CV(s)	ρ^2
Spitsbergen	1669-1800	132	-0.00299	0.106**	0.334	0.009	0.90	0.0974
Spitsbergen	1691-1800	110	-0.000902	0.00726	0.337	0.003	0.91	0.0748
- Spitsbergen	1669-1690	22	-0.0219	0.352**	0.193	0.113	0.46	
- Spitsbergen	1700-1725	26	-0.0186	0.164*	0.327	0.057	0.87	
- Spitsbergen	1740-1765	26	-0.0175	0.303**	0.207	0.085	0.51	
Davis Strait	1719-1779	77	0.00118	0.00658	0.332	0.004	0.89	0.0567[a]
Davis Strait	1814-1911	98	-0.00890	0.377***	0.325	0.027	0.87	0.0441
Western Arctic	1848-1915	67	-0.00374	0.102**	0.220	0.017	0.54	0.0891

The periods for which short-term trends in the catch rates near Spitsbergen were calculated were chosen after visual inspection of Fig. 9.12. An iterative optimisation procedure by which the full series was fragmented by minimising the residuals around subsections of the series and starting with a separation into two, revealed major changes around 1696, 1734 and 1767 (Machiels, unpublished results). These years largely corresponded with the break points chosen subjectively.

Information on catch rates near Spitsbergen in the period 1613-1668, i.e. before the first record of yearly catches (1669) in the listing by Zorgdrager (1729) (Fig. 9.2) is scanty. Hacquebord (1999) estimated that in the period before 1669 a total of approximately 15,000 whales, were caught by a mixed fleet of circa 30-50 mainly Dutch and English whalers. This fleet later expanded to circa 200 around 1670. Assuming that the fleet consisted of 40 vessels on average, annual catch rate must have been around 15,000/56/40 = 7 whales per vessel. That catch rates were high in the early days of whaling for bowheads, can be inferred from the fact that the capacity of the land stations for boiling blubber was not always sufficient. In some years blubber was even buried for next year's season or special transport vessels had to collect the blubber from Spitsbergen (Hacquebord, personal communication). The resultant truncation at the higher end of the catch frequency distributions per year, must have reduced the intra-annual variability (CV). So these distributions might have been essentially different from those in the 18th century when average catch rates were lower and with the lingering in the whaling area of the less successful whalers affecting the lower end of the catch frequency distribution.

Average annual catch rates in the whaling fishery in Davis Strait 1719-1800 showed no long-term trend either (Fig. 9.12). The annual average catch rate in Davis Strait (AM = 2.63 and GM = 2.07 whales per vessel) was not significantly different from that for Spitsbergen. Variability in the annual catches was very similar to the one for Spitsbergen since 1691 (CV(s) = 0.89). Variability seems to have increased over the years, possibly due to the smaller number of vessels heading for Davis Strait after 1740, by which time the random variability between vessels contributes to the inter-annual variability for the fleet as a whole. Persistence in this shorter series is hardly detectable. As near Spitsbergen, numbers were particularly high around 1745.

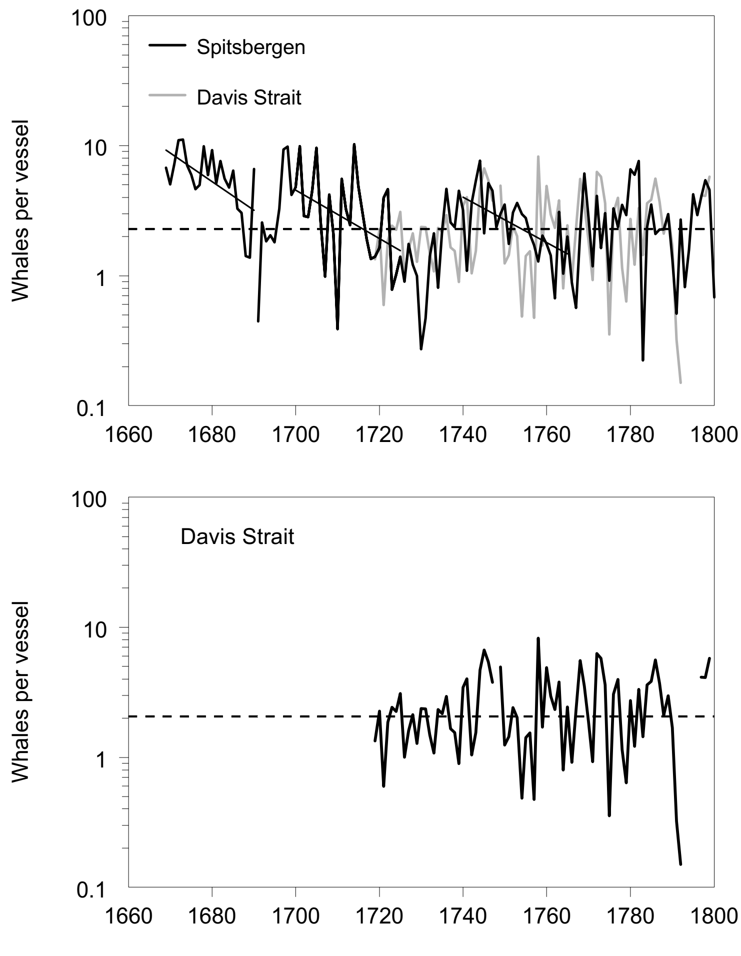


Fig. 9.12 Average annual catch rates for the total fleet near Spitsbergen 1669 – 1800 and in Davis Strait 1719-1800. The dashed lines represent geometric means, for Spitsbergen from 1691 onwards (data in Leinenga (1995)).

Inter-annual variabilities, as year-to-year variability and as persistent short-term trends at the whaling grounds near Spitsbergen, can theoretically be explained by changes in stock size and in whaling conditions. Stock size of a long-lived mammal like the bowhead, will however be conservative and catch rates must thus have changed slowly over time leading to short-term trends, if any. There might have been pulses of rejuvenation followed by periods of maturation, comparable to the appearance and shift of strong year-classes through a fish population. The larger sizes of bowheads caught around 1730 possibly indicate a temporal maturation of the population structure (see Fig. 9.17).

Whaling conditions were thought to vary with the extent of the pack ice. Lower summer temperatures meant that the ice was more densely packed, and that the bowheads had a smaller chance to escape through the ice (Hacquebord 1984). It is possible now to reconstruct summer temperature in the Arctic from ice cores, but not with high spatial or temporal resolution. For the Spitsbergen area of the 17th and 18th centuries at best 5 year averages can be obtained (Hacquebord 1999). In the period 1650-1800 there is no observable long-term trend in mean summer temperature, but there were periods of consistently higher or lower temperature in that area (Fig. 9.13). Catch rates, now averaged for the same 5 year intervals were not correlated with these summer temperatures (1675 – 1795, $R^2 = 0.008$). Hacquebord (1983) concluded from more recent series that there is a delay in the response of pack ice to temperature of around 10 years. When accounting for such a delay there might indeed be more of an association between catch rates and extent of pack ice (Fig. 9.13). The mechanism behind such delay and persistence in the growth of ice cover is the temperature – ice – albedo effect, whereby the extent of highly reflective sea ice has an amplifying effect on its own developments (Johannes & Miles 2000).

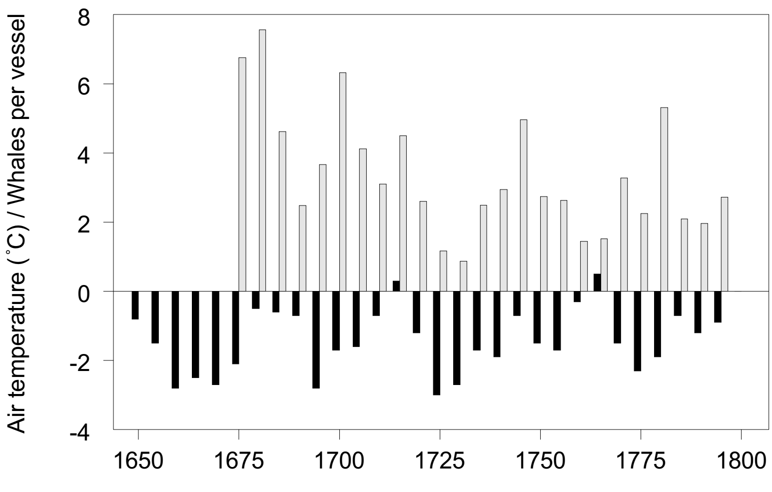


Fig. 9.13 Average summer air temperature per 5 -year interval (1650-1800) and average annual catch rates per 5-year interval of the whaling fleet in the Spitsbergen area (1675 -1800) (Data on temperature from Hacquebord 1999, his Fig. 3).

It is hard to say whether persistent short-term trends in the arctic climate in the 18th century occurred more frequently and were sharper than in the 20th century. The increasing temperature in the Arctic over the last decades has in any case resulted in a gradual retreat of the ice cover. The spatial extent of the arctic ice reduced at a rate of minus 3% per decade and the average ice thickness decreased over a 30-year time span from 3.1 to 1.8 m (Johanessen & Miles 2000). Changes of a similar extent in the 17th and 18th century would certainly have had an impact on the spatial distribution and efficiency of pelagic whaling along the pack ice.

In conclusion, explanation cannot be given for the high inter-annual variability in catch rates for the fleet as a whole. The short-term trends of 20-25 years could have been due to either persistence in stock structure and abundance or in ice cover, where the two are possibly interrelated.

9.6 Whaling for bowheads in the 19th century

After the turmoil of the late 18th and early 19th century, whaling activities were resumed near Spitsbergen and in Davis Strait, but by shrinking fleets and with significant declines in catch rates (Figs. 9.14, 15, 16, Table 9.4). The decline in catch rates was less sharp in Davis Strait and in the Western Arctic where whaling for bowheads had developed in the course of the 19th century. Although bowheads were chased by smaller fleets, this was with increased efficiency after the introduction of the harpoon gun invented in 1864. In the second half of the 19th century the Western Arctic, with its own stocks in the Bering-Chukchi-Beaufort Seas and in the Okhotsk Sea, became the major whaling ground in term of total number of bowheads caught (Fig. 9.15).

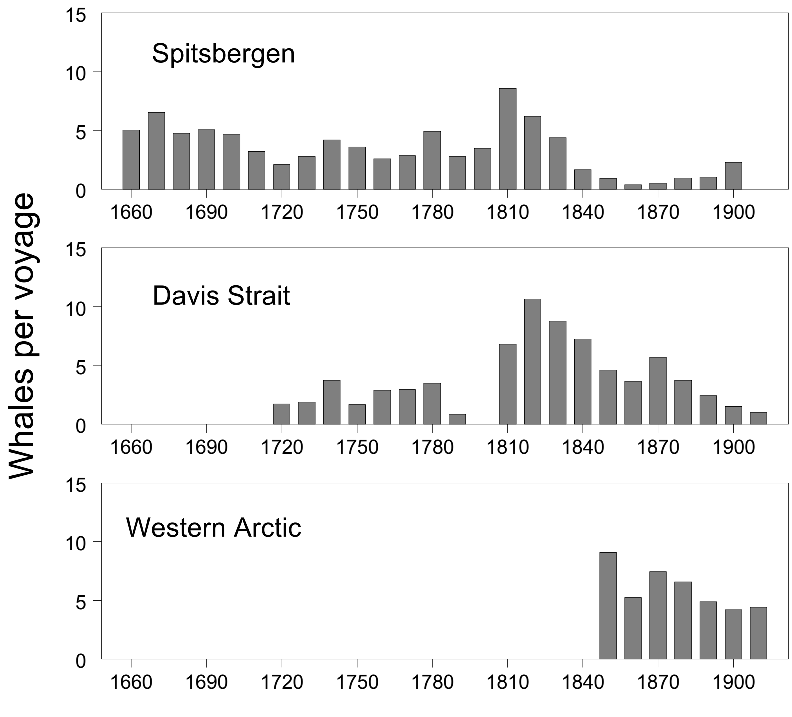


Fig. 9.14 Catch rates as average number of bowheads per voyage during 10 -year intervals near Spitsbergen, in Davis Strait and in the Western Arctic (Data from Ross 1993).

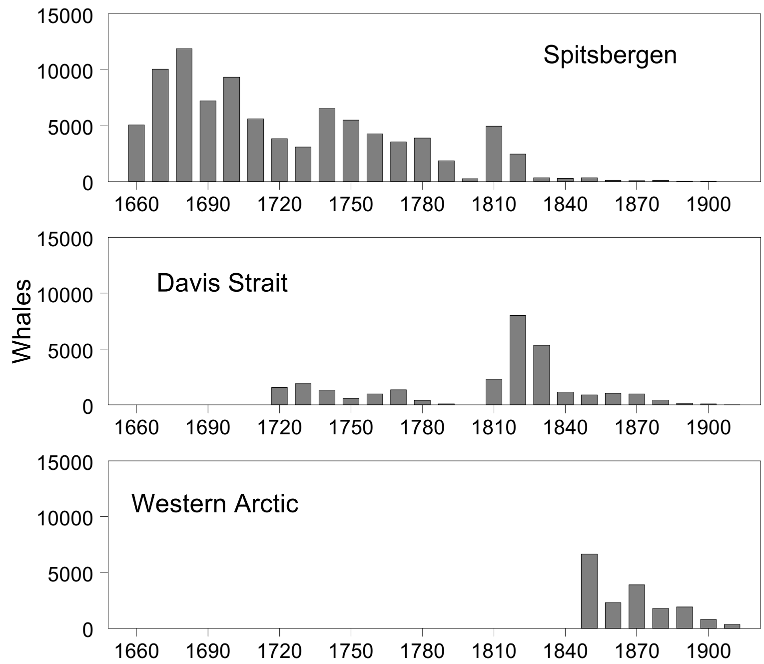


Fig. 9.15 Total catch of bowheads during 10 -year intervals near Spitsbergen, in Davis Strait and in the Western Arctic (Data from Ross 1993).

Total fleet size decreased both near Spitsbergen and in Davis Strait from about 100 at the beginning to less than 10 vessels at the end of the century. In the beginning of the 19th century catch rates in both areas were higher than in the 18th century, probably because of the hunting of ever younger whales. They however decreased steadily thereafter, and already halfway through the 19th century, average catch rate near Spitsbergen had become as low as 1 whale per voyage (Fig. 9.14). Bowhead whaling near Spitsbergen ended in 1911. In the first decade of the 19th century the fleet near Spitsbergen was still a mixture of Dutch, German and English vessels, but then the whaling became an almost completely English enterprise. In Davis Strait catch rates decreased almost as steadily as near Spitsbergen, but less dramatically and reached a level of 1 per voyage not earlier than the end of the century (Figs 9.14, 16, Table 9.4). The small improvement in catch rates in Davis Strait around 1870 was possibly due to the extension of the resource area from the traditional whaling grounds along the western coast of Greenland towards the shores of the Canadian mainland to the west (Leinenga 1995).

Halfway through the 19th century whaling for bowheads also developed in the Western Arctic. Initially as many as 100-200 whalers were operating, but here also fleet size declined until the end of the 19th century only circa 20 vessels were left (Fig. 9.16). Catch rates were higher and the decline was less steep than in Davis Strait and near Spitsbergen (Table 9.4). In 1915 the only whaler that still chased bowheads in the Western Arctic caught 7 whales. Persistent short term trends can hardly be perceived in the series of annual catch rates in the Western Arctic and in Davis Strait (Fig. 9.16).

It now seems that only the stock of bowheads in the Bering Seas, in the Western Arctic, has recovered or maintained a viable population (Table 9.5). It is the only stock still exploited, very lightly and only by the aboriginal Inuit (Klinovska 1991). The present aboriginal whaling scheme of the International Whaling Commission allows only a proportion of the replacement yield of 41-196 whales (depending on model assumptions) to be taken. How important whaling is for the economy and vitality of the Inuit communities is evident from the brisk discussion on the permissibility of aboriginal whaling (Caulfield 1997, Milton *et al*. 1998, www.worldcouncilofwhalers.com). The most endangered stock is still the one near Spitsbergen, for which Jonsgård (1981) even speculated that it had become extinct and that recent sightings may represent immigration from another stock.

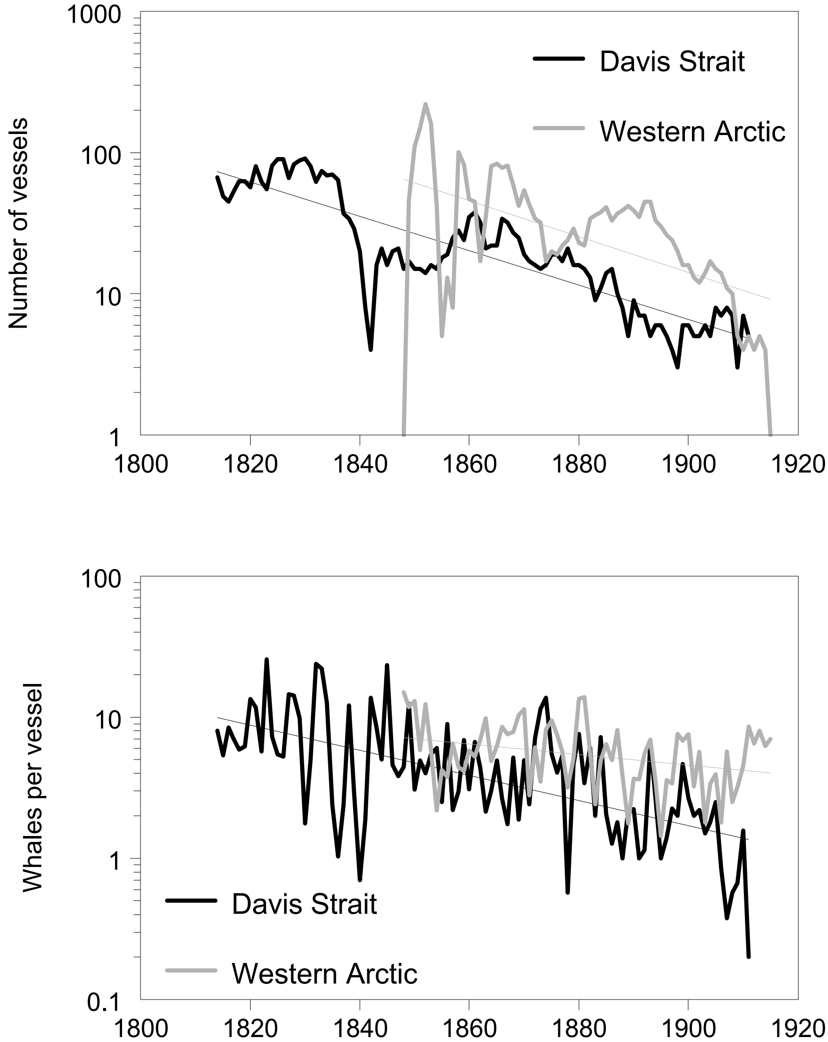


Fig. 9.16 Effort (vessels, top) and CpUE (whales per vessel, bottom) for Davis Strait 1814 -1911 (data in Ross 1979) and for the Western Arctic (based on data in Bockstoce (1980)).

Table 9.5 Estimates of the number of bowhead whales for stocks in Eastern and Western Arctic waters.

Stock	Before exploitation (Woody & Botkin 1993, their Table 10.4)	Present (Zeh *et al*. 1993, their Table 11.14)
Spitsbergen	25,000	Several 10-s
Davis Strait - Hudson Bay	11,575	Several 100-s
Bering-Chukchi-Beaufort Seas	18,000	7,500
Okhotsk Sea	6,500	150-200

In conclusion, long-term downward trends in the catch rates of bowheads in a time window of at least one century, have never been strong. Only in the first half of the 19th century did the decrease near Spitsbergen come close to the dramatic decline in blue and fin whales in the 20th century. Inter-annual variability has always been relatively large (CV(s) = 0.5 – 0.9), and so the trend-to-noise ratio relatively low (b/s = 0.01 – 0.03). This ratio was higher during the periods with short-term downward trends in the 18th century (b/s = 0.06 – 0.11). These short-term trends must have been the most confusing factor in the perception of the long-term trend by both whaling commanders and companies.

9.7 Compounded perceptions

Over 300 years the stock of bowheads near Spitsbergen, estimated at 25,000 individuals before exploitation, has virtually been fished to extinction. During these three centuries altogether more than 100,000 bowheads were caught there. Numbers taken in Davis Strait totaled circa 30,000 and in the Western Arctic circa 20,000. When the whaling started in the early 17th century in the western bays of Spitsbergen the whalers encountered bowheads in such abundance that not all those caught could be processed even. Total catches peaked in the second half of the 17th century when circa 200 vessels caught almost 10 whales each on average along the pack ice. The whaling ended in the early 20th century when a few steam-powered whalers, equipped with harpoon guns, could catch hardly any bowheads. Theoretically, a steady decrease in numbers of 2% per year from an initial number of 25,000 bowheads, would leave only 50 after three centuries.

The first question to be answered is whether whaling commanders were able to perceive any trend, either long- or short-term, given the variability they experienced in their own, individual catch rates. This variability was a combination of systematic differences between years in the average for the fleet as a whole and of intra-annual variability for each whaler independently. The second question is then whether companies perceived such trends more clearly (‘administrative gain’), because these companies had access to records of aggregated and averaged catches?

Variability in catch rates as experienced by an individual commander in the 18th century combined variability between years for the fleet as a whole (1669 – 1800, CV = 0.9, see Table 9.4) and per vessel within years (CV = 0.7, see Table 9.2). Thus:

$$CV = \sqrt{0.9^2 + 0.7^2} = 1.1$$

With such individual variability the long-term downward trend (b = -0.00299, b/s = 0.0077) could be perceived in a time window of at least 114 years, but not during a career of 20 years as whaling commander, when critical values for Type I and II errors are $\alpha = \beta = 0.1$ (see 3.3). Even the steeper short-term downward trends after 1669 and 1740 could hardly be perceived by individual commanders, because for them this still required time windows of 29 (b/s = 0.0061) and 35 years (b/s = 0.046) years. In the listings of annual averages for the fleet of 100-200 whalers, consulted by the administrators of the whaling companies, intra-annual variability was largely averaged out, but this made the long-term trend hardly more visible for them (CV = 0.9 instead of 1.1, 100 years). The short-term downward trends after 1669 and

1740 could indeed more easily be perceived by them than by the individual commanders (19 and 23 years).

So far the capacity to perceive trends has been assessed on the basis of catch rates. But 'one voyage to the arctic' may have been a poor standard unit of whaling effort, without clear indication of in which area whales were searched for. At the very beginning of the whaling fishery bowheads were easily chased in the western bays of Spitsbergen and blubber was boiled immediately at the land stations. Already around 1636 whaling started in more open waters around Jan Mayen Island and near the eastern coast of Greenland, where whalers searched the margins of the pack ice ("west ice"), expanding the spatial allocation of their fishing effort (Box 9.2). Around the year 1650 the land stations were moved from the western to the northern shores of Spitsbergen (Hacquebord 1984). Hacquebord explains this move not so much as an expansion of the resource area, but as resulting from a warmer period of several decades in which the pack ice, along which bowheads feed, retreated northwards.

When, in 1719, more than a century after the start of whaling near Spitsbergen, some of the whalers headed for Davis Strait, west of Greenland it meant the inclusion of a new, separate stock of bowheads with its own stock dynamics. Later, whaling effort expanded further, not only by the exploitation of larger resource areas (space), but also by the extension of the whaling season (time). At the end of the 18th century, English whalers started to chase immature bowheads early in the season with strengthened vessels, which were capable of penetrating the pack ice earlier. So they started whaling as early as April and May, when juvenile whales were also more vulnerable to being caught. It meant that actual fishing effort per whaler and year was further increased and directed to an as yet unexploited part of the stocks. In all, one has to conclude that one voyage to the arctic was a poorly standardised unit of whaling effort, the shortcoming of which individual vessel commanders may have been particularly aware.

Besides the necessity to spend more time searching, the decrease in the average size of the whales caught, might have been alarming. Until around 1720 there was even no trend whatsoever in the average number of casks of blubber yielded per whale (ca 40) caught near Spitsbergen (Fig. 9.17). Around 1730 there was even a slight increase. But from then onwards the number of casks per whale declined, although with ever larger variability towards the end of the 18th century, when only around 25 casks of blubber per whale were obtained. This decrease from 40 to 25 casks of blubber can be translated into a percentage decrease in the average length of whales caught by assuming a cubic relationship between the length of the whale and its volume of blubber:

$$\left(1-\sqrt[3]{\frac{25}{40}}\right)*100\%=15\%$$

Not an impressive decrease in a time window of around half a century. Vessel commanders, however, might have been very aware of any such change because the size of the whales translated directly into the storage capacity on board that was utilised. This must have been most apparent during the circa 4-week return journey. The average size of whales caught in Davis Strait was always larger than of those caught near Spitsbergen (Fig. 9.17).

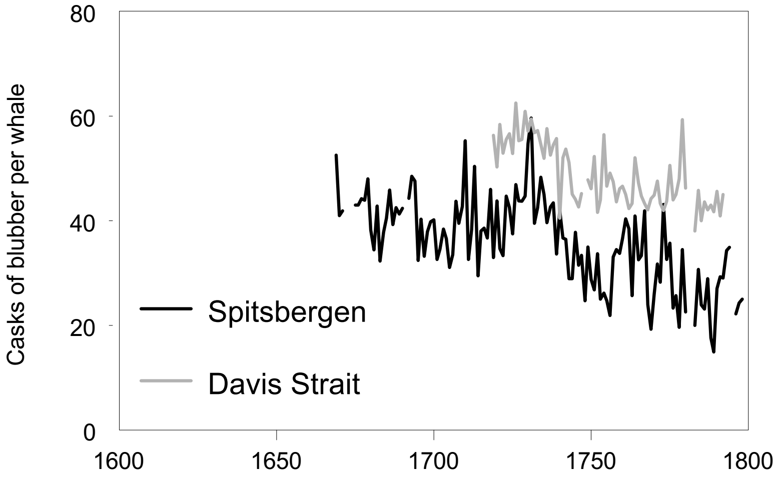


Fig. 9.17 Average number of casks obtained per whale from Spitsbergen and from Davis Strait (data from de Jong 1979, Table 9).

That catch data were not prepared for trend and probability analysis by plotting them in graphs or grouping them in frequency distributions, does not imply that whaling companies did not evaluate and respond to developments in resource outcome. That they certainly did is evident from their allocation of whaling effort in space and time: from sending their whalers to either Spitsbergen or Davis Strait from 1719 onwards, and from the total number of whalers they kept in service (Fig. 9.18).

The question is, whether the whaling companies decided on a year-by-year comparison, so in the smallest time window possible, and on the basis of their own results only instead of those averaged for the fleet as a whole, i.e. without the full use of the data as compiled by, for instance, Zorgdrager (1729) and van Sante 1771. From the description by van der Woude (1972) of the responses in terms of spatial and temporal allocation of whaling effort by a few companies, it seems that the evaluation of resource outcome did indeed have a narrow basis. He calculated that 41 companies based in the Rijp, a whaling village north of Amsterdam, between 1700 and 1769 sent 698 whalers to Spitsbergen and 62 to Davis Strait. Some of these companies existed longer than others, depending on their catching success, but on average they existed only circa five years. Nine companies sent vessels to Spitsbergen every year and in some years to Davis Strait as well. One of these, the "Windig Company", responded in a very *ad hoc* manner to its results in the year before, by keeping more or less vessels in service (time), or sending them to either Spitsbergen or Davis Strait (space) (van der Woude, pp. 454-455, his Fig. 6.19).

The allocation of whaling effort for the fleet as a whole shows as a more gradual development over time for both whaling areas and for areas combined (Fig. 9.18 top). Total fleet size fluctuated strongly until 1719 in response to the developments in resource output, expressed as number of quarteels per vessel (Fig. 9.18 bottom). Van der Woude concluded that there was a response time of around 3-5 years. Once, in 1719, whaling had started in Davis Strait as well, total fleet size fluctuated less and slowly decreased over the years. In the first 15 years of whaling in Davis Strait not only were catch rates higher here than near Spitsbergen, but also the size of the whales caught was larger (see Fig 9.17). This development ended in the 1730s when average return on effort became similar for both whaling areas. In the 1750s and 1760s the whaling in Davis Strait was again more profitable, and this explains the development towards the situation of around 1780, when equal numbers of vessels headed for Spitsbergen and for Davis Strait.

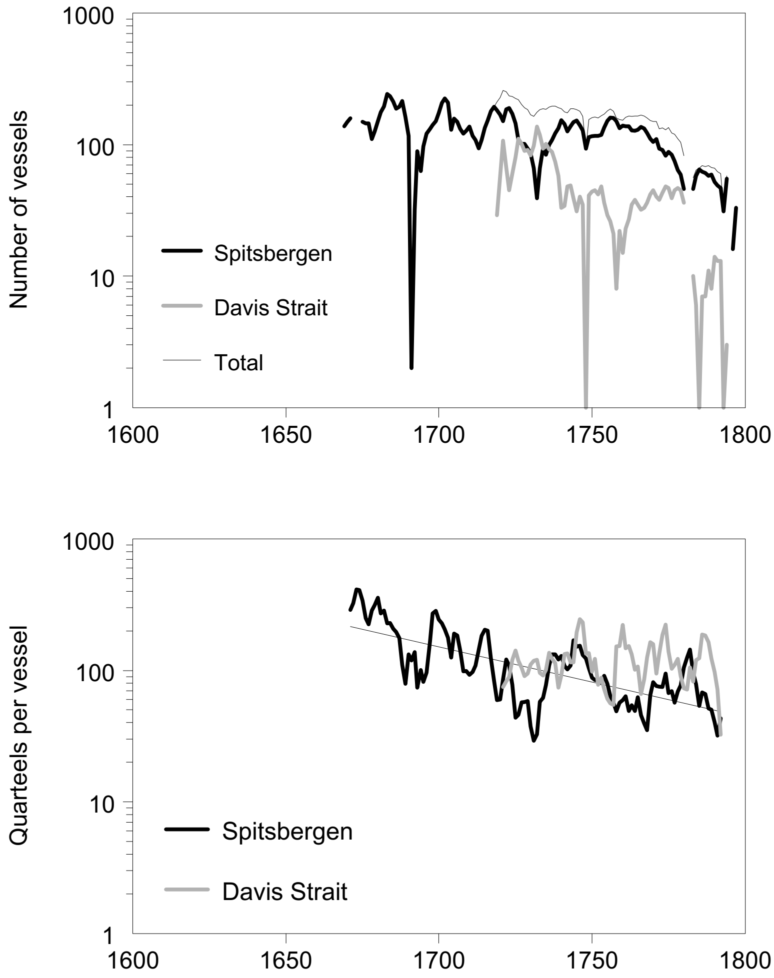


Fig. 9.18 Top: Total number of vessels send to the Arctic 1669-1799 for the two whaling areas separately. Bottom: Catch rates expressed as number of quarteels per voyage.

Not only is the comparison between whaling areas more informative on the basis of the amount of blubber obtained per voyage, but also the trend in resource outcome over the years. The smaller sizes of whales caught after around 1750, made the downward trend near Spitsbergen more clearly to perceive with a higher trend to noise ratio. The trend in the period 1669-1794 was b = -0.00553 (R^2 = 0.328), twice as strong as the downward trend in numerical catches (see Table 9.4). The variability around this trend was s^{10}logCpUE = 0.290 (CV(s) = 0.54), and the trend to noise ratio b/s = 0.019. The time window for the trend to be perceived was still as much as 62 years, under conditions $\alpha = \beta = 0.1$. Serial correlation in the detrended series was $\rho^2 = 0.0517$.

The conclusion from the above is that the average vessel commander during a 20 year career in the Arctic, could not have the slightest idea about possible long-term trends in stock abundance. He experienced, and also by observing the performance of other vessels in his whaling area or harbour, large intra- and inter-annual variability. The short-term trends lasted as long as the average career of a vessel commander, which is much longer than the short-term trends known from regular types of fisheries and those due to the dominance of strong year-classes in the catch (see Chapter 6). It is hardly to be expected that vessel owners, traders and investors who had access to information on catch rates per vessel averaged for the fleet as a whole, would evaluate these catch rates for possible trends in a time window that was so much longer than 20 years.

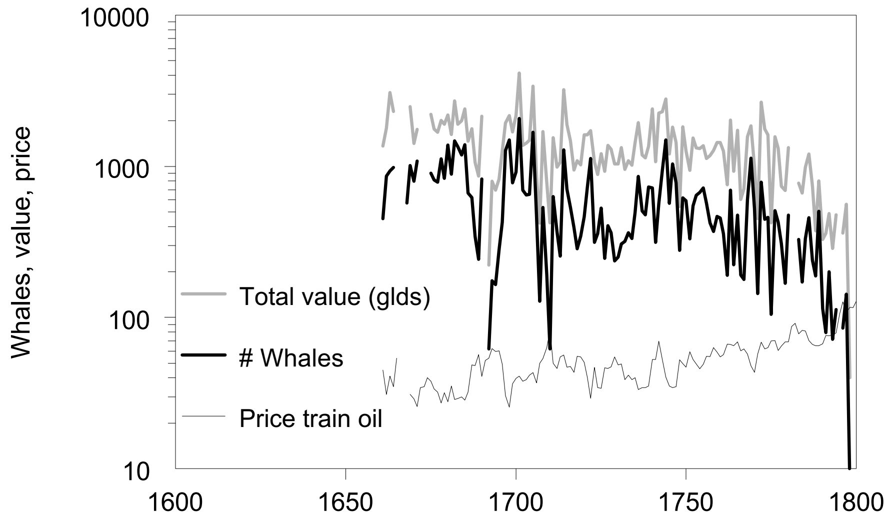


Fig. 9.19 Total money value of train oil rendered from the whales caught by the Dutch fleet near Spitsbergen and after 1719 also in Davis Strait, total number of whales caught by the Dutch fleet and the price of train oil on the Amsterdam market 1661 -1800 (Total money value and price of train oil from Table 7 in de Jong 1979; Number of whales from Table 4 in de Jong 1979).

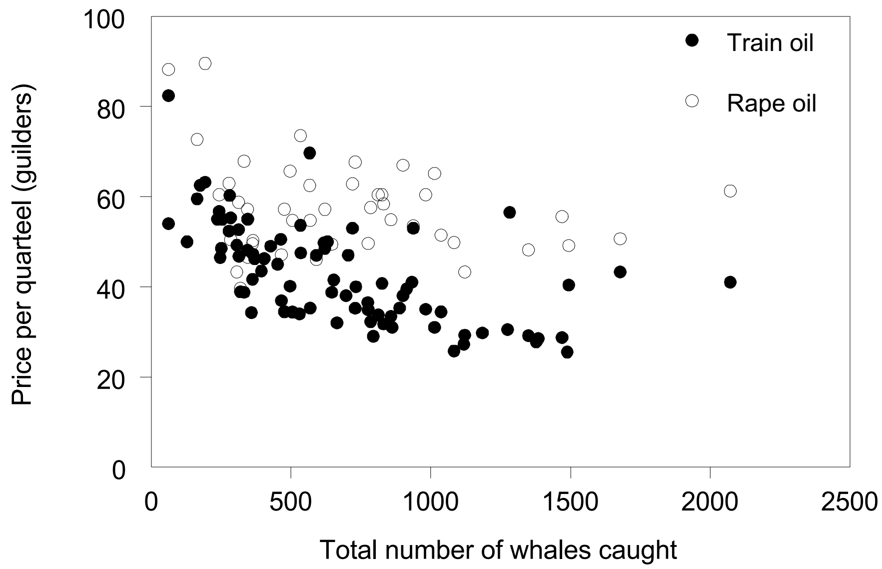


Fig. 9.20 Price (in Dutch guilders) of train oil and rape oil per quarteel on the Amsterdam market plotted against the total number of whales caught by the Dutch fl eet near Spitsbergen and in Davis Strait 1661-1750 (Price of rape oil from Table 20 in de Jong (1979)).

Finally, from a resource management point of view one is inclined to focus on developments in numerical catches and on the average size of whales caught. From an economic point of view it is as relevant to evaluate developments in the money value of the resource outcome, in this case mainly the value of train oil (Fig. 9.19). Until halfway through the 18th century the price per quarteel of train oil varied around an average of 43 Dutch guilders (CV = 0.25) with clear price elasticity. Even the price of the (until the mid 18th century) more valuable rape oil seems to have been affected by the supply of train oil from the whaling industry (Fig. 9.20). After 1750 the price of train oil steadily increased.

9.8 Investments in whaling as a lottery

When, halfway through the 17th century, catches were still high and relatively stable willingness to invest in the whaling industry must have been considerable. Although catch rates were so much smaller in the 18th century, it was still interesting for many to risk small money in the whaling industry, because of the high variability between vessels and years and thus there was still a small chance of achieving a large gain.

Until halfway through the 17th century, variability in annual catches between vessels and years must have been relatively small. First, because of the lower variability in a binomial distribution with a higher average. Second, because of truncation of the catch frequency distribution. Initially whales were encountered in abundance in the western bays of Spitsbergen and so catch rates were high. Also, in these early days the limited capacity of the whaling industry for processing whales and blubber at the land stations, and for transporting train oil to the Netherlands, will have truncated catch frequency distributions at their upper end. This truncation will also have reduced the variability in catch rates between vessels and years so in those days resource outcome was relatively high and stable.

From the systematically recorded catches after 1669 (annual averages) and from 1700 onwards (per vessel and year), it is known how variable resource outcome became once catch levels dropped and the blubber of all whales could be transported to the Netherlands for further processing. Probably in response to the increased variability a growing number of investors took a share in the generally small companies. Most of these companies sent just one vessel to the Arctic. One share in one company meant that one's chance varied according to the inter-annual variability in catch rate averaged for the fleet as a whole and to the intra-annual variability in catch rate between vessels (CV_{tot} ~ 1.1, see 9.7).

The variability in the return on the small investments made in the 18th century must thus have been enormous. The average costs of one trip to the arctic only increased slightly, from 12,000 guilders around 1700 to 14,500 guilders around 1772 (van der Woude 1972). In the period 1691-1798 the annual profit for the average vessel in the fleet was a marginal 568 guilders per vessel (Fig. 9.21). The standard deviation therein, however, was more than 10 times as large (6189 guilders, so CV = 10.9). So not an attractive enterprise in which to make a large, long-term investment, but for some it was worthwhile to risk small money, and wait for the unique large catch to come in. The profitability of the average vessel was never as large as in 1714, when the profit was around two times the investment made (see Fig. 9.21). In that year there must have been individual companies and vessels that reaped a profit that was several times the investment they had made. So investment in whaling was a kind of lottery with a high initial price.

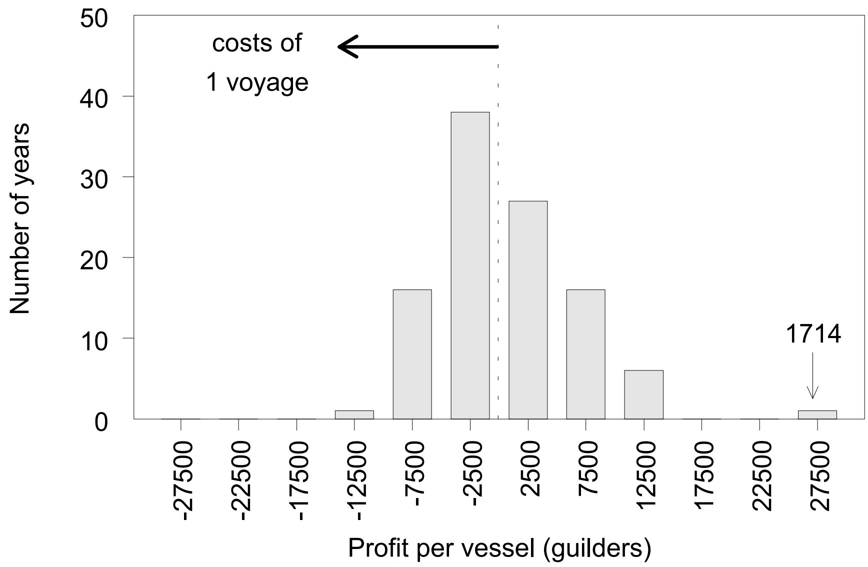


Fig. 9.21 The profit per average vessel and year in the period 1691 -1798, as calculated by de Jong (1979, Table 16), grouped per 5000 guilders category of profitability (mid -point). The average profit was 500 guilders in 1713 and 7100 guilders in 1 715. The average costs of one voyage to the arctic during the period was taken as 13,250 guilders.

Many recognised this lottery character of investments made in the whaling industry of the 18th century. Few probably realised its marginal profitability in the long-term. The profitability of Dutch whaling was fiercely discussed in a weekly paper for trading and navigation "De Koopman", published in the late 18th century. The discussions in this weekly demonstrate that some had an interest in stressing the sometimes high profitability of investments in the whaling industry (Box 9.4). The rationale for those advocating investments in this risky business may have been more in assuring the continuity of the whaling industry than in communicating an impartial evaluation of catch rates and profits. The explanation is that some were both investors ánd traders, supplying goods and equipment to the whaling industry. They were well aware that théir profit depended on the continuity of the whaling industry. For them influencing the public debate may have been very effective, because decisions were taken in a most democratic manner. In the end it was the general members' meeting, both in holding companies and in shareholder companies, which determined the management (Leinenga 1995). Even forces outside the whaling industry had an interest in its continuity. The national government, for instance, had an interest in maintaining a pool of seamen, who would be able to assist the marine forces during times of war, and therefore subsidised the whaling in various indirect ways, for instance by lowering the tax rates for vessel stores (Leinenga 1995, p. 109).

In conclusion, it is hard to value the arguments and evaluations given in "De Koopman", as a true reflection of the capacity for data and information handling in natural resource management at that time.

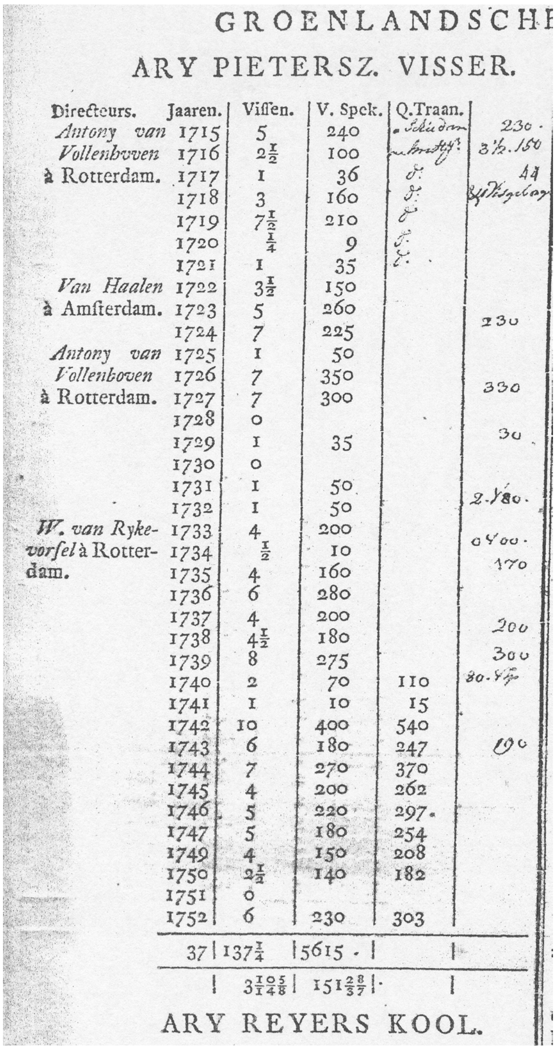
9.9 Constraints on the perception of time trends

The stock of bowheads near Spitsbergen must have been continuously over-exploited but to a limited extent throughout the 17^{th} and 18^{th} century. The weakness of the long-term trend, the high and sometimes persistent noise around it, and the poorly standardised unit of effort are all explanations for a poor perception of the downward trend in stock size. The short-term downward trends in numerical catches in the 18^{th} century (4-5% per year) could last as long as 20 years. This is circa five times longer than most of the short-term trends due to the dominance of a strong year-class (blue noise) as discussed in Chapter 6. With the same absolute time scale, the short-term trends in whale catches could thus be categorised more as red noise. Whaling companies could have experienced the short-term downward trend in catch rates followed by a period of recovery, as an indication that long-term dynamics in stock size were unpredictable and catch rates not clearly causally related to whaling pressure during the same time interval. Technical or biological explanations for the short-term trends are hard to give. They may have been related to persistence in the extent of the pack ice and thus in whaling conditions. Periods of increase and decrease in the total size of the stock could have natural causes related to recruitment patterns, as in fish stocks, but this is speculative as yet.

The strong call for a general meeting on the more rational exploitation of the bowhead stocks in the late 18^{th} century (Box 9.4) must have been inspired by the combination of various sources of information on the size and quality of the stock, and possibly still from a relatively small time window. The series of tabulated catch rates may, after all, have been the least instructive of those. The smaller average size of the whales caught, certainly after 1740, may have been the most alarming, although this indicator also showed large inter-annual variability, even in aggregated data (Fig. 9.17). Anyway, the trend to noise ratio was circa twice as much in the downward trend for the amount of blubber yielded per voyage (b/s = 0.019) as in the number of whales per voyage (b/s = -0.009).

Although the performance of Dutch whaling during most of the 17^{th} and 18^{th} centuries was very accurately documented, the use of catch and effort data for evaluation and decision-making in the whaling industry must have been constrained by the contemporary inability to turn data into information. In these days the mathematical formulation of variabilities and of future probabilities, let alone their practical use in resource management, was still far off. For a long time tables have been the major form of output for monetary algorithms (Klein 1997). It was not until the late 18^{th} century that time series charts began to appear in scientific writings (Tuft 1983). William Playfair (1759-1823) developed nearly all the fundamental graphic designs, seeking to replace conventional tables of numbers with systematic visual representations, amongst which long-term developments in grain prices, wages of labours and other indicators of resource output and use. But the golden age for graphs, even in science, was still to come with the era of empirical investigation in the late 19^{th} and early 20^{th} centuries (Klein 1997).

Similar constraints existed in the use of catch data for estimating probabilities. Although statistical probability theory has its roots in 17^{th} century science when stable probability ratios were assessed for games of chance, European merchants at that time did not borrow from this probability theory for analyzing fluctuations in their enterprises (Klein 1997). The same holds for the development and use of descriptive statistics by which variability could be expressed. It is only with the investigation of natural selection in the 19th century, that deviation from the mean became an analytical concept, and it is with the biometric work of Pearson that the standard deviation was first articulated (Klein 1997, p. 177). So a simple measure of variability, such as the coefficient of variation, being the standard deviation over the mean, is of relatively recent date.



GROENLANDSCHE

ARY PIETERSZ. VISSER.

Directeurs.	Jaaren.	Vissen.	V. Spek.	Q.Traan.
Antony van	1715	5	240	
Vollenhoven	1716	2½	100	
à Rotterdam.	1717	1	36	
	1718	3	160	
	1719	7½	210	
	1720	¼	9	
	1721	1	35	
Van Haalen	1722	3½	150	
à Amsterdam.	1723	5	260	
	1724	7	225	
Antony van	1725	1	50	
Vollenhoven	1726	7	350	
à Rotterdam.	1727	7	300	
	1728	0		
	1729	1	35	
	1730	0		
	1731	1	50	
	1732	1	50	
W. van Ryke-	1733	4	200	
vorsel à Rotter-	1734	½	10	
dam.	1735	4	160	
	1736	6	280	
	1737	4	200	
	1738	4½	180	
	1739	8	275	
	1740	2	70	110
	1741	1	10	15
	1742	10	400	540
	1743	6	180	247
	1744	7	270	370
	1745	4	200	262
	1746	5	220	297
	1747	5	180	254
	1749	4	150	208
	1750	2½	140	182
	1751	0		
	1752	6	230	303
	37	137¼	5615	
		3 105/148	151 28/37	

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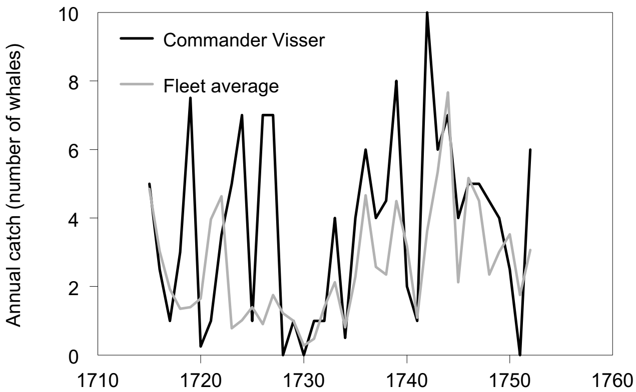

Fig. 9.22 Left: Part of a page from van Sante (1771) with the performance of commander Ary Pietersz Visser who operated near Spitsbergen for from 1715 to 1752 , only interrupted in 1748. 1 st column, owner; 2nd column, year; 3rd column, number of whales, 4th column, casks of blubber, 5th column, quarteels of train oil. Right: Graphed time series for the annual catch of the commander and for the annual catch averaged for the fleet as a whole.

Thus, it seems that catch data on Dutch whaling in the 17th and 18th century were neatly prepared for their potential transformation into management-relevant information with the aid of graphs and probability distributions, but the time was yet not ripe for such transformation and use. In the publications of Zorgdrager (1729) and van Sante (1771) average annual catch rates were tabulated as average catch per vessel and year, but van Sante also published 'raw data'. He listed catch records per commander and year in alphabetical order of the commander's first name (Fig. 9.22). One could wonder: why this data structure, what purpose was served, what information was it hoped to extract? Van Sante (1771) could easily have applied another data structure. He could, for instance, have sorted all individual catches by calendar year. This would possibly have invited him to tally catches per catch size category and so could have lead to a catch frequency distribution for each year and thus a possible quantitative assessment of probabilities and of intra-annual variability between vessels.

Once in the 20th century long-term evaluation of annual catch rates from the whaling industry of the 17th and 18th century was tried via graphical presentation and historians gratefully used the data recorded so neatly and sometimes processed them into 9-10 year progressive means for the detection of possible short-term trends (van der Woude 1972, Leinenga 1995). Van der Woude (1972), in his study of the history of the Noorderkwartier, an area north of Amsterdam where many whaling companies were based, used log-transformations in 28 out of his 47 graphed time series of developments in annual quantities from agriculture, fisheries, whaling, human population etc. Although not mentioned as such by the author, this allowed for variability to be more easily read and compared from the variance around the trends.

At the beginning of the 20th century the processing of the time series with data on historical whaling into informative graphs, let alone into log-plots, still seemed beyond their scope. For his 1919 publication on historical whaling the historian Wätjen only used tables, in which he listed the complete data set of number of whalers heading for Spitsbergen and Davis Strait, number wrecked and number privateered, average annual catch rates and the number of casks, both as found in the 'Amsterdam lists' and in van Sante (1771). He did not process the data into a graph or any other format, which by then had become more common in studies on resource outcome, and that would have enabled their evaluation for possible time trends and for inter-annual variability in particular. He seemed even overwhelmed by the large amount of data available, not always knowing how to extract the information they possibly contained.

"Im allgemeinen lechzt ja der Wirtschafshistoriker nach Zahlen. Treten sie ihm aber bei archivalischen Untersuchungen in solchen Massen entgegen, dann segnet er den Augenblick, der ihm ein ziffernloses Dokument in die Hände spielt"

"The historian of economics generally craves for numbers, however, when in the study of archives they run into him in such masses, he will bless the moment that brings him a cipherless document" (translation)

Wätjen 1919, p. 257

When comparing the 17th and 18th century, mainly Dutch whaling for bowheads near Spitsbergen with 20th century world-wide whaling, one could wonder whether the format in which information was available could have played a role in the reckless fishing up of the large whales in the period 1930-1970. Would fishing effort in the 20th century have been controlled more strictly, if information on catch rates had been made available and communicated in time plots that now, with hindsight, show the disastrously steep downward trends so clearly (see Box 9.1)? Was it also because whaling was dispersed world-wide, targeted several species and stocks at the same time, operated by several nations and, until the founding of the IWC in 1946, monitored by a weak central administration, that the sharp downward trends in CpUE of blue and fin whale were obscured? Most of the explanation for the dramatic depletion of the stocks of large whales must be in the irresponsible and non-sustainable operation of the whaling industry, but data processing and the presentation of the information must have played a role as well, the importance of which still has to be assessed.

9 Variabilities and the perception of time trends in Dutch whaling in the 17th and 18th century - Conclusions

- Inter-annual variability in the catch of bowhead whales near Spitsbergen by an individual whaler was, in the 18th century, as high as CV = 1.1. The variability in the fleet's average catch was still as high as CV = 0.9, and the 'administrative gain' of reduced variability thus marginal.
- Only around 10% of the variance between whalers but within years (CV = 0.7) was due to systematic differences between them, which might reflect differences in individual whaling skill.
- During the 18th century there was no significant long-term trend in the annual catch averaged for the fleet as a whole, but there were persistent short-term trends of 20 years and more ('red noise'), which were probably due to gradual changes in the catchability of the whales as affected by persistent changes in ice cover.
- For the individual whaling commander during a lifetime career of around 30 years in the Arctic, ànd for the administrators, it was only just possible to detect these persistent short-term trends.
- The high variability in the catch between years and between whalers combined with the, very low average profitability of the whale fishery (4% return on investments), ensured that whaling companies were small and on average existed only briefly. But because of the high variability, many individuals invested small amounts of money in these companies hoping for the occasional return on investment of sometimes more than 100%.
- Graphed time series and probability distributions might have been helpful in rationalising the whaling strategy through space (choosing between whaling grounds) and time (more or fewer vessels), but the these statistical tools were unknown until the late 18th century, and this must have meant another constraint on the perception of time trends in the resource and its outcome.

Box 9.1 - Dramatic decline in whale catches in the 20th century

Downward trends in catch rates and in the size of an aquatic resource can never have been perceived more clearly than from the history of 20th century whaling. All the basics a student of natural resource management could learn about the management of renewable resources and about capturing signals of serious over-exploitation, is contained in this short story of no more than half a century's duration (1930 - 1980) (Fig. B9.1). In the period 1930 – 1965 total whaling effort increased by a factor 4, but the numerical catch increased by a factor of only 2, and the annual catch in terms of total body mass even remained the same throughout (factor 1). The average size of the whales caught, however, decreased continuously mainly because they had to target ever smaller species.

The species replacements were fast and took 20 years each at the most. In the 1930s the 30m blue whale, the largest animal in the world, still dominated total catch weight, but this species had already been replaced by the smaller fin whale in the 1950s (Fig. B9.1, B9.2, Table B9.1). The fin whale in its turn had to give way to the sperm whale, which dominated total catch weight in the 1970s. After 1965 total catch weight was already sharply on the decline. Ultimately, just before the ban on whaling in 1985, the minke whale, the smallest in the series with a body length one-third of that of the blue whale, dominated whale catches. Total annual catch of minke whale output in terms weight, however, was only marginal when compared to the catches of blue and fin whales during their peak periods.

The downward trends and species shifts in 20th century whaling were unidirectional, fast and dramatic. Total stock size of some whale species is at present little larger than their former annual catch (Table B9.1). Population growth of these large mammals is relatively slow and for most whale species it will take a century before they reach their pre-exploitation levels, if ever (Perry *et al.* 1999). The two exceptions to this are the sperm whale and the minke whale, the last two species in the series of progressive exploitation, which are still numerous. These two species could certainly stand future exploitation by an industrial whaling fishery. Those in favour of such exploitation blame the world community for opposing such exploitation of these two species on non-scientific grounds or mere ignorance (e.g. Aron *et al.* 2000). The authors refer to a Gallup poll in 1993, in which 53% of the US population answered that there were less than 10,000 sperm whales left, not aware that the number of sperm whales now approaches 2 million. Whether or not this is the result of poor perception of the state and developments in the whale stocks, it is not surprising that people now oppose whaling in general, when they have grasped some notion of the detrimental impact of the whaling industry in the years 1930 – 1980. Leading authors on the sustainable use of the global environment (Ehrlich & Ehrlich 1970, Meadows 1972), copied the illustrations of the disastrous developments in the whaling fishery by Payne (1968) to demonstrate, for a wide audience, how detrimental the exploitation of a major natural resource could be.

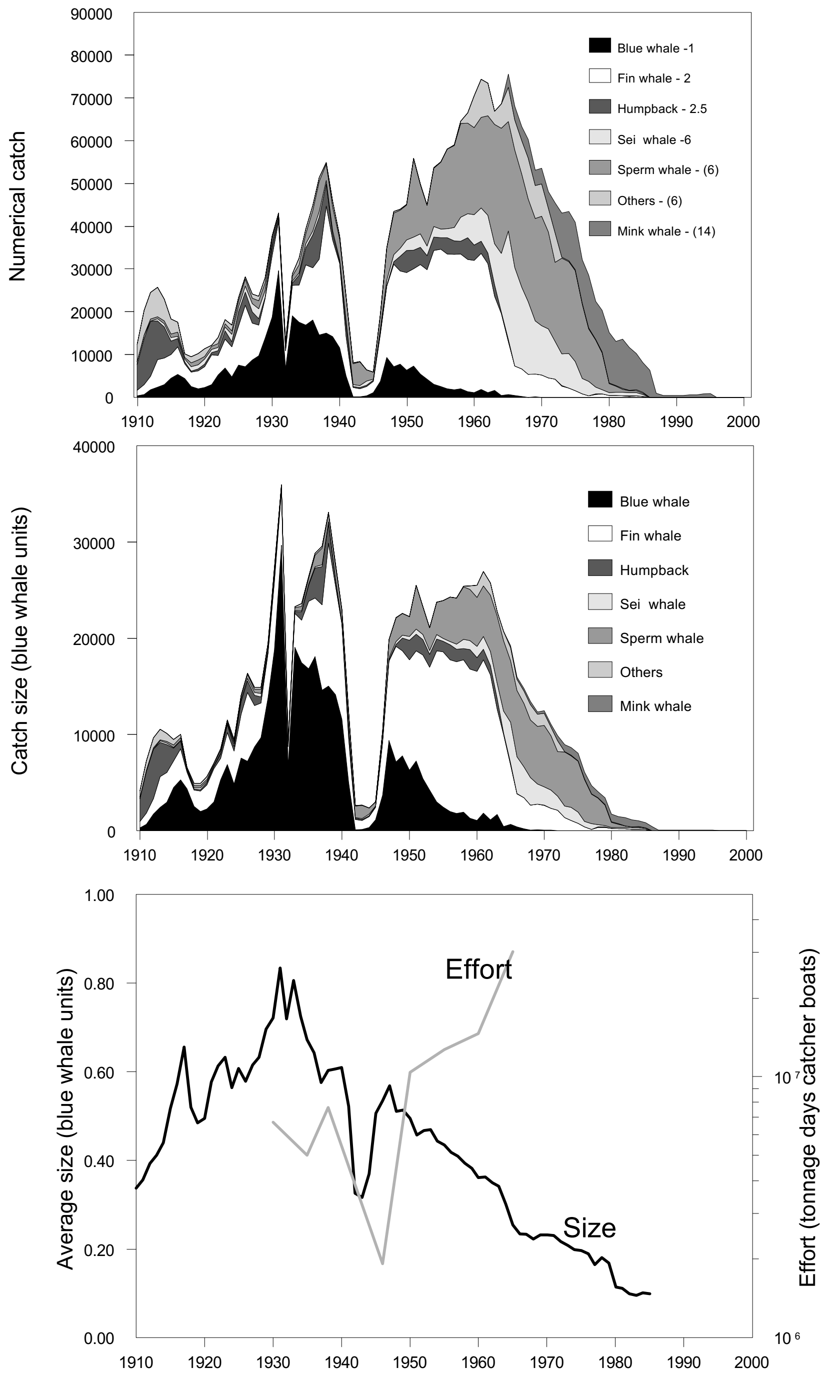

Fig. B9.1 Top. Number of whales per species caught in the period 1910-1995. After 1969 the Bryde's whale is categorised as sei whale. After 1957 the category "Others" could include other species mentioned in the legend, but not blue whale (Numerical catches from the International Whaling Commission). The number in the legend refers to the number of individuals of that particular species, which according to the IWC produces the same amount of whale oil as 1 blue whale (= Blue Whale Unit). The numbers between brackets are based on the comparison of the individual weight of mature individuals per species taken from the literature. The number for "Others" is a conservative assumption. Middle: Quantity of whales caught in BWUs. Bottom: Average size of all whales combined in Blue Whale Units and Total fishing effort expressed in gross tonnage days of catcher boats. Fishing effort was calculated from figures in Payne (1968).

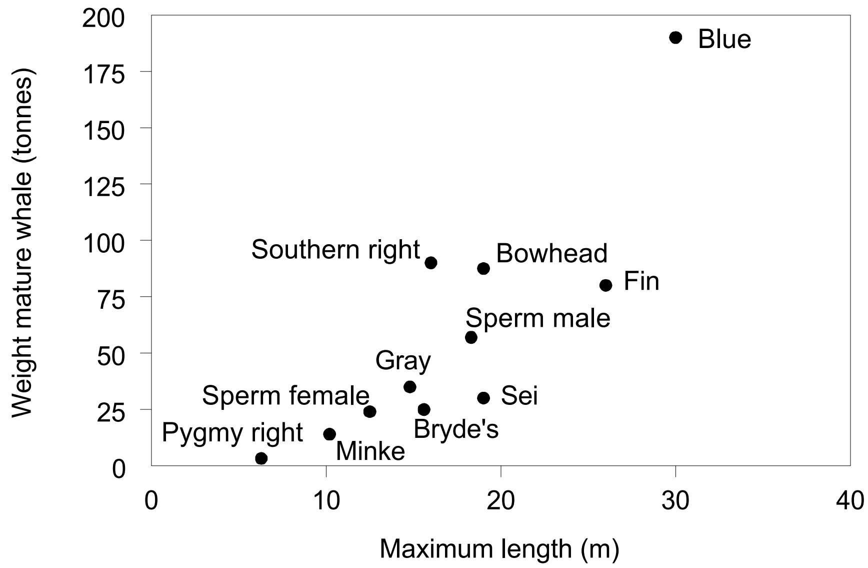

Fig. B9.2 Individual weight (tonnes) of mature whales per species plotted against their maximum length (m). Only in the case of the sperm whale do males grow to larger sizes than females and only for this species is the sex difference in weight of mature individuals considerable.

Table B9.1 Current status of large whales, their maximum annual catch as published by the IWC, and their weight once mature. Population sizes as given in Table 15.2 in Berta & Sumich (1999). Weight from Würtz & Repetto (1998). *) Weight for the southern right whale only. **) For sei and Bryde's whale combined. ***) From Leinenga (1995).

Common name	Population size at present	Maximum annual catch in numbers (year)	Weight mature individuals (tonnes)
Baleen whales (Mystacoceti)			
Blue whale, *Balaenoptra musculus*	< 9,000	29,649 (1939)	190
Fin whale, *Balaenoptra physalus*	119,000	32,185 (1955)	80
Bowhead whale, *Balaena mysticetus*	8,000	2,764 (1701)***)	75 – 100
Right whale*), *Eubalaena australis (southern) and glacialis (northern)*	> 2,000		80 – 100
Sei whale, *Balaenoptra borealis*	25,000	25,453 (1965)**)	30
Bryde's whale, *Balaenoptra edeni*	90,000		25
Humpback, *Megaptera novaeangliae*	> 10,000	12,829 (1912) 5,055 (1959)	2?
Gray whale, *Eschrichtius robustus*	22,000		35
Minke whale, *Balaenoptra acutorostrata*	725,000	12,500 (1977)	14
Toothed whales (Odontoceti)			
Sperm whale, *Physeter catodon*	1,810,000	29,255 (1964)	57 (m) – 24 (f)

Box 9.2 - Shifts in the spatial allocation of the whaling near Spitsbergen

In 1729 Zorgdrager published his account of the Dutch whale fishery near Spitsbergen, from its very beginning in the early 17th century. In Chapter 5 of the book he describes the various stages in the whale fishery, the bay fishery along the west coast of Spitsbergen, the shift to other bays along the coast, and finally the shift to whaling along the pack ice in the west and the dangerous whaling in between the pack ice along the east coast of Greenland. All these shifts are considered the consequence of chasing away the whales, not of their over-exploitation, although at the time of publication the whaling near Spitsbergen had already been operated for more than a century. The following paragraphs were selected from Chapter 5 (page 234-240).

Paragraph 1 *Falling catches near Spitsbergen, the major land station on the west coast of Spitsbergen in the early phases of the whale fishery, were explained from the chasing away of the whales. The shift to a nearby whaling ground turned out to be rewarding.*

Deeze Visch, die door zyn groote meenigte en sterke voortteeling, gelyk uit het aangetoonde ruime queekveldt kan afgeleid worden, niet lichtelyk was t'eenemaal op te vangen, kon echter door dit geweldig vervolgen, moorden en dooden van de vescheiden Natiën langs de geheele kust, zyn hoofdt door de meenigte zyner vijanden naaulyks boven water opbeuren; dies werdze genoodzaakt dit Gewest, alhoewel hun aangenaam allenks te verlaaten. Om nu kortheitshalven by de Visschery der Hollanders alleen te blyven, waar uit alle de andere Visscherijen konnen afgeleid worden, zoo begonnen deeze Visschen, het gemelde Smeerenburg in de Hollandsche Baay, 't allereerst te leeren kennen en bemerkende dat alhier de verzaamelplaats hunnenr Vyanden was begonnenze die te schuuwen; want zoo dra zy deeze Baay gewaar wierden, als meede de Schepen en meenigte der Sloepen daar om heen zwervende kendenze aan dit gevoel, wat hun naaakende was, schoon zy te vooren in hunnen onnozelheit op dezelven aan en om zwommen, en zich dus als weerloze schepselen lieten dooden; maar nu op het enkele beschouwen van dezelven, leerdenze hunnen vyandt kennen, en stelden 't eerlang op 't vluchten. Dus moest men dan deeze schuuwe en vliedende Visschen, met zeer grooten arbeidt naroeyen, en eindelyk waren 'er zoo weinig meer overgebleeven, dat men somtyds na veel gedaane moeite en krachtig naroeyen, echter niets opdeed, zulks de Sloepen wederom leedig aan boordt quamen. Dit nu klaagde men den Commandeurs, en men pleegde raad wat verder te doen stond; de Visschen vond men 'er niet meer zoo overvloedig, en die daar gevonden wierden, waren zo schuuw, dat ze bezwaarlyk konden gevangen worden. Hier op gaf men last naar de Noordbank te vaaren, dewyl daar nog Visch genoeg was. Deeze Noordbank legt voor aan in de Noordbaay, omtrent twee mylen van de Schepen die onder Smeerenburg laggen; deeze gemelde Baay is groot en wyd, en was boven dien benevens meer andere Bayen, ten die tyde, een ongemeene Vischryke Baay. Op deeze Noordbank, als gezegt is, vond men Visch genoeg, want schoonze om de gemelde redenen van Smeeerenburg afweek, echter was ze noch op andere plaatsen t'eenemaal niet geweeken.

Paragraph 2 *Once the whales were chased in the open sea, they became more difficult to catch. Whalers searched for the more productive feeding areas where the bowhead whales concentrated, but even here catches fell.*

De Visch dus van de Wal in Zee geweeken, en van de Zee-visschers aldaar geduurig vervolgt, werd allenks nog wilder en schuuwer, zulks ze in de ruime Zee t'eenemaal vestrooiden, 't welk de Visschery nu gevalliger en moeilyker maakt; want schoon de gehele Zee tusschen Jan Mayen-Eilandt en Spitsbergen, alwaar de Visschery toen wierd gepleegt, voor eerst met deeze en meer andere Visschen gelykzaam was bezaait, zoo werd echter deeze Visch, door 't gestadig jaagen en vervolgen, mede aldaar in Zee zodanig ontrust, en in deeze ruimte van de eene ter andere plaats gedreeven, dat 'er dikmaals maar een enkele en somstyds geheel geen Visch wierd gezien. Men begon dan in Zee mede naar de Banken te zoeken, alwaar men toen veeltyds groote Schoolen by elkander kon aantreffen, vermist de Visch alhier op hun aas afquam. Maar eerlang wierden deeze Banken zoo sterk met Schepen en Sloepen bezocht, dat het de Visch daar mede niet lang houden kon. Ten dien tyden was 'er onder anderen een ongemeene Vischryke Bank voor de Zuid Baay, omtrent ter halver gezicht onder 't Landt, alwaar door een zekere Commandeur, Keere genoemt, verscheiden Jaaren na den anderen veel Visch gevangen wierd, en derhalven lang na dien tydt, en ook heden nog door eenige oude Commandeurs Keers Kaar geheeten word, maar 't is door het gestaadig vervolgen nu mede een ledige Kaar geworden.

Paragraph 3 *The next phase was the whaling along the margins of pack ice in the west, followed by the more dangerous hunting of whales in between the pack ice. The conclusion reached is that the whales are not fished up but simply chased from one place to another*.

Ook begon de Visch allenks zich meer naar 't Ys, als in een sterkte of borstweering te begeeven, zulks dat het dikmaals gebeurde, zoo dra men een Visch geschoten, had dat hy zich aanstonds naar 't Ys wende, schoon men nergens daar omtrent geen Ys beoogen kon; waar uit dan genoegzaam kon voorspelt worden, dat hy zyn koers wel wist te houden, en men derhalven niet verre van 't Ys wezen moest. Wanneer dan de Visch in 't Ys liep, vermits men toen met de Schepen schroomde in 't Ys te zeilen, kapte men de lyn af, en liet hem dus gewond met de harpoen in 't Ys vluchten; hier mede raakte hy, zich gewond voelende, noch verder aan 't vluchten, en met zodaanig een verbaastheit, als of hy noch gestaadig met de Sloepen vervolgt wierd, zulks hy byna tot geen bedaaren komen kon, en zodanig een vluchtende Visch bragt 'er meer anderen aan 't vluchten. Hier door kreeg nu de Visch zodanige scherpe en gevoelige indrukselen, en een geweldigen afkeer voor 't Landt en de open Zee, dat het hen scheen in 't zaadt, merg en gebeente als doorgedrongen, zoo dat ook de Jongen dezelfde indrukselen schynen aangeboren te zyn want zoowel de Jongen als de Ouden zyn alle gezaamentlyk uit Zee geweeken, en zwemmen nu zelden in de ruime Zee, en met den rug bloot, maar onthouden zich liever in 't Ys, waar in zy zich beter bedekt konden houden. Deeze Visch dan aldus van het Landt af in Zee gedreeven, en door de meenigte zyner Vyanden het daar meede niet konnende harden, is ze allenks t'eenemaal in 't Ys, het Westys genoemt, geweeken; maar eer zy de Zee ruimden, onthielden 'er zich noch veel aan den Zoom van 't Ys, en somstyds in en buiten 't Ys. Nu werd goede raad duur; men schroomde het Ys te naaderen, en echter noodzaakte hen de Visch, dat men ’t derwaarts wenden moest, doch eermen besloot in ’t Ys te loopen, viste men langs den zoom en in groote bogten en kommen met een taamelyke vangst; maar eindelyk, om zyn Vyandt, waar ’t mogelyk, noch verder te ontwyken, hieldt zich de Visch gelyk als schuil en bleef in ’t Ys. De Visschers dit merkende, vermits ‘er buiten ‘t Ys niet meer te vinden was, maar dat ze echter van van de Steng in ’t Ys konden gezien worden, alwaar men mede by stilte hun geblaas kon hooren, beslooten, alhoewel schroomlyk om ze in ’t Ys op te zoeken, ’t welk ze eerst niet verre behoefden te onderneemen, of vonden de Visch; men maakte dan slegts de Schepen aan eenige Schotsen vast, eer men zich noch aan de Ys-velden betrouwde, en veelen hadden toen in ’t los Ys noch een goede vangst; want in ’t eerste vond men ‘er zeer veel Visch, waar door by ondervinding geleert wierd, dat de visch niet was opgevangen, maar alleen van de eene naar de andere plaats verjaagt.

Box 9.3 - Hostile attitude to those providing data on the performance of the whale fishery

In 1771 van Sante published his full account of catch rates in the whale fishery near Spitsbergen and Davis Strait, including individual catch rates per commander. It was a major effort in making data available for all those interested in the exploitation of the resource. The reactions in a weekly paper for Dutch trading and navigation, "De Koopman", so many years later, were outright hostile. Those critisising van Sante expected that the availability of the data and the information they contained would deter investors in the whaling industry. Van Sante himself did not process his tabulated data in a format which allowed for the evaluation of possible long-term trends to exist or for assessing the degree of uncertainty in catch rates. Nor did he add any text which expressed the evaluations he possibly made for himself. In just one sentence, in his preface, he stated only that the fishery was average profitable:

"En schoon de Visschery geen Wiskonst is, en voor eenige nadeelig is geweest, zy heeft egter voor het grootste gedeelte gewenschte Voordeelen aangebragt"

"De Koopman" IVe Deel, No. 12, p. 94.

Opinion expressed in the journal: *Although van Sante correctly stated that the results were mostly negative, he did not account for all those who earned a living by supplying goods and services to the whaling industry.*

"Als men niet ontbloot is van eenig oordeel, en de reeden niet ten eenemaal wil tegenspreeken, zo moet men zekerlyk met den makelaar van SANTE bekennen, dat 'er gewisselyk jaarlyks meer kosten aan de Vlooten der Visschery werden gedaan, als de Vangst derzelver kunnen opbrengen: Maar de VOORDEELEN die de Houtkooper, Timmerbaas, Lynslager en de verdere Arbeiders en Leveranciers hebben, en dit gevoegd by de Inkomst van de Vangst, zo zoude het VERLIES of de SCHAADE die hy voor de Rederyen der Straatdavidse en Groenlandse Vissery stelt, vry wat minder zyn, als nu uit zyn gemaakte Lyst is blykende. En ik oordeel dat hy dan de Inwoonders van ons Land vry wat meerder dienst zoude gedaan hebben, als nu, met een Lyst uit te geeven, waardoor hy Lands Inkomsten zoekt te verminderen, en de kwynende Zeevaart den doodsteek tragt toe te brengen; en zo hy zulks niet had goedgevonden, als blykt, zo ware het wel goed geweest zyne geheele observatie hier omtrent maar agterwege te laaten, en die maar voor zig zelven en voor zyn Famielje te houden."

"De Koopman" IVe Deel, No. 28, p. 220

Opinion expressed in the journal: *The outcome of the whale fishery is truly stochastic, and the listing of data by van Sante only satisfied general curiosity, although it is known that some tried to evaluate these data for possible trends.*

"De Groenlandse en Straatdavidse Visschery, was voorlang een Onderwerp van veele naspooringen; 't ongestadig fortuin, en zo veele veranderlyke Keren en Wisselvalligheden, die dezelve geduurig by beurten met Voor- en Nadeelen, maar inzonderheid het laatste, nu op dan neder dreef: maakte, de Belanghebberen al vroeg oplettend, om 'er den uitslag jaarlyks van nategaan; om 'er, was 't mooglyk, een netter' pyl op te treffen: dan de ondervinding heeft geleerd, dat het 'er al veel op gelyke wyze mede gelegen is, als met Waarnemingen van het Weder, daar even min een vasten regel op te vinden is, waaruit al voor jaaren het zeggen geboren weird: *de Wind, het Weer, de Wissel en de Walvischvangst, zyn vier Wisselvalligheden*. Evenwel heeft men meer uit nieuwsgierigheid, dan om 'er een' weezenlyken staat op te maaken, voorlang zig al bediend van jaarlyks gedrukte Lysten der uitgaande Visschers. Men tekende daarop van tyd tot tyd, in eene geschikte orde aan, de Vangsten enz. Der Scheepen, om eem Verzaameling daar van, te doen dienen, tot een rigtsnoer kon het zyn der volgende Vooruitzigten"

"De Koopman" IVe Deel, No. 28, p. 224

Opinion expressed in the journal: *The publication of van Sante spread information on the high uncertainties and low profitability of the whale fishery amongst many, who better should not possess such information. It deterred potential investors and those who really needed such data already had access to them.*

"Ik voor my, wil dit met al myn hart toestemmen, maar zie daar! Welk Voordeel brength hy zelve met zyn Boek, de Visschery aan, voor zo verre het de particuliere Reederyen raakt? En men mag hier vraagen, waartoe het diene? Ten welke einde het eigenlyk nut is? waarlyk ik heb niet kunnen zien, ooit tot iets anders, dan blootlyk om de nieuwgierigheid te voldoen. Die lysten met de Kanscyfferring, behoorden een diep geheim gebleeven te zyn voor duizenden: zy waren van zelve in handen van hen wien ze volstrekt noodig hadden, en ze raakten niemand anders. De Heer van Sante mag dan hoopen geenzints vrugtloos werk verrigt te hebben met zyn Verzaamling, maar voor my, ik zie nog niet welke vrugt het doet. - Het opend al te veel oogen, en animeert niet veel om Scheepen aan te leggen: want als men by hem de jaaren narekend, zo is 'er in lang geen Voordeel by de visschery: want jaar door jaar, en Schip door Schip 2 17/20, in ordinaire jaaren 2 1/16, en zo als in den laatsten tyd naauwelyks 1 1/4 Vissch, daar konnen immers de Onksten niet uit, en 'er moet Geld by."

Box 9.4 - Measures as suggested in 1778 to improve the Dutch whale fishery

In a weekly paper for Dutch trading and navigation, "De Koopman", a discussion on the profitability of the whale fishery in the 18th century ended with the listing of four major ways in which the fishery could be improved:

1. It is recognised that both over-exploitation and scaring away of bowhead whales were reasons for lower catch rates and competition in this fishery should thus be reduced.
2. It is advised to venture into old, deserted whaling grounds and into new resource areas. If necessary longer voyages should be made to chase the bowhead whale up to the coast of America.
3. It is advised to fish pair wise so to assure that at least one of the vessels is not blown by the wind into the pack ice, keeping manoeuvrability.
4. Whalers should be stimulated in all ways to improve the efficiency of their whaling, including harpooning and research on the feeding behaviour of the bowheads.

These measures should all be discussed during a general assembly of stakeholders in the whaling industry.

"De Koopman", IVe Deel, No. 29, p. 231-232

"Middelen ter Verbetering op de Walvischvangst

1. Voorheen toen men die langs de Kusten van de Eilanden en in de Baaiën kon verrigten, was ze merklyk beter en voordeliger, dan men ze in volle Zee, tussen de Ysschotsen vol gevaar, moet uitvoeren, en dan niet minder moeilyk. De Walvisch, door dat men ze zo sterk wegvangt, heeft eens deels den tyd niet om zyn volle grootte te erlangen, en word anderdeels zo zeeer schuw gemaakt en verjaagt, dat 'er wel weinig ten beste valt. Daar moet een bepaaling zyn ten aanzien der Winzugt, die dit verbeterde, en die maakte dat men elkander minder bedurf.

2. De Visch houd zig op van de Straatdavis en Ysland af, langs den zoom van 't West ys tot aan Jan Maaien Eiland, en zo langs dien zoom tot aan Spitsbergen; verders Zuidwaarts op tot aan de Waaigats en Nova Zembla, en dus aan de Noord- en de Zuid-Kaap; En zints jaaren kiest men hier de Vischplaatsen niet zeer gelukkig uit. Men behoorde minder alle op een hoogte te blyven, maar liever de oude verlaaten Velden en Baaiën eens weder op te zoeken, en zig niet zo naauw aan Spitsbergen en 't nieuwe Groenland te bepaalen; dan moest men 't waagen om de Visch, zelfs tot op de Americaansche Kusten te volgen, en 'er niet naar zien al maakte men de Reizen dan al wat langer, en moest 'er de Scheepen naar proviandeeren.

3. Men vangt met enkele Scheepen, seperaat; op de Vischvangsten draaid de Wind algeduurig, en dryft de Scheepen die hem tegen hebben, te zeer het ys toe, verjaagende dus al mede de Visch. Dit moest men voorkoomen: één Reeery moest altyd twee Scheepen by een doen blyven om de Vangst te deelen; als dan het eene Schip aan de eene, en het ander aan de andere zyde lag, moest een van beiden ontwyfelbaar, de Wind was dan goed of kwaad, altoos open water en goede gelegenheid om te visschen hebben.

4. Er wordne in 't algemeen een ménigte zaaken verwaarloosd. Men kon een belooning stellen als een Donatie van Lands wege, op het uitrusten van yder Walvischvaarder; men kon 'er om die verder aan te moedigen, zékere glorie aan hegten, by voorbeeld, in een nabuurig

Ryk mag niemand zékere Eerämten bekleeden, zo hy geen vast aan deel in de Visschery heeft; Men most de Visschery en Uitrusting, aanmerkelyk zien te bezuinigen, zonder vooreerst meer Scheepen ter Vangst aftezenden, indien men voor 't minst op het bestaan der Reederyen wil zien; men moest Præemie belooven, op de ontdekking van nieuwe en favorable Viscgplaatsen; op het uitvinden, waarin het Aas der Walvisschen besta; als mede aan hen die de meeste Visch zouden vangen; op het verbeterd Harpoenen, waar van PISCATOR ten opzigte van Engelland spreekt, en diergelyke Encouragementen meer.

Dan moet de verdere hier bovengenoemde Herstelmiddelen, met ernst in effect gelegd worden, en 'er viel geen twyfel aan den goeden uitslag ter Redres. - 't Een by 't ander gevoegd, alles eene wydere Uitbreiding eisschende, behoorde in een soort van ALGEMEENE ZAAMENKOMST van GEINTRESSEERDERS in de Visschery, daar de Kunde, Eensgezindheid, en Vaderlandliefde Voorzitters waren, overwoogen te worden."

Chapter 10

The governance dilemma, the administrative gain and the building of evaluative capacity

10.1 The governance dilemma

The present study has questioned how well signals of resource depletion are captured, and how easy it is to perceive a true recovery (sections 2.6, 3.7). Weak perception of a step trend after measures have been taken implies a 'governance dilemma' for the management: whether to take all measures selected that are enforceable, including those with small effects, which will only show up as effective in the long-term, òr to implement only draconian measures with large effects which will be apparent in the short term (section 6.7).

Long-term downward trends in the outcome of fishery resource exploitation are mainly man-induced. The impact of mankind on some aquatic resources and ecosystems can be traced from centuries old records (Hacquebord 1999, Jackson *et al*. 2001). Natural variability and the persistence therein obscure the perception of these man-induced long-term trends, particularly within smaller time-windows. Therefore, the time-window for the evaluation of annual catches should preferably be as large as possible, in order to be clear about short-term trends of only a few years (blue noise) or of longer duration (red noise), as distinct from any long-term trend (Fig. 10.1).

Both blue and red noise have mainly natural causes. Blue noise in annual fish catches is explained by the dominance of a strong year-class in the fishery over a number of years (section 6.4). The appearance of such strong year-classes is related to variability in one environmental factor, in most cases random variations of annual temperature (white noise), but also in an abiotic factor like temperature, there is some coloured noise, which makes it likely that recruitment series also contain coloured noise. The red noise in the annual series for bowhead whale catches is a particular case, with climate driven persistence in catchability due to conservatism in the development of pack ice (section 9.5).

Resource users respond on short-term trends, and to the long-term trend when it is apparent. Each temporary increase in stock size, no matter how short, induces a reaction in the fishery. Economic considerations ensure that fishermen grasp every such opportunity to persuade the authorities to allow a temporary increase in fishing effort. Such a responsive type of management, as for instance is known from the North Sea quota system, inevitably narrows the attention of all players towards smaller time-windows and away from the long-term trends. The response from the European Union to this has been to propagate multi-annual guidance programmes in managing this fishery, in order to broaden the time window (Salz 1996).

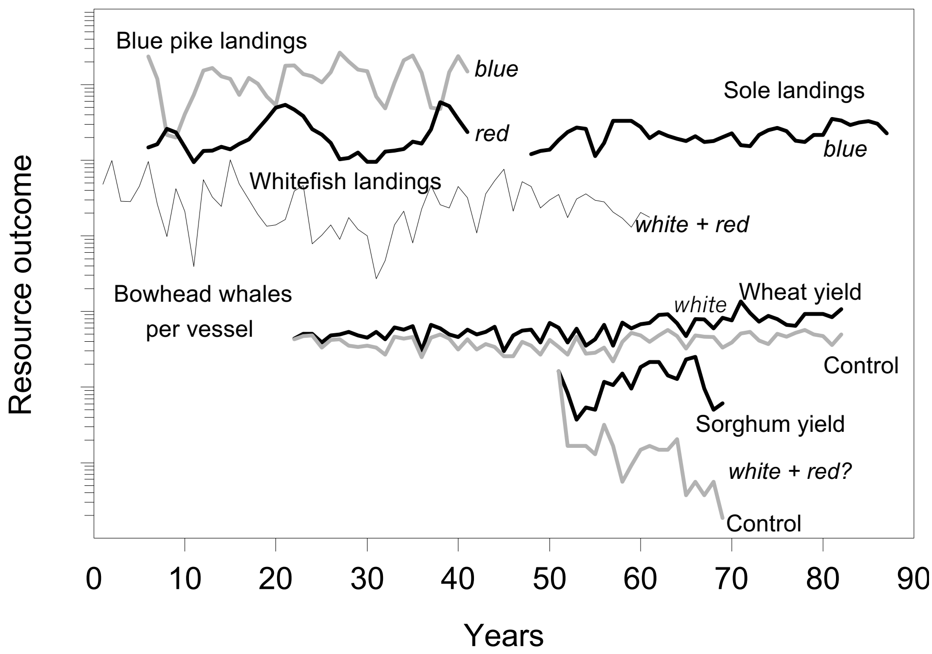

Fig. 10.1 Noise in time series for resource outcome. White: random fluctuations. Blue: short-term trends, Red: short-term trends of longer duration. Blue pike (CV = 0.53) see Fig. 6.13, Whitefish (CV = 0.65) see Fig. 6.13, Sole (CV(s) = 0.27) see Fig. 6.3, Bowhead whales (low around 1730, CV = 0.73) see Fig. 9.12, Wheat manure treatment, Oregon, USA (from Steiner & Herdt 1993) (CV = 0.22 in control), Sorghum fertilizer and manure treatment (CV = 0.69) see Fig. 8.6. Units along the Y-axis (log-scale) have no meaning because series are compared for their inter-annual variability only.

The same noise constrains the perception of a step trend in annual catches after a measure, like effort reduction or mesh size enlargement, has been taken. In the case of step trends there is a lag time as well of around 3 years that widens the time window in which the measure might show up as even more effective. The effectiveness of the management measures taken will seldom show up as a knife-edge step trend from one stable catch level to the next. As exemplified in section 6.7, moderate variability in annual catches (CV = 0.4), in combination with a response time of circa 3 years due to the multi-age character of the resource, ensures that measures taken to enlarge catch levels by less than 100% can hardly be perceived as effective in a time-window of less than 10 years. In contrast, effort restrictions that woúld show up as effective would probably be seen as draconian by most fishermen who do not have the economic reserves to handle the large, although temporary, reductions in their annual catch. This is the 'administrative gain' for the authorities: either they need public proof of their wise and efficient management when taking draconian measures with high transition costs for the fishery, òr they must themselves be convinced that less sweeping measures are also effective although their effect is less significant.

The choice for less sweeping measures is more common because of the generally small room for manoeuvre. The consequence is that the administration has to engage, more or less continuously, in arguments with the resource users and the general public about whether or not there is proof of the effectiveness of its management. This situation harbours the danger that the ongoing management lacks demonstrable effectiveness, and that this could carry on for years. It could lead to a loss in power of governance. Statistical power analysis *a priori* could in any case tell the authorities how effective their management measures will probably appear, and then enable them to decide on their strategy (McAllister & Peterman 1992, McAllister *et al*. 1992, Ham & Pearsons 2000). A political consideration could thus be that the time-window within which measures must be seen as effective must not be too large, say about 10 years.

The situation in agriculture is not fundamentally different from that in fisheries. Long-term upward trends in crop yield as a global average, shown in the largest time-window possible, underpin the success of controlled crop production via tillage, seed selection, manuring, addition of fertiliser, irrigation and so on. Locally, however, there are long-term downward trends as well, many of them due to the continuous process of soil degradation via water and wind erosion, nutrient depletion, decline in soil structure and the like (Bouma & Batjes 2000). These negative trends are possibly even more alarming than those due to stock depletion in fisheries, because recovery of soil quality is most difficult to achieve and, if still feasible, it takes much longer.

As in fisheries, also in crop agriculture, natural variability and its possible persistence obscures the perception of trends and step trends. This is particularly so with rainfed agriculture in dryland areas, where inter-annual variability in rainfall is large and persistence, mainly red noise, therein more likely (Figs 6.31, 10.1). The red noise in annual rainfall translates directly into that for the annual crop. In the temperate zone agriculture, variability in crop yields such as that for wheat, is less governed by that of rainfall, and rainfall contains less coloured noise anyway (Fig. 10.1). Nomads in dryland areas experience similar large variability and persistence in their resource outcome to crop farmers there. Milk production by their herds varies almost in proportion to the rainfed production of forage on the common pastures. And here also, long-term downward trends in resource outcome, due to soil degradation, for instance because of intensive grazing around new water points, will be difficult to perceive because of both high variability and red noise (section 8.6, Fernandez-Gimenez 2000).

In crop farming, unlike fisheries, the effect of management measures should show up almost instantly because there is generally no lag phase, except for measures that aim to enhance soil quality by building up organic matter for example. The general absence of a lag phase, together with the low inter-annual variability in his crop yield ($CV \rightarrow 0.1$), ensure that the western farmer is very alert for already small improvements from which to gain. Also, in this respect he lives in another world from the Sub-Sahelian millet or sorghum farmer, who experiences inter-annual variability as high as $CV = 0.7$. Such high inter-annual variability makes the effect of a change in management hard to perceive from a step trend in his annual series. This must have a bearing on the way the agricultural extension worker discusses the effectiveness of a change in farm management with the dryland farmer. For this farmer, instant comparison of plots subjected to different treatments at an agricultural research station is a most instructive way to demonstrate the possibility of improvement (Fig. B8.1, top). This latter facility has no equivalent in fisheries. There, the effect of management measures must always be evident from the development in annual landings through time. At best, fishermen can take notice of model predictions by fisheries scientists.

10.2 The administrative gain

What could possibly be criticised most in this study are the premises that capacity to perceive time trends can be quantified with the statistical power to detect true trends, and that this is possible for both authorities and resource users. The difference can be assessed as a quantified 'administrative gain'. This, I admit, is a simplification. In favour of these two premises is the observation that, when resource outcome is the only source of information with which to value developments in the fish stock or the fishery, fishermen lag behind, at least to the extent assessed here, because of their poorer facilities and skills for the evaluation of time series data.

The statistical power of the authorities to perceive true trends is generally greater because, first, their data series span longer time periods, second, their series contain less inter-annual variability after data aggregation than is perceived by individual fishermen and, third, authorities select a higher critical value α than do fishermen for the probability that they will commit a Type I error, and so conclude that there is a trend where there is not (Chapter 7). Both the time-window used and the critical value α selected have to do with the management setting and are more contextual factors. Variability reduction after data aggregation is of a more bio-technical nature. The extent of this reduction in variability depends on the randomness in inter-annual changes in the spatial distribution of resource presence and exploitation (fish) or in resource productivity (crops).

The reduction in inter-annual variability after data aggregation will be large, and so will be the administrative gain, where inter-annual variability in resource outcome per fishing unit, due to random changes in the spatial distribution of the fish or fishing activities, is large relative to inter-annual variability due to changes in total stock size, and so in catch rates averaged for the whole of the resource area (Fig. 10.2). Only then will inter-annual variability as experienced by the authorities, after data aggregation for the fleet as a whole, be significantly smaller than variability as experienced by an individual fisherman. The situation in the Lake IJssel fishery, where inter-annual variability in gillnet catches of pikeperch as recorded for the lake as a whole was hardly lower than in the series per individual fisherman (Figs 6.21, 6.23), is thus one of low administrative gain.

There is as yet little information on how the annual series of catch records of individual fishermen differ from those for the fleet's average. The question in which situations such difference is most pronounced, has therefore still to be answered. Fisheries for which the administrative gain may be large are probably those which are operated throughout larger ecospaces, such as the North Sea. Here the area of operation of the individual fisherman is small relative to the total resource space, and the spatial distribution of fish is governed by environmental gradients which position change from one year to the next. Actually, most target species in the North Sea fishery, such as plaice, sole, cod, whiting and herring, change their large-scale spatial distribution from one year to the next, as governed by abiotic factors such as the North Atlantic Oscillation and the variable inflow of Atlantic water (de Veen 1976, Horwood & Milner 1998, Corten 2001, Zheng et al. 2001, A. Rijnsdorp, personal communication). But it is still necessary to assess from CpUE data whether the North Sea is indeed a system with a larger administrative gain when aggregating catch data. Inter-annual variability in the total landings per species from the North Sea, experienced by the authorities in the aggregated data series is relatively small (section 6.7). This could be due to the possible existence of sub-units, which stabilise total resource outcome when they vary more or less independently from each other ('portfolio effect'). The total stock of North Sea sole, for example, might be composed of several populations (Kleyn & de Veen 1967).

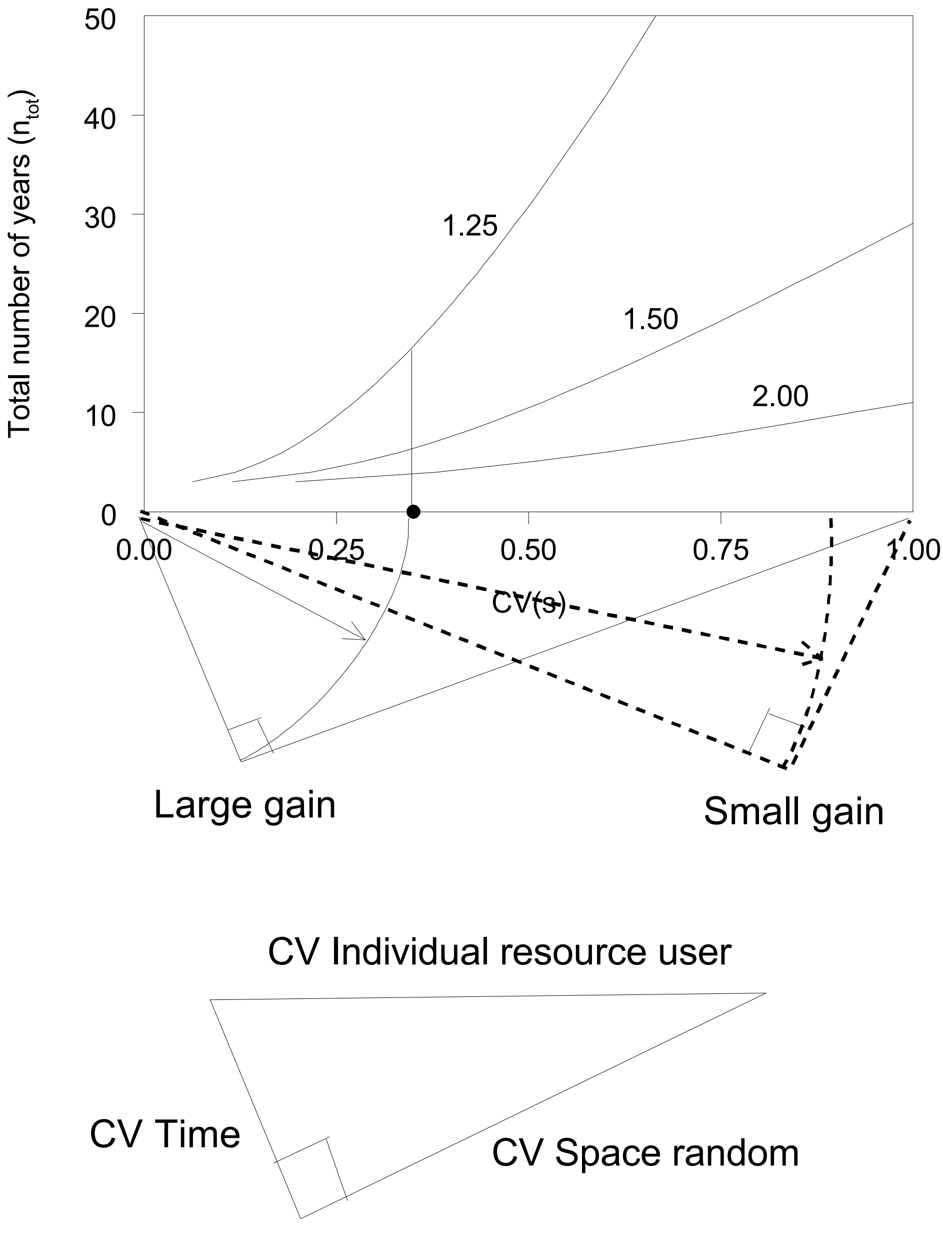

Fig. 10.2 Administrative gain in the capacity to perceive a step trend of 25, 50 and 100% (factor 1.25, 1.50 and 2.00) measured by the smaller number of years ($n_{tot} = n_1 + n_2$) it will take for the authorities than for the fishermen to detect the step trend as significant under conditions $\alpha = \beta = 0.1$ (see also section 3.3.2 and Fig 3.19). Equal number of years before and after measures are taken ($n_1 = n_2$). The individual resource user experiences inter-annual variability composed of variability in both dimensions $CV = \sqrt{CV_{time}^2 + CV_{space}^2}$, also depicted with Pythagoras rule. Where the random component in the spatial distribution is nil, co-variance between resource users is complete and the 'administrative gain' is then absent. See Fig. 3.9 and section 3.5 for background of figures and formula.

Similar mechanisms are at work in crop agriculture. There is randomness in the spatial distribution of crop productivity that shows up at various spatial scales, starting from the individual farmer's field up to ever larger administrative spaces. Unexplained variability in crop production per field can be as high as CV = 0.35 in dryland agriculture (see section 8.2). This, which is partly random variability, will already have disappeared after data aggregation across one farming village. Aggregation through larger administrative spaces averages out inter-annual variability in crop yield per field as a result of the patchy rainfall patterns in dryland areas. This explains why some individual farmers apply a risk-coping strategy of growing their crops on several fields spread throughout an area of manageable size (Graef & Haigis 2001). Random variability per field in western crop farming must be low. Intra-annual variability between individual fields of wheat, in the UK for example, encompassing all kinds of sources of variability, is already as low as CV = 0.14 to 0.19 (see section 8.5). The administrative gain here must be less and the views of farmers and authorities on developments over time are more alike because of strong co-variance. See also the series for wheat in Fig. 10.1.

To put it in the more general context of natural resource management: the administrative gain will be particularly large where resource elements are strongly clustered, are very mobile, and migrate large distances through an ecosystem to whose spatial characteristics the resource adjusts its changes in spatial distribution throughout the years. A clear example might be the caribou hunted in the vast resource areas of the North-American subarctic (Kruse *et al*. 1998, Berkes 1998, Klein *et al*. 1999, Bergman *et al*. 2000). Hunters and managers here have markedly different perceptions of possible downward trends in the herd size of the caribou (Table 10.1). It is actually the only quantified divergence in the perception of time trends by resource users and authorities found in the literature so far. Although the managers dó admit that the quality of their own survey data, obtained through aerial photocensus, recruitment surveys and calving-ground surveys, is constrained by the extent of the resource areas (Kruse *et al*. 1998), the systematic divergence in trend perception between hunters and managers in the two areas is likely to be explained by hunters operating more locally than managers. Hunters thus experience more inter-annual variability in herd size due to strong inter-annual changes in the spatial distribution of the caribou.

Table 10.1 Percentage of hunters and managers that answered positively during interviews on the question of whether the caribou population has declined since 1970. Data from Kruse *et al*. (1998, Their Fig. 6).

	Western arctic herd	Eastern arctic Beverly-Qamanirjuaq herds
Hunters	22%	25%
Managers	77%	82%

10.3 The building of evaluative capacity

To bridge the gap between resource users and authorities in their capacity to perceive true trends, action is needed on both sides. Resource users on the one hand should be assisted in developing skills for the evaluation of time series of resource output and for effort applied. The authorities on the other hand should improve their communication skills in making such series available as non-aggregated as well as aggregated series, and in an accessible format (Chapter 7).

The focus here on time trends in resource outcome and their perception is not a refutation of the relevance of scientific understanding or of local knowledge for resource management. But time series of resource outcome will always be the basis for both the broad recognition that there is a problem at hand, as well as for the public proof that management measures were wise and efficient. It thus makes sense to adjust the balance, in the capacity for evaluation of these time series, of both resource users ánd managers.

When authorities provide fishermen with graphed time series in a more complete and structured manner this will enhance the analytical capacity of the fishermen as well. There is an opportunity here for the EU, which seeks the participation of fishermen in defining the New Fisheries Policy from 2003 onwards. The documentation for the broad discussion by all involved in EU fisheries, an EU Green Paper, contains annual series per species and statistical area for four parameters: Total catch (C), Fishing mortality (F, as the ratio of the annual catch relative to exploitable biomass present on average during that each year = C/B), Spawning stock biomass (B_s), and Recruitment (R) (EU 2000). By adding annual series for growth rate as a fifth parameter, the dataset would, although not complete, become more informative still, when presented in combination with a relational scheme as in Fig. B2.2. North Sea fishermen could gain from such cohesive presentation of time series data. Fishermen dó realise already that persistent changes in the individual growth rate of fish affect the productivity of the exploitable stock. When and how this possible short-term trend is important for developments in the stock and for the catch to be taken, they could infer from comparing the various interrelated series, in this way building their analytical capacity as well.

Above all, evaluation of time series by resource users means reading graphs. To develop this skill, cultural, intellectual and cognitive problems have to be overcome (Friel *et al*. 2001). Even in the western scientific tradition it was not until halfway through the 18th century that the idea of plotting two related variables against each other was published (Lambert 1765 in Tilling 1975). How the skill of making and, more important, interpreting graphed time series spread throughout society is difficult to tell. It must have been slow because, even in science, data were mainly tabulated until the late 19th century (Klein 1997). Since then, graphs have increasingly been used also in every day life and now appear ever more frequently in newspapers and TV-news editions. This is possibly also in response to the higher average level of education of the general public, although many still have difficulty in grasping the information these graphs contain.

In perspective, there might be all kinds of cultural and cognitive constraints in developing a skill for graphing and evaluating time series for resource outcome. But such constraints can surely be overcome, when data series are well presented and in a cohesive manner, and when resource users are invited to practice the evaluation of such information routinely (see section 7.6). The quality of co-management would in any case gain from a greater capacity amongst fishermen for evaluating times series data. This would be even more true when fishermen know how to differentiate between white, blue and red noise as affecting their perception of long-term trends in resource outcome. Closely following and reading fishermen's arguments in a management debate tells us that in essence such capacity is there and only needs to be stimulated.

10 The governance dilemma, the administrative gain and the building of evaluative capacity - Recommendations

1. Broaden the time window when presenting developments in the resource and its outcome in order to be clear about the short-term trends (coloured noise) that constrain the perception of any long-term trend.
2. Assess and inform resource users about the lag time in the response in resource outcome after a management measure has been taken.
3. Apply statistical power analysis *a priori* where possible, also for the sake of public proof of wise management and its consequences for the power of governance.
4. Account for inter-annual variability in crop yields when discussing the effectiveness of a change in farm management, in dryland agriculture especially.
5. Be aware, both authorities ànd fishermen, of the extent to which trends and step trends are more easily perceived in aggregated data than in the catch records of an individual fisherman. Assess and demonstrate this possible administrative gain.
6. Assess and in that way build awareness of variabilities as experienced by individual fishermen at the smaller temporal scale of days and months. Account for these experiences when discussing long-term trends in fish stock biomass and in annual catches for the fleet as a whole.
7. Improve the evaluative and analytical capacity of resource users by inviting them to evaluate time series that are presented in a cohesive and informative manner.

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Summary

World-wide, fisheries have to contend with the problem of over-fishing. Still, it seems as if authorities are not fully able to convince fishermen, with the aid of catch and effort data, that measures should be taken. Moreover, fishermen will always compare the developments in their own, individual catches with developments in the catch for the fleet as a whole or with developments in the size of the stock, which the authorities use to formulate their management policy. Fishermen and authorities thus have different perceptions of these developments. Co-management, i.e. management by authorities and fishermen together, is now considered a panacea for a series of management problems, amongst which the communication on developments (trends, step trends) in annual catch and effort. A trend is taken as a monotonous increase or decrease in fish catch. A step trend is a more sudden switch from one average level to the other.

Three questions on the perception of trends and step trends

In this study, starting from sociological concepts with regard to the management of natural resources, three questions are formulated, all three referring to the perception of trends in fisheries (Chapter 2): 1) Which trends and step trends are detectable, given the sometimes high inter-annual variability in the catches; 2) What are the causes for a possible difference in the capacity of fishermen and authorities to detect a truly existing trend in the catches?, 3) How to improve in such a situation of inequality?

'Statistical power' as a measure for the capacity to perceive true trends

First, the capacity to perceive trends have been formalised with 'statistical power' defined as the probability (1 - β), between 0 and 1, that one concludes for a trend where such a trend truly exists. This 'power' is stronger with a steeper trend, a larger time window, a smaller variance around the trend, and a larger probability (α), between 0 and 1, that one concludes for a trend where such trend does not truly exist (Type I error). The probability that one does not a truly existing trend equals β (Type II error). A time window is the length of the period for which one evaluates developments in annual catches.

Variabilities and the perception of trends and step trends in fisheries

To answer the first question the variability (coefficient of variation or CV) of fish catches at various temporal and spatial scales is assessed from example studies The effects of aggregating catch data for the fleet as a whole on the ultimate variabilities is also investigated (Chapters 4, 5 and 6). Variability in the daily catch of a fisherman is more or less random and changes with the fish species and the scale at which the fishery is operated: trawling ($CV < 0.5$), gillnetting ($CV = 0.5 – 1.0$), angling ($CV > 1$), fisheries with light attraction ($CV > 2$) (Chapter 4). After aggregation of daily catches for larger time intervals (A days), the random variability reduces in a predictable manner according to $CV/\sqrt{A}$, and few if any of this random variability remains in annual catches. Only light fishermen who target schools of pelagics for 200 days per year still experience random variability in annual catches as high as $CV \sim 0.2$. Besides variability in the catch from day to day there is variability in the catch from month to month due to the seasonality in the presence and catchability of fish (Chapter 5). This seasonality contributes to the overall variability in daily catches within a year, but does not contribute to the variability between years, and because of that, is not of much relevance for the evaluation of long-term developments.

Inter-annual variability in catches or catch rates for the fleet as a whole is the most relevant parameter for fisheries management (Chapter 6). This variability is mainly governed by changes in the size of the fish stock. For a number of target species in Dutch fisheries it ranges from $CV = 0.2$ for plaice from the North Sea to $CV = 1.1$ for pikeperch from Lake IJssel. Changes in stock size are mainly caused by the variability in the annual number of recruits. The variability in annual number of recruits ranges from $CV = 0.5$ for plaice to $CV = 1.6$ for perch in Lake IJssel. The variability in annual landings is 3 to 4 times as low because several year-classes are exploited simultaneously (‘portfolio effect’). Still, for a series of years annual catches can be dominated by one strong year-class. These strong year-classes cause short-term trends or persistence in the annual series (blue noise), and, just like high variability, persistence weakens the ‘statistical power’ of the detection of long-term trends, certainly when the chosen time window is small.

With statistical power analysis it is possible to assess which trends are just detectable in a given time window and with a given variability in an annual series, while setting acceptable limits to Type I and Type II errors. In a time window of 10 years, with modal variability of $CV = 0.4$ and maximum α and β of both 0.1, the trend should lead to a reduction in catch of at least 70% if it should become visible at all to the fishermen. In the same time window and under the same boundary conditions ($\alpha = \beta = 0.1$), a management measure should lead to at least a doubling in annual catches (100% increase), should the step trend become visible to the fishermen. In most cases the authorities have to take measures, like reductions in fishing effort and the lowering of minimum mesh sizes, that certainly will contribute to the recovery of stocks, but they are generally not sweeping enough to prove their efficiency and with that demonstrate their legitimacy. Besides, after measures have been taken, it takes three years on average before a fish stock has grown to a new equilibrium. Those three years should not be taken into account with the evaluation of these measures, while politics generally require changes that are detectable sooner. It seems that only draconian measures with apparent effects for everybody would contribute to the legitimacy of management measures. Such measures however are costly, and in this way the authorities are confronted with a 'governance dilemma'.

Difference in 'statistical power' between authorities and resource users

In answering the second question, it is concluded that the authorities are better capable than the individual fisherman to detect true trends and step trends ('administrative gain'), because: a) the authorities have a larger number of observations at their disposal in combination with a larger time window in which to evaluate these observations, b) the authorities experience lower variability in annual catches after data aggregation for the fleet as a whole, and c) the authorities accept a higher chance for a Type I error (Chapter 7). The explanations are as follows. First, the time window in which individual fishermen are able to evaluate their own catches is not more than 15–20 years on average. This is the period during which the average fisherman in the fleet has gained his experience with fisheries. Within a time window of that size, the above-mentioned large inter-annual variability, short-term trends of a round 3-5 years (blue noise), and the transition phase of three years all obscure the perception of long-term trends or step trends. For the observation of short-term trends of longer duration (red noise) as distinct from a long-term trend, a time window of that size is certainly too small.

Secondly, most individual fishermen experience larger variability in the annual catches than the authorities do, because apart from inter-annual variability in the size of the stock they come across, there is variability in the spatial distribution of the fish and of fishing activities. Only in a small system, like a freshwater lake, where every fisherman operates throughout the whole system, or in a system where the spatial distribution of fish hardly changes from one year to the next, co-variance between the annual catch series of an individual fisherman is likely. In these situations the reduction in variability after aggregation is small.

Thirdly, the acceptance of a higher risk (α) of making a Type I error by the authorities is related to the fact that when a downward trend is not signalled in time and measurements are not taken, stocks will later only recover at great economical and social costs. Fishermen instead, out of necessity, give more weight to economic efficiency in the short term, not wanting to under-utilise their fishing capacity as a consequence of fishing regulations that, after all, might turn out to be based on false alarm.

The difference between fishermen and authorities in their capacity to perceive trends in the outcome of the fishery leads to a second governance problem. It could happen that the authorities know for certain that the stocks are on the decline (trend), or that it increases e.g. following an effective management measure (step trend) At the same time they know, on the basis of *a priori* statistical power analysis, that individual fisherman can hardly perceive such trends in their own catches. This stresses the necessity to strive for high-quality modes of communication between fishermen and authorities on the outcome of the fishery and on the efficiency of its management.

This leads to the third and last question of how to tackle the problem of differences in perceptions between fishermen and authorities. Before all, the evaluative capacity of fishermen should be enhanced by facilitating them in technical and statistical sense to evaluate the developments in their own catches and in those for the fishery as a whole (Chapter 7). On the other hand, the evaluative capacity of fisheries' administration could be stimulated for example by installing routine procedures for analysing time series of catch data, including the assessment of variance and the coloured noise therein. If this were to be done for time series from individual fishermen as well, administrators would become more aware of the variability in space and time experienced by fishermen in their daily fishing practice. Fishermen are able to contribute to the analysis on the basis of their own experiences with management-relevant information ('local knowledge'). However, if they have no experience with evaluating highly aggregated data for the fishery as a whole, they lag behind in communication on a more equal basis in co-management situations.

Variabilities and the perception of trends in agriculture

As in fisheries management, in agriculture too it is important to know which developments in annual yield are just detectable, such as downward trends resulting from soil degradation, or step trends after a change in farming practices (Chapter 8). Analogous with fisheries, the resource users (farmers) and authorities differ in their capacity to detect trends and step trends for larger administrative areas. This has consequences for how agricultural extension services must communicate their information.

To assess the capacity to perceive trends in agriculture, first the variabilities in annual yield (production per unit area) of various crops, like millet and wheat, are compared at various spatial scales. The variability in the production per field is largest in the rainfed production of millet in the Sub-Sahel (CV = 0.6). For the wheat farmer in the temperate zone (England) the variability is many times smaller (CV ~ 0.1). The variability in the national average yield is generally less than CV = 0.1. In countries with a poorly controlled production mode, however, even the national average could still be extremely large, like for millet in Niger (CV = 0.27). At the global scale variability in average yield is lowest, with CV= 0.05 for both millet and wheat.

Downward trends in the production per field, only just detectable in a time window of 10 years with $\alpha = \beta = 0.1$, are considerably larger for farmers in the Sub-Sahel, growing millet, namely an 80% decrease, when variability is CV = 0.6, than for the wheat farmer in the temperate zone, who with a variability as low as CV = 0.1 already detects a decrease of 20%. In the same time window and under the same boundary conditions, agricultural measures in the Sub-Sahel should lead to a 150% increase to be perceived, whereas in the temperate zone an improvement by 20% is already visible. In areas with a less controlled production mode, the efficiency of management measures is thus much less visible. This would certainly apply to measures to improve soil quality whereby, as in fisheries, there is a lag phase of at least several years. Moreover, precisely, these drier areas are known for short-term trends of longer duration with series of relatively dry or wet years (more red than blue noise). Together with the high inter-annual variability, this red noise weakens the statistical power for detecting trends and step trends in crop yields.

The extent to which authorities have better possibilities than farmers to perceive developments in annual yield depends of the ratio between inter-annual variability for the total area and the random variability between fields within that area. In the Sub-Sahel, the variability in yield per field within a village, after correction for differences in soil type and farming practice, is large (CV = 0.3–0.4). Aggregation and averaging of the yield per field does not lead to a large 'administrative gain' in terms of reduced inter-annual variability, because the inter-annual variability for an average field (CV = 0.6) is much larger than the random variability between them. Still, individual millet farmers try to spread their risks by tilling several fields distributed over the area ('portfolio effect'). They hope to average out some of the variability in annual yield due to the sparse and spatially and temporally very erratic rainfall.

Farmers and fishermen do not differ systematically in the uncertainty assessment of the annual outcome of their resource. Also, differences with respect to insecurity of their livelihood are large within both groups. Many fishermen stabilise their income by fishing several species at the time ('portfolio effect'). However, for most fishermen it will be difficult to obtain the same stability in the annual yield as compared to the variability that the crop farmer in the temperate zone has become used to already since the 19th century (CV = 0.15).

Variabilities and the perception of trends in 17th and 18th century whaling

The problem of trend perceptions, including the cognitive constraints that play a role therein, could not be explained more clearly than through the history of Dutch whaling in the 17th and 18th century (Chapter 9). At that time, the stock of bowhead or Greenland whales between Greenland and Spitsbergen was a major natural resource for The Netherlands. From the blubber of these bowheads train oil was rendered. The annual catch was meticulously recorded per individual whaling commander for more than a century as number of whales and as casks of blubber. Because of this high quality catch recording system, it is now possible to assess to what extent individual whaling commanders, from their own catch record, and administrators, on the basis of the fleet average (200 whalers), could have been able to detect trends in the outcome of this fishery. There was no significant long-term trend in the annual catch for the fleet as a whole in the 18th century, in a time window of 100 years. Not only the inter-annual variability in the fleet average was extremely large, also the variability between whaling commanders within years was large (CV = 0.7). Of this within-year variability only a very small part can be explained by systematic differences between individual whaling commanders. These differences are possibly due to differences in the capacity to find and chase the whales.

The inter-annual variability for an individual whaling commander was CV = $(0.9^2 = 0.7^2)^{1/2}$ = 1.1. The 'administrative gain' was therefore small (CV = 0.9 instead of 1.1). Because, on average, whaling was hardly profitable, and because the inter-annual variability in the catch per whaler was extremely high, the whaling companies were small and survived for only a few years. Still, the unique but real chance of a very high catch encouraged many to make a small investment in these small whaling companies, just as one buying a ticket in a lottery.

The high variability in the annual catch of bowhead whales, also for the fleet as a whole, together with the occurrence of longer duration short-term trends of circa 20 years (red noise), made it difficult for the Dutch administrators to detect a possible long-term trend. Still, the intensively exploited stock must already have been severely diminished during that time. The high variability and the changing fishing patterns must therefor have obscured and biased the perception of developments in stock size. The short-term trends were probably caused by persistence in the extent of the pack ice that affected the catchability of the bowhead whales. But even these sharper short-term trends could have been only just detectable for the whaling commanders and for the administrators. At that time one was ignorant of graphs and of probability calculations, and only had tables as a tool for assessment. So for cognitive reasons as well it would have been difficult for the administrators to assess whether any trend in catch rates existed. It is concluded that in the 18th century a very reliable catch recording system was available, but the evaluative capacity was missing to derive management-relevant information from the extensive tables of catch records.

Governance dilemma, administrative gain and the building of evaluative capacity

In the last chapter it is indicated that it in management of natural resources in general, a ‘governance dilemma’ appears should all socially and economically feasible measures be taken or only sweeping and thus efficient but costly ones? (Chapter 10). Sweeping measures will by clear effects enhance the legitimacy of the management. The room for manoeuvring with respect to this dilemma is dictated by the politically acceptable time window in which measures must publicly show their effect and by the extent of inter-annual variability and the persistence therein (blue and red noise). Further, arguments are given on why the ‘administrative gain’ of spatial aggregation of catch or yield data will be largest where the total stock shows small inter-annual variability, but where there are large random changes in the spatial variability of the resource, so large that fishermen, farmers or hunters are hardly able to respond to them. In all cases, but certainly in a situation of co-management, it is important to enhance the ‘evaluative capacity’ of both resource users and authorities. The study ends with a number of recommendations to that purpose:

1. Enlarge the time window when presenting developments in the resource and its outcome in order to be clear about the short-term trends (coloured noise) that constrains the perception of any long-term trend.
2. Assess and inform resource users about the lag time in the response in resource outcome after a management measure has been taken.
3. Apply *a priori* statistical power analysis where possible, also for the sake of public proof of wise management and its consequences for the power of governance.
4. Account for inter-annual variability in crop yields when discussing the effectiveness of a change in farm management, especially in dryland agriculture.
5. Be aware, both authorities ànd fishermen, of the extent to which trends and step trends are more easily perceived in aggregated data than in the catch records of an individual fisherman. Assess and demonstrate this possible administrative gain.
6. Assess and in that way build awareness of variabilities as experienced by individual fishermen at the smaller temporal scale of days and months. Account for these experiences when discussing long-term trends in fish stock biomass and in annual catches for the fleet as a whole.
7. Improve the evaluative and analytical capacity of resource users by inviting them to evaluate time series that are presented in a cohesive and informative manner.

Samenvatting

Wereldwijd kampt de visserij met het probleem van overbevissing. Toch lijkt het er vaak op dat de overheid onvoldoende in staat is om de vissers aan de hand van de vangstgegevens ervan te overtuigen dat maatregelen geboden zijn. Daarbij komt dat vissers de ontwikkelingen in hun eigen, individuele vangsten altijd zullen afzetten tegen de ontwikkeling in de vangst voor de vloot als geheel of tegen die in de omvang van het bestand, waar de overheid haar beleid op baseert. Vissers en overheden hebben dan ook vaak verschillende percepties van die ontwikkelingen. Co-management als het beheer door overheid én vissers gezamenlijk, wordt nu gezien als hét antwoord op een aantal beheersproblemen, waaronder dat van de communicatie over ontwikkelingen (trends, steptrends) in de jaarlijkse vangst en visserijinspanning. Een trend is een monotone toe- of afname in de vangst. Een steptrend is een abrupte verandering naar een gemiddeld hoger of lager niveau.

Drie vragen rond de perceptie van trends en steptrends

In deze studie zijn, uitgaande van sociologische concepten met betrekking tot het beheer van natuurlijke hulpbronnen, drie vragen geformuleerd, die allen betrekking hebben op de perceptie van trends in de visserij (Hoofdstuk 2): 1) Welke trends en steptrends zijn nog juist waarneembaar, gegeven de soms grote tussen-jaarlijkse variatie in de vangsten?, 2) Wat zijn de oorzaken voor een mogelijk verschil tussen individuele vissers en overheden in hun vermogen om een bestaande trend in de vangsten waar te nemen?, 3) Op welke wijze kan er ten behoeve van het co-management in de visserij verbetering worden gebracht in deze ongelijkheid?

'Statische power' als maat voor het vermogen werkelijk bestaande trends waar te nemen

Eerst is het vermogen tot het waarnemen van tijdtrends geformaliseerd met de 'statistische power' als de waarschijnlijkheid (1- β), tussen 0 en 1, dat men tot een trend concludeert waar die ook werkelijk bestaat (Hoofdstuk 3). Die 'power' is sterker naarmate: de trend sterker is, het tijdsraam groter, de variatie rond de trend kleiner en de maximale kans (α) die men wil lopen om tot een trend te concluderen waar die niet echt bestaat (Type I fout) groter is. De kans dat men in het geval van een wèl bestaande trend deze toch niet waarneemt is gelijk β (Type II fout). Een tijdsraam is een periode waarover men ontwikkelingen in de vangsten beschouwt.

Variaties en waar te nemen trends in de visserij

Voor het beantwoorden van de eerste vraag is aan de hand van praktijkvoorbeelden onderzocht hoe variabel (variatiecoëfficiënt of CV) visvangsten zijn op verschillende tijd- en ruimteschalen, en wat het effect van ruimtelijke aggregatie voor de vloot als geheel daarbij is (Hoofdstukken 4, 5 en 6). Variatie in de vangst van een visser van dag op dag is min of meer random (witte ruis) en verschilt afhankelijk van de vissoort en van de schaal waarop en de methode waarmee wordt gevist: trawlvisserij (CV < 0.5), kieuwnetvisserij (CV = 0.5-1.0), sportvisserij (CV > 1), lichtvisserij (CV > 2) (Hoofdstuk 4). Na aggregatie van de vangsten over grotere tijdsintervallen (A dagen) neemt de random variatie hier voorspelbaar af volgens CV/($\sqrt{A}$) en blijft er op jaarbasis weinig van deze variatie over. Een lichtvisser, die 200 visdagen per jaar vist, ervaart echter nog steeds een random variatie in zijn jaarvangsten van CV ~ 0.2. Naast variatie van dag op dag is er variatie van maand op maand als gevolg van de seizoensveranderingen in de aanwezigheid en/of de vangbaarheid van de vis (Hoofdstuk 5). Deze seizoensvariatie draagt weliswaar bij aan de totale variatie in dagvangsten, maar draagt niet bij aan de variatie tussen jaren, en is daarmee niet relevant voor het beoordelen van lange termijn ontwikkelingen.

De tussen-jaarlijkse variatie in de vangsten voor de vloot als geheel is het meest beheerrelevant (Hoofdstuk 6). Deze variatie wordt vooral beheerst door veranderingen in de omvang van het visbestand. Zij loopt voor een aantal voor de Nederlandse visserij belangrijke doelsoorten van CV = 0.2 voor schol uit de Noordzee tot CV = 1.1 voor snoekbaars uit het IJsselmeer. De variaties in de omvang van het bestand worden vooral veroorzaakt door de variabiliteit in de jaarlijkse hoeveelheid recruten. Deze loopt van CV = 0.5 voor schol in de Noordzee tot CV = 1.6 voor baars in het IJsselmeer. Echter, de variabiliteit in de aanvoer is gemiddeld 3-4 keer zo laag als die in de recrutering, omdat er op meerdere jaarklassen tegelijkertijd wordt gevist (‘portfolio effect’). Wel kunnen numeriek sterke jaarklassen de vangst voor een reeks van jaren domineren. Zij veroorzaken daarmee korte termijn trends in de jaarlijkse vangst (blauwe ruis). Naast grote variabiliteit verzwakken ook deze korte termijn trends de ‘statistische power’ om lange termijn trends te kunnen waarnemen, zeker wanneer men een klein tijdsraam hanteert.

Met statistische power analyse valt te berekenen welke trends nog juist waarneembaar zijn in een tijdsraam van bekende omvang , bij een gegeven variabiliteit en bij acceptabele risico’s (α, β) voor het maken van Type I en Type II fouten. In een tijdsraam van 10 jaar, bij modale tussen-jaarlijkse variabiliteit van CV = 0.4 en onder de conditie dat α en β ieder maximaal 0.1 mogen zijn, moet de trend minstens tot een afname van 70% leiden, wil die in die 10 jaar zichtbaar worden. In hetzelfde tijdsraam van 10 jaar en onder dezelfde condities ($\alpha = \beta = 0.1$), moet een beheersmaatregel minstens tot een verdubbeling van de vangsten leiden (100% toename), wil een dergelijke steptrend zichtbaar worden. In de meeste gevallen zal de overheid genoodzaakt zijn maatregelen door te voeren, zoals reducties in visserijinspanning of maaswijdteverhogingen, die weliswaar bijdragen aan het herstel van de visstand, maar waarvan de efficiëntie en daarmee de legitimiteit moeilijk publiekelijk valt aan te tonen. Daarbij komt dat direct na het nemen van de maatregel, het gemiddeld 3 jaar duurt voor de visstand naar een nieuwe evenwichtsituatie is gegroeid. Die 3 jaar gaan dus verloren voor de evaluatie van het beheer. Het alternatief is alleen verstrekkende maatregelen te nemen, die een voor ieder zichtbaar effect hebben en zo bijdragen aan de legitimiteit van het beheer. Degelijke maatregelen zijn echter duur. De overheid wordt hiermee voor een 'bestuurlijk dilemma' geplaatst.

Verschil in 'statische power' tussen overheid en brongebruikers

In antwoord op de tweede vraag wordt geconcludeerd dat de overheid beter in staat is dan de individuele visser om werkelijk bestaande trends en steptrends te detecteren ('administratief voordeel'), omdat a) de overheid over een grotere aantal waarnemingen beschikt in combinatie met een groter tijdsraam waarin zij die waarnemingen evalueert, b) de overheid te maken heeft met een geringere tussen-jaarlijkse variabiliteit in vangsten na aggregatie voor de vloot als geheel, en c) de overheid een hogere kritische waarde voor α accepteert (Hoofdstuk 7). Ter toelichting, ten eerste is het tijdsraam waarin de individuele visser de ontwikkelingen in zijn eigen vangsten kan evalueren niet meer dan 15 – 20 jaar. Dat is namelijk de periode waarin de gemiddeld aanwezige visser ervaring heeft opgedaan met zijn visserij. Binnen een tijdsraam van een dergelijke omvang ontnemen grote tussen-jaarlijkse variatie, korte termijn trends van 3-5 jaar (blauwe ruis) en een overgangsfase van 3 jaar, het zicht op een lange termijn trend of steptrend. Voor het waarnemen van korte termijn trends van langere duur (rode ruis), als onderscheidenlijk van een lange termijn trend, is een dergelijk tijdsraam zeker te klein.

Ten tweede, vissers ervaren individueel een grotere variabiliteit in de jaarvangsten dan de overheid omdat er naast variabiliteit in de omvang van het bestand ook sprake is van variatie per visserijeenheid als gevolg van verschillen van jaar op jaar in de ruimtelijke patronen van de vis en van visserijactiviteiten. Alleen bij een klein systeem, zoals een zoetwatermeer, waarbinnen iedere visser een grote actieradius heeft, of in een systeem waarin de ruimtelijke verdeling van de vis van jaar op jaar hetzelfde is, zal er sprake zijn van sterke co-variatie in de jaarvangsten tussen de vissers. Dan is de reductie in variabiliteit na aggregatie klein.

Tenslotte, dat overheden een groter risico (α) accepteren om een Type I fout te maken, komt omdat het niet op tijd signaleren van een neergaande trend en daarmee het uitblijven van maatregelen, grote schade aan de visstand kan toebrengen, die later alleen tegen hoge maatschappelijke kosten is te herstellen. Vissers daarentegen geven noodzakelijkerwijs meer gewicht aan economische efficiëntie op korte termijn, waarbij zij hun vangstcapaciteit niet onbenut willen laten als gevolg van vangstbeperkingen, die achteraf op vals alarm blijken te berusten (Type I fout).

Het verschil tussen vissers en overheid in hun vermogen om trends in de natuurlijke hulpbron waar te nemen voert tot een tweede bestuurlijk-technisch probleem. Het kan namelijk zijn dat de overheid zeker weet dat de visstand afneemt (trend), of juist toeneemt omdat een genomen beheersmaatregel effect sorteert (steptrend), terwijl diezelfde overheid op basis van statistische power analyse weet dat individuele vissers deze trends of steptrends moeilijk kunnen waarnemen aan de hand van hun eigen vangsten. Dit onderstreept de noodzaak om zeker in co-management situaties te streven naar een hoogwaardige vorm van communicatie tussen vissers en overheid met betrekking tot de uitkomsten van de visserij en de effectiviteit van het beheer.

Daarmee komt men aan de derde vraag; hoe is het probleem van trendpercepties en van het verschil tussen vissers en overheid daarbij zo goed als mogelijk op te vangen? Om te beginnen zou de evaluatieve capaciteit van vissers moeten worden versterkt door hen in technische en statistische zin in staat te stellen de ontwikkelingen in eigen vangsten én in de vangst voor de visserij als geheel beter te kunnen beoordelen (Hoofdstuk 7). Anderzijds zou de evaluatieve capaciteit van het administratief apparaat kunnen worden gestimuleerd, door op meerdere niveaus daarbinnen routinematig conclusies te laten verbinden aan tijdreeksen met vangstgegevens, inclusief het vaststellen van de variantie en de gekleurde ruis daarin. Door tijdreeksen voor individuele vissers te evalueren worden ambtenaren zich ook meer bewust van de varianties in ruimte en tijd, die vissers in hun dagelijkse praktijk ervaren. Vissers kunnen op basis van eigen ervaringen weliswaar bijdragen met beheerrelevante informatie (‘local knowledge’), maar zij blijven zonder ervaring in het evalueren van hoog geaggregeerde gegevens voor de visserij als geheel, gehandicapt om op een meer evenwaardige manier over die gegevens te communiceren in co-management situaties.

Variaties en waar te nemen trends in de landbouw

Evenals in het visserijbeheer is het in de landbouw van belang te weten welke ontwikkelingen in de jaarlijkse oogst waarneembaar zijn, zoals neergaande trends tengevolge van uitputting van de grond en steptrends bij verbetering van de landbouwpraktijk (Hoofdstuk 8). Verder verschillen, in analogie met de visserij, ook hier brongebruikers, in dit geval boeren, en overheden in hun vermogen om trends en steptrends voor een bepaald administratief gebied te detecteren. Dit heeft consequenties voor de wijze waarop de landbouwvoorlichting moet opereren.

Om de capaciteit tot het detecteren van trends in de landbouw vast te stellen is de variabiliteit in de jaarlijkse oogst van gewassen als gierst en tarwe op verschillende ruimtelijke schalen met elkaar vergeleken. De variabiliteit in de oogst per akker is het grootst in de regen-afhankelijke productie van gierst in de Sub-Sahel (CV = 0.6). Voor de tarweboer in de gematigde zone (Engeland) is de variabiliteit in de oogst vele malen kleiner (CV -> 0.1). De variabiliteit in de nationale oogst, dus na aggregatie voor een groot administratief gebied, is meestal minder dan CV = 0.1. Echter, in landen met een minder gecontroleerde productiewijze kan deze variabiliteit nog extreem hoog zijn, zoals die voor gierst in Niger (CV = 0.27). Op wereldschaal is de variabiliteit het laagst; CV = 0.05 voor zowel gierst als voor tarwe.

Neergaande trends in de oogst per akker, die nog net zijn waar te nemen in een tijdsraam van 10 jaar onder condities $\alpha = \beta = 0.1$, zijn aanzienlijk groter voor de boer in de Sub-Sahel, die gierst verbouwt, namelijk 80% afname bij CV = 0.6, dan voor de tarweboer in het westen, die bij CV = 0.1 in 10 jaar tijd al een afname van 20% waarneemt. In hetzelfde tijdsraam en onder dezelfde condities, moeten landbouwmaatregelen in de Sub-Sahel tot een oogstverbetering van 150% leiden, terwijl in het westen een verbetering met 20% al zichtbaar is. In gebieden met een minder gecontroleerde productie is de effectiviteit van beheersmaatregelen dus veel moeilijker zichtbaar te maken. Dit geldt zeker voor maatregelen tot grondverbetering waarbij, evenals in de visserij, sprake is van een lag fase van minstens enige jaren. Daarbij komt dat er juist in droge gebieden sprake is van tussentijdse trends in regenval of droogte, die relatief lang kunnen houden (meer rode dan blauwe ruis). Deze rode ruis vermindert naast de hoge variabiliteit de statistische power om trends en steptrends in de oogst te kunnen detecteren.

De mate waarin overheden, beter dan individuele boeren, in staat zijn om ontwikkelingen in de jaarlijkse oogst waar te nemen, hangt af van de verhouding in tussen-jaarlijkse variatie in het gemiddelde voor het gehele administratieve gebied en de random variatie tussen akkers bínnen dat gebied. In de Sub-Sahel blijkt de variatie binnen een dorp in de oogst per akker, ook na correctie voor grondsoort en landbouwpraktijk, nog groot te zijn (CV = 0.3 - 0.4). Aggregatie en middelen van de oogst per akker, levert hier echter geen groot 'administratief voordeel' op in termen van verminderde tussen-jaarlijkse variabiliteit, omdat de tussen-jaarlijkse variatie voor een gemiddelde akker (CV = 0.6) veel groter is dan de ruimtelijke variabiliteit. Toch proberen individuele gierstboeren iets van hun risico te spreiden door meerdere veldjes te bewerken in een groter gebied ('portfolio effect'). Ze hopen daarmee de oogstvariaties tengevolge van de geringe en zeer plaatselijke regenval in de Sub-Sahel enigszins uit te middelen.

Na vergelijking, blijken vissers en boeren niet systematisch te verschillen in hun onzekerheid met betrekking tot de uitkomsten van hun natuurlijke hulpbron. Binnen beide groepen zijn de verschillen in bestaansonzekerheid groot. Veel vissers stabiliseren hun inkomen door meerdere soorten tegelijkertijd te vangen ('portfolio effect'). Voor de meeste vissers echter, zal het moeilijk zijn om een zelfde stabiliteit in hun jaarlijkse oogst te bereiken, als die welke voor de akkerbouwer in de gematigde zone al sinds de 19^{e} eeuw heel gewoon is (CV = 0.15).

Variaties en waar te nemen trends in de 17^{e}- en 18^{e}-eeuwse walvisvaart

De problematiek rond trendpercepties, maar ook die van de cognitieve beperkingen daarbij, is zeer compleet te schetsen aan de hand van de Nederlandse walvisvaart in de 17^{e} en 18^{e} eeuw (Hoofdstuk 9). Het bestand van de Groenlandse walvis tussen Spitsbergen en Groenland was voor Nederland een natuurlijke hulpbron van groot economisch belang. Uit het spek van deze walvissen werd traanolie gewonnen. De jaarlijkse vangst per individuele walviskapitein werd gedurende meer dan een eeuw nauwkeurig bijgehouden. Dankzij dit hoogkwalitatieve vangstregistratiesysteem is het achteraf mogelijk te onderzoeken in hoeverre individuele walviskapiteins op basis van hun eigen vangsten, en administrateurs op basis van het vlootgemiddelde daarin (circa 200 schepen), in staat waren trends in de uitkomsten van deze visserij waar te nemen. Er blijkt gedurende de gehele 18^{e} eeuw geen significante trend in de vangsten te hebben bestaan. Daarbij was niet alleen de tussen-jaarlijkse variatie in het vlootgemiddelde hoog (CV = 0.9), maar ook de variatie in de vangst per kapitein binnen de jaren (CV = 0.7). Van deze variatie blijkt een verwaarloosbaar klein deel te verklaren door systematische verschillen tussen individuele kapiteins. Die kleine verschillen zijn mogelijk terug te voeren op verschillen in persoonlijke vaardigheid om walvissen te vinden en te vangen.

De tussen-jaarlijkse variatie voor de individuele walvisvaarder was $CV = (0.9^2 + 0.7^2)^{1/2} = 1.1$. Daarmee was het 'administratief voordeel' dus gering (CV = 0.9 in plaats van 1.1). Omdat de walvisvaart gemiddeld nauwelijks lonend was én omdat de tussen-jaarlijkse variabiliteit in de vangst per schip zo extreem hoog was, waren de walvismakelaardijen klein en overleefden zij slechts voor korte tijd. Toch zorgde de unieke, maar reële kans op een zeer hoge vangst ervoor, dat velen kleine investeringen bleven doen in de kleine walvismakelaardijen, net zoals men een lot in een loterij koopt.

De ook voor de vloot als geheel hoge variabiliteit in de vangst aan walvissen samen met het voorkomen van tussentijdse korte termijn trends van circa 20 jaar (rode ruis), maakten het ook voor de administrateurs in Nederland niet gemakkelijk een lange termijn trend waar te nemen. Toch moet het zwaar beviste bestand ook toen al sterk zijn afgenomen. Hoge variabiliteit en veranderingen in de vangstpatronen hebben dit waarschijnlijk gemarkeerd. De verwarrende trends van circa 20 jaar werden waarschijnlijk veroorzaakt door persistentie in de omvang van het pakijs, dat de vangkans sterk beïnvloedde. Maar zelfs die scherpere korte termijn trends waren voor walviskapiteins en administrateurs nog maar net waarneembaar. Omdat het gebruik van grafieken en van waarschijnlijkheidsberekening in die tijd nog onbekend was, moet het voor de administrateurs in Nederland ook om die reden moeilijk zijn geweest om een lange termijn trend vast te stellen. De conclusie is dat men beschikte over een ongekend betrouwbaar vangstregistratiesysteem, maar dat het ontbrak aan evaluatieve capaciteit om beheerrelevante informatie aan de uitgebreide tabellen met vangsten per walviskapitein en jaar te ontlenen.

Bestuurlijk dilemma, administratief voordeel en het versterken van de evaluatieve capaciteit

In het laatste hoofdstuk wordt aangegeven dat er bij het beheer van natuurlijke hulpbronnen in het algemeen, sprake is van een 'bestuurlijke dilemma' in het nemen van alle sociaal en economisch haalbare of van alleen krachtige maar dure maatregelen (Hoofdstuk 10). Het duidelijke effect van krachtige maatregelen versterkt de legitimiteit van het beheer. De manoeuvreerruimte hierbij wordt bepaald door het politiek haalbare tijdsraam en door de mate van tussen-jaarlijkse variabiliteit en de persistentie daarin (blauwe en rode ruis). Verder wordt aangegeven dat het 'administratief voordeel' door reductie in tussen-jaarlijkse variabiliteit na ruimtelijke aggregatie van vangst- of oogstgegevens, groter zal zijn voor bestanden met een relatief geringe tussen-jaarlijkse variabiliteit, maar met grote willekeurige veranderingen in de ruimtelijke verdeling, waarop vissers, boeren of jagers moeilijk adequaat kunnen reageren. In alle gevallen, maar zeker waar sprake is van co-management van de visserij, is het belangrijk de 'evaluatieve capaciteit' van overheden én vissers te versterken. De studie sluit af met een aantal aanbevelingen daarvoor:

- Presenteer informatie over de uitkomsten van de visserij in een zo groot mogelijk tijdsraam om vissers bewust te laten zijn van het verhullend effect van korte termijn trends.
- Pas statische power analyse *a priori* toe, om te weten in welk tijdsraam de effectiviteit van een beheersmaatregel pas publiek duidelijk wordt.
- Bepaal de duur van de overgangsfase, die volgt op iedere te nemen maatregel, en maak de vissers op voorhand duidelijk na hoeveel tijd pas echt aan de vangsten kan worden afgemeten of de maatregel succes heeft gehad.

- Bepaal het ‘administratief voordeel’ voor de overheid, die vangstgegevens aggregeert voor een gehele visserij en daarmee minder tussen-jaarlijkse variatie ervaart dan de individuele visser. Communiceer dat voordeel naar de vissers.
- Laat de overheid bij het bediscussiëren van de uitkomsten van de visserij zich realiseren dat vissers variaties ervaren op een kleinere ruimte- en tijdschaal, die invloed hebben op de perceptie van lange termijn trends door vissers.
- Stimuleer vissers als brongebruikers om tijdseries met eigen vangsten en met de vangst voor de visserij als geheel zelf te evalueren, en waar mogelijk ook series met andere voor de visserij belangrijke parameters.

Dankwoord

Door deze studie heb ik beter leren kijken. Ik was eenvoudig benieuwd naar variaties die als een soort mist het zicht op patronen in ruimte en tijd vervagen. Perceptie van patronen in de ruimte spreekt meerdere disciplines aan, dus niet alleen kunsthistorici. Men rekent bijvoorbeeld al uit waarom wij het Melkmeisje van Vermeer mooi vinden. Perceptie van patronen in de tijd is misschien een taaier onderwerp, maar daarom niet minder boeiend.

Verder meen ik dat variatie in de oogst van bijvoorbeeld kabeljauw, gierst of kokkels, en daarmee in bestaansonzekerheid van brongebruikers een uitstekend onderwerp voor interdisciplinair onderzoek vormt (β, γ én α). Mijn ervaring zegt in ieder geval dat voor de ontwikkeling van interdisciplinaire onderzoeksmethoden, het minstens zo belangrijk is een voor ieder interessant onderzoeksobject te selecteren, als het grondig bediscussiëren van verschillende concepten of modellen.

Ten derde denk ik dat studenten er zeer bij gebaat zijn wanneer ze leren beheersituaties sneller te koppelen aan daarvoor kenmerkende variaties. Ze zullen dan beter inzien welke de consequenties zijn van het stellen van bepaalde doelen en het nemen van bepaalde maatregelen. Kortom, ze leren iets dat belangrijk is voor beheer en bestuur.

Noch uit de visserij, noch uit de landbouw kende ik een overzicht van variaties, waarmee je maar bij benadering zou kunnen afleiden wie in staat is veranderingen in het bestand of de oogst te bemerken. Dat betekende dat deze studie voor een belangrijk deel ook inventariserend was. Menige tijdserie heb ik opgediept uit een bibliotheek of, zoals in het geval van de walvisvaart, uit het Stadsarchief van Amsterdam. Bibliotheekpersoneel is zonder uitzondering hulpvaardig, en zeker dat van de Universiteitsbibliotheek in Wageningen (Dannie de Kleijn, Dicky van Donselaar, Gerrie Holmer, Ton Kamphuis).

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Curriculum vitae

Wilhelmus (Wim) Leonardus Theodorus van Densen werd geboren in Den Haag op 10 augustus 1948. Na het behalen van het diploma HBS-B aan het Sint-Janscollege aldaar (1966), studeerde hij biologie aan de Rijksuniversiteit Leiden, waar hij in 1973 afstudeerde. Van 1974 tot 1983 werkte hij op het veldstation van het Limnologisch Instituut (LI) van de KNAW in Friesland, waar hij onderzoek deed aan de ecologie van zoetwatervis, doctoraalstudenten begeleidde en van waaruit hij colleges visserij verzorgde aan de Universiteit Wageningen. Van 1984 tot 2000 werkte hij bij de Universiteit Wageningen als docent visserijbiologie en visserijbeheer. In die functie begeleidde hij studenten en promovendi bij onderzoeksprojecten aan de visserij en visecologie in het Nederlandse binnenwater, zoals die in het IJsselmeer en in de grote rivieren, aan de binnenvisserij in meren en stuwmeren in Afrika en Azië en aan de kustvisserij van met name Indonesië. Naast het verzorgen van cursorisch onderwijs ten behoeve van deze projecten, zette hij samen met het Internationaal Agrarisch Centrum (IAC) cursussen op ten behoeve van visserijstatistiek en beheer in ontwikkelingslanden. Sinds 2001 werkt hij bij het Rijksinstituut voor Visserijonderzoek (RIVO). Daar is hij onder meer betrokken bij het overleg met Noordzeevissers over de uitkomsten van het visserijkundig onderzoek en over de ontwikkelingen in de vangsten.