Oxidative Enolate Cyclizations of 6,8-Nonadienoates: Towards the Synthesis of Prostanes

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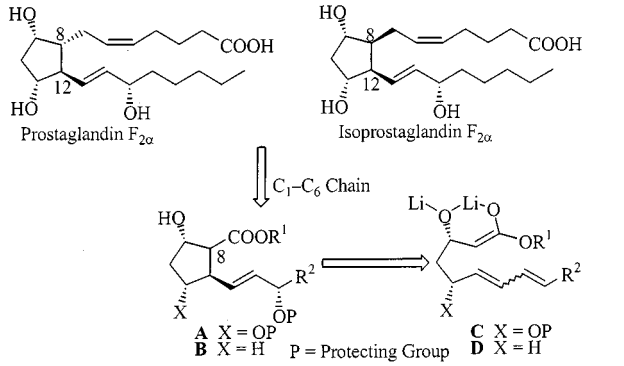
6,8-Nonadienoate enolates, which undergo radical 5-*exo* cyclization on SET oxidation with ferrocenium hexafluorophosphate, were studied as radical cyclization precursors. The trapping of the cyclized allylic radicals occurred with good regioselectivity through dimerization, TEMPO trapping, or SET oxidation/deprotonation reactions. 3-Alkoxido enolates were chemoselectively oxidized to β-oxy α-carbonyl radical anions, which cyclized to produce functionalized cyclopentane derivatives. These cyclizations serve as a model study for the synthesis of prostaglandins and derivatives.

Introduction

Because of their biological action as local hormones, inflammation and pain mediators, or oxidative stress probes, prostaglandins, isoprostanes, and other autoxidatively formed metabolites are inspiring targets for organic chemistry.[1] While there are numerous approaches to these compounds, many of them are multistep syntheses.[1,2] There is thus still a need for efficient strategies for the preparation of these complex molecules and analogs.

Recently, we reported that enolates could be used as efficient precursors for radical reactions. In these reaction sequences, enolates are oxidized by the mild and *recyclable* SET oxidant ferrocenium hexafluorophosphate to provide α-carbonyl radicals that can be oxygenated or cyclized.[3] In this context, we became interested in the question of whether this new methodology might serve as a strategy for construction of prostaglandins or the recently isolated isoprostanes.[1c,4] Retrosynthetic analysis of the target molecules along these lines requires initial disconnection of the C1−C6 chain (Scheme 1). This gives ester fragments **A** or **B**, which should be accessible by a sequence consisting of SET oxidation of alkoxido enolates **C** or **D**, radical anion 5-*exo* cyclization, and allyl radical oxygenation as the key step.



Scheme 1

To accomplish such an approach to prostane skeletons, several problems have to be addressed; the most important are as follows. 1) It has to be established that functionalized enolates of **C** or **D** selectively undergo SET oxidation followed by radical 5-*exo* cyclizations to 1,3-dienes[5] to provide cyclopentane derivatives **A** or **B**. The diastereoselectivity of the process has to be determined. 2) The regioselectivity of allylic radical oxygenation to **A** or **B** by a suitable oxygen source needs to be explored in order to construct the allylic alcohol unit of the lower side chain. 3) The susceptibility of the allyl radical towards further oxidation to an allylic carbenium ion in competition to oxygenation must be investigated.

Here we report the results of fundamental investigations aimed at providing solutions to these problems. Oxidative 5-*exo* cyclizations of 6,8-nonadienoate enolates, with subsequent regioselective oxygenation of allylic radicals, prove that the cyclic core of prostanes can be reached in a single

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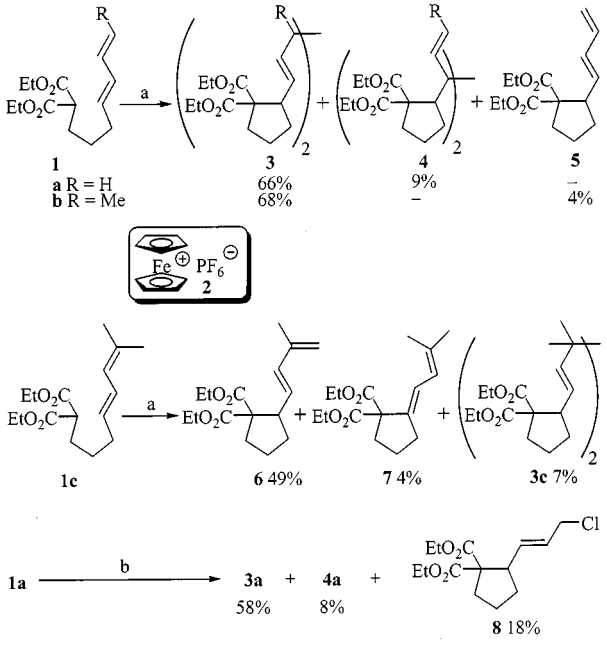
step. Studies on oxidative radical cyclizations of appropriately functionalized, but truncated dianions of 3-hydroxy esters **C** or **D** to cyclopentanes **A** or **B** are presented.

Results and Discussion

Oxidative Cyclizations of Dienylmalonate Enolates

Dienylmalonate enolates **1**[6] were studied initially, in order to obtain information on the behavior of substituted dienes in oxidative enolate cyclizations (Scheme 2). Deprotonation of **1a** by LDA in 0.05 M DME solution, followed by treatment with **2** at 0 °C, gave a mixture of distal and proximal dimers **3a** and **4a** in a ratio of 7.3:1 and in 75% yield. Similarly, oxidative enolate cyclization of **1b** afforded **3b** in 68% yield as a mixture of four diastereomers. In addition, 4% of the monomeric disproportionation product **5** was detected. When the dimethyl-substituted **1c** was subjected to the same reaction conditions, only 7% of dimer **3c** was isolated. The major products were dienylcyclopentanedicarboxylates **6** and **7** in 49% and 4% yields, respectively.

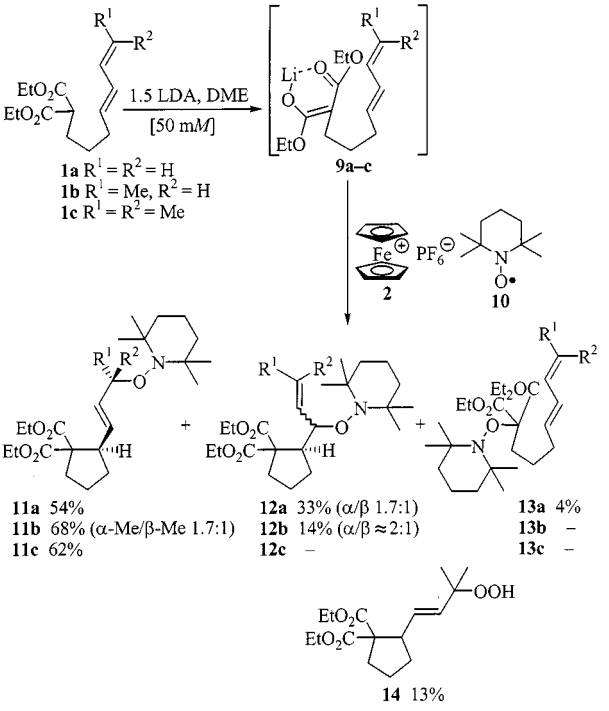


a) 1.3 equiv. LDA, [50 m*M*] DME, –78 – 0 °C, 30 min, then **2**, 0 °C, 1 h
b) 1.3 equiv. LDA, [50 m*M*] DME, –78 – 0 °C, 30 min, then 2.5 equiv. $CuCl_2$, 0 °C, 1.5 h

Scheme 2

We have recently found $CuCl_2$ to be another convenient mediator for oxidative cyclizations of enolates **1**.[3c] However, when **1a** was subjected to treatment with $CuCl_2$, the yield of **3a**/**4a** dropped to 66%. In addition, 18% of allylic chloride **8**, resulting from ligand transfer, was isolated as a side product. Because of this complicating side reaction, investigation of $CuCl_2$ was not pursued further.

On the basis of these results, the cyclization of **1a**–**c** in the presence of stable free radical TEMPO (**10**) as the oxygenating agent was investigated from the point of view of the regioselectivity of allyl radical oxygenation after 5-*exo* cyclization (Scheme 3). The cyclization of **9a** proceeded as desired, but provided only 54% of distal oxygenated **11a** together with 33% of proximal trapped **12a** and 4% of acyclic **13a**. This low distal vs. proximal oxygenation regioselectivity of the allyl radical is in sharp contrast to most precedents involving acyclic allyl radical trapping by **10**, which largely relate to controlled diene polymerization under thermal conditions.[7] Surprisingly, the cyclization of **9b** gave much better regiodifferentiation in favor of the distal trapping product **11b**, which was formed in 68% yield.



Scheme 3

The relative configuration of the major diastereomer of **11b** was established by X-ray crystal structure analysis (Figure 1). Compound **11b** crystallizes with one independent molecule in the centrosymmetric space group $P\bar{1}$. The alkenyl side chain resides on the β-face of the cyclopentane ring, while the piperidinyloxy group is located on the α-face of the alkenyl unit, as required for the natural prostaglandins. The five-membered ring has an envelope conformation, in which the carbon atoms C2, C3, C4, and C5 are approximately coplanar (mean deviation from planarity 4.1 pm). The carbon atom C1 lies 58.0(3) pm out of this plane. The two carbonyl groups are involved in two nonclassical intermolecular hydrogen bonds: C23–H23B···O1 284 pm, 378.4(2) pm, 161° and C11–H11B···O3 266 pm, 357.4(3) pm, 153°. These interactions give rise to double chains parallel to [110].

The NMR spectra of the two diastereomers of **11b** were very similar. In the ^{13}C NMR spectra, however, the alkenyl unit and the TEMPO-bearing carbon atom of the major diastereomer 8α-**11b** were shifted downfield in comparison with those resonances in the minor diastereomer 8β-**11b** (vide infra).

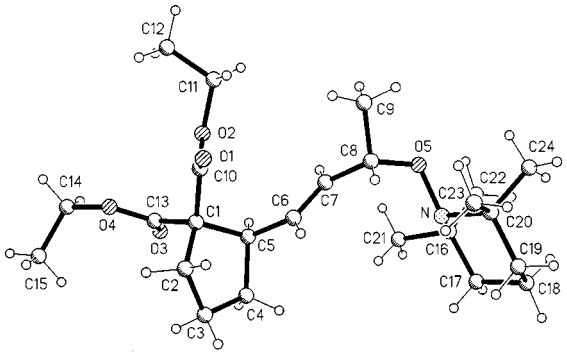
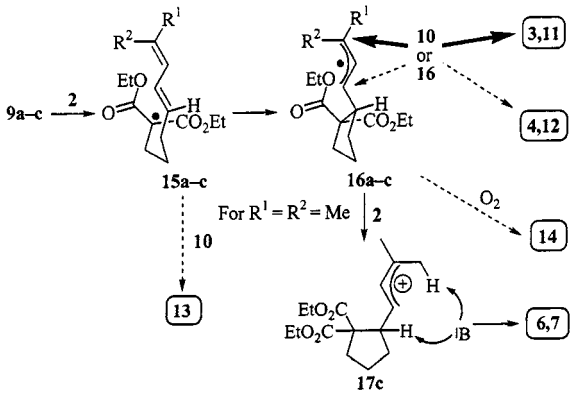


Figure 1. X-ray crystal structure analysis of the major diastereomer of **11b**



Scheme 4

Nonetheless, some proximal trapped **12b** had been formed. Because of strong signal overlap in the NMR spectra, the diastereomeric ratio of **12b** could only be estimated as approximately 2:1 at this stage. The structure and diastereomeric ratios were, however, confirmed by reductive N−O bond cleavage/lactonization of **12b** (vide infra).

The disubstituted malonate **1c** afforded the slightly unstable distal TEMPO adduct **11c** as a single isomer in 62% yield. As side products, alkene **6** was isolated in 10% yield and the allylic hydroperoxide **14** was formed in 13% yield. The structural assignment of **14** was based on the fact that the NMR spectra were very similar to those of the corresponding alcohol **18c** (vide infra). In line with previous findings, the quaternary allylic carbon resonance shifted from $\delta = 70.4$ in **18c** to $\delta = 81.7$ in **14**.[8] In the EI mass spectrum, no molecular ion peak was found, while in the CI spectrum an $[M^+ - O + NH_4]$ peak of reasonable intensity was observed.[9] However, the limited stability of **14** precluded further characterization.

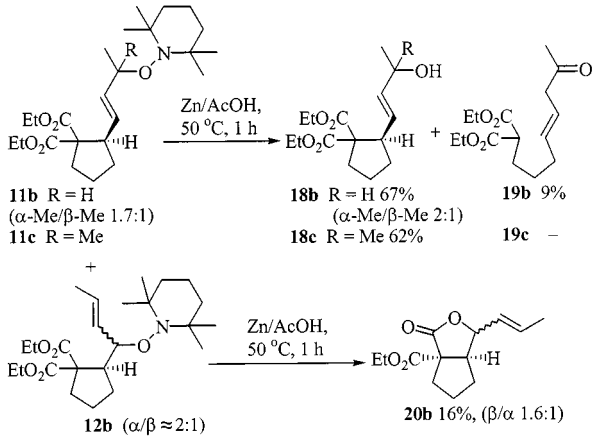
These results can be interpreted as follows (Scheme 4). Malonate enolates **9a**−**c** were oxidized by **2** to malonyl radicals **15a**−**c**.[3] These underwent facile 5-*exo* cyclization to cyclopentylallyl radicals **16a**−**c**, as indicated by the fact that no dimerization and almost no TEMPO trapping of **15a**−**c** competed. For radicals **16a** and **16b** in the absence of TEMPO (**10**), dimerization in the distal position from the ring to give compounds **3** and **4** occurred preferentially. In contrast, in the triply substituted allyl radical **16c**, dimerization to **3c** and allyl radical oxidation to **17c** competed. The allylic cation **17c** was finally deprotonated to **6** and **7** under the basic reaction conditions.

The chemo- and regioselective trapping of radicals **15** and **16** by TEMPO (**10**) was determined by a combination of electronic and steric factors. Coupling of electrophilic malonyl radicals **15** with electrophilic TEMPO (**10**) was evidently unfavorable, as the cyclization occurred efficiently in the presence of excess **10**.

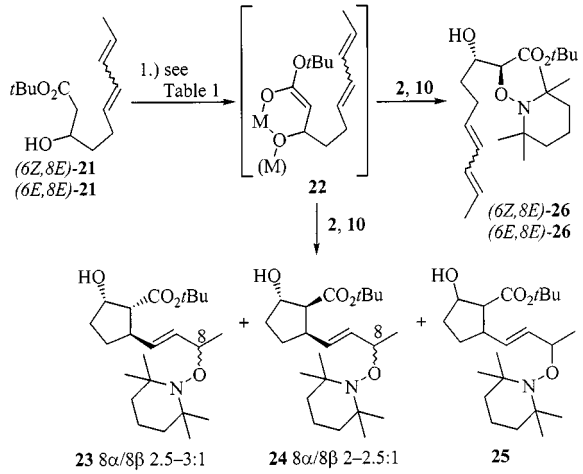
The coupling regioselectivity of **10** with allylic radicals **16a**−**c** was surprising, since trapping selectivity increased as the degree of substitution of the distal position increased. Known rate constants for TEMPO trapping of simple alkyl radicals decrease in the order primary > secondary > tertiary as the degree of substitution of the radical increases.[10] The opposite trend was found for coupling between **10** and radicals **16a**−**c**. In **16a**, the distal position from the cyclopentane ring should be more easily accessible for coupling with **10**, but the proximal position has the higher spin density.[11] Consequently, coupling of **16a** with TEMPO still occurs preferentially at the distal allyl radical position, but the highest proportion of proximal trapping among the allylic radicals **16** was observed. In allylic radical **16b**, in contrast, electronic effects do not play any significant role since the substituent effects for both allyl radical positions are similar. Thus, the higher regioselectivity must be ascribed to a preferred coupling of **10** at the sterically less congested distal position. Finally, in **16c** the highest spin density resides in the distal position,[11] and this now provides **11c** exclusively, despite a somewhat greater steric demand in this position. Thus, the coupling regioselectivity is determined by interplay of the radical stabilizing effects of alkyl substituents and the steric environments at both the proximal and the distal allyl radical positions. Finally, the formation of the major diastereomers of **3b**, **11b**, and **12b** may be explained in terms of a preferred Beckwith−Houk transition state, followed by attack of TEMPO (**10**) or a second allylic radical **16** at the less hindered top-face, as depicted in Scheme 4.

As a crucial prerequisite for later application in prostaglandin synthesis, the deprotection of the allylic alcohol function had to be ensured (Scheme 5). Compounds **11b**, **11c**, and **12b** were therefore subjected to reductive N−O bond cleavage induced by Zn/AcOH.[3,12] Both **11b** and **11c** were cleanly converted into the corresponding free allylic alcohols **18b** and **18c** without significant change in the diastereomeric ratios. In addition, the acyclic β,γ-unsaturated ketone **19b** was isolated from the deprotection of **11b** in 9% yield; it may have been formed from **18b** by malonate protonation/ring cleavage/1,2-hydride shift.[13]

Proximal trapped **12b** underwent spontaneous lactonization under the reductive reaction conditions to give **20b**. The structures and configurations of both diastereomers of **20b** were assigned by comparison of their NMR spectra with those of known lactones.[3c] In the ^{1}H NMR spectra, the CH−O resonances of the major diastereomer β-**20b** appeared shifted downfield at $\delta = 5.09$ compared to $\delta = 4.44$



Scheme 5



Scheme 6

in the minor α-**20b**. An opposite trend was found in the ^{13}C NMR spectra. This indicated a β-configuration for the propenyl group in the major diastereomer of **20b**, while the resonances for the minor diastereomer were typical for an α-arrangement[3c] of the propenyl group.

Oxidative Cyclizations of 3-Hydroxy Ester Dianions to the Prostane Skeleton

Having established that dienes were suitable radical acceptors in oxidative enolate cyclizations and that allyl radical oxygenations occurred regioselectively, we proceeded to investigate the approach to the prostane/isoprostane ring system by oxidative cyclization of 3-alkoxido enolates. Several issues needed to be investigated; the most important were:

1.) the applicability of hitherto almost unexplored, less stabilized, ester enolates in oxidative cyclizations[14] to alkenes,

2.) the chemoselectivity of enolate oxidation versus alkoxide oxidation, and

3.) the efficiency and stereoselectivity of the cyclization with respect to enolate structure and diene configuration.

Accordingly, the cyclization of 3-hydroxy esters **21** was studied (Scheme 6, Table 1). *C*,*O*-Dideprotonation of (6*Z*,8*E*)-**21** by 3.2 equiv. of LDA in the presence of HMPA gave the dianion **22**, which was oxidatively cyclized by **2** in the presence of TEMPO (**10**) (Entry 1). The major products of this cyclization were the easily separable cyclopentane derivatives **23** and **24** in a ratio of 1:1 and in a combined yield of 60%. Both **23** and **24** were isolated as a 2−3:1 diastereomeric mixture with respect to the configuration at the TEMPO-bearing carbon atom C-8. In addition, a minor, unassigned diastereomer **25** was formed in very low yield. Gratifyingly, no products from proximal TEMPO trapping (cf. **12** in Scheme 3) were detected. Cyclization of **22** in the absence of HMPA afforded **23** and **24** in a slightly lower yield of 49% without any change in the diastereoselectivity. The ester (6*E*,8*E*)-**21** behaved quite similarly under these reaction conditions, giving 65% of **23** and **24** (Entry 2). The minor diastereoisomer **25**, however, was not detected in this experiment.

Table 1. Oxidative radical cyclizations of 3-alkoxido enolates **21**

Entry	**21**	Conditions[a]	**21**[b]	**23**[c]	**24**[c]	**26**
1	(6*Z*,8*E*)	LDA/HMPA	12	31	29	15
2	(6*E*,8*E*)	LDA/HMPA	24	34	31	5
3	(6*Z*,8*E*)	LDA/$MgBr_2$/HMPA	17	34	34	2
4	(6*Z*,8*E*)	MeMgCl/LDA	12	29	7	12
5	(6*E*,8*E*)	MeMgCl/LDA/HMPA	44	28	6	15
6	(6*Z*,8*E*)	MeZnBr/LDA/HMPA	28	17	22	10
7	(6*Z*,8*E*)	LDA/$ZnCl_2$	41	10	14	4

[a] 1.) Base (50 mM), THF, −78 to −10 °C, 2 h; 2.) 1.2 equiv. **10**, 2.0 equiv. **2**, −78 °C, 1 h, see Exp. Sect. [b] Recovered **21**. [c] Isolated as a 2−3:1 diastereomeric mixture at C-8.

The metal counterion to the enolate **22** had some influence on the cyclization outcome. When 1.3 equiv. of $MgBr_2$ was added after double deprotonation of (6*Z*,8*E*)-**21** by LDA, the 68% yield and 1:1 diastereoselectivity for **23**/**24** were similar (Entry 3). On the other hand, alcohol deprotonation by MeMgCl and subsequent ester deprotonation with LDA changed the cyclization outcomes for both (6*Z*,8*E*)-**21** and (6*E*,8*E*)-**21**, providing a 4:1 ratio of **23**/**24**, albeit in only 36% and 34% combined yields, respectively (Entries 4, 5). Use of MeZnBr for alcohol deprotonation of (6*Z*,8*E*)-**21** also provided only a 39% yield of **23**/**24**, but in a 1:1.3 ratio (Entry 6). Cyclization of **22** after Li/Zn transmetallation with $ZnCl_2$ gave **23**/**24** in only 24% yield, but a similar preference for **24** was found (Entry 7). In all the experiments, acyclic trapping product **26** was formed in small amounts as a single *anti* diastereomer. At this point we did not work on improving the TEMPO trapping diastereoselectivity, since the configuration at the TEMPO-bearing carbon atom can be corrected after conversion into the alcohol.[15]

The configuration assignment of the major diastereomer of **23** was accomplished with the help of an X-ray crystal structure analysis (Figure 2). Compound **23** crystallizes with one independent molecule in the centrosymmetric

space group $P2_1/c$, allowing the relative configuration of the molecule to be determined as (1*R**,2*S**,5*R**,8*S**). This compound thus possesses the prostaglandin relative configuration at all four stereocenters and in the alkene. The five-membered ring has an envelope conformation, in which the carbon atoms C1, C3, C4, and C5 are nearly coplanar (mean deviation from planarity 3.6 pm); the carbon atom C2 lies 60.7(5) pm out of this plane. The substitution pattern, involving a hydroxy and a carbonyl group, results in an intermolecular hydrogen bond: O3−H03···O1 206(6) pm, 291.3(3) pm, 160(6)°. A nonclassical hydrogen bond is also formed (C2−H2···O1 255 pm, 345.1(4) pm, 150°) giving rise to dimers with bifurcated hydrogen bonds at the acceptor oxygen atom O1.

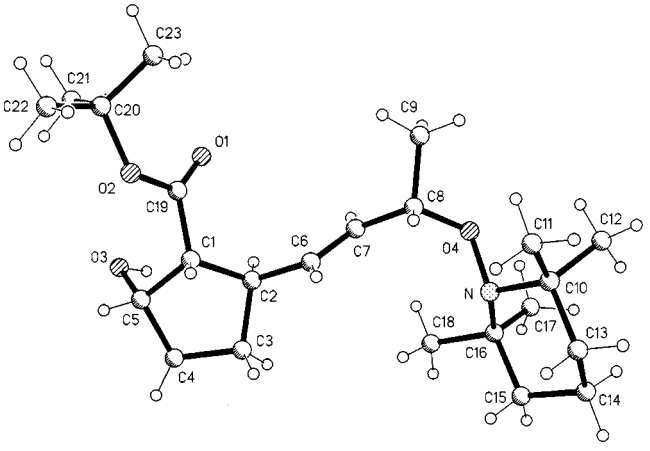
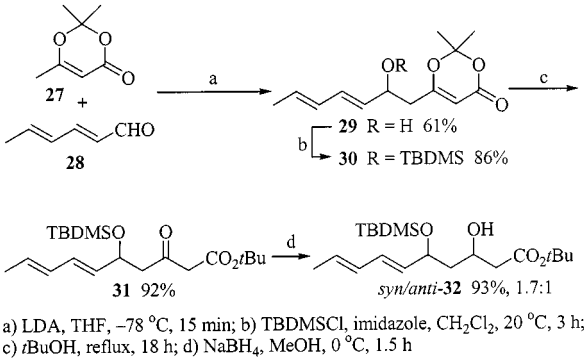


Figure 2. X-ray crystal structure analysis of the major C-8 diastereomer of **23**

The NMR spectra of both diastereomers of **23** were very similar. However, as observed in **11**, the ^{13}C NMR resonances of the alkenyl unit and the TEMPO-bearing carbon atom C-8 of the major diastereomer 8α-**23** were shifted downfield from those of 8β-**23** (vide supra). This assignment was further strengthened by the fact that similar NOE enhancements of the ring protons were observed for both 8α-**23** and 8β-**23** (Supporting Information).

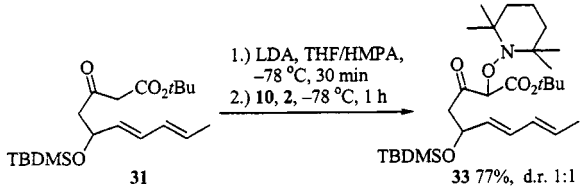
The NMR spectra of the two diastereomers of **24** were again very similar to each other, but differed markedly from those of **23**. The isoprostane configurations of the cyclopentane rings in both diastereomers of **24** were assigned on the basis of NOE studies (Supporting Information). The configuration at C-8 in the major diastereomer of **24** was assumed to be 8α, since an orientation of the side chain similar to that in **11** or **23** was to be expected (vide infra). Furthermore, the ^{13}C NMR resonances of the alkenyl unit and C-8 obeyed the same trends as those observed in **11** and **23** (vide supra).

On the basis of these results, the cyclization behavior of the 3,5-dioxy esters *syn*- and *anti*-**32** was examined. The starting esters were easily synthesized by means of a vinylogous aldol addition of 6-methyl-1,3-dioxin-4-one **27** to sorbic aldehyde **28**, furnishing the dioxinone **29** in 61% yield (Scheme 7). *O*-Silylation of **29** under standard conditions with subsequent transesterification of the resulting **30** with *t*BuOH according to Carreira and co-workers[16] provided 5-silyloxy oxo ester **31** in good overall yield. This material was subjected to a variety of reduction methods to give *syn*-3-hydroxy ester **32**. Unfortunately, only inseparable *syn*/*anti* diastereomeric mixtures of **32** were obtained. The best result was achieved with $NaBH_4$, providing a 1.7:1 mixture of *syn*- and *anti*-**32**. In the end, it was not important to separate the diastereomers, since the relevant information on cyclization abilities could be gained on mixtures of both *syn*- and *anti*-**32**.



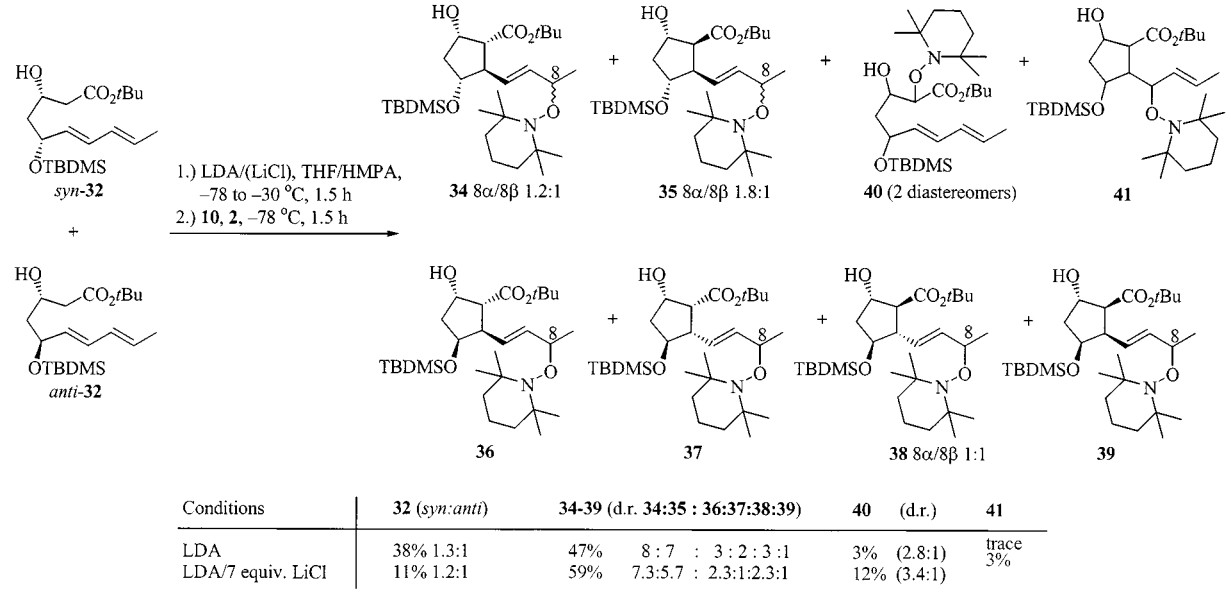
Scheme 7

Compound **31** and the 1.7:1 *syn*/*anti*-**32** mixture were subjected (after deprotonation) to oxidative cyclization induced by **2**. The β-oxo ester enolate of **31** did undergo SET oxidation after deprotonation by LDA, indicated by the consumption of **2** (Scheme 8). However, only the acyclic TEMPO trapping product **33** was isolated, in 77% yield. This result reflects the decrease in the rate of 5-*exo* cyclization when an oxo group is present in the forming cyclopentane ring.[17] Thus, trapping of the oxo ester radical, generated by SET oxidation of the enolate by TEMPO (**10**), was faster than 5-*exo* cyclization.



Scheme 8

When **32** was subjected to oxidative cyclization conditions similar to those used with **21**, two major series of partly separable cyclized products, namely **34**−**35** and **36**−**39**, respectively, were isolated in a combined yield of 47% (Scheme 9). Furthermore, 3% of acyclic TEMPO trapping product **40** was isolated and 38% of **32** was recovered as a 1.3:1 *syn*/*anti* mixture. It was speculated that the additional oxygen substituent might result in undesired aggregation, and so the cyclization was repeated in the presence of excess anhydrous LiCl. Under these conditions, the yield of **34**−**39** was increased considerably to 59%. The diastereomeric composition did not change significantly, however. The ratios of (**34**+**35**)/(**36**−**39**) amounted to 1.6:1 and 1.9:1, respectively, which was in good agreement with the 1.7:1 *syn*/



Conditions	32 (*syn*:*anti*)	34-39 (d.r. 34:35 : 36:37:38:39)	40 (d.r.)	41
LDA	38% 1.3:1	47% 8 : 7 : 3 : 2 : 3 :1	3% (2.8:1)	trace
LDA/7 equiv. LiCl	11% 1.2:1	59% 7.3:5.7 : 2.3:1:2.3:1	12% (3.4:1)	3%

Scheme 9

anti ratio of starting **32**. Small amounts of a single cyclized proximal TEMPO-trapped compound **41** were detected in these experiments.

The NMR spectra of the two diastereomers of **34** and **35** were similar to those of **23** and **24**, respectively. The prostaglandin and isoprostane configurations for compounds **34** and **35** were assigned on the basis of NOE experiments. The configuration assignment of C-8 was made on the same basis as for **11** or **23/24** (vide supra). In the series of compounds **36**−**39**, on the other hand, the NMR ring resonances varied much more, indicating that all diastereomers differed in their relative ring configurations. The ring configurations in **36**−**39** were tentatively assigned on the basis of chemical shifts, coupling constants, and NOE studies (Supporting Information).

Mechanistic Features of the Oxidative Cyclizations of 3-Hydroxy Ester Dianions

The results clearly indicate the following:

1.) As well as the established malonate enolates, less stabilized enolates such as **21** or **32** can also conveniently be applied as precursors in oxidative radical cyclizations induced by **2** under very mild conditions.

2.) SET oxidation induced by **2** is chemoselective for the enolate in the presence of an alkoxide, since no products resulting from alkoxyl radical reactions were detected.

3.) Additional functionalities can be introduced into the precursors, since both the *syn*- and the *anti*-3,5-dioxy esters **32** underwent useful oxidative cyclizations of their alkoxido enolates at approximately the same rates. On the basis of their relative proportions in the starting *syn*/*anti* mixture of **32**, the combined yield of **34** and **35** amounts to 62%, while the yield of **36**−**39** corresponds to 54%. This indicates that the precursor configuration does not give rise to any significant effect on the general reactivity of the 1,3-radical anions generated by SET oxidation.

4.) In cyclizations of **21** or **32**, additives such as HMPA and LiCl improved the yields of cyclization products. It can be assumed that both additives give rise to modifications of the definitely aggregated lithium enolates[18] and cyclizing radical anions. LiCl and HMPA may partly deaggregate the alkoxido enolates or form mixed aggregates monomeric in the enolates.[19] These should possess greater flexibility, thus facilitating SET oxidation of the enolate and cyclization of the alkoxido radical anions. However, it must be emphasized that only supramolecular structures can be modified by these additives. Intramolecular chelation (vide infra) is apparently not changed, since the cyclization diastereoselectivities are hardly influenced by these additives.

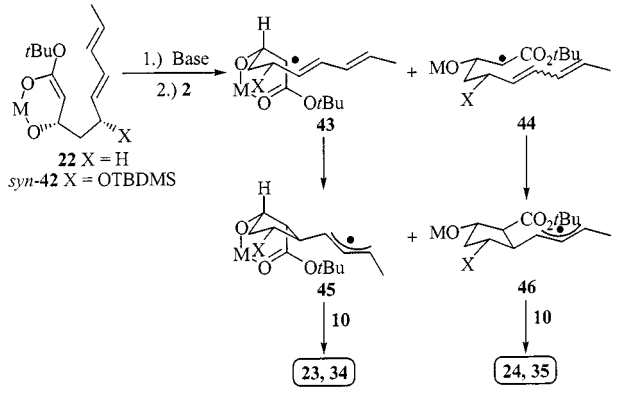
5.) The cyclization diastereoselectivity reveals several interesting features. The diene configuration of **21** displays a small effect on the product distribution. Ester (*E*,*E*)-**21** furnishes only products **23/24** with prostaglandin/isoprostane configuration, while another diastereomer **25** was formed in small amounts in oxidative cyclizations of (*Z*,*E*)-**21**.

Only four out of sixteen possible diastereomers were formed in the cyclization of *syn*-**32**, while five diastereomers arising from cyclization of *anti*-**32** were isolated. However, the cyclizations of *syn*- and *anti*-**32** revealed significant differences. Four diastereomers **36**−**39**, differing in their relative ring configurations, were detected in the cyclization of *anti*-**32**. This low diastereoselectivity must be ascribed to several similarly populated arrangements in the transition state of cyclization. On the other hand, only **38** was isolated as a 1:1 diastereomeric mixture with respect to the configuration at the TEMPO-bearing carbon atom C-8, while **36**−**37** and **39** were single diastereomers with regard to C-8.[20]

In contrast, cyclization of *syn*-**32** produced only two diastereomers **34** and **35**, with prostaglandin and isoprostane ring configurations. Similarly to **23/24**, moreover, both **34**

and **35** were diastereomeric mixtures with respect to the configuration at allylic C-8. Thus, the cyclization diastereoselectivities for **21**, unsubstituted in the 5-position, and 5-silyloxy ester *syn*-**32** do not differ significantly from each other. However, the coupling diastereoselectivity of the cyclized allylic radical was observed to be lower in **34** than in **23**.

Most significantly, the 1,2-diastereoselectivity clearly deviates from the generally preferred 1,2-*trans* selectivity in cyclizations of 1,2-disubstituted 5-hexenyl radicals (Schemes 9−10).[21] In addition, the relative orientation of the hydroxy group towards the diene group is almost or completely *trans* in products **23**/**24** and **34**/**35**, resulting from cyclizations of alkoxido enolates **22** or *syn*-**42**. This indicates that chelation control[22] must operate in part in the cyclization of alkoxido enolates **22**, *syn*- and *anti*-**42**. Prostaglandin-type isomers **23** or **34** are most probably produced by cyclization of a six-membered chelated radical anion **43** via a chair-like transition state (Scheme 10). The oxygen substituents are arranged in a favorable equatorial disposition and the dienyl group in the typical orientation for the cyclization of a 4-substituted 5-hexenyl radical to avoid A-strain. A similar transition state was recently proposed for the cyclization of an aluminum-chelated radical.[23] On the other hand, isoprostane structures **24** or **35** should form through the nonchelated radical anion **44** in an open Beckwith−Houk transition state[24] accommodating all substituents in favorable orientations and resulting in the same relative alkoxide/diene orientation. Thus, the simple 1,5-diastereoselection in oxidative cyclizations of **22** or *syn*-**42** through either **43** or **44** is high, since alternative diastereomers (**25**) were detected only in minor amounts or not at all.



Scheme 10

The cyclization results for **22** also demonstrate that the metal cation used is important for control of the diastereoselectivity of the cyclization. The lithium and zinc radical anions **43** formed on oxidation of **22** apparently do not form sufficiently stable chelated radical anions **43** and cyclize from an approximately 1:1 mixture of **43** and **44**. On the other hand, the chelated radical anion **43** seems to be much more robust for M = Mg,[22,25] giving **23** preferentially − albeit in as yet not very useful yields. Overall, promising high cyclization diastereoselectivity can be expected in oxidative cyclizations of alkoxido enolates once the issue of 1,2-stereocontrol can be better controlled. At this point we did not pursue studies on model substrates such as **21** or **32**, since the basic features of the alkoxido enolate cyclizations had now been established.

Conclusion

We have shown for the first time that 3-hydroxy ester dianions **22** or **42** are oxidized chemoselectively at the enolate in the presence of an alkoxide to afford 1,3-radical anions **43** or **44**, which cyclize to prostaglandin/isoprostane models. We have shown that dienes are valuable cyclization acceptors in oxidatively induced radical cyclizations. Allyl radical stabilization by TEMPO (**10**) occurred mostly regioselectively at the distal position from the cyclopentane ring. Further thorough investigations on the metal/chelation influence on the cyclization diastereoselectivity for fully elaborated prostane cyclization precursors are clearly warranted and will be reported in due course.

Experimental Section

General Remarks: All reactions were conducted in flame-dried glassware under nitrogen. THF, DME, HMPA, and diisopropylamine were dried by standard methods. $ZnCl_2$ and $ZnBr_2$ were dried in vacuum (170 °C, 0.8 mbar) for 2−5 h. A 0.2 M solution of $MgBr_2$ in THF was prepared as described.[26] POLYGRAM SIL G/UV_{254} TLC plates (Macherey−Nagel) were used for monitoring reactions. Chromatographic separations were performed on 60 silica gel (Fluka, 230−400 mesh) with *n*-hexane/ethyl acetate as eluent in the given ratio. Melting points are uncorrected. IR spectra were taken with a Nicolet DX-320 FT-IR spectrometer. UV/Vis spectra were taken in CH_3CN with a Hewlett Packard 8452 diode array spectrometer. ^1H and ^{13}C NMR spectra were recorded in $CDCl_3$, unless otherwise noted, with Bruker DRX 400 or AC 200 spectrometers at 400 or 200, and 100 or 50 MHz, respectively. Connectivity was determined by ^1H-^1H COSY experiments. ^{13}C NMR assignments were obtained from DEPT and C,H-correlation experiments. EI mass spectra were recorded with Finnigan MAT 8430 and MAT 8400 spectrometers at 70 eV. Combustion analyses were performed at the Microanalytical Laboratories of the Technical University of Braunschweig.

Preparation of 4,6-Dienylmalonates 1a−c (General Procedure): At 0 °C under N_2, diethyl malonate (3.20 g, 20.0 mmol) was added to a suspension of NaH (80% in mineral oil, 450 mg, 15.0 mmol) in a dry THF/DMF mixture (50 mL/10 mL) and stirred for 30 min. 4,6-Dienyltosylates (10 mmol) and anhydrous NaI (600 mg, 4 mmol) were added at room temperature. The reaction mixture was heated to reflux until complete by TLC (12−60 h). The mixture was quenched with saturated NH_4Cl solution. The aqueous layer was extracted three times with ether. The combined organic layers were dried with Na_2SO_4 and the solvent was evaporated. Excess diethyl malonate was distilled off at 50 °C and 0.8 mbar. Purification of the residue by flash chromatography yielded malonates **1a−c**.

Diethyl 2-(Hepta-4,6-dien-1-yl)malonate (1a): Flash chromatography (50:1) gave 1.93 g (76%) of **1a** [R_f (10:1) = 0.44] as a color-

less oil. IR (film): $\tilde{\nu}$ = 2984 cm^{-1}, 1751, 1733, 1178, 1154. UV: λ_{max} (lg ε) = 226 nm (4.42). ^1H NMR (200 MHz): δ = 1.22 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.39 (quint, *J* = 7.7 Hz, 2 H, $=CHCH_2CH_2$), 1.86 (m, 2 H, CH_2CHCO_2), 2.08 (q, *J* = 7.1 Hz, 2 H, $=CHCH_2$), 3.28 (t, *J* = 7.5 Hz, 1 H, $CHCO_2$), 4.15 (q, *J* = 7.1 Hz, 4 H, OCH_2), 4.91 (dd, *J* = 10.5, 1.5 Hz, 1 H, $=CH_2$), 5.04 (dd, *J* = 16.4, 1.2 Hz, 1 H, $=CH_2$), 5.61 (dt, *J* = 15.0, 6.9 Hz, 1 H, $=CHCH_2$), 6.01 (dd, *J* = 15.0, 10.3 Hz, 1 H, $CH=CHCH$), 6.24 (dt, *J* = 16.8, 10.1 Hz, 1 H, $CH=CH_2$). ^{13}C NMR (50 MHz): δ = 13.9 (q, OCH_2CH_3), 26.7 (t), 28.1 (t), 31.9 (t, $=CHCH_2$), 51.7 (d, $CHCO_2$), 61.1 (t, OCH_2), 114.9 (t, $=CH_2$), 131.5 (d, =CH), 133.9 (d, =CH), 137.0 (d, =CH), 169.2 (s, CO_2). MS: *m*/*z* (%) = 254 (21) [M^+], 209 (8), 208 (10), 180 (26), 163 (33), 162 (46), 135 (31), 134 (100), 80 (38), 79 (34). $C_{14}H_{22}O_4$ (254.3): calcd. C 66.12, H 8.72; found C 65.94, H 8.84.

Diethyl (6*Z*,8*E*)-2-(Octa-4,6-dien-1-yl)malonate (1b): Flash chromatography (50:1) gave 1.99 g (74%) of **1b** [R_f (10:1) = 0.32] as a colorless oil. IR (film): $\tilde{\nu}$ = 2984 cm^{-1}, 1751, 1734, 1236, 1213, 1154. UV: λ_{max} (lg ε) = 230 nm (4.37). ^1H NMR (200 MHz): δ = 1.23 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.38 (m, 2 H, $=CHCH_2CH_2$), 1.74 (d, *J* = 6.7 Hz, 3 H, $=CHCH_3$), 1.87 (m, 2 H, CH_2CHCO_2), 2.15 (q, *J* = 7.4 Hz, 2 H, $=CHCH_2$), 3.29 (t, *J* = 7.5 Hz, 1 H, $CHCO_2$), 4.15 (q, *J* = 7.1 Hz, 4 H, OCH_2), 5.21 (m, 1 H, =CH), 5.62 (m, 1 H, =CH), 5.91 (t, *J* = 10.8 Hz, 1 H, =CH), 6.27 (m, 1 H, =CH). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 18.2 (q, $=CHCH_3$), 27.1 (t), 27.3 (t), 28.2 (t), 51.8 (d, $CHCO_2$), 61.2 (t, OCH_2), 126.8 (d, =CH), 128.3 (d, =CH), 129.1 (d, =CH), 129.4 (d, =CH), 169.3 (s, CO_2). MS: *m*/*z* (%) = 268 (33) [M^+], 223 (11), 222 (15), 194 (13), 176 (23), 149 (31), 148 (100), 121 (20), 94 (36), 93 (24), 81 (27), 79 (77), 55 (26). HRMS: $C_{15}H_{24}O_4$: calcd. 268.1675; found 268.1668 ± 3 ppm. $C_{15}H_{24}O_4$ (268.4): calcd. C 67.14, H 9.01; found C 66.96, H 9.08.

Diethyl 2-(7-Methylocta-4,6-dien-1-yl)malonate (1c): Flash chromatography (50:1) gave 2.09 g (74%) of a 3:1 (*E*/*Z*) mixture of **1c** [R_f (15:1) = 0.25] as a colorless oil. IR (film): $\tilde{\nu}$ = 2982 cm^{-1}, 1752, 1734, 1238, 1149. UV: λ_{max} (lg ε) = 238 nm (4.43). **(*E*)-1c:** ^1H NMR (200 MHz): δ = 1.21 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.36 (m, 2 H, $=CHCH_2CH_2$), 1.68 (s, 3 H, $=CCH_3$), 1.69 (s, 3 H, $=CCH_3$), 1.84 (m, 2 H, CH_2CHCO_2), 2.06 (m, 2 H, $=CHCH_2$), 3.26 (t, *J* = 7.5 Hz, 1 H, $CHCO_2$), 4.14 (q, *J* = 7.1 Hz, 4 H, OCH_2), 5.44 (dt, *J* = 15.0, 7.0 Hz, 1 H, $=CHCH_2$), 5.71 (d, *J* = 10.8 Hz, 1 H, $CH=CCH_3$), 6.17 (dd, *J* = 15.0, 10.8 Hz, 1 H, $CH=CHCH$). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 18.1 (q, $=CCH_3$), 25.8 (q, $=CCH_3$), 27.2 (t), 28.2 (t), 32.3 (t, $=CHCH_2$), 51.9 (d, $CHCO_2$), 61.2 (t, OCH_2), 124.9 (d, $CH=CCH_3$), 127.3 (d, $CH=CHCH$), 130.5 (d, $CH_2CH=$), 133.0 (s, $=CCH_3$), 169.4 (s, CO_2). **(*Z*)-1c:** ^1H NMR (200 MHz): δ = 1.21 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.36 (m, 2 H, $=CHCH_2CH_2$), 1.69 (s, 3 H, $=CCH_3$), 1.75 (s, 3 H, $=CCH_3$), 1.84 (m, 2 H, CH_2CHCO_2), 2.14 (m, 2 H, $=CHCH_2$), 3.27 (t, *J* = 7.5 Hz, 1 H, $CHCO_2$), 4.14 (q, *J* = 7.1 Hz, 4 H, OCH_2), 5.22 (m, 1 H, $=CHCH_2$), 5.98 (d, *J* = 11.9 Hz, 1 H, $CH=CCH_3$), 6.15 (m, 1 H, $CH=CHCH$). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 18.0 (q, $=CCH_3$), 26.2 (q, $=CCH_3$), 27.0 (t), 27.4 (t), 28.3 (t), 51.9 (d, $CHCO_2$), 61.2 (t, OCH_2), 120.1 (d, $CH=CCH_3$), 125.3 (d, $CH=CHCH$), 128.1 (d, $CH_2CH=$), 135.3 (s, $=CCH_3$), 169.4 (s, CO_2). MS: *m*/*z* (%) = 282 (45) [M^+], 237 (18), 236 (18), 208 (34), 163 (45), 162 (100), 145 (21), 122 (20), 108 (44), 93 (55). HRMS: $C_{16}H_{26}O_4$: calcd. 282.1831; found 282.1825 ± 2 ppm. $C_{16}H_{26}O_4$ (282.4): calcd. C 68.06, H 9.28; found C 67.91, H 9.38.

Oxidative Cyclization of Malonates 1a−c Induced by 2 (General Procedure): At −78 °C under N_2, **1a−c** (1 mmol) was added to a solution of LDA [1.3 mmol, prepared from 0.18 mL diisopropylamine and 0.81 mL *n*BuLi (1.6 M in *n*-hexane)] in dry DME (20 mL). The solution was stirred for 30 min between −78 and −60 °C. Solid **2** was added in portions at 0 °C until a blue-green color persisted in the reaction mixture for 30 min. The mixture was stirred at 0 °C for 1 h. The mixture was quenched with four drops of a saturated NH_4Cl solution and allowed to warm to room temperature. The reaction mixture was diluted with 20 mL ether and filtered through a pad of silica gel. The solvent was evaporated and the inhomogeneous residue was preadsorbed on silica gel. Crude flash chromatography (50:1 gradient to 1:1) gave > 90% ferrocene followed by the products **5**, **6**, **7**, **3**, and **4**. The individual compounds were, if necessary, further purified by flash chromatography as indicated in the characterization section.

(1*E*,5*E*)-1,6-Bis[1,1-bis(ethoxycarbonyl)cyclopent-2-yl]-1,5-hexadiene (3a) and 3,4-Bis[1,1-bis(ethoxycarbonyl)cyclopent-2-yl]-1,5-hexadiene (4a): Flash chromatography (50:1) gave an inseparable mixture of 190 mg (75%) **3a** and **4a** (7.3:1) [R_f (5:1) = 0.43] as a colorless oil. IR (film): $\tilde{\nu}$ = 2981 cm^{-1}, 1728, 1259, 1216, 1180. **3a:** ^1H NMR (400 MHz): δ = 1.17 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.20 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.54 (m, 4 H, $CHCH_2CH_2CH_2$), 1.79 (m, 2 H, $CHCH_2CH_2CH_2$), 1.89 (m, 2 H, $CHCH_2CH_2CH_2$), 1.94 (m, 4 H, $=CHCH_2$), 2.01 (m, 2 H, CCH_2), 2.40 (dt, *J* = 13.6, 8.3 Hz, 2 H, CCH_2), 3.15 (q, *J* = 7.7 Hz, 2 H, $=CHCH$), 4.03 (dq, *J* = 10.8, 7.1 Hz, 2 H, OCH_2), 4.09 (dq, *J* = 10.6, 7.1 Hz, 2 H, OCH_2), 4.11 (dq, *J* = 10.6, 6.9 Hz, 2 H, OCH_2), 4.17 (dq, *J* = 10.8, 7.1 Hz, 2 H, OCH_2), 5.34 (dd, *J* = 14.8, 7.0 Hz, 2 H, $CHCH=CH$), 5.44 (m, 2 H, $CHCH=CH$). ^{13}C NMR (100 MHz): δ = 13.9 (q, OCH_2CH_3), 14.1 (q, OCH_2CH_3), 23.0 (t, $CHCH_2CH_2$), 31.3 (t, $CHCH_2CH_2CH_2$), 31.4 (t, $CHCH_2CH_2CH_2$), 32.2 (t, $=CHCH_2$), 33.7 (t, CCH_2), 48.68 (d, $=CHCH$), 48.70 (d, $=CHCH$), 60.7 (t, OCH_2), 60.9 (t, OCH_2), 64.2 (s, CCO_2), 129.50 (d, $CHCH=CH$), 129.51 (d, $CHCH=CH$), 131.0 (d, $CHCH=CH$), 131.1 (d, $CHCH=CH$), 170.7 (s, CO_2), 172.2 (s, CO_2). **Detectable Resonances of 4a:** ^1H NMR (400 MHz): δ = 1.21 (t, *J* = 7.0 Hz, 6 H, OCH_2CH_3), 2.31 (m, 2 H), 4.89 (m, 4 H, $=CH_2$). ^{13}C NMR (50 MHz): δ = 13.8 (q, OCH_2CH_3), 13.9 (q, OCH_2CH_3), 22.7 (t), 22.8 (t), 36.8 (t), 48.8 (d, $=CHCHCH$), 50.5 (d, $=CHCH$), 60.7 (t, OCH_2), 60.9 (t, OCH_2), 64.1 (s, CCO_2), 114.7 (t, $=CH_2$), 141.1 (d, =CH), 171.1 (s, CO_2), 171.3 (s, CO_2). MS: *m*/*z* (%) = 506 (23) [M^+], 461 (20), 387 (20), 386 (31), 253 (47) [$M^+/2$], 179 (100), 173 (22), 133 (31), 107 (20), 105 (64), 91 (23), 79 (40). HRMS: $C_{28}H_{42}O_8$: calcd. 506.2879; found 506.2868 ± 2 ppm. $C_{28}H_{42}O_8$ (506.6): calcd. C 66.37, H 8.36; found C 66.45, H 8.41.

1,6-Bis[1,1-bis(ethoxycarbonyl)cyclopent-2-yl]-3,4-dimethyl-1,5-hexadiene (3b): Flash chromatography (50:1) gave 182 mg (68%) **3b** as an inseparable mixture of four diastereomers [R_f (5:1) = 0.51] as a colorless oil. IR (film): $\tilde{\nu}$ = 2979 cm^{-1}, 1729, 1261, 1208, 1178, 1098. **Major Diastereomer 3b:** ^1H NMR (400 MHz): δ = 0.79 (d, *J* = 6.4 Hz, 6 H, $CHCH_3$), 1.15 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.18 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.45−1.59 (m, 6 H, $CHCH_2CH_2$, $=CHCHCH_3$), 1.77 (m, 2 H, $CHCH_2CH_2CH_2$), 1.87 (m, 2 H, $CHCH_2CH_2CH_2$), 2.00 (m, 2 H, CCH_2), 2.37 (m, 2 H, CCH_2), 3.14 (q, *J* = 7.2 Hz, 2 H, $=CHCHCH_2$), 3.95 (dq, *J* = 10.7, 7.2 Hz, 2 H, OCH_2), 4.11 (q, *J* = 7.1 Hz, 2 H, OCH_2), 4.12 (q, *J* = 7.1 Hz, 2 H, OCH_2), 4.13 (q, *J* = 7.1 Hz, 2 H, OCH_2), 5.24 (m, 4 H, $CH=CH$). ^{13}C NMR (100 MHz): δ = 14.0 (q, OCH_2CH_3), 14.1 (q, OCH_2CH_3), 18.5 (q, $=CHCHCH_3$), 23.0 (t, $CHCH_2CH_2$), 31.7 (t, $CHCH_2CH_2CH_2$), 33.8 (t, CCH_2), 42.3 (d, $=CHCHCH_3$), 48.9 (d, $=CHCHCH_2$), 60.8 (t, OCH_2), 61.0 (t, OCH_2), 64.4 (s, CCO_2), 128.6 (d, $CH_2CHCH=CH$), 136.2 (d, $CH_2CHCH=CH$), 170.8 (s, CO_2), 172.3 (s, CO_2). **Detectable Res-**

onances of the Minor Diastereomers of 3b: ^{1}H NMR (400 MHz): δ = 0.77 (d, *J* = 6.6 Hz, 6 H, CHC*H*$_3$), 1.16 (t, *J* = 7.1 Hz, 6 H, OCH$_2$C*H*$_3$), 1.21 (t, *J* = 7.2 Hz, 6 H, OCH$_2$C*H*$_3$), 4.03 (q, *J* = 7.1 Hz, 2 H, OCH$_2$). ^{13}C NMR (100 MHz): δ = 16.7 (q, =CHCH*C*H$_3$), 16.9 (q, =CHCH*C*H$_3$), 17.1 (q, =CHCH*C*H$_3$), 18.0 (q, =CHCH*C*H$_3$), 18.2 (q, =CHCH*C*H$_3$), 18.7 (q, =CHCH*C*H$_3$), 22.9 (t), 23.0 (t), 30.0 (t), 31.5 (t), 31.6 (t), 31.7 (t), 31.8 (t), 33.9 (t), 34.0 (t), 41.3 (d), 41.7 (d), 42.25 (d), 42.29 (d), 48.8 (d, =CH*C*HCH$_2$), 49.0 (d, =CH*C*HCH$_2$), 60.5 (t, OCH$_2$), 60.8 (t, OCH$_2$), 61.0 (t, OCH$_2$), 64.1 (s, *C*CO$_2$), 64.2 (s, *C*CO$_2$), 128.4 (d, CH$_2$CH*C*H=CH), 128.8 (d, CH$_2$CH*C*H=CH), 128.9 (d, CH$_2$CH*C*H=CH), 135.1 (d, CH$_2$CHCH=*C*H), 135.4 (d, CH$_2$CHCH=*C*H), 135.5 (d, CH$_2$CHCH=*C*H), 136.17 (d, CH$_2$CHCH=*C*H), 136.27 (d, CH$_2$CHCH=*C*H), 136.32 (d, CH$_2$CHCH=*C*H), 171.0 (s, CO$_2$), 172.3 (s, CO$_2$). MS: *m*/*z* (%) = 534 (0.7) [M$^+$], 489 (3), 267 (100) [M$^+$/2], 193 (85), 192 (40), 165 (38), 164 (30), 140 (28), 119 (42), 95 (34). $C_{30}H_{46}O_8$ (534.7): calcd. C 67.39, H 8.67; found C 67.32, H 8.86.

Diethyl 2-(Buta-1,3-dien-1-yl)cyclopentane-1,1-dicarboxylate (5): Flash chromatography (50:1) gave 11 mg (4%) of **5** [R_f (10:1) = 0.37] as a colorless oil. ^{1}H NMR (200 MHz): δ = 1.15 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.50−2.10 (m, 5 H, CHC*H*$_2$C*H*$_2$C*H*$_2$), 2.44 (m, 1 H, CCH$_2$), 3.22 (q, *J* = 7.9 Hz, 1 H, =CHC*H*CH$_2$), 4.00−4.28 (m, 4 H, OCH$_2$), 4.95 (dd, *J* = 9.9, 2.0 Hz, 1 H, =CH$_2$), 5.07 (dd, *J* = 15.4, 2.0 Hz, 1 H, =CH$_2$), 5.62 (dd, *J* = 14.8, 8.3 Hz, 1 H, =C*H*CH), 6.06 (dd, *J* = 15.2, 10.4 Hz, 1 H, =C*H*CH), 6.23 (dt, *J* = 16.2, 10.1 Hz, 1 H, C*H*=CH$_2$). Detectable resonances: ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH$_2$*C*H$_3$), 14.1 (q, OCH$_2$*C*H$_3$), 23.2 (t, CHCH$_2$*C*H$_2$), 31.2 (t, CH*C*H$_2$CH$_2$), 33.9 (t, C*C*H$_2$), 48.8 (d, =CH*C*HCH$_2$), 61.0 (t, OCH$_2$), 61.2 (t, OCH$_2$), 116.0 (t, =CH$_2$), 132.0 (d, =CH), 133.6 (d, =CH), 136.9 (d, =CH).

1,6-Bis[1,1-bis(ethoxycarbonyl)cyclopent-2-yl]-3,3,4,4-tetramethyl-1,5-hexadiene (3c): Flash chromatography (50:1) gave 20 mg (7%) of a strongly predominating diastereomer (> 5:1) of **3c** [R_f (10:1) = 0.26] as a colorless oil. IR (film): $\tilde{\nu}$ = 2979 cm^{-1}, 1729, 1261, 1178. ^{1}H NMR (200 MHz): δ = 0.80 (s, 12 H, =CHCC*H*$_3$), 1.15 (t, *J* = 7.1 Hz, 6 H, OCH$_2$C*H*$_3$), 1.17 (t, *J* = 7.1 Hz, 6 H, OCH$_2$C*H*$_3$), 1.43−2.07 (m, 10 H), 2.38 (m, 2 H), 3.16 (m, 2 H, =CHC*H*CH$_2$), 3.91 (dq, *J* = 10.1, 7.1 Hz, 2 H, OCH$_2$), 4.09 (m, 4 H, OCH$_2$), 4.15 (dq, *J* = 10.7, 7.1 Hz, 2 H, OCH$_2$), 5.17 (dd, *J* = 14.7, 8.3 Hz, 2 H, =C*H*CH), 5.53 (d, *J* = 15.7 Hz, 2 H, =C*H*CCH$_3$). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH$_2$*C*H$_3$), 22.8 (q, =CHC*C*H$_3$), 23.0 (t), 23.1 (q, =CHC*C*H$_3$), 23.2 (q, =CHC*C*H$_3$), 31.9 (t), 34.0 (t), 40.6 (s, =CH*C*CH$_3$), 49.3 (d, =CH*C*HCH$_2$), 60.8 (t, OCH$_2$), 61.0 (t, OCH$_2$), 64.3 (s, *C*CO$_2$), 126.4 (d, =CH), 139.4 (d, =CH), 171.1 (s, CO$_2$), 172.3 (s, CO$_2$). **Detected Resonances of Minor Diastereomer:** ^{1}H NMR (200 MHz): δ = 0.85 (s, 6 H, =CHCC*H*$_3$), 5.25 (m, 2 H, =C*H*CH), 5.81 (d, *J* = 16.6 Hz, 2 H, =C*H*CCH$_3$). MS (NH$_3$, CI, pos.): *m*/*z* (%) = 580 (89) [M$^+$ + NH$_4$], 281 (8) [M$^+$/2], 133 (100).

Diethyl 2-[(1*E*)-3-Methylbuta-1,3-dien-1-yl]cyclopentane-1,1-dicarboxylate (6), Diethyl 2-(3-Methylbut-2-en-1-ylidene)cyclopentane-1,1-dicarboxylate (7): Flash chromatography (50:1) gave a partly separable mixture of 138 mg (49%) of **6** and 11 mg (4%) of **7** [R_f (10:1) = 0.35] as a colorless oil. IR (film): $\tilde{\nu}$ = 3082 cm^{-1}, 2980, 1729, 1261, 1205, 1101. UV: λ_{max} (lg ε) = 232 nm (4.40). **6:** ^{1}H NMR (200 MHz): δ = 1.14 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.20 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.54 (m, 2 H), 1.54 (t, *J* = 0.9 Hz, 3 H, =CHCC*H*$_3$), 1.88 (m, 2 H), 2.05 (m, 1 H, CC*H*$_2$CH$_2$), 2.45 (m, 1 H, CC*H*$_2$CH$_2$), 3.27 (q, *J* = 7.6 Hz, 1 H, =CHC*H*CH$_2$), 3.96 (dq, *J* = 10.8, 7.1 Hz, 1 H, OCH$_2$), 4.07 (dq, *J* = 10.8, 7.1 Hz, 1 H, OCH$_2$), 4.11 (dq, *J* = 10.9, 7.1 Hz, 1 H, OCH$_2$), 4.20 (dq, *J* = 10.8, 7.1 Hz, 1 H, OCH$_2$), 4.85 (s, 2 H, =CH$_2$), 5.55 (dd, *J* = 15.7, 8.3 Hz, 1 H, =C*H*CH), 6.15 (dd, *J* = 15.7, 0.4 Hz, 1 H, =C*H*CCH$_3$). ^{13}C NMR (50 MHz): δ = 13.98 (q, OCH$_2$*C*H$_3$), 14.01 (q, OCH$_2$*C*H$_3$), 18.5 (q, =CHC*C*H$_3$), 23.2 (t, CHCH$_2$*C*H$_2$), 31.4 (t, CH*C*H$_2$CH$_2$), 34.0 (t, C*C*H$_2$), 48.9 (d, =CH*C*HCH$_2$), 60.9 (t, OCH$_2$), 61.1 (t, OCH$_2$), 64.1 (s, *C*CO$_2$), 115.4 (t, =CH$_2$), 129.3 (d, =CH), 133.9 (d, =CH), 141.7 (s, =*C*CH$_3$), 170.8 (s, CO$_2$), 172.1 (s, CO$_2$). MS: *m*/*z* (%) = 280 (14) [M$^+$], 206 (16), 133 (100). **7:** ^{1}H NMR (200 MHz): δ = 1.19 (t, *J* = 7.1 Hz, 6 H, OCH$_2$C*H*$_3$), 1.46−2.10 (m, 4 H), 1.69 (s, 3 H, =CCH$_3$), 1.74 (s, 3 H, =CCH$_3$), 2.24 (t, *J* = 6.9 Hz, 2 H), 3.89−4.25 (m, 4 H, OCH$_2$), 5.83 (d, *J* = 11.4 Hz, 1 H, =CH), 6.43 (d, *J* = 11.4 Hz, 1 H, =CH). ^{13}C NMR (50 MHz): δ = 14.00 (q, OCH$_2$*C*H$_3$), 18.3 (q, =CH*C*H$_3$), 24.0 (t, =CCH$_2$*C*H$_2$), 26.2 (q, =CH*C*H$_3$), 29.9 (t, =C*C*H$_2$CH$_2$), 36.0 (t, *C*H$_2$CCO$_2$), 61.3 (t, OCH$_2$), 64.2 (s, *C*CO$_2$), 122.5 (d, =CH), 123.0 (d, =CH), 136.1 (s, =C), 138.0 (s, =C), 171.1 (s, CO$_2$). HRMS: $C_{16}H_{24}O_4$: calcd. 280.1675; found 280.1667 ± 2 ppm. $C_{16}H_{24}O_4$ (280.4): calcd. C 68.55, H 8.63; found C 68.33, H 8.65.

Diethyl 2-[(1*E*)-3-Chloroprop-1-en-1-yl]cyclopentane-1,1-dicarboxylate (8): At −70 °C under N$_2$, malonate **1a** (300 mg, 1.18 mmol) was added to a solution of LDA [1.53 mmol, 1.3 equiv., prepared from 0.22 mL diisopropylamine and 0.96 mL *n*BuLi (1.6 M in *n*-hexane)] in dry DME (24 mL) and the resulting solution was stirred between −70 and 0 °C for 30 min. Solid CuCl$_2$ (397 mg, 2.95 mmol) was added in portions at 0 °C until a brown-green color persisted in the reaction mixture and a brown suspension of excess CuCl$_2$ had been observed for 30 min. The mixture was stirred at 0 °C for 90 min. The mixture was quenched with four drops of a saturated NH$_4$Cl solution and warmed to room temperature. The reaction mixture was diluted with 25 mL of ether and filtered through a pad of silica gel, and the solvent was evaporated. Crude flash chromatography of the residue (50:1 gradient to 2:1) gave 200 mg (66%) of an inseparable mixture of **3a/4a** (7.3:1) and 60 mg (18%) of **8** [R_f (10:1) = 0.27] as a colorless oil. IR (film): $\tilde{\nu}$ = 2982 cm^{-1} (w), 1728 (s), 1264 (m), 1184 (m), 1100 (m). UV: λ_{max} (lg ε) = 206 nm (3.84), 226 (3.02). ^{1}H NMR (400 MHz): δ = 1.18 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH$_2$C*H*$_3$), 1.53−1.67 (m, 2 H, CHC*H*$_2$C*H*$_2$), 1.82 (m, 1 H, CHCH$_2$C*H*$_2$), 1.92 (m, 1 H, CHC*H*$_2$CH$_2$), 2.04 (m, 1 H, CC*H*$_2$CH$_2$), 2.40 (dt, *J* = 13.6, 8.0 Hz, 1 H, CC*H*$_2$CH$_2$), 3.20 (q, *J* = 7.7 Hz, 1 H, =CHC*H*), 3.96 (d, *J* = 6.8 Hz, 2 H, CH$_2$Cl), 4.06 (dq, *J* = 10.8, 7.1 Hz, 1 H, OCH$_2$), 4.12 (dq, *J* = 10.6, 7.1 Hz, 1 H, OCH$_2$), 4.16 (dq, *J* = 10.6, 7.1 Hz, 1 H, OCH$_2$), 4.22 (dq, *J* = 10.7, 7.0 Hz, 1 H, OCH$_2$), 5.63 (dt, *J* = 15.2, 6.9 Hz, 1 H, =C*H*CH$_2$Cl), 5.75 (dd, *J* = 15.2, 7.8 Hz, 1 H, =C*H*CH). ^{13}C NMR (100 MHz): δ = 13.97 (q, OCH$_2$*C*H$_3$), 14.04 (q, OCH$_2$*C*H$_3$), 23.0 (t, CCH$_2$*C*H$_2$), 30.7 (t, CH*C*H$_2$CH$_2$), 33.8 (t, C*C*H$_2$), 44.9 (t, CH$_2$Cl), 48.2 (d, =CH*C*H), 61.1 (t, OCH$_2$), 61.2 (t, OCH$_2$), 64.0 (s, *C*CO$_2$), 127.1 (d, =*C*HCH$_2$Cl), 134.6 (d, =*C*HCH), 170.6 (s, CO$_2$), 171.9 (s, CO$_2$). MS: *m*/*z* (%) = 253 (100) [M$^+$ − Cl], 197 (16), 179 (63) [M$^+$ − EtOH, − CO], 165 (27), 105 (30). MS (NH$_3$, CI, pos.): *m*/*z* (%) = 308/306 (28/85) [M$^+$ + NH$_4$], 291/289 (32/100) [M$^+$ + H], 253 (28) [M$^+$ − Cl]. HRMS: $C_{14}H_{21}ClO_4$ [M$^+$ − Cl]: calcd. 253.1498; found 253.1440 ppm.

Oxidative Cyclization of 1a−c in the Presence of TEMPO (10) (General Procedure): At −78 °C under N$_2$, **1a−c** (1.5 mmol) was added to a solution of LDA [1.95 mmol, prepared from 0.28 mL diisopropylamine and 1.22 mL *n*BuLi (1.6 M in *n*-hexane)] in 30 mL of dry DME. The solution was stirred between −78 and −60 °C for 30 min. At 0 °C, **10** (328 mg, 2.1 mmol) was added and the red solution was stirred for 5 min. Solid **2** was added in portions at 0

°C until a blue-green color persisted in the reaction mixture for 30 min. The mixture was stirred at 0 °C for 90 min, quenched with four drops of a saturated NH_4Cl solution, and allowed to warm to room temperature. The reaction mixture was diluted with 20 mL of ether and filtered through a pad of silica gel. The solvent was evaporated and the inhomogeneous residue was preadsorbed on silica gel. Crude flash chromatography (50:1 gradient to 1:1) gave > 90% ferrocene, followed by products **11**, **12**, **13**, and **14**. The individual compounds were further purified by flash chromatography as indicated in the characterization section.

Diethyl 2-[(1*E*)-3-(2,2,6,6-Tetramethylpiperidin-1-yloxy)prop-1-en-1-yl]cyclopentane-1,1-dicarboxylate (11a) and Diethyl 2-[1-(2,2,6,6-Tetramethylpiperidin-1-yloxy)allyl]cyclopentane-1,1-dicarboxylate (12a): Flash chromatography (50:1) gave a partially separable mixture of 331 mg (54%) of **11a** and 203 mg (33%) of **12a** (1.7:1 diastereomeric mixture) [R_f (5:1) = 0.46] as colorless oils. IR (film): $\tilde{\nu}$ = 2977 cm^{-1}, 1732, 1262, 1177, 1029. **11a:** ^1H NMR (200 MHz): δ = 1.04 (s, 6 H, $NCCH_3$), 1.10 (s, 6 H, $NCCH_3$), 1.17 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.31−1.71 (m, 8 H), 1.73−2.09 (m, 3 H), 2.42 (dt, *J* = 13.6, 8.2 Hz, 1 H, $CHCCH_2$), 3.22 (m, 1 H, =CHCH), 4.01−4.24 (m, 6 H, OCH_2, CH_2ON), 5.58 (m, 2 H, CH=CH). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 14.1 (q, OCH_2CH_3), 17.1 (t, $NCCH_2CH_2$), 20.1 (q, $NCCH_3$), 23.2 (t, $CHCH_2CH_2$), 31.1 (t, $CHCH_2CH_2$), 32.9 (q, $NCCH_3$), 33.8 (t, CH_2CCO), 39.6 (t, $NCCH_2$), 48.5 (d, =CHCH), 59.6 (s, ONC), 60.9 (t, OCH_2), 61.1 (t, OCH_2), 64.2 (s, CCO_2), 77.9 (t, CH_2ON), 127.1 (d, =CH), 131.9 (d, =CH), 170.7 (s, CO_2), 172.1 (s, CO_2). **Major Diastereomer 12a:** ^1H NMR (200 MHz): δ = 1.00 (s, 3 H, $NCCH_3$), 1.04 (br. s, 3 H, $NCCH_3$), 1.09 (s, 6 H, $NCCH_3$), 1.20 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.20−1.93 (m, 9 H), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 2.06 (m, 2 H), 2.40 (m, 1 H, $CHCCH_2$), 2.77 (dt, *J* = 7.8, 6.3 Hz, 1 H, =CHCHCH), 4.13 (m, 4 H, OCH_2), 4.47 (m, 1 H, CHON), 5.05 (m, 2 H, $=CH_2$), 5.91 (ddd, *J* = 17.0, 10.2, 9.4 Hz, 1 H, =CH). ^{13}C NMR (50 MHz): δ = 13.90 (q, OCH_2CH_3), 13.94 (q, OCH_2CH_3), 17.2 (t, $NCCH_2CH_2$), 20.6 (q, $NCCH_3$), 20.7 (q, $NCCH_3$), 22.4 (t, $CHCH_2CH_2$), 27.2 (t, $CHCH_2CH_2$), 34.0 (br. q, $NCCH_3$), 34.6 (br. q, $NCCH_3$), 35.9 (t, $CHCCH_2$), 40.2 (br. t, $NCCH_2$), 50.8 (d, CHCHON), 58.9 (br. s, ONC), 60.8 (t, OCH_2), 61.1 (t, OCH_2), 63.2 (s, CCO_2), 84.4 (d, CHON), 117.4 (t, $=CH_2$), 139.6 (d, =CH), 170.7 (s, CO_2), 172.5 (s, CO_2). **Minor Diastereomer 12a:** ^1H NMR (200 MHz): δ = 1.00 (s, 3 H, $NCCH_3$), 1.04−1.09 (2 br. s, 9 H, $NCCH_3$), 1.20 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.20−1.93 (m, 9 H), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 2.06 (m, 2 H), 2.40 (m, 1 H, $CHCCH_2$), 2.94 (dt, *J* = 8.0, 6.6 Hz, 1 H, =CHCHCH), 4.13 (m, 4 H, OCH_2), 4.47 (m, 1 H, CHON), 5.05 (m, 2 H, $=CH_2$), 5.76 (ddd, *J* = 17.0, 9.9, 9.6 Hz, 1 H, =CH). ^{13}C NMR (50 MHz): δ = 13.90 (q, OCH_2CH_3), 13.94 (q, OCH_2CH_3), 17.3 (t, $NCCH_2CH_2$), 20.6 (q, $NCCH_3$), 20.7 (q, $NCCH_3$), 22.3 (t, $CHCH_2CH_2$), 27.2 (t, $CHCH_2CH_2$), 34.0 (q, $NCCH_3$), 34.6 (q, $NCCH_3$), 36.4 (t, $CHCCH_2$), 40.5 (t, $NCCH_2$), 49.4 (d, $CH_2CHCHON$), 58.9 (s, ONC), 60.7 (t, OCH_2), 61.1 (t, OCH_2), 62.1 (s, CCO_2), 84.8 (d, CHON), 118.4 (t, $=CH_2$), 138.0 (d, =CH), 170.6 (s, CO_2), 172.4 (s, CO_2). MS: *m*/*z* (%) = 364 (4), 253 (59), 179 (100), 156 (18), 105 (28). $C_{23}H_{39}NO_5$ (409.6): calcd. C 67.45, H 9.60, N 3.42; found C 67.75, H 9.74, N 3.02.

Diethyl 2-(Hepta-4,6-dien-1-yl)-2-(2,2,6,6-tetramethylpiperidin-1-yloxy)malonate (13a): Yield: 25 mg (4%). ^1H NMR (200 MHz): δ = 1.05 (s, 6 H, $NCCH_3$), 1.13 (s, 6 H, $NCCH_3$), 1.22 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.17−1.47 (m, 8 H), 2.09 (m, 4 H), 4.15 (q, *J* = 7.1 Hz, 4 H, OCH_2), 4.88 (d, *J* = 9.6 Hz, 1 H, $=CH_2$), 5.01 (d, *J* = 16.6 Hz, 1 H, $=CH_2$), 5.61 (dt, *J* = 15.1, 7.7 Hz, 1 H, $CHCH_2$), 5.98 (dd, *J* = 15.1, 10.6 Hz, 1 H, CH=CHCH), 6.24 (dt, *J* = 16.7, 10.1 Hz, 1 H, $CH=CH_2$).

Diethyl 2-[(1*E*)-3-(2,2,6,6-Tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentane-1,1-dicarboxylate (11b) and Diethyl 2-[(1*E*)-1-(2,2,6,6-Tetramethylpiperidin-1-yloxy)but-2-enyl]cyclopentane-1,1-dicarboxylate (12b): Flash chromatography (50:1) gave an inseparable diastereomeric mixture of 432 mg (68%) of **11b** (1.7:1) and 89 mg (14%) of **12b** (2:1) [R_f (15:1) = 0.27] as a colorless oil. IR (film): $\tilde{\nu}$ = 2976 cm^{-1}, 1731, 1260. **Major Diastereomer 11b:** ^1H NMR (400 MHz): δ = 1.03 (br. s, 9 H, $NCCH_3$), 1.10 (br. s, 3 H, $NCCH_3$), 1.13 (d, *J* = 6.5 Hz, 3 H, $CHCH_3$), 1.18 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3), 1.20 (t, *J* = 7.2 Hz, 3 H, OCH_2CH_3), 1.26 (m, 1 H), 1.38 (m, 4 H), 1.51−1.67 (m, 3 H), 1.75−2.07 (m, 3 H), 2.39 (q, *J* = 8.2 Hz, 1 H, $CHCCH_2$), 3.22 (m, 1 H, $=CHCHCH_2$), 3.96−4.36 (m, 5 H, OCH_2, CHON), 5.37 (dd, *J* = 15.4, 8.4 Hz, 1 H, $=CHCHCH_2$), 5.50 (m, 1 H, =CHCHON). ^{13}C NMR (100 MHz): δ = 13.89 (q, OCH_2CH_3), 13.94 (q, OCH_2CH_3), 17.1 (t, $NCCH_2CH_2$), 20.0 (br. q, $NCCH_3$), 20.3 (br. q, $NCCH_3$), 20.8 (q, $CHCH_3$), 22.8 (t, $CHCH_2CH_2$), 31.2 (t, $CHCH_2CH_2$), 33.5 (t, $CHCCH_2$), 34.1 (br. q, $NCCH_3$), 40.0 (t, $NCCH_2$), 48.5 (d, =CHCHCH), 59.0 (br. s, ONC), 60.7 (t, OCH_2), 60.9 (t, OCH_2), 64.2 (s, CCO_2), 80.5 (d, CHON), 128.6 (d, $=CHCHCH_2$), 135.7 (d, =CHCHO), 170.6 (s, CO_2), 172.1 (s, CO_2). **Minor Diastereomer 11b:** ^1H NMR (400 MHz): δ = 1.03 (br. s, 9 H, $NCCH_3$), 1.10 (br. s, 3 H, $NCCH_3$), 1.14 (d, *J* = 6.5 Hz, 3 H, $CHCH_3$), 1.19 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.21 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.26 (m, 1 H), 1.38 (m, 4 H), 1.51−1.67 (m, 3 H), 1.75−2.07 (m, 3 H), 2.43 (q, *J* = 8.3 Hz, 1 H, $CHCCH_2$), 3.22 (m, 1 H, $=CHCHCH_2$), 3.96−4.36 (m, 5 H, OCH_2, CHON), 5.50 (m, 2 H, CH=CH). ^{13}C NMR (100 MHz): δ = 13.9 (q, OCH_2CH_3), 14.0 (q, OCH_2CH_3), 17.1 (t, $NCCH_2CH_2$), 20.0 (br. q, $NCCH_3$), 20.3 (br. q, $NCCH_3$), 20.7 (q, $CHCH_3$), 22.8 (t, $CHCH_2CH_2$), 30.6 (t, $CHCH_2CH_2$), 33.9 (t, $CHCCH_2$), 34.6 (br. q, $NCCH_3$), 40.5 (t, $NCCH_2$), 48.9 (d, $=CHCHCH_2$), 59.9 (br. s, ONC), 60.7 (t, OCH_2), 60.9 (t, OCH_2), 63.8 (s, CCO_2), 80.1 (d, CHON), 128.4 (d, $=CHCHCH_2$), 134.8 (d, =CHCHON), 170.8 (s, CO_2), 172.1 (s, CO_2). MS: *m*/*z* (%) = 378 (7), 267 (96), 193 (100), 156 (15), 119 (36). **Major Diastereomer 12b:** ^1H NMR (200 MHz): δ = 0.98 (br. s, 6 H, $NCCH_3$), 1.09 (br. s, 6 H, $NCCH_3$), 1.20 (t, *J* = 7.1 Hz, 6 H, OCH_2CH_3), 1.26−2.07 (m, 9 H), 1.62 (d, *J* = 4.7 Hz, 3 H, $CHCH_3$), 2.08 (m, 2 H), 2.43 (m, 1 H), 2.73 (m, 1 H), 4.10 (m, 4 H, OCH_2), 4.35 (m, 1 H, CHON), 5.42 (m, 2 H, CH=CHCHON). ^{13}C NMR (50 MHz): δ = 13.8 (q, OCH_2CH_3), 16.8 (t, $NCCH_2CH_2$), 20.1 (br. q, $NCCH_3$), 20.3 (br. q, $NCCH_3$), 20.6 (q, $=CHCH_3$), 22.4 (t, $CHCH_2CH_2$), 27.8 (t, $CHCH_2CH_2$), 34.6 (br. q, $NCCH_3$), 35.6 (t, $CHCCH_2$), 39.4 (t, $NCCH_2$), 48.7 (d, =CHCHCH), 59.4 (br. s, ONC), 59.9 (br. s, ONC), 60.57 (t, OCH_2), 60.64 (t, OCH_2), 62.2 (s, CCO_2), 83.7 (d, CHON), 129.5 (d, =CH), 130.5 (d, =CH), 170.8 (s, CO_2), 172.5 (s, CO_2). Resonances of the second diastereomer were detected. A confidential assignment was, however, not possible, due to strong signal overlap. The second diastereomer was, however, confirmed by reductive N−O bond cleavage/lactonization to give the minor diastereomer of compound **20b**. $C_{24}H_{41}NO_5$ (423.6): calcd. C 68.05, H 9.76, N 3.31; found C 67.91, H 9.93, N 3.14.

Diethyl 2-[(1*E*)-3-Methyl-3-(2,2,6,6-tetramethylpiperidin-1-yloxy)-but-1-en-1-yl]cyclopentane-1,1-dicarboxylate (11c): Flash chromatography (50:1) gave 407 mg (62%) of **11c** [R_f (15:1) = 0.39] as a colorless oil. IR (film): $\tilde{\nu}$ = 2934 cm^{-1}, 1732, 1260. ^1H NMR (200 MHz): δ = 0.99 (s, 9 H, $NCCH_3$), 1.15 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.17 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.21 (s, 3 H, $=CHCCH_3$), 1.23 (s, 3 H, $=CHCCH_3$), 1.38 (br. s, 3 H, $NCCH_3$),

1.44−2.18 (m, 11 H), 2.38 (m, 1 H), 3.16 (m, 1 H), 3.92 (dq, J = 10.8, 7.1 Hz, 1 H, OCH_2), 4.11 (m, 3 H, OCH_2), 5.27 (dd, J = 15.9, 8.2 Hz, 1 H, =C*H*CH), 5.82 (d, J = 16.0 Hz, 1 H, =CHCON). ^{13}C NMR (50 MHz): δ = 14.1 (q, OCH_2CH_3), 17.1 (t, $NCCH_2CH_2$), 20.4 (q, $NCCH_3$), 23.0 (t, $CHCH_2CH_2$), 26.7 (q, =CHCCH_3), 27.8 (q, =CHCCH_3), 31.4 (t, CHCH_2CH_2), 33.9 (t, CHCCH_2), 34.4 (q, $NCCH_3$), 34.5 (q, $NCCH_3$), 40.8 (t, $NCCH_2$), 48.8 (d, =CH$CHCH_2$), 59.1 (s, ONC), 59.2 (s, ONC), 60.8 (t, OCH_2), 61.0 (t, OCH_2), 64.1 (s, CCO_2), 78.7 (s, CON), 124.6 (d, =CH), 141.3 (d, =CH), 170.8 (s, CO_2), 172.2 (s, CO_2). MS (NH_3, CI, pos.): *m*/*z* (%) = 438 (11) [M^+ + H], 298 (80), 281 (100), 158 (26), 142 (51). $C_{25}H_{43}NO_5$ (437.6): calcd. C 68.62, H 9.90, N 3.20; found C 68.29, H 10.29, N 2.91.

Diethyl 2-(3-Hydroperoxy-3-methylbut-1-en-1-yl)cyclopentane-1,1-dicarboxylate (14): Flash chromatography (15:1) gave 61 mg (13%) of **14** as a colorless oil. IR (film): $\tilde{\nu}$ = 3435 cm^{-1} (w), 2980 (m), 1729 (s), 1263 (s), 1217 (m), 1181 (m). ^{1}H NMR (200 MHz): δ = 1.20 (t, J = 7.1 Hz, 3 H, OCH_2CH_3), 1.22 (t, J = 7.1 Hz, 3 H, OCH_2CH_3), 1.27 (s, 6 H, CCH_3), 1.20−1.46 (m, 1 H), 1.64 (m, 2 H), 1.91 (m, 1 H), 2.11 (m, 1 H), 2.40 (m, 1 H), 3.19 (m, 1 H, C*H*CH_2), 3.97−4.24 (m, 4 H, OCH_2), 5.54 (d, J = 15.9 Hz, 1 H, =C*H*COOH), 5.69 (dd, J = 15.9, 7.6 Hz, 1 H, =C*H*CH). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 23.0 (t, $CHCH_2CH_2$), 24.3 (q, CCH_3), 24.6 (q, CCH_3), 30.7 (t, $CHCH_2$), 33.8 (t, CCH_2), 48.8 (d, =CH$CHCH_2$), 61.3 (t, OCH_2), 64.7 (s, CCO_2), 81.7 (s, =CH$COOH$), 131.3 (d, =$CHCH$), 134.7 (d, =$CHCOOH$), 171.6 (s, CO_2), 172.2 (s, CO_2). MS: *m*/*z* (%) = 297 (3) [M^+ − OH], 296 (2) [M^+ − H_2O], 281 (59) [M^+ − OOH], 235 (20), [M^+ − OOH, − EtOH], 207 (100) [M^+ − OOH, − EtOH, − CO], 161 (26) [M^+ − OOH, − 2 EtOH, − CO], 133 (80) [M^+ − OOH, − 2 EtOH, − 2 CO], 109 (35), 69 (41), 55 (29), 43 (24). MS (NH_3, CI, pos.): *m*/*z* (%) = 332 (2) [M^+ + NH_4], 316 (24) [M^+ − O + NH_4], 298 (14), 297 (12) [M^+ − OH], 286 (13), 281 (59) [M^+ − OOH], 187 (35), 170 (58), 158 (36), 142 (47).

Deprotection of 11b, 11c, and 12b: Zn dust (1.28 g, 19.5 mmol) was added at 50 °C to a solution either of a 4.9:1 mixture of **11b/12b** (635 mg, 1.5 mmol) or of **11c** (656 mg, 1.5 mmol) in AcOH/H_2O/THF (13 mL/4 mL/4 mL). The mixture was stirred at 50 °C until the starting materials had been consumed (TLC). After cooling to room temperature, the mixture was diluted with ether and filtered through a pad of silica gel. The filtrate was neutralized with saturated $NaHCO_3$ solution and washed twice with water. The solvent was removed in vacuum, and the crude products **18b**, **18c**, minor diethyl 2-[(4*E*)-7-oxooct-4-en-1-yl]malonate **19b**, and lactone **20b** were purified by flash chromatography (*n*-hexane/ethyl acetate, 50:1 gradient to 15:1).

Diethyl 2-(3-Hydroxybut-1-en-1-yl)cyclopentane-1,1-dicarboxylate (18b): Flash chromatography (15:1) gave 286 mg (67%) of a ca. 2:1 diastereomeric mixture of **18b** [R_f (3.5:1) = 0.18] as a colorless oil. IR (film): $\tilde{\nu}$ = 3436 cm^{-1}, 2978, 1727, 1264, 1179. ^{1}H NMR (400 MHz): δ = 1.08 (d, J = 6.4 Hz, 3 H, $CHCH_3$), 1.09 (d, J = 7.2 Hz, 3 H*, $CHCH_3$*), 1.11 (t, J = 7.2 Hz, 6 H, OCH_2CH_3), 1.13 (t, J = 7.2 Hz, 6 H*, OCH_2CH_3*), 1.50 (m, 2 H, 2 H*, $CHCH_2CH_2$, $CHCH_2CH_2$*), 1.73 (m, 1 H, 1 H*, CCH_2CH_2, CCH_2CH_2*), 1.87 (m, 1 H, 1 H*, $CHCH_2$, $CHCH_2$*), 1.95 (m, 1 H, 1 H*, CCH_2, CCH_2*), 2.30 (m, 1 H, 1 H*, CCH_2, CCH_2*), 2.73 (s, 1 H, 1 H*, OH, OH*), 3.08 (m, 1 H, 1 H*, =CHC*H*CH_2, =CHC*H*CH_2*), 3.90−4.13 (m, 5 H, 5 H*, OCH_2, =CHC*H*OH, OCH_2*, =CHC*H*OH*), 5.45 (m, 2 H, 2 H*, C*H*=C*H*, C*H*=C*H*). **Major Diastereomer 18b:** ^{13}C NMR (100 MHz): δ = 13.66 (q, OCH_2CH_3), 13.73 (q, OCH_2CH_3), 22.6 (t, $CHCH_2CH_2$), 23.0 (q, $CHCH_3$), 30.8 (t, $CHCH_2$), 33.4 (t, CCH_2), 48.0 (d, =CH$CHCH_2$), 60.6 (t, OCH_2), 60.8 (t, OCH_2), 64.0 (s, CCO_2), 67.9 (d, *C*HOH), 128.7 (d, =$CHCHCH_2$), 135.6 (d, =$CHCHOH$), 170.4 (s, CO_2), 171.7 (s, CO_2). **Minor Diastereomer 18b:** ^{13}C NMR (100 MHz): δ = 13.66 (q, OCH_2CH_3), 13.73 (q, OCH_2CH_3), 22.5 (t, $CHCH_2CH_2$), 22.9 (q, $CHCH_3$), 30.5 (t, $CHCH_2$), 33.3 (t, CCH_2), 47.9 (d, =CH$CHCH_2$), 60.6 (t, OCH_2), 60.8 (t, OCH_2), 64.0 (s, CCO_2), 67.8 (d, =CH$CHOH$), 128.6 (d, =$CHCHCH_2$), 135.5 (d, =$CHCHOH$), 170.5 (s, CO_2), 171.7 (s, CO_2). MS: *m*/*z* (%) = 284 (5) [M^+], 266 (28), 227 (36), 221 (29), 193 (38), 192 (85), 165 (50), 164 (80), 149 (45), 147 (90), 137 (50), 121 (73), 119 (100), 95 (49), 93 (48), 91 (45), 79 (47), 77 (37), 67 (37), 43 (72). HRMS: $C_{15}H_{24}O_5$: calcd. 284.1624; found 284.1617 ± 2 ppm. * Marked resonances belong to minor diastereomer **18b**.

Diethyl 2-[(4*E*)-7-Oxooct-4-en-1-yl]malonate (19b): Flash chromatography (20:1) gave 38 mg (9%) of a 3:1 diastereomeric mixture of **19b** [R_f (5:1) = 0.23] as a colorless oil. IR (film): $\tilde{\nu}$ = 2984 cm^{-1}, 1747, 1732, 1370, 1257, 1156, 1028. **Major Diastereomer:** ^{1}H NMR (400 MHz): δ = 1.23 (t, J = 7.1 Hz, 6 H, OCH_2CH_3), 1.37 (quint, J = 7.7 Hz, 2 H, =$CHCH_2CH_2$), 1.86 (q, J = 7.7 Hz, 2 H, CH_2CHCO_2), 2.03 (m, 2 H, =$CHCH_2CH_2$), 2.11 (s, 3 H, $OCCH_3$), 3.14 (d, J = 5.3 Hz, 2 H, =$CHCH_2CO$), 3.27 (t, J = 7.5 Hz, 1 H, CH_2CHCO_2), 4.15 (q, J = 7.1 Hz, 2 H, OCH_2), 4.16 (q, J = 7.1 Hz, 2 H, OCH_2), 5.55 (m, 2 H, C*H*=C*H*). ^{13}C NMR (100 MHz): δ = 13.9 (q, OCH_2CH_3), 26.9 (t), 27.0 (t), 28.2 (t), 29.4 (q, $OCCH_3$), 42.3 (t, =$CHCH_2CO$), 51.8 (d, CH_2CHCO_2), 61.23 (t, OCH_2), 121.5 (d, =$CHCH_2CO$), 132.5 (d, =$CHCH_2CH_2$), 169.3 (s, CO_2), 206.5 (s, $OCCH_3$). **Minor Diastereomer:** ^{1}H NMR (400 MHz): δ = 1.23 (t, J = 7.1 Hz, 6 H, OCH_2CH_3), 1.37 (m, 2 H, =$CHCH_2CH_2$), 1.85 (q, J = 7.8 Hz, 2 H, CH_2CHCO_2), 2.03 (m, 2 H, =$CHCH_2CH_2$), 2.11 (s, 3 H, $OCCH_3$), 3.07 (d, J = 5.3 Hz, 2 H, =$CHCH_2CO$), 3.27 (m, 1 H, CH_2CHCO), 4.15 (m, 4 H, OCH_2), 5.50 (m, 2 H, C*H*=C*H*). ^{13}C NMR (100 MHz): δ = 13.9 (q, OCH_2CH_3), 26.8 (t), 28.1 (t), 29.3 (q, $OCCH_3$), 32.0 (t), 47.5 (t, =$CHCH_2CO$), 51.8 (d, CH_2CHCO_2), 61.21 (t, OCH_2), 122.5 (d, =$CHCH_2CO$), 134.1 (d, =$CHCH_2CH_2$), 169.3 (s, CO_2), 207.2 (s, $OCCH_3$). MS: *m*/*z* (%) = 284 (5) [M^+], 239 (13), 173 (59), 160 (30), 150 (31), 122 (35), 80 (28), 79 (24), 43 (100). HRMS: $C_{15}H_{24}O_5$: calcd. 284.1624; found 284.1618 ± 2 ppm.

Ethyl 3-Oxo-1-[(1*E*)-prop-1-en-1-yl]tetrahydrocyclopenta[*c*]furan-3a-carboxylate (20b): Flash chromatography gave 57 mg (16%) of a 1.6:1 diastereomeric mixture of **20b** [R_f (5:1) = 0.37] as a colorless oil. IR (film): $\tilde{\nu}$ = 2967 cm^{-1}, 1778, 1772, 1740, 1450, 1341, 1253, 1206, 1137. **Major Diastereomer 20b:** ^{1}H NMR (200 MHz): δ = 1.26 (t, J = 7.1 Hz, 3 H, OCH_2CH_3), 1.53−2.09 (m, 4 H), 1.70 (d, J = 6.1 Hz, 3 H, =$CHCH_3$), 2.12−2.41 (m, 2 H), 2.96 (m, 1 H), 4.20 (q, J = 7.1 Hz, 2 H, OCH_2), 5.09 (t, J = 7.3 Hz, 1 H, CHO), 5.54 (dd, J = 17.9, 7.6 Hz, 1 H, =C*H*CH), 5.79 (dq, J = 17.8, 6.4 Hz, 1 H, =C*H*CH_3). ^{13}C NMR (50 MHz): δ = 14.0 (q, OCH_2CH_3), 17.8 (q, =$CHCH_3$), 25.6 (t), 26.2 (t), 34.1 (t), 50.9 (d, *C*HCH_2), 62.0 (t, OCH_2), 63.5 (s, CCO_2), 81.5 (d, CHO), 125.1 (d, =CH), 131.6 (d, =CH), 170.0 (s, CO_2), 176.0 (s, CO_2). **Minor Diastereomer 20b:** ^{1}H NMR (200 MHz): δ = 1.26 (t, J = 7.1 Hz, 3 H, OCH_2CH_3), 1.53−2.09 (m, 4 H), 1.74 (d, J = 6.4 Hz, 3 H, =$CHCH_3$), 2.12−2.41 (m, 2 H), 2.85 (m, 1 H), 4.18 (q, J = 7.0 Hz, 2 H, OCH_2), 4.44 (dd, J = 7.7, 3.8 Hz, 1 H, CHO), 5.47 (dd, J = 17.9, 7.4 Hz, 1 H, =C*H*CH), 5.85 (dq, J = 17.8, 6.5 Hz, 1 H, =C*H*CH_3). ^{13}C NMR (50 MHz): δ = 13.9 (q, OCH_2CH_3), 17.6 (q, =$CHCH_3$), 28.1 (t), 33.5 (t), 35.6 (t), 51.7 (d, *C*HCH_2), 62.3 (s, CCO_2), 86.3 (d, CHO), 129.2 (d, =CH), 130.3 (d, =CH), 170.4 (s, CO_2), 175.9 (s, CO_2). MS: *m*/*z* (%) = 238 (50) [M^+], 210 (49), 193 (49), 192 (55), 165 (82), 164 (100), 141 (54), 140 (47), 137 (28), 121 (39), 119 (25), 112 (28), 95 (100), 93 (38), 79 (30), 67(50). HRMS:

$C_{13}H_{18}O_4$: calcd. 238.1205; found 238.1201 ± 2 ppm. $C_{13}H_{18}O_4$ (238.3): calcd. C 65.53, H 7.61; found C 65.71, H 7.79.

Diethyl 2-(3-Hydroxy-3-methylbut-1-en-1-yl)cyclopentane-1,1-dicarboxylate (18c): Flash chromatography (15:1) gave 277 mg (62%) of **18c** [R_f (2:1) = 0.33] as a colorless oil. IR (film): $\tilde{\nu}$ = 3519 cm^{-1}, 2977, 1728, 1264, 1212, 1182. ^1H NMR (400 MHz): δ = 1.17 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.18 (t, *J* = 7.1 Hz, 3 H, OCH_2CH_3), 1.21 (s, 6 H, CCH_3), 1.55 (m, 2 H, $CHCH_2CH_2$), 1.67 (br. s, 1 H, OH), 1.75 (m, 1 H, $CHCH_2CH_2$), 1.89 (m, 1 H, $CHCH_2$), 2.01 (m, 1 H, CCH_2), 2.39 (m, 1 H, CCH_2), 3.15 (q, *J* = 7.5 Hz, 1 H, $CHCH_2$), 3.96 (dq, *J* = 10.8, 7.1 Hz, 1 H, OCH_2), 4.09 (dq, *J* = 10.6, 7.1 Hz, 1 H, OCH_2), 4.12 (m, 1 H, OCH_2), 4.16 (dq, *J* = 10.7, 7.1 Hz, 1 H, OCH_2), 5.53 (dd, *J* = 15.6, 7.8 Hz, 1 H, =CHCH), 5.62 (d, *J* = 15.7 Hz, 1 H, =CHCOH). ^{13}C NMR (100 MHz): δ = 13.98 (q, OCH_2CH_3), 14.04 (q, OCH_2CH_3), 22.9 (t, $CHCH_2CH_2$), 29.6 (q, CCH_3), 31.1 (t, $CHCH_2$), 33.7 (t, CCH_2), 48.2 (d, =CHCHCH$_2$), 60.9 (t, OCH_2), 61.1 (t, OCH_2), 64.3 (s, CCO_2), 70.4 (s, COH), 126.1 (d, =CHCH), 139.4 (d, =CHCOH), 170.7 (s, CO_2), 172.1 (s, CO_2). MS: *m*/*z* (%) = 298 (1) [M^+], 280 (80), 237 (27), 235 (25), 209 (30), 207 (56), 206 (80), 191 (28), 177 (23), 167 (40), 165 (28), 163 (63), 135 (50), 133 (100), 43 (48). $C_{16}H_{26}O_5$ (298.4): calcd. C 64.41, H 8.78; found C 64.22, H 8.99.

Cyclization of *tert*-Butyl (6*Z*,8*E*)- or (6*E*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21, (6*E*,8*E*)-21] (Table 1, Entries 1, 2): At −78 °C under N_2, (6*Z*,8*E*)-**21** or (6*E*,8*E*)-**21** (240 mg, 1.0 mmol) was added to a solution of LDA [3.2 mmol, prepared from 0.45 mL diisopropylamine and 2.00 mL *n*BuLi (1.6 M in *n*-hexane)] in dry THF (21 mL) and the resulting solution was stirred between −20 and −10 °C for 90 min. HMPA (0.56 mL, 3.2 mmol) was added and the mixture was stirred for 30 min. Compound **10** (187 mg, 1.2 mmol) was added, followed by **2** (662 mg, 2.0 mmol) in one portion at −78 °C. The blue mixture was stirred at −78 °C for 1 h. Workup was conducted according to the General Procedure for **11**.

Cyclization of *tert*-Butyl (6*Z*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21] (Table 1, Entry 3): At −78 °C under N_2, (6*Z*,8*E*)-**21** (240 mg, 1.0 mmol) was added to a solution of LDA [2.5 mmol, prepared from 0.35 mL diisopropylamine and 1.56 mL *n*BuLi (1.6 M in *n*-hexane)] in dry THF (15 mL) and the resulting solution was stirred for 90 min between −20 and −10 °C. To this mixture, a solution of $MgBr_2$ (0.2 M, 6.49 mL, 1.3 mmol) in THF was added at −78 °C. After this had stirred between −78 and −70 °C for 45 min, HMPA (0.43 mL, 2.5 mmol) was added. After 5 min, **10** (187 mg, 1.2 mmol) was added, followed by **2** (662 mg, 2.0 mmol) in one portion at −78 °C. The blue mixture was stirred at −78 °C for 1 h. Workup was conducted according to the General Procedure for **11**.

Cyclization of *tert*-Butyl (6*Z*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21] (Table 1, Entry 4): At 0 °C under N_2, MeMgCl (3 M in THF, 0.33 mL, 1.0 mmol) was added to a solution of (6*Z*,8*E*)-**21** (240 mg, 1.0 mmol) in dry THF (21 mL), and the mixture was stirred for 1 h. At −78 °C, LDA (2 M in THF/*n*-hexane, 1.10 mL 2.2 mmol) was added to the solution, which was stirred between −78 and −10 °C for 2 h. At −78 °C, **10** (187 mg, 1.2 mmol) was added, followed by **2** (662 mg, 2.0 mmol) in one portion. The blue mixture was stirred at −78 °C for 1 h. Workup was conducted according to the General Procedure for **11**.

Cyclization of *tert*-Butyl (6*E*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*E*,8*E*)-21] (Table 1, Entry 5): At −78 °C under N_2, MeMgCl (3 M in THF, 0.37 mL, 1.1 mmol) was added to a solution of (6*E*,8*E*)-**21** (240 mg, 1.0 mmol) in dry THF (20 mL), and the mixture was stirred for 5 min. At −78 °C, LDA (2 M in THF/*n*-hexane, 0.75 mL, 1.5 mmol) was added to the solution and stirred for 1 h at −70 °C. HMPA (0.45 mL, 2.6 mmol) was added and the solution was stirred at −70 °C for 15 min. Compound **10** (1.2 mmol, 187 mg) was added, followed by **2** (960 mg, 2.9 mmol) in three portions at −70 °C. The blue mixture was stirred at −70 °C for 90 min. The mixture was quenched with six drops of D_2O and warmed to room temperature. Workup was conducted according to the General Procedure for **11**.

Cyclization of *tert*-Butyl (6*Z*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21] (Table 1, Entry 6): At −30 °C under N_2, MeLi (1.6 M in Et_2O, 0.72 mL, 1.1 mmol) was added to a solution of anhydrous $ZnBr_2$ (258 mg, 1.1 mmol) in dry THF (20 mL). After 30 min, (6*Z*,8*E*)-**21** (240 mg, 1.0 mmol) in dry THF (1 mL) was added, and the mixture was stirred for 30 min. At −78 °C, LDA (2 M in THF/*n*-hexane, 1.10 mL, 2.2 mmol) was added, and the mixture was stirred between −78 and −10 °C for 90 min. Subsequently, HMPA (0.54 mL, 3.1 mmol) and **10** (187 mg, 1.2 mmol) were added at −78 °C, followed by **2** (662 mg, 2.0 mmol) in one portion. The blue mixture was stirred at −78 °C for 1 h. Workup was conducted according to the General Procedure for **11**.

Cyclization of *tert*-Butyl (6*Z*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21] (Table 1, Entry 7): At −78 °C under N_2, (6*Z*,8*E*)-**21** (240 mg, 1.0 mmol) was added to a solution of LDA [3.2 mmol, prepared from 0.45 mL diisopropylamine and 2.00 mL *n*BuLi (1.6 M in *n*-hexane)] in dry THF (6 mL) and the resulting solution was stirred between −78 and −20 °C for 30 min. The solution was transferred by cannula to a suspension of anhydrous $ZnCl_2$ (558 mg, 4.1 mmol) in dry THF (14 mL) at −70 °C and stirred for 2 h between −70 and −20 °C. At −78 °C, **10** (187 mg, 1.2 mmol) was added, followed by **2** (662 mg, 2.0 mmol) in one portion. The blue mixture was stirred at −78 °C for 1 h. Workup was conducted according to the General Procedure for **11**.

***tert*-Butyl (6*Z*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*Z*,8*E*)-21]:** R_f (5:1) = 0.39. IR (film): $\tilde{\nu}$ = 3446 cm^{-1}, 2933, 1729, 1716, 1369, 1217, 1154. UV: λ_{max} (lg ε) = 232 nm (4.36). ^1H NMR (400 MHz): δ = 1.40 (s, 9 H, CCH_3), 1.42 (m, 1 H, CH_2CH_2CHOH), 1.52 (dt, *J* = 8.0, 6.6 Hz, 1 H, CH_2CH_2CHOH), 1.70 (d, *J* = 7.5 Hz, 3 H, =$CHCH_3$), 2.22 (m, 2 H, =$CHCH_2$), 2.29 (dd, *J* = 16.3, 8.8 Hz, 1 H, CH_2CO_2), 2.35 (dd, *J* = 16.3, 3.4 Hz, 1 H, CH_2CO_2), 2.96 (br. s, 1 H, OH), 3.91 (m, 1 H, $CHOH$), 5.21 (dt, *J* = 10.5, 7.7 Hz, 1 H, =$CHCH_2$), 5.61 (dq, *J* = 14.9, 6.8 Hz, 1 H, =$CHCH_3$), 5.90 (t, *J* = 10.9 Hz, 1 H, CH=$CHCH_2$), 6.27 (m, 1 H, CH=$CHCH_3$). ^{13}C NMR (100 MHz): δ = 18.2 (q, =$CHCH_3$), 23.6 (t, =$CHCH_2$), 28.0 (q, CCH_3), 36.3 (t, CH_2CH_2CHOH), 42.3 (t, CH_2CO_2), 67.5 (d, CHOH), 81.2 (s, CCH_3), 126.8 (d, CH=$CHCH_3$), 128.4 (d, =$CHCH_2$), 129.2 (d, CH=$CHCH_2$), 129.5 (d, =$CHCH_3$), 172.4 (s, CO_2). MS: *m*/*z* (%) = 240 (10) [M^+], 184 (28), 167 (16), 166 (48), 106 (18), 57 (100). HRMS: $C_{14}H_{24}O_3$: calcd. 240.1725; found 240.1719 ± 2 ppm. $C_{14}H_{24}O_3$ (240.3): calcd. C 69.96, H 10.07; found C 69.69, H 10.37.

***tert*-Butyl (6*E*,8*E*)-3-Hydroxydeca-6,8-dienoate [(6*E*,8*E*)-21]:** R_f (5:1) = 0.39. IR (film): $\tilde{\nu}$ = 3458 cm^{-1} (w), 2933 (m), 1729 (s), 1713 (s), 1368 (m), 1218 (w), 1154 (s). UV: λ_{max} (lg ε) = 230 nm (4.10). ^1H NMR (400 MHz): δ = 1.42 (s, 9 H, CCH_3), 1.45 (m, 1 H, CH_2CH_2CHOH), 1.55 (m, 1 H, CH_2CH_2CHOH), 1.68 (d, *J* = 6.2 Hz, 3 H, =$CHCH_3$), 2.15 (m, 2 H, =$CHCH_2$), 2.29 (dd, *J* = 16.4, 8.8 Hz, 1 H, CH_2CO_2), 2.37 (dd, *J* = 16.4, 3.3 Hz, 1 H, CH_2CO_2), 3.10 (br. s, 1 H, OH), 3.92 (m, 1 H, $CHOH$), 5.51 (m, 2 H, CH=$CHCH$=$CHCH_3$), 5.96 (m, 2 H, =$CHCH$=$CHCH_2$). ^{13}C NMR (100 MHz): δ = 17.9 (q, =$CHCH_3$), 28.1 (q, CCH_3), 28.4 (t, =$CHCH_2$), 36.0 (t, CH_2CH_2CHOH), 42.2 (t, CH_2CO_2), 67.4 (d,

CHOH), 81.2 (s, *C*CH_3), 127.2 (d, =*C*HCH_3), 130.82 (d, =*C*HCH_2), 130.84 (d, *C*H=$CHCH_3$), 131.4 (d, *C*H=$CHCH_2$), 172.4 (s, CO_2). MS: *m*/*z* (%) = 240 (11) [M^+], 184 (80), 167 (42), 166 (100), 107 (6), 106 (92), 93 (73), 57 (100). HRMS: $C_{14}H_{24}O_3$: calcd. 240.1725; found 240.1722 ppm.

***tert*-Butyl 2-Hydroxy-5-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentanecarboxylates (23):** Flash chromatography (25:1) gave **23** (for yields, see Table 1) as an inseparable 2.5−3:1 diastereomeric mixture [R_f (3.5:1) = 0.44] as a colorless oil, from which the major diastereomer slowly crystallized. IR (film): $\tilde{\nu}$ = 3003 cm^{-1}, 2977, 1716, 1367, 1154, 1041. **Major (1*R**,2*S**,5*R**,8*S**)-23:** M.p. 36−37 °C. ^{1}H NMR (400 MHz): δ = 1.01 (br. s, 9 H, NCCH_3), 1.09 (br. s, 3 H, NCCH_3), 1.15 (d, *J* = 6.5 Hz, 3 H, CHC*H*$_3$), 1.21 (m, 1 H, $CH_2CH_2CH_2$), 1.36−1.58 (m, 6 H, $CH_2CH_2CH_2$, =CHCHC*H*$_2$), 1.39 (s, 9 H, OCCH_3), 1.66 (m, 1 H, C*H*$_2$CHOH), 1.80 (m, 1 H, C*H*$_2$CHOH), 2.04 (m, 1 H, =CHCHC*H*$_2$), 2.24 (dd, *J* = 10.9, 4.4 Hz, 1 H, $CHCO_2$), 2.91 (dddd, *J* = 10.7, 8.5, 7.9 Hz, 1 H, =CHC*H*CH_2), 3.53 (d, *J* = 1.4 Hz, 1 H, OH), 4.13 (quint, *J* = 6.6 Hz, 1 H, CHON), 4.34 (sept, *J* = 2.2 Hz, 1 H, C*H*OH), 5.35 (dd, *J* = 15.4, 7.5 Hz, 1 H, =C*H*$CHCH_2$), 5.43 (dd, *J* = 15.4, 7.1 Hz, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = 17.3 (t, $NCCH_2CH_2$), 20.2 (br. q, NC*C*H_3), 20.4 (br. q, NC*C*H_3), 21.1 (q, CH*C*H_3), 28.2 (q, OC*C*H_3), 29.6 (t, =CHCH*C*H_2), 33.6 (t, *C*H_2CHOH), 34.1 (br. q, NC*C*H_3), 35.3 (br. q, NC*C*H_3), 40.2 (t, NC*C*H_2), 44.4 (d, =CHC*H*CH_2), 55.7 (d, *C*HCO_2), 59.2 (s, ONC), 59.7 (s, ONC), 74.1 (d, CHOH), 80.7 (d, CHON), 81.4 (s, O*C*CH_3), 132.1 (d, =*C*H$CHCH_2$), 134.3 (d, =*C*HCHON), 174.2 (s, CO_2). **Minor (1*R**,2*S**,5*R**,8*R**)-23:** ^{1}H NMR (400 MHz): δ = 1.01 (br. s, 9 H, NCCH_3), 1.07 (d, *J* = 6.5 Hz, 3 H, CHC*H*$_3$), 1.09 (br. s, 3 H, NCCH_3), 1.27 (m, 1 H, $CH_2CH_2CH_2$), 1.30−1.58 (m, 6 H, $CH_2CH_2CH_2$, =CHCHC*H*$_2$), 1.32 (s, 9 H, OCCH_3), 1.66 (m, 1 H, C*H*$_2$CHOH), 1.80 (m, 1 H, C*H*$_2$CHOH), 2.04 (m, 1 H, =CHCHC*H*$_2$), 2.25 (dd, *J* = 10.9, 4.7 Hz, 1 H, $CHCO_2$), 2.91 (m, 1 H, =CHC*H*CH_2), 3.21 (d, *J* = 2.7 Hz, 1 H, OH), 4.13 (m, 1 H, CHON), 4.34 (m, 1 H, C*H*OH), 5.35 (m, 1 H, =C*H*$CHCH_2$), 5.43 (m, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = 17.2 (t, $NCCH_2CH_2$), 20.2 (br. q, NC*C*H_3), 20.4 (br. q, NC*C*H_3), 20.9 (q, CH*C*H_3), 28.1 (q, OC*C*H_3), 29.6 (t, =CHCH*C*H_2), 33.7 (t, *C*H_2CHOH), 34.1 (br. q, NC*C*H_3), 35.3 (br. q, NC*C*H_3), 40.2 (t, NC*C*H_2), 43.4 (d, =CHC*H*CH_2), 55.6 (d, *C*HCO_2), 59.2 (s, ONC), 59.7 (s, ONC), 74.2 (d, CHOH), 80.1 (d, CHON), 81.3 (s, O*C*CH_3), 132.7 (d, =*C*H$CHCH_2$), 133.4 (d, =*C*HCHON), 173.9 (s, CO_2). MS: *m*/*z* (%) = 395 (0.3) [M^+], 322 (4), 183 (50), 165 (21), 157 (33), 156 (36), 142 (100), 84 (26), 57 (32). $C_{23}H_{41}NO_4$ (395.6): calcd. C 69.83, H 10.45, N 3.54; found C 69.82, H 10.71, N 3.38.

***tert*-Butyl 2-Hydroxy-5-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentanecarboxylates (24) and Unassigned Diastereomer 25:** Flash chromatography (25:1) gave an inseparable diastereomeric mixture of **24** (for yields, see Table 1) and trace amounts of **25** [R_f (3.5:1) = 0.32] as a colorless oil. IR (film): $\tilde{\nu}$ = 3429 cm^{-1}, 2975, 1723, 1337, 1153, 1043. **Major (1*S**,2*S**,5*R**,8*S**)-24:** ^{1}H NMR (400 MHz): δ = 1.00 (br. s, 9 H, NCCH_3), 1.07 (br. s, 3 H, NCCH_3), 1.12 (d, *J* = 6.5 Hz, 3 H, CHC*H*$_3$), 1.21 (m, 1 H, $CH_2CH_2CH_2$), 1.36−1.58 (m, 7 H, $CH_2CH_2CH_2$, $CHCH_2CH_2$), 1.36 (s, 9 H, OCCH_3), 1.93 (m, 1 H, =CHCHC*H*$_2$), 2.12 (m, 1 H, C*H*$_2$CHOH), 2.29 (br. s, 1 H, OH), 2.62 (dd, *J* = 8.3, 6.7 Hz, 1 H, $CHCO_2$), 2.95 (m, 1 H, =CHC*H*CH_2), 4.09 (quint, *J* = 6.7 Hz, 1 H, CHON), 4.43 (q, *J* = 6.7 Hz, 1 H, C*H*OH), 5.32 (dd, *J* = 15.4, 8.5 Hz, 1 H, =C*H*$CHCH_2$), 5.43 (dd, *J* = 15.4, 7.3 Hz, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = 17.2 (t, $NCCH_2CH_2$), 20.2 (br. q, NC*C*H_3), 20.4 (br. q, NC*C*H_3), 20.8 (q, CH*C*H_3), 28.2 (q, OC*C*H_3), 29.1 (t, =CHCH*C*H_2), 32.5 (t, *C*H_2CHOH), 34.1 (br. q, NC*C*H_3), 35.2 (br. q, NC*C*H_3), 40.1 (t, NC*C*H_2), 43.4 (d, =CH*C*HCH_2), 58.0 (d, *C*HCO_2), 59.2 (s, ONC), 59.7 (s, ONC), 74.3 (d, CHOH), 80.47 (d, CHON), 80.54 (s, O*C*CH_3), 129.8 (d, =*C*HCHCH_2), 134.9 (d, =*C*HCHON), 172.4 (s, CO_2). **Minor (1*S**,2*S**,5*R**,8*R**)-24:** ^{1}H NMR (400 MHz): δ = 1.01 (br. s, 9 H, NCCH_3), 1.06 (br. s, 3 H, NCCH_3), 1.15 (d, *J* = 6.5 Hz, 3 H, CHC*H*$_3$), 1.20 (m, 1 H, $CH_2CH_2CH_2$), 1.33−1.62 (m, 7 H, $CH_2CH_2CH_2$, $CHCH_2CH_2$), 1.38 (s, 9 H, OCCH_3), 1.90 (m, 2 H, =CHCHC*H*$_2$, OH), 2.12 (m, 1 H, C*H*$_2$CHOH), 2.62 (dd, *J* = 8.4, 5.7 Hz, 1 H, $CHCO_2$), 2.95 (quint, *J* = 7.5 Hz, 1 H, =CHC*H*CH_2), 4.15 (quint, *J* = 6.5 Hz, 1 H, CHON), 4.42 (m, 1 H, C*H*OH), 5.41 (dd, *J* = 15.6, 7.4 Hz, 1 H, =C*H*$CHCH_2$), 5.49 (dd, *J* = 15.6, 6.4 Hz, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = 17.3 (t, $NCCH_2CH_2$), 20.3 (br. q, NC*C*H_3), 20.6 (q, CH*C*H_3), 28.3 (q, OC*C*H_3), 29.0 (t, =CHCH*C*H_2), 32.9 (t, *C*H_2CHOH), 34.3 (br. q, NC*C*H_3), 35.2 (br. q, NC*C*H_3), 40.2 (t, NC*C*H_2), 43.1 (d, =CH*C*HCH_2), 58.0 (d, *C*HCO_2), 59.6 (s, ONC), 74.8 (d, CHOH), 80.0 (d, CHON), 80.7 (s, O*C*CH_3), 129.4 (d, =*C*HCHCH_2), 134.6 (d, =*C*HCHON), 172.4 (s, CO_2). **25:** ^{1}H NMR (400 MHz): δ = 1.00 (br. s, 9 H, NCCH_3), 1.04 (br. s, 3 H, NCCH_3), 1.14 (d, *J* = 6.5 Hz, 3 H, CHC*H*$_3$), 1.21 (m, 1 H, $CH_2CH_2CH_2$), 1.37−1.62 (m, 7 H, $CH_2CH_2CH_2$, $CHCH_2CH_2$), 1.38 (s, 9 H, OCCH_3), 1.68 (br. s, 1 H, OH), 1.78 (q, *J* = 8.0 Hz, 1 H, =CHCHC*H*$_2$), 1.93 (m, 1 H, C*H*$_2$CHOH), 2.27 (dd, *J* = 10.1, 6.9 Hz, 1 H, $CHCO_2$), 2.61 (m, 1 H, =CHC*H*CH_2), 4.09 (m, 1 H, CHON), 4.30 (m, 1 H, C*H*OH), 5.41 (m, 2 H, C*H*=C*H*CHON). ^{13}C NMR (100 MHz): δ = 17.3 (t, $NCCH_2CH_2$), 20.2 (br. q, NC*C*H_3), 20.4 (br. q, NC*C*H_3), 21.1 (q, CH*C*H_3), 28.2 (q, OC*C*H_3), 29.4 (t, =CHCH*C*H_2), 33.2 (t, *C*H_2CHOH), 34.1 (br. q, NC*C*H_3), 35.2 (br. q, NC*C*H_3), 40.2 (t, NC*C*H_2), 45.0 (d, =CHC*H*CH_2), 59.2 (s, ONC), 59.7 (s, ONC), 60.1 (d, *C*HCO_2), 76.3 (d, CHOH), 80.6 (d, CHON), 80.7 (s, O*C*CH_3), 132.0 (d, =*C*HCHCH_2), 134.1 (d, =*C*HCHON), 173.6 (s, CO_2). MS: *m*/*z* (%) = 322 (8), 183 (51), 165 (19), 157 (33), 156 (16), 142 (100), 57 (40). MS (NH_3, CI, pos.): *m*/*z* (%) = 396 (100) [M^+ + H], 274 (23). $C_{23}H_{41}NO_4$ (395.6): calcd. C 69.83, H 10.45, N 3.54; found C 69.94, H 10.44, N 3.34.

***tert*-Butyl *anti*-(6*Z*,8*E*)-3-Hydroxy-2-(2,2,6,6-tetramethylpiperidin-1-yloxy)deca-6,8-dienoate [*anti*-(6*Z*,8*E*)-26]:** Flash chromatography (30:1) gave *anti*-(6*Z*,8*E*)-**26** (for yields, see Table 1) [R_f (5:1) = 0.48] as a colorless oil. IR (film): $\tilde{\nu}$ = 3510 cm^{-1}, 2933, 1729, 1367, 1153. UV: λ_{max} (lg ε) = 230 nm (4.30). ^{1}H NMR (400 MHz): δ = 1.07 (br. s, 12 H, NCCH_3), 1.26 (m, 1 H, $CH_2CH_2CH_2$), 1.41 (m, 7 H, $CH_2CH_2CH_2$, C*H*$_2$CHOH), 1.42 (s, 9 H, OCCH_3), 1.70 (d, *J* = 6.4 Hz, 3 H, =CHC*H*$_3$), 2.25 (m, 2 H, =CHC*H*$_2$), 2.54 (br. s, 1 H, OH), 4.08 (m, 2 H, C*H*C*H*OH), 5.22 (m, 1 H, =C*H*CH_2), 5.61 (dq, *J* = 14.7, 6.8 Hz, 1 H, =C*H*CH_3), 5.90 (t, *J* = 10.9 Hz, 1 H, CH_2CH=C*H*), 6.29 (dd, *J* = 14.7, 11.2 Hz, 1 H, C*H*=$CHCH_3$). ^{13}C NMR (100 MHz): δ = 16.8 (t, $NCCH_2CH_2$), 18.0 (q, =CH*C*H_3), 19.9 (br. q, NC*C*H_3), 23.8 (t, =CH*C*H_2), 27.9 (q, OC*C*H_3), 33.1 (t, *C*H_2CHOH), 33.2 (br. q, NC*C*H_3), 33.7 (br. q, NC*C*H_3), 40.1 (t, NC*C*H_2), 59.8 (s, ONC), 71.3 (d, CHOH), 81.6 (s, O*C*CH_3), 87.0 (d, CHON), 126.7 (d, *C*H=$CHCH_3$), 128.1 (d, =*C*HCH_2), 129.1 (d), 129.2 (d), 169.9 (s, CO_2). MS: *m*/*z* (%) = 395 (5) [M^+], 156 (100) [TEMPO], 142 (29). $C_{23}H_{41}NO_4$ (395.6): calcd. C 69.83, H 10.45, N 3.54; found 70.01, H 10.59, N 3.62.

***tert*-Butyl *anti*-(6*E*,8*E*)-3-Hydroxy-2-(2,2,6,6-tetramethylpiperidin-1-yloxy)deca-6,8-dienoate [*anti*-(6*E*,8*E*)-26]:** Flash chromatography (30:1) gave *anti*-(6*E*,8*E*)-**26** (for yields, see Table 1) [R_f (5:1) = 0.39] as a colorless oil. IR (film): $\tilde{\nu}$ = 3506 cm^{-1} (w), 2933 (s), 1728 (s), 1367 (m), 1153 (s). UV: λ_{max} (lg ε) = 230 nm (4.39). ^{1}H NMR (400 MHz): δ = 1.12 (br. s, 12 H, NCCH_3), 1.29 (m, 1 H,

NCCH$_2$C*H$_2$*), 1.37−1.54 (m, 7 H, CH$_2$C*H$_2$*CHOH, NCC*H$_2$*C*H$_2$*C*H$_2$*), 1.45 (s, 9 H, OCCH$_3$), 1.68 (d, J = 6.6 Hz, 3 H, =CHC*H$_3$*), 2.08−2.24 (m, 2 H, =CHC*H$_2$*), 2.56 (br. s, 1 H, OH), 4.09 (d, J = 3.3 Hz, 1 H, CHON), 4.13 (dt, J = 10.8, 3.3 Hz, 1 H, C*H*OH), 5.52 (m, 2 H, C*H*=CHCH=C*H*CH$_3$), 5.95 (m, 2 H, =C*H*CH=CHCH$_2$). ^{13}C NMR (100 MHz): δ = 17.1 (t, NCCH$_2$*C*H$_2$), 17.9 (q, =CH*C*H$_3$), 20.1 (br. q, NC*C*H$_3$), 28.1 (q, OC*C*H$_3$), 28.8 (t, =CH*C*H$_2$), 33.1 (t, *C*H$_2$CHOH), 33.5 (br. q, NC*C*H$_3$), 33.9 (br. q, NC*C*H$_3$), 40.4 (t, NC*C*H$_2$), 60.0 (s, ONC), 71.6 (d, CHOH), 81.8 (s, O*C*CH$_3$), 87.1 (d, CHON), 127.1 (d, =*C*HCH$_3$), 130.6 (d, =*C*HCH$_2$), 130.9 (d, *C*H=CHCH$_3$), 131.5 (d, *C*H=CHCH$_2$), 170.2 (s, CO$_2$). MS: *m*/*z* (%) = 395 (12) [M$^+$], 183 (27), 156 (100) [TEMPO], 142 (57), 126 (27), 69 (24), 57 (30), 41 (25). HRMS: $C_{23}H_{41}NO_4$: calcd. 395.3036; found 395.3037 ppm.

6-[(3*E*,5*E*)-2-(*tert*-Butyldimethylsilyloxy)hepta-3,5-dienyl]-2,2-dimethyl-1,3-dioxin-4-one (30): At room temperature under N$_2$, **29** (1.00 g, 4.2 mmol) and imidazole (1.00 g, 14.7 mmol) were dissolved in dichloromethane (11 mL). TBDMSCl (0.89 g, 5.9 mmol) was added to the homogeneous reaction solution and the mixture was stirred for 3 h. The yellow solution was quenched with water and the aqueous layer was extracted three times with ether. The combined organic layers were dried with Na$_2$SO$_4$ and the solvent was evaporated. Purification of the residue by flash chromatography (10:1) yielded 1.27 g (86%) of **30** as a pale yellow oil. ^{1}H NMR (200 MHz): δ = −0.02 (s, 3 H, SiCH$_3$), 0.00 (s, 3 H, SiCH$_3$), 0.83 (s, 9 H, SiCCH$_3$), 1.62 (s, 3 H, OCCH$_3$), 1.64 (s, 3 H, OCCH$_3$), 1.72 (d, J = 6.5 Hz, 3 H, =CHC*H$_3$*), 2.25−2.45 (m, 2 H, C*H$_2$*CHOSi), 4.36 (q, J = 6.5 Hz, 1 H, CHOSi), 5.21 (s, 1 H, =CHCO$_2$), 5.42 (dd, J = 14.0, 6.9 Hz, 1 H, =C*H*CHOSi), 5.65 (m, 1 H, C*H*=CHCH$_3$), 5.95 (m, 1 H, =C*H*CH$_3$), 6.08 (dd, J = 13.9, 10.1 Hz, 1 H, C*H*=CHCH$_2$). ^{13}C NMR (50 MHz): δ = −4.3 (q, SiCH$_3$), 18.1 (q, =CH*C*H$_3$), 18.1 (s, Si*C*CH$_3$), 24.6 (q, OC*C*H$_3$), 25.6 (q, OC*C*H$_3$), 25.7 (q, SiC*C*H$_3$), 43.1 (t, *C*H$_2$CHOSi), 70.4 (d, CHOSi), 95.3 (d, =*C*HCO$_2$), 106.3 (s, O*C*CH$_3$), 130.3 (d), 130.4 (d), 131.0 (d), 131.8 (d), 161.1 (s), 168.5 (s).

***tert*-Butyl (6*E*,8*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-oxodeca-6,8-dienoate (31):** Under N$_2$, dioxinone **30** (1.00 g, 2.8 mmol), dissolved in dry *t*BuOH (25 mL), was heated to reflux for 18 h. The solvent was evaporated and the residue was purified by flash chromatography (25:1) to give 0.90 g (85%) of **31** as a colorless oil. IR (film): $\tilde{\nu}$ = 2931 cm^{-1} (m), 1744 (m), 1719 (m), 1252 (m), 1146 (m), 837 (m). UV: λ_{max} (lg ε) = 230 nm (4.46). ^{1}H NMR (400 MHz): δ = −0.02 (s, 3 H, SiCH$_3$), 0.00 (s, 3 H, SiCH$_3$), 0.83 (s, 9 H, SiCCH$_3$), 1.42 (s, 9 H, OCCH$_3$), 1.70 (d, J = 6.9 Hz, 3 H, =CHC*H$_3$*), 2.53 (dd, J = 15.1, 4.9 Hz, 1 H, CHC*H$_2$*), 2.74 (dd, J = 15.1, 7.7 Hz, 1 H, CHC*H$_2$*), 3.33 (s, 2 H, CH$_2$CO$_2$), 4.58 (m, 1 H, CHOSi), 5.47 (dd, J = 15.2, 6.7 Hz, 1 H, =C*H*CHOSi), 5.65 (dq, J = 14.9, 6.7 Hz, 1 H, =C*H*CH$_3$), 5.96 (ddd, J = 15.0, 10.5, 1.5 Hz, 1 H, C*H*=CHCHOSi), 6.10 (dd, J = 15.1, 10.5 Hz, 1 H, C*H*=CHCH$_3$). ^{13}C NMR (100 MHz): δ = −5.0 (q, SiCH$_3$), −4.3 (q, SiCH$_3$), 18.1 (q, =CH*C*H$_3$), 18.1 (s, Si*C*CH$_3$), 25.8 (q, SiC*C*H$_3$), 28.0 (q, OC*C*H$_3$), 51.2 (t, *C*H$_2$CHOSi), 52.2 (t, *C*H$_2$CO$_2$), 70.1 (d, CHOSi), 81.8 (s, O*C*CH$_3$), 130.0 (d, =*C*HCH$_3$), 130.4 (d, *C*H=CHCHOSi), 130.6 (d, *C*H=CHCH$_3$), 132.2 (d, =*C*HCHOSi), 166.3 (s, CO$_2$), 201.7 (s, CH$_2$*C*OCH$_2$). MS: *m*/*z* (%) = 368 (1) [M$^+$], 312 (13), 255 (32), 237 (8) [M$^+$ − OTBDMS], 211 (47), 187 (20), 159 (100), 97 (31), 75 (25), 73 (28), 57 (27). $C_{20}H_{36}O_4Si$ (368.6): calcd. C 65.17, H 9.84; found C 65.39, H 10.17.

***tert*-Butyl *syn*- and *anti*-(6*E*,8*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-hydroxydeca-6,8-dienoate (32):** At 0 °C under N$_2$, NaBH$_4$ (187 mg, 4.9 mmol) was added to a solution of oxo ester **31** (1.52 g, 4.1 mmol) in methanol (20 mL), and the mixture was stirred for 90 min. The reaction mixture was quenched with a saturated NaHCO$_3$ solution (10 mL) and the methanol was evaporated. The residue was extracted three times with ether. The combined organic layers were dried with Na$_2$SO$_4$ and the solvent was evaporated. Purification of the residue by flash chromatography (25:1) yielded 1.42 g (93%) of a 1.7:1 mixture of *syn*/*anti*-**32** [R_f (5:1) = 0.50] as a colorless oil. IR (film): $\tilde{\nu}$ = 3450 cm^{-1} (w), 2931 (m), 1731 (s), 1369 (m), 1256 (m), 1155 (s), 1082 (w), 838 (m). UV: λ_{max} (lg ε) = 214 nm (3.44), 224 (3.34), 236 (3.11), 248 (2.77). ***syn*-32:** ^{1}H NMR (400 MHz): δ = 0.00 (s, 3 H, SiCH$_3$), 0.04 (s, 3 H, SiCH$_3$), 0.85 (s, 9 H, SiCCH$_3$), 1.41 (s, 9 H, OCCH$_3$), 1.55 (m, 1 H, C*H$_2$*CHOSi), 1.71 (m, 1 H, C*H$_2$*CHOSi), 1.71 (d, J = 6.7 Hz, 3 H, =CHC*H$_3$*), 2.35 (m, 2 H, CH$_2$CO$_2$), 3.46 (m, 1 H, OH), 4.04 (m, 1 H, C*H*OH), 4.33 (dt, J = 13.5, 7.1 Hz, 1 H, CHOSi), 5.44 (dd, J = 15.0, 7.4 Hz, 1 H, =C*H*CHOSi), 5.64 (dq, J = 14.4, 6.9 Hz, 1 H, =C*H*CH$_3$), 5.97 (dd, J = 14.7, 10.5 Hz, 1 H, C*H*=CHCH$_3$), 6.06 (dd, J = 14.9, 10.7 Hz, 1 H, C*H*=CHCH$_2$). ^{13}C NMR (100 MHz): δ = −4.8 (q, SiCH$_3$), −4.0 (q, SiCH$_3$), 18.08 (q, =CH*C*H$_3$), 18.13 (s, Si*C*CH$_3$), 25.9 (q, SiC*C*H$_3$), 28.1 (q, OC*C*H$_3$), 42.7 (t, *C*H$_2$CO$_2$), 44.4 (t, *C*H$_2$CHOSi), 66.6 (d, CHOH), 72.9 (d, CHOSi), 80.9 (s, O*C*CH$_3$), 129.8 (d, =*C*HCH$_3$), 130.6 (d, *C*H=CHCHOSi), 130.7 (d, *C*H=CHCH$_3$), 133.0 (d, =*C*HCHOSi), 171.8 (s, CO$_2$). ***anti*-32:** ^{1}H NMR (400 MHz): δ = 0.01 (s, 3 H, SiCH$_3$), 0.05 (s, 3 H, SiCH$_3$), 0.86 (s, 9 H, SiCCH$_3$), 1.41 (s, 9 H, OCCH$_3$), 1.55 (m, 1 H, C*H$_2$*CHOSi), 1.63 (m, 1 H, C*H$_2$*CHOSi), 1.71 (d, J = 6.7 Hz, 3 H, =CHC*H$_3$*), 2.35 (m, 2 H, CH$_2$CO$_2$), 3.46 (m, 1 H, OH), 4.20 (m, 1 H, C*H*OH), 4.44 (m, 1 H, CHOSi), 5.51 (dd, J = 15.2, 6.5 Hz, 1 H, =C*H*CHOSi), 5.64 (dq, J = 14.4, 6.9 Hz, 1 H, =C*H*CH$_3$), 5.97 (dd, J = 14.7, 10.5 Hz, 1 H, C*H*=CHCH$_3$), 6.06 (dd, J = 14.9, 10.7 Hz, 1 H, C*H*=CHCH$_2$). ^{13}C NMR (100 MHz): δ = −5.0 (q, SiCH$_3$), −4.4 (q, SiCH$_3$), 18.1 (q, =CH*C*H$_3$), 18.1 (s, Si*C*CH$_3$), 25.9 (q, SiC*C*H$_3$), 28.1 (q, OC*C*H$_3$), 43.1 (t, *C*H$_2$CO$_2$), 43.8 (t, *C*H$_2$CHOSi), 65.1 (d, CHOH), 71.1 (d, CHOSi), 80.8 (s, O*C*CH$_3$), 129.4 (d, =*C*HCH$_3$), 130.0 (d, *C*H=CHCHOSi), 130.8 (d, *C*H=CHCH$_3$), 133.0 (d, =*C*HCHOSi), 171.7 (s, CO$_2$). MS: *m*/*z* (%) = 370 (< 1) [M$^+$], 145 (19), 132 (40), 105 (22), 103 (40), 75 (100). $C_{20}H_{38}O_4Si$ (370.6): calcd. C 64.82, H 10.33; found C 65.04, H 10.63.

***tert*-Butyl (6*E*,8*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-oxo-2-(2,2,6,6-tetramethylpiperidin-1-yloxy)deca-6,8-dienoate (33):** At −78 °C under N$_2$, **31** (300 mg, 0.81 mmol) was added to a solution of LDA [1.06 mmol, prepared from 0.15 mL diisopropylamine and 0.66 mL *n*BuLi (1.6 M in *n*-hexane)] in dry THF (16 mL) and the resulting solution was stirred for 30 min. At −70 °C, HMPA (0.28 mL, 1.63 mmol) and TEMPO (140 mg, 0.90 mmol) were added. After this had stirred for 5 min, **2** (440 mg, 1.33 mmol) was added in three portions at −70 °C. The blue mixture was stirred at −70 °C for 90 min. Workup was conducted according to the General Procedure for **11**. Flash chromatography (50:1 gradient to 2:1) gave 330 mg (77%) of an inseparable 1:1 diastereomeric mixture of *syn*/*anti*-**33** [R_f (10:1) = 0.41] as a pale yellow oil. IR (film): $\tilde{\nu}$ = 2958 cm^{-1} (s), 1721 (s), 1369 (s), 1256 (s), 1135 (m), 1072 (m), 990 (s), 778 (s). UV: λ_{max} (lg ε) = 230 nm (4.43). ^{1}H NMR (400 MHz): δ = 0.00 (s, 6 H, SiCH$_3$), 0.01 (s, 3 H, SiCH$_3$), 0.02 (s, 3 H, SiCH$_3$), 0.821 (s, 9 H, SiCCH$_3$), 0.823 (s, 9 H, SiCCH$_3$), 0.91 (s, 3 H, NCCH$_3$), 0.94 (s, 3 H, NCCH$_3$), 1.06 (s, 6 H, NCCH$_3$), 1.12 (s, 6 H, NCCH$_3$), 1.15 (s, 6 H, NCCH$_3$), 1.25 (m, 2 H, CH$_2$C*H$_2$*CH$_2$), 1.40 (s, 9 H, OCCH$_3$), 1.40 (m, 8 H, C*H$_2$*CH$_2$C*H$_2$*), 1.41 (s, 9 H, OCCH$_3$), 1.50 (m, 2 H, CH$_2$C*H$_2$*CH$_2$), 1.69 (d, J = 7.5 Hz, 6 H, =CHC*H$_3$*), 2.65 (dd, J = 18.5, 5.8 Hz, 1 H, CH$_2$CO), 2.81 (dd, J = 18.4, 6.0 Hz, 1 H, CH$_2$CO), 2.89 (dd, J = 18.5, 6.7 Hz, 1 H, CH$_2$CO), 3.09 (dd, J = 18.6, 6.5 Hz, 1 H, CH$_2$CO), 4.65 (s, 1 H, CHON), 4.66 (m, 2 H, CHOSi), 4.66 (s, 1 H, CHON), 5.47 (dd,

J = 15.2, 6.6 Hz, 2 H, =C*H*CH$_2$), 5.61 (dq, J = 14.8, 6.8 Hz, 2 H, =C*H*CH$_3$), 5.83 (ddd, J = 15.0, 10.6, 1.5 Hz, 2 H, CH$_2$CH=C*H*), 6.14 (ddd, J = 15.2, 10.4, 2.7 Hz, 2 H, C*H*=CHCH$_3$). ^{13}C NMR (100 MHz): δ = −4.91 (q, SiCH$_3$), −4.87 (q, SiCH$_3$), −4.5 (q, SiCH$_3$), 16.9 (t, NCCH$_2$*C*H$_2$), 18.0 (q, =CH*C*H$_3$), 18.08 (s, Si*C*CH$_3$), 18.09 (s, Si*C*CH$_3$), 20.1 (q, NC*C*H$_3$), 25.8 (q, SiC*C*H$_3$), 27.78 (q, OC*C*H$_3$), 27.81 (q, OC*C*H$_3$), 31.5 (br. q, NC*C*H$_3$), 32.7 (br. q, NC*C*H$_3$), 33.0 (br. q, NC*C*H$_3$), 40.1 (t, *C*H$_2$CH$_2$*C*H$_2$), 47.7 (t, *C*H$_2$CO), 48.3 (t, *C*H$_2$CO), 59.9 (br. s, ONC), 60.1 (br. s, ONC), 67.88 (d, CHOSi), 67.89 (d, CHOSi), 82.5 (s, O*C*CH$_3$), 82.6 (s, O*C*CH$_3$), 94.0 (d, CHON), 94.3 (d, CHON), 129.27 (d), 129.29 (d), 130.0 (d), 130.1 (d), 130.8 (d), 132.6 (d), 132.7 (d), 166.6 (s, CO$_2$), 166.7 (s, CO$_2$), 201.8 (s, CH$_2$*C*O), 202.2 (s, CH$_2$*C*O). MS: *m*/*z* (%) = 523 (8) [M$^+$], 311 (27), 156 (100) [TEMPO]. $C_{29}H_{53}NO_5Si$ (523.6): calcd. C 66.49, H 10.20, N 2.67; found C 66.71, H 10.48, N 2.49.

Oxidative Cyclization of *tert*-Butyl (6*E*,8*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-hydroxydeca-6,8-dienoate (32): At −78 °C under N$_2$, *syn*/*anti*-**32** (1.7:1, 233 mg, 0.63 mmol) was added to a mixture of anhydrous LiCl (190 mg, 4.48 mmol) and LDA [1.59 mmol, prepared from 0.22 mL diisopropylamine and 1.00 mL *n*BuLi (1.6 M in *n*-hexane)] in dry THF (7 mL) and the resulting solution was stirred between −45 and −30 °C for 90 min. At −78 °C, dry THF (5 mL) and TEMPO (119 mg, 0.76 mmol) were added; 2 min later, HMPA (0.28 mL, 1.59 mmol) was added, followed by **2** (450 mg, 1.36 mmol) in four portions at −70 °C. The blue mixture was stirred at −70 °C for 90 min. Workup was conducted according to the General Procedure for **11**. Flash chromatography (50:1 gradient to 1:1) gave 50 mg (15%) of **40/41**, 25 mg (11%) of *syn*/*anti*-**32** (1.2:1), 110 mg (32%) of 8α/8β-**34/36/37** (4:3.3:2.3:1), 20 mg (6%) of 8β-**35**, and 70 mg (21%) of 8α-**35**/8β- and 8α-**38/39** (3.7:2.3:1). The above product fractions were analyzed by combustion analysis and then further separated by flash chromatography as indicated below to facilitate stereochemical analysis. **8α/8β-34/36/37:** $C_{29}H_{55}NO_5Si$ (525.8): calcd. C 66.24, H 10.54, N 2.66; found C 66.11, H 10.95, N 2.64. **8β-35:** $C_{29}H_{55}NO_5Si$ (525.8): calcd. C 66.24, H 10.54, N 2.66; found C 65.87, H 10.38, N 2.84. **8α-35/8β/8α-38/39:** $C_{29}H_{55}NO_5Si$ (525.8): calcd. C 66.24, H 10.54, N 2.66; found C 66.23, H 10.51, N 2.76.

***tert*-Butyl (1*R**,2*R**,3*R**,5*S**,8*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentanecarboxylate (8α-34):** Further flash chromatography (25:1) gave 8α-**34** as the major component, together with minor amounts of 8β-**34** and **36** [R_f (5:1) = 0.47] as a colorless oil. IR (film): $\tilde{\nu}$ = 3465 cm^{-1} (w), 2931 (m), 1720 (s), 1366 (m), 1256 (m), 1156 (m), 1130 (m), 835 (m). ^{1}H NMR (400 MHz): δ = −0.02 (s, 3 H, SiCH$_3$), 0.00 (s, 3 H, SiCH$_3$), 0.81 (s, 9 H, SiCCH$_3$), 1.01 (br. s, 9 H, NCCH$_3$), 1.07 (br. s, 3 H, NCCH$_3$), 1.13 (d, J = 6.5 Hz, 3 H, CHC*H*$_3$), 1.23 (m, 1 H, CH$_2$C*H*$_2$CH$_2$), 1.36−1.44 (m, 5 H, C*H*$_2$C*H*$_2$C*H*$_2$), 1.39 (s, 9 H, OCCH$_3$), 1.76 (br. d, J = 13.8 Hz, 1 H, C*H*$_2$CHOH), 1.92 (m, 1 H, C*H*$_2$CHOH), 2.49 (dd, J = 9.2, 5.3 Hz, 1 H, CHCO$_2$), 3.03 (dt, J = 8.5, 3.8 Hz, 1 H, =CHC*H*CHOSi), 3.19 (br. s, 1 H, OH), 3.91 (dt, J = 5.8, 3.3 Hz, 1 H, CHOSi), 4.12 (quint, J = 6.7 Hz, 1 H, CHON), 4.32 (m, 1 H, C*H*OH), 5.28 (dd, J = 15.4, 8.1 Hz, 1 H, =C*H*CHCHOSi), 5.48 (dd, J = 15.4, 7.4 Hz, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = −4.9 (q, SiCH$_3$), −4.7 (q, SiCH$_3$), 17.3 (t, NCCH$_2$*C*H$_2$), 17.9 (s, Si*C*CH$_3$), 20.2 (br. q, NC*C*H$_3$), 20.4 (br. q, NC*C*H$_3$), 21.0 (q, CH*C*H$_3$), 25.8 (q, SiC*C*H$_3$), 28.2 (q, OC*C*H$_3$), 34.1 (br. q, NC*C*H$_3$), 35.3 (br. q, NC*C*H$_3$), 40.2 (t, NC*C*H$_2$), 43.2 (t, *C*H$_2$CHOH), 51.8 (d, =CH*C*HCHOSi), 56.4 (d, *C*HCO$_2$), 59.5 (br. s, ONC), 59.8 (br. s, ONC), 74.6 (d, CHOH), 79.0 (d, CHOSi), 80.6 (d, CHON), 80.8 (s, O*C*CH$_3$), 129.8 (d, =*C*HCHCHOSi), 135.1 (d, =*C*HCHON), 171.3 (s, CO$_2$). MS: *m*/*z* (%) = 270 (29), 224 (13), 179 (22), 156 (100) [TEMPO], 142 (22), 123 (27), 108 (23), 93 (27), 69 (55), 55 (30), 41 (50).

***tert*-Butyl (1*R**,2*R**,3*R**,5*S**,8*R**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (8β-34):** Further flash chromatography (25:1) gave 8β-**34** as the major component, with very minor amounts of 8α-**34** and **36** [R_f (5:1) = 0.47] as a colorless oil. ^{1}H NMR (400 MHz): δ = 0.00 (s, 3 H, SiCH$_3$), 0.02 (s, 3 H, SiCH$_3$), 0.82 (s, 9 H, SiCCH$_3$), 1.02 (br. s, 9 H, NCCH$_3$), 1.08 (br. s, 3 H, NCCH$_3$), 1.14 (d, J = 6.5 Hz, 3 H, CHC*H*$_3$), 1.24 (m, 1 H, CH$_2$C*H*$_2$CH$_2$), 1.36−1.43 (m, 5 H, C*H*$_2$C*H*$_2$C*H*$_2$), 1.40 (s, 9 H, OCCH$_3$), 1.76 (br. d, J = 13.9 Hz, 1 H, C*H*$_2$CHOH), 1.94 (m, 1 H, C*H*$_2$CHOH), 2.46 (dd, J = 9.3, 5.3 Hz, 1 H, CHCO$_2$), 3.04 (dt, J = 8.8, 4.0 Hz, 1 H, =CHC*H*CHOSi), 3.28 (br. s, 1 H, OH), 3.97 (m, 1 H, CHOSi), 4.17 (m, 1 H, CHON), 4.33 (br. s, 1 H, C*H*OH), 5.32 (dd, J = 15.5, 8.1 Hz, 1 H, =C*H*CHCHOSi), 5.50 (m, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = −5.0 (q, SiCH$_3$), −4.7 (q, SiCH$_3$), 17.2 (t, NCCH$_2$*C*H$_2$), 17.8 (s, Si*C*CH$_3$), 20.3 (br. q, NC*C*H$_3$), 20.9 (q, CH*C*H$_3$), 25.7 (q, SiC*C*H$_3$), 28.0 (q, OC*C*H$_3$), 34.0 (br. q, NC*C*H$_3$), 34.9 (br. q, NC*C*H$_3$), 40.0 (t, NC*C*H$_2$), 43.1 (t, *C*H$_2$CHOH), 51.6 (d, =CH*C*HCHOSi), 56.2 (d, *C*HCO$_2$), 59.4 (br. s, ONC), 74.1 (d, CHOH), 78.5 (d, CHOSi), 80.1 (d, CHON), 80.7 (s, O*C*CH$_3$), 129.6 (d, =*C*HCHCHOSi), 134.7 (d, =*C*HCHON), 171.3 (s, CO$_2$).

***tert*-Butyl (1*S**,2*R**,3*R**,5*S**,8*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentanecarboxylate (8α-35):** Further flash chromatography (25:1) gave 8α-**35** as the major component, with minor amounts of **38** and **39** [R_f (5:1) = 0.33] as a colorless oil. IR (film): $\tilde{\nu}$ = 3439 cm^{-1} (w), 2931 (m), 1726 (m), 1368 (m), 1257 (m), 1155 (m), 838 (m). ^{1}H NMR (400 MHz): δ = 0.00 (s, 3 H, SiCH$_3$), 0.01 (s, 3 H, SiCH$_3$), 0.82 (s, 9 H, SiCCH$_3$), 1.01 (br. s, 9 H, NCCH$_3$), 1.06 (br. s, 3 H, NCCH$_3$), 1.12 (d, J = 6.5 Hz, 3 H, CHC*H*$_3$), 1.24 (m, 1 H, CH$_2$C*H*$_2$CH$_2$), 1.36−1.43 (m, 5 H, C*H*$_2$C*H*$_2$C*H*$_2$), 1.36 (s, 9 H, OCCH$_3$), 1.63 (br. d, J = 14.4 Hz, 1 H, C*H*$_2$CHOH), 2.27 (ddd, J = 14.2, 7.5, 5.0 Hz, 1 H, C*H*$_2$CHOH), 2.49 (br. d, J = 7.5 Hz, 1 H, OH), 2.88 (m, 1 H, =CHC*H*CHOSi), 3.04 (dd, J = 8.1, 5.1 Hz, 1 H, CHCO$_2$), 4.04 (m, 1 H, CHOSi), 4.08 (quint, J = 6.7 Hz, 1 H, CHON), 4.43 (m, 1 H, C*H*OH), 5.12 (dd, J = 15.4, 9.7 Hz, 1 H, =C*H*CHCHOSi), 5.51 (dd, J = 15.3, 7.6 Hz, 1 H, =C*H*CHON). ^{13}C NMR (100 MHz): δ = −4.9 (q, SiCH$_3$), −4.7 (q, SiCH$_3$), 17.2 (t, NCCH$_2$*C*H$_2$), 17.9 (s, Si*C*CH$_3$), 20.1 (br. q, NC*C*H$_3$), 20.4 (br. q, NC*C*H$_3$), 20.8 (q, CH*C*H$_3$), 25.8 (q, SiC*C*H$_3$), 28.2 (q, OC*C*H$_3$), 34.1 (br. q, NC*C*H$_3$), 35.4 (br. q, NC*C*H$_3$), 40.2 (t, NC*C*H$_2$), 42.4 (t, *C*H$_2$CHOH), 54.1 (d, =CH*C*HCHOSi), 57.1 (d, *C*HCO$_2$), 58.0 (br. s, ONC), 74.1 (d, CHOH), 78.4 (d, CHOSi), 80.5 (d, CHON), 80.6 (s, O*C*CH$_3$), 126.7 (d, =*C*HCHCHOSi), 137.1 (d, =*C*HCHON), 172.4 (s, CO$_2$). MS: *m*/*z* (%) = 270 (62), 224 (25), 179 (45), 156 (71) [TEMPO], 142 (58), 108 (51), 93 (54), 81 (37), 69 (88), 55 (54), 41 (100).

***tert*-Butyl (1*S**,2*R**,3*R**,5*S**,8*R**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (8β-35):** Flash chromatography (25:1) gave 8β-**35** [R_f (5:1) = 0.40] as a single diastereomer as a colorless oil. IR (film): $\tilde{\nu}$ = 3440 cm^{-1} (w), 2932 (m), 1721 (m), 1367 (m), 1257 (m), 1133 (m), 837 (m). ^{1}H NMR (400 MHz): δ = 0.000 (s, 3 H, SiCH$_3$), 0.003 (s, 3 H, SiCH$_3$), 0.83 (s, 9 H, SiCCH$_3$), 1.03 (br. s, 9 H, NCCH$_3$), 1.07 (br. s, 3 H, NCCH$_3$), 1.14 (d, J = 6.6 Hz, 3 H, CHC*H*$_3$), 1.26 (m, 1 H, CH$_2$C*H*$_2$CH$_2$), 1.36−1.50 (m, 5 H, C*H*$_2$C*H*$_2$C*H*$_2$), 1.40 (s, 9 H, OCCH$_3$), 1.62 (dt, J = 13.9, 3.9 Hz, 1

H, CH_2CHOH), 2.30 (ddd, J = 14.0, 7.0, 5.7 Hz, 1 H, CH_2CHOH), 2.37 (br. s, 1 H, OH), 2.89 (dt, J = 8.8, 3.2 Hz, 1 H, =CHCHCHOSi), 3.00 (dd, J = 8.6, 4.2 Hz, 1 H, CHCO$_2$), 4.03 (dt, J = 5.5, 3.5 Hz, 1 H, CHOSi), 4.18 (quint, J = 6.6 Hz, 1 H, CHON), 4.40 (br. s, 1 H, CHOH), 5.25 (ddd, J = 15.5, 9.1, 0.8 Hz, 1 H, =CHCHCHOSi), 5.58 (dd, J = 15.5, 6.6 Hz, 1 H, =CHCHON). ^{13}C NMR (100 MHz): δ = −4.8 (q, SiCH$_3$), −4.7 (q, SiCH$_3$), 17.3 (t, NCCH$_2$CH_2), 17.9 (s, SiCCH$_3$), 20.2 (br. q, NCCH$_3$), 20.4 (br. q, NCCH$_3$), 20.5 (q, CHCH$_3$), 25.8 (q, SiCCH$_3$), 28.2 (q, OCCH$_3$), 34.2 (br. q, NCCH$_3$), 34.7 (br. q, NCCH$_3$), 40.2 (t, NCCH$_2$), 42.7 (t, CH$_2$CHOH), 53.3 (d, =CHCHCHOSi), 57.1 (d, CHCO$_2$), 59.6 (s, ONC), 74.0 (d, CHOH), 78.2 (d, CHOSi), 79.8 (d, CHON), 80.7 (s, OCCH$_3$), 126.5 (d, =CHCHCHOSi), 136.8 (d, =CHCHON), 172.4 (s, CO$_2$). MS: m/z (%) = 206 (2), 162 (8), 156 (100) [TEMPO], 123 (16), 117 (10), 86 (16), 84 (24), 69 (29), 41 (18).

***tert*-Butyl (1*R**,2*R**,3*S**,5*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (36):** Flash chromatography (25:1) gave **36** as an inseparable mixture with **34** [R_f (5:1) = 0.47] as a colorless oil. ^{1}H NMR (400 MHz): δ = −0.03 (s, 3 H, SiCH$_3$), 0.01 (s, 3 H, SiCH$_3$), 0.80 (s, 9 H, SiCCH$_3$), 1.02 (br. s, 9 H, NCCH$_3$), 1.08 (br. s, 3 H, NCCH$_3$), 1.14 (m, 3 H, CHCH$_3$), 1.24 (m, 1 H, CH$_2$CH$_2$CH$_2$), 1.36−1.43 (m, 5 H, CH$_2$CH$_2$CH$_2$), 1.39 (s, 9 H, OCCH$_3$), 1.89−1.99 (m, 2 H, CH$_2$CHOH), 2.74 (dd, J = 12.4, 6.3 Hz, 1 H, CHCO$_2$), 2.82 (m, 1 H, =CHCHCHOSi), 3.28 (br. s, 1 H, OH), 4.11−4.20 (m, 2 H, CHOSi, CHON), 4.48 (m, 1 H, CHOH), 5.50 (m, 2 H, CH=CH). ^{13}C NMR (100 MHz): δ = −4.8 (q, SiCH$_3$), −4.7 (q, SiCH$_3$), 17.2 (t, NCCH$_2$CH$_2$), 17.9 (s, SiCCH$_3$), 20.3 (br. q, NCCH$_3$), 20.7 (q, CHCH$_3$), 25.7 (q, SiCCH$_3$), 28.1 (q, OCCH$_3$), 34.0 (br. q, NCCH$_3$), 34.9 (br. q, NCCH$_3$), 40.0 (t, NCCH$_2$), 45.8 (t, CH$_2$CHOH), 50.8 (d, =CHCHCHOSi), 52.4 (d, CHCO$_2$), 59.2 (br. s, ONC), 72.1 (d, CHOH), 74.5 (d, CHOSi), 80.1 (d, CHON), 81.2 (s, OCCH$_3$), 127.8 (d, =CHCHCHOSi), 135.8 (d, =CHCHON), 173.7 (s, CO$_2$).

***tert*-Butyl (1*R**,2*S**,3*S**,5*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (37):** Further flash chromatography (25:1) gave **37** as an inseparable mixture with **34** [R_f (5:1) = 0.47] as a colorless oil. ^{1}H NMR (400 MHz): δ = −0.03 (s, 3 H, SiCH$_3$), −0.02 (s, 3 H, SiCH$_3$), 0.80 (s, 9 H, SiCCH$_3$), 1.01 (br. s, 9 H, NCCH$_3$), 1.07 (br. s, 3 H, NCCH$_3$), 1.15 (d, J = 6.4 Hz, 3 H, CHCH$_3$), 1.24 (m, 1 H, CH$_2$CH$_2$CH$_2$), 1.36−1.41 (m, 5 H, CH$_2$CH$_2$CH$_2$), 1.39 (s, 9 H, OCCH$_3$), 1.77 (m, 1 H, CH$_2$CHOH), 2.10 (m, 1 H, CH$_2$CHOH), 2.63 (dt, J = 8.6, 4.4 Hz, 1 H, =CHCHCHOSi), 2.99 (dd, J = 8.3, 4.9 Hz, 1 H, CHCO$_2$), 4.16 (m, 2 H, CHOSi, CHON), 4.44 (m, 1 H, CHOH), 5.50 (m, 2 H, CH=CH). ^{13}C NMR (100 MHz): δ = −5.0 (q, SiCH$_3$), −4.8 (q, SiCH$_3$), 17.1 (t, NCCH$_2$CH$_2$), 17.9 (s, SiCCH$_3$), 20.1 (br. q, NCCH$_3$), 20.3 (q, CHCH$_3$), 25.7 (q, SiCCH$_3$), 28.1 (q, OCCH$_3$), 34.1 (br. q, NCCH$_3$), 40.0 (t, NCCH$_2$), 43.5 (t, CH$_2$CHOH), 51.9 (d, CHCO$_2$), 53.5 (d, =CHCHCHOSi), 59.4 (br. s, ONC), 72.1 (d, CHOH), 77.6 (d, CHOSi), 79.3 (d, CHON), 80.7 (s, OCCH$_3$), 128.6 (d, =CHCHCHOSi), 135.8 (d, =CHCHON), 173.2 (s, CO$_2$). OH resonance not assigned.

***tert*-Butyl (1*S**,2*S**,3*S**,5*S**,8*R**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (8β-38):** Further flash chromatography (25:1) gave 8β-**38** as an inseparable mixture with **39** and 8α-**35** [R_f (5:1) = 0.33] as a colorless oil. ^{1}H NMR (400 MHz): δ = −0.04 (s, 3 H, SiCH$_3$), −0.03 (s, 3 H, SiCH$_3$), 0.80 (s, 9 H, SiCCH$_3$), 1.01 (br. s, 9 H, NCCH$_3$), 1.06 (br. s, 3 H, NCCH$_3$), 1.15 (d, J = 6.6 Hz, 3 H, CHCH$_3$), 1.27 (m, 1 H, CH$_2$CH$_2$CH$_2$), 1.36−1.44 (m, 5 H, CH$_2$CH$_2$CH$_2$), 1.39 (s, 9 H, OCCH$_3$), 1.86 (m, 2 H, CH$_2$CHOH), 2.11 (br. s, 1 H, OH), 2.35 (dd, J = 10.2, 6.6 Hz, 1 H, CHCO$_2$), 2.54 (m, 1 H, =CHCHCHOSi), 3.93 (q, J = 6.7 Hz, 1 H, CHOSi), 4.17 (sext, J = 6.6 Hz, 1 H, CHON), 4.41 (m, 1 H, CHOH), 5.40 (dd, J = 15.4, 7.5 Hz, 1 H, =CHCHCHOSi), 5.51 (m, 1 H, =CHCHON). ^{13}C NMR (100 MHz): δ = −4.68 (q, SiCH$_3$), −4.66 (q, SiCH$_3$), 17.3 (t, NCCH$_2$CH$_2$), 18.0 (s, SiCCH$_3$), 20.3 (br. q, NCCH$_3$), 20.7 (br. q, NCCH$_3$), 21.0 (q, CHCH$_3$), 25.8 (q, SiCCH$_3$), 28.1 (q, OCCH$_3$), 34.1 (br. q, NCCH$_3$), 35.3 (br. q, NCCH$_3$), 40.2 (t, NCCH$_2$), 42.9 (t, CH$_2$CHOH), 53.3 (d, =CHCHCHOSi), 57.7 (d, CHCO$_2$), 59.5 (br. s, ONC), 59.8 (br. s, ONC), 73.4 (d, CHOH), 76.0 (d, CHOSi), 80.3 (d, CHON), 80.8 (s, OCCH$_3$), 129.5 (d, =CHCHCHOSi), 135.1 (d, =CHCHON), 172.9 (s, CO$_2$). MS: m/z (%) = 313 (11), 295 (12), 270 (48), 255 (23), 224 (25), 185 (15), 179 (50), 156 (43) [TEMPO], 142 (100), 108 (42), 93 (58), 75 (80), 73 (72), 69 (91), 41 (100).

***tert*-Butyl (1*S**,2*S**,3*S**,5*S**,8*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]-cyclopentanecarboxylate (8α-38):** Further flash chromatography (25:1) gave 8α-**38** as an inseparable mixture with 8α-**35** [R_f (5:1) = 0.33] as a colorless oil. ^{1}H NMR (400 MHz): δ = 0.00 (s, 6 H, SiCH$_3$), 0.83 (s, 9 H, SiCCH$_3$), 1.04 (br. s, 9 H, NCCH$_3$), 1.08 (br. s, 3 H, NCCH$_3$), 1.18 (d, J = 6.5 Hz, 3 H, CHCH$_3$), 1.27 (m, 1 H, CH$_2$CH$_2$CH$_2$), 1.38−1.46 (m, 5 H, CH$_2$CH$_2$CH$_2$), 1.40 (s, 9 H, OCCH$_3$), 1.82−2.05 (m, 2 H, CH$_2$CHOH), 2.09 (br. s, 1 H, OH), 2.32 (dd, J = 10.2, 6.9 Hz, 1 H, CHCO$_2$), 2.54 (dt, J = 10.2, 7.2 Hz, 1 H, =CHCHCHOSi), 4.00 (q, J = 6.5 Hz, 1 H, CHOSi), 4.23 (quint, J = 6.4 Hz, 1 H, CHON), 4.46 (m, 1 H, CHOH), 5.44 (dd, J = 15.5, 7.7 Hz, 1 H, =CHCHCHOSi), 5.55 (m, 1 H, =CHCHON). ^{13}C NMR (100 MHz): δ = −4.7 (q, SiCH$_3$), −4.6 (q, SiCH$_3$), 17.3 (t, NCCH$_2$CH$_2$), 18.0 (s, SiCCH$_3$), 20.3 (br. q, NCCH$_3$), 20.8 (br. q, NCCH$_3$), 21.0 (q, CHCH$_3$), 25.8 (q, SiCCH$_3$), 28.1 (q, OCCH$_3$), 40.2 (t, NCCH$_2$), 42.9 (t, CH$_2$CHOH), 53.6 (d, =CHCHCHOSi), 58.0 (d, CHCO$_2$), 73.2 (d, CHOH), 75.9 (d, CHOSi), 80.0 (d, CHON), 80.8 (s, OCCH$_3$), 129.5 (d, =CHCHCHOSi), 135.1 (d, =CHCHON), 172.9 (s, CO$_2$).

***tert*-Butyl (1*S**,2*R**,3*S**,5*S**)-3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[3-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-1-en-1-yl]cyclopentanecarboxylate (39):** Further flash chromatography (25:1) gave **39** as an inseparable mixture with 8β-**38** and 8α-**35** [R_f (5:1) = 0.33] as a colorless oil. Detectable resonances: ^{1}H NMR (400 MHz): δ = 0.80 (s, 9 H, SiCCH$_3$), 1.37 (s, 9 H, OCCH$_3$), 1.75 (m, 1 H, CH$_2$CHOH), 2.05 (m, 1 H, CH$_2$CHOH), 2.50 (br. s, 1 H, OH), 2.63 (t, J = 7.6 Hz, 1 H, CHCO$_2$), 2.94 (m, 1 H, =CHCHCHOSi), 4.17 (m, 1 H, CHON), 4.28 (m, 1 H, CHOSi), 4.69 (m, 1 H, CHOH), 5.40 (m, 1 H, =CHCHCHOSi), 5.51 (m, 1 H, =CHCHON). ^{13}C NMR (100 MHz): δ = 18.1 (s, SiCCH$_3$), 25.8 (q, SiCCH$_3$), 28.3 (q, OCCH$_3$), 41.7 (t, CH$_2$CHOH), 50.4 (d, =CHCHCHOSi), 56.4 (d, CHCO$_2$), 71.5 (d, CHOH), 73.4 (d, CHOSi), 79.8 (d, CHON), 80.6 (s, OCCH$_3$), 125.7 (d, =CHCHCHOSi), 136.7 (d, =CHCHON).

***tert*-Butyl (6*E*,8*E*)-5-(*tert*-Butyldimethylsilyloxy)-3-hydroxy-2-(2,2,6,6-tetramethylpiperidin-1-yloxy)deca-6,8-dienoate (40) and *tert*-Butyl 3-(*tert*-Butyldimethylsilyloxy)-5-hydroxy-2-[1-(2,2,6,6-tetramethylpiperidin-1-yloxy)but-2-en-1-yl]cyclopentanecarboxylate (41):** Flash chromatography (50:1) gave an inseparable diastereomeric mixture of two unassigned diastereomers **40** and **41** (configurations not assigned, due to strong signal overlap) [R_f (10:1) = 0.35] as a colorless oil. IR (film): $\tilde{\nu}$ = 3457 cm^{-1} (w), 2932 (m), 1734 (m), 1368 (m), 1256 (m), 1155 (m), 837 (m). UV: λ_{max} (lg ε) = 208 nm (4.14), 230 (4.44). **Major Diastereomer 40:** ^{1}H NMR

(400 MHz): δ = −0.05 (s, 3 H, $SiCH_3$), 0.00 (s, 3 H, $SiCH_3$), 0.81 (s, 9 H, $SiCCH_3$), 1.05−1.13 (m, 14 H), 1.36 (m, 4 H), 1.39 (s, 9 H, $OCCH_3$), 1.43−1.63 (m, 2 H, CH_2CHOSi), 1.67 (d, *J* = 6.6 Hz, 3 H, $=CHCH_3$), 2.70 (d, *J* = 3.6 Hz, 1 H, OH), 4.02 (d, *J* = 3.3 Hz, 1 H, CHON), 4.28−4.38 (m, 2 H, $CHCH_2CHOSi$), 5.43 (dd, *J* = 15.0, 6.4 Hz, 1 H, $=CHCHOSi$), 5.57 (dq, *J* = 14.6, 6.7 Hz, 1 H, $=CHCH_3$), 5.93 (ddd, *J* = 14.8, 10.5, 1.4 Hz, 1 H, $CH=CHCH_3$), 6.04 (dd, *J* = 14.9, 10.6 Hz, 1 H, $CH=CHCH_2$). ^{13}C NMR (100 MHz): δ = −5.0 (q, $SiCH_3$), −4.3 (q, $SiCH_3$), 17.1 (t, $NCCH_2CH_2$), 18.05 (s, $SiCCH_3$), 18.08 (q, $=CHCH_3$), 20.1 (br. q, $NCCH_3$), 20.6 (br. q, $NCCH_3$), 25.9 (q, $SiCCH_3$), 28.1 (q, $OCCH_3$), 33.5 (br. q, $NCCH_3$), 34.1 (br. q, $NCCH_3$), 40.4 (t, $CH_2CH_2CH_2$), 41.4 (t, CH_2CHOSi), 60.1 (br. s, ONC), 68.7 (d, CHOH), 70.0 (d, CHOSi), 81.5 (s, $OCCH_3$), 88.0 (d, CHON), 129.1 (d, $=CHCH_3$), 129.8 (d, $CH=CHCHOSi$), 131.0 (d, $CH=CHCH_3$), 133.6 (d, $=CHCHOSi$), 170.3 (s, CO_2). **Minor Diastereomer 40 (Detectable Resonances):** ^1H NMR (400 MHz): δ = −0.04 (s, 3 H, $SiCH_3$), −0.03 (s, 3 H, $SiCH_3$), 0.80 (s, 9 H, $SiCCH_3$), 1.41 (s, 9 H, $OCCH_3$), 2.80 (d, *J* = 3.6 Hz, 1 H, OH), 4.04 (d, *J* = 3.6 Hz, 1 H, CHON), 4.13 (m, 1 H, CHOH), 4.28−4.38 (m, 1 H, CHOSi), 5.43 (m, 1 H, $=CHCHOSi$), 5.57 (m, 1 H, $=CHCH_3$), 5.93 (m, 1 H, $CH=CHCH_3$), 6.03 (dd, *J* = 14.7, 10.6 Hz, 1 H, $CH=CHCH_2$). ^{13}C NMR (100 MHz): δ = −4.8 (q, $SiCH_3$), −4.1 (q, $SiCH_3$), 41.7 (t, CH_2CHOSi), 69.8 (d, CHOH), 72.3 (d, CHOSi), 81.5 (s, $OCCH_3$), 87.6 (d, CHON). **41:** ^1H NMR (400 MHz): δ = −0.04 (s, 3 H, $SiCH_3$), −0.01 (s, 3 H, $SiCH_3$), 0.81 (s, 9 H, $SiCCH_3$), 1.40 (s, 9 H, $OCCH_3$), 1.62 (dd, *J* = 6.3, 1.3 Hz, 3 H, $=CHCH_3$), 1.63 (m, 1 H, CH_2CHOH), 1.84 (br. d, *J* = 13.6 Hz, 1 H, CH_2CHOH), 2.75 (m, 2 H, $CHCHCHON$), 3.91 (dd, *J* = 9.4, 5.8 Hz, 1 H, CHON), 4.23 (m, 1 H, CHOH), 4.28−4.38 (m, 1 H, CHOSi), 5.25 (ddd, *J* = 15.2, 9.4, 1.4 Hz, 1 H, $=CHCHON$), 5.43 (m, 1 H, $=CHCH_3$). ^{13}C NMR (100 MHz): δ = −4.8 (q, $SiCH_3$), −4.7 (q, $SiCH_3$), 25.7 (q, $SiCCH_3$), 28.2 (q, $OCCH_3$), 43.4 (t, CH_2CHOH), 53.9 (d), 54.7 (d), 76.9 (d, CHOH), 77.2 (d, CHOSi), 80.1 (s, $OCCH_3$), 85.1 (d, CHON), 129.5 (d, $=CHCH_3$), 132.2 (d, $=CHCHON$), 171.1 (s, CO_2). MS: *m*/*z* (%) = 525 (2) [M^+], 510 (2), 468 (3), 452 (3), 412 (9), 369 (1), 313 (29), 295 (27), 257 (26), 239 (17), 211 (30), 197 (23), 165 (96), 156 (48) [TEMPO], 145 (53), 119 (33), 101 (30), 84 (42), 75 (100), 74 (60), 57 (76), 41 (43).

Table 2. Crystal data, data collection, and refinement parameters for **11b** and **23**

Compound	**11b**	**23**
Empirical formula	$C_{24}H_{41}NO_5$	$C_{23}H_{41}NO_4$
M_r	423.58	395.57
Crystal habit	colorless prism	colorless prism
Crystal size [mm]	0.36 × 0.22 × 0.19	0.58 × 0.36 × 0.34
Crystal system	triclinic	monoclinic
Space group	$P\bar{1}$	$P2_1/c$
Cell constants:		
a [pm]	927.65(10)	1585.5(3)
b [pm]	1145.27(14)	1242.4(3)
c [pm]	1186.92(14)	1257.6(2)
α [°]	98.597(3)	90
β [°]	101.010(3)	96.403(16)
γ [°]	95.100(3)	90
V [nm^3]	1.2149	2.4617
Z	2	4
D_x [Mg m^{-3}]	1.158	1.067
μ [mm^{-1}]	0.080	0.071
Transmissions		
F(000)	464	872
T [°C]	−90	−100
$2\theta_{max}$ [°]	56	50
No. of reflections:		
measured	7825	5393
unique	4945	4291
R_{int}	0.029	0.046
Parameters	278	265
Restraints	0	248
wR (F^2, all refl.)	0.130	0.151
R [$F, > 4\sigma(F)$]	0.047	0.059
S	1.03	0.84
max. Δρ [e $Å^3$]	0.37	0.27

X-ray Crystallographic Study of 11b and 23:[27] A summary of the crystal data, data collection, and refinement parameters for the two crystal structures reported in this paper is given in Table 2. **Structure Determination of 11b:** A cut prism was mounted on a glass fiber in inert oil and transferred to the cold gas stream of a Bruker SMART 1000 CCD diffractometer fitted with a Siemens LT-3 low-temperature attachment. Below 183 K the crystals shattered, presumably because of a phase change. Data were collected with the ω-scan method, using graphite-monochromated Mo-K_α radiation (λ = 71.073 pm). All unique data were used for calculations.[28] The structure was solved by direct methods and refined anisotropically by full-matrix, least squares on F^2. The hydrogen atoms were refined with a riding model or as rigid methyl groups. **Structure Determination of 23:** A cut prism was mounted in inert oil and measured by ω-scans using Mo-K_α radiation (graphite monochromator) with a Siemens P4 diffractometer fitted with an LT-2 low-temperature attachment. Because **23** diffracted more weakly, similarity restraints were applied to the *U* components. All other details as above, except for the freely refined hydroxy hydrogen atom.

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[1] Reviews: [1a] F. Marks, G. Fürstenberger, *Prostaglandins, Leukotrienes, and Other Eicosanoids*, Wiley-VCH, Weinheim, **1999**. [1b] P. W. Collins, S. W. Djuric, *Chem. Rev.* **1993**, *93*, 1533−1564. Isoprostanes: [1c] J. Rokach, S. P. Khanapure, S.-W. Hwang, M. Adiyaman, L. Schio, G. A. FitzGerald, *Synthesis* **1998**, 569−580 and cited ref. For other arachidonic acid derived constitutional isomers, see: [1d] D. F. Taber, Q. Jiang, *J. Org. Chem.* **2001**, *66*, 1876−1884 and cited ref. [1e] D. F. Taber, K. Kanai, R. Pina, *J. Am. Chem. Soc.* **1999**, *121*, 7773−7777.

[2] Reviews: [2a] R. C. Larock in *Studies in Natural Products Chemistry* (Ed.: Atta-ur-Rahman), Elsevier, Amsterdam, **1995**, vol. 16, p. 365−393. [2b] R. J. K. Taylor, S. G. Pyke, S. M. Pyke in *Rodd's Chemistry of Carbon Compounds, Second Supplement to the 2nd Edition*, vol. 2 ("Alicyclic Compounds") (Ed.: M. Sainsbury), Elsevier, Amsterdam, **1994**. [2c] R. Noyori, H. Koyano, M. Mori, R. Hirata, Y. Shiga, T. Kokura, M. Suzuki, *Pure Appl. Chem.* **1994**, *66*, 1999−2005. [2d] *New Synthetic Routes to Prostaglandins and Thromboxanes* (Eds.: S. M. Roberts, F. Scheinmann), Academic Press, London, **1982**. [2e] J. S. Bindra in *The Total Synthesis of Natural Products* (Ed.: J. ApSimon), Wiley, **1981**, vol. 4, p. 353−449. [2f] R. Noyori, M. Suzuki, *Chemtracts: Org. Chem.* **1990**, *3*, 173−197.

[3] [3a] U. Jahn, *J. Org. Chem.* **1998**, *63*, 7130−7131. [3b] U. Jahn, P. Hartmann, *Chem. Commun.* **1998**, 209−210. [3c] U. Jahn, P. Hartmann, I. Dix, P. G. Jones, *Eur. J. Org. Chem.* **2001**, 3333−3355.

[4] For previous, mainly tin-mediated, reductive radical approaches to the prostane skeleton, see: [4a] E. J. Corey, K. Shi-

moji, C. Shih, *J. Am. Chem. Soc.* **1984**, *106*, 6425−6427. [4b] E. J. Corey, C. Shih, N.-Y. Shih, K. Shimoji, *Tetrahedron Lett.* **1984**, *25*, 5013−5016. [4c] G. Stork, P. M. Sher, H.-L. Chen, *J. Am. Chem. Soc.* **1986**, *108*, 6384−6385. [4d] N. Ono, Y. Yoshida, K. Tani, S. Okamoto, F. Sato, *Tetrahedron Lett.* **1993**, *34*, 6427−6430. [4e] Y. Yoshida, N. Ono, F. Sato, *J. Org. Chem.* **1994**, *59*, 6153−6155. [4f] B. Rondot, T. Durand, J. P. Girard, J. C. Rossi, L. Schio, S. P. Khanapure, J. Rokach, *Tetrahedron Lett.* **1993**, *34*, 8245−8248. [4g] S. W. Hwang, M. Adiyaman, S. Khanapure, L. Schio, J. Rokach, *J. Am. Chem. Soc.* **1994**, *116*, 10829−10830. [4h] S.-W. Hwang, M. Adiyaman, S. P. Khanapure, J. Rokach, *Tetrahedron Lett.* **1996**, *37*, 779−782. [4i] J. Weiguny, H. J. Schäfer, *Liebigs Ann. Chem.* **1994**, 235−242. [4j] J.-P. Vionnet, P. Renaud, *Helv. Chim. Acta* **1994**, *77*, 1781−1790. [4k] F. E. Ziegler, A. K. Petersen, *Tetrahedron Lett.* **1996**, *37*, 809−812. [4l] A. Guy, T. Durand, J.-P. Vidal, J.-C. Rossi, *Tetrahedron Lett.* **1997**, *38*, 1543−1546. [4m] F. Belval, A. Fruchier, C. Chavis, J.-L. Montero, M. Lucas, *J. Chem. Soc., Perkin Trans. 1* **1999**, 697−703. [4n] M. Sannigrahi, D. L. Mayhew, D. L. J. Clive, *J. Org. Chem.* **1999**, *64*, 2776−2788. [4o] A. Roland, T. Durand, D. Egron, J.-P. Vidal, J.-C. Rossi, *J. Chem. Soc., Perkin Trans. 1* **2000**, 245−251. [4p] T. Durand, A. Guy, J.-P. Vidal, J. Viala, J.-C. Rossi, *Tetrahedron Lett.* **2000**, *41*, 3859−3862. [4q] J. Mulzer, A. K. Kermanchahi, J. Buschmann, P. Luger, *Liebigs Ann. Chem.* **1994**, 531−539. [4r] J. Mulzer, M. Czybowski, J.-W. Bats, *Tetrahedron Lett.* **2001**, *42*, 2961−2964.

[5] For radical cyclizations to 1,3-dienes, see: [5a] Ref.[4a,4b,4l][5b] S. Hanessian, D. S. Dhanoa, P. L. Beaulieu, *Can. J. Chem.* **1987**, *65*, 1859−1866. [5c] T. K. Hayes, R. Villani, S. M. Weinreb, *J. Am. Chem. Soc.* **1988**, *110*, 5533−5543. [5d] C. E. Schwartz, D. P. Curran, *J. Am. Chem. Soc.* **1990**, *112*, 9272−9284. [5e] D. P. Curran, A. C. Abraham, H. Liu, *J. Org. Chem.* **1991**, *56*, 4335−4337. [5f] E. Nakamura, T. Inubushi, S. Aoki, D. Machii, *J. Am. Chem. Soc.* **1991**, *113*, 8980−8982. [5g] W.-W. Weng, T.-Y. Luh, *J. Org. Chem.* **1993**, *58*, 5574−5575. [5h] J.-P. Dulcere, E. Dumez, R. Faure, *Synlett* **1996**, 391−392. [5i] P. Jones, W.-S. Li, G. Pattenden, N. M. Thomson, *Tetrahedron Lett.* **1997**, *38*, 9069−9072. [5j] D. P. Curran, J. Sisko, A. Balog, N. Sonoda, K. Nagahara, I. Ryu, *J. Chem. Soc., Perkin Trans. 1* **1998**, 1591−1593. [5k] M.-C. P. Yeh, F.-C. Wang, J.-J. Tu, S.-C. Chang, C.-C. Chou, J.-W. Liao, *Organometallics* **1998**, *17*, 5656−5662. [5l] T. Zoller, P. Breuilles, D. Uguen, A. De Cian, J. Fischer, *Tetrahedron Lett.* **1999**, *40*, 6253−6256. [5m] N. G. Halligan, R. F. Brown, D. O. Spry, L. C. Blaszczak, *Tetrahedron* **2000**, *56*, 5679−5685. [5n] J. Robertson, H. W. Lam, S. Abazi, S. Roseblade, R. K. Lush, *Tetrahedron* **2000**, *56*, 8959−8965. [5o] L. Fensterbank, E. Mainetti, P. Devin, M. Malacria, *Synlett* **2000**, 1342−1344. [5p] B. Patro, J. A. Murphy, *Org. Lett.* **2000**, *2*, 3599−3601.

[6] Prepared from the known alcohols by standard tosylation and subsequent malonate alkylation (Exp. Sect.).

[7] For preferred terminal allyl radical trapping by TEMPO in acyclic systems, see: [7a] M. K. Georges, G. K. Hamer, N. A. Listigovers, *Macromolecules* **1998**, *31*, 9087−9089. [7b] P. C. Venneri, J. Warkentin, *J. Am. Chem. Soc.* **1998**, *120*, 11182−11183. [7c] J. L. Pradel, B. Boutevin, B. Ameduri, *J. Polym. Sci. A: Polym. Chem.* **2000**, *38*, 3293−3302. [7d] J.-L. Pradel, B. Ameduri, B. Boutevin, *Macromol. Chem. Phys.* **1999**, *200*, 2304−2308. [7e] O. T. Magnusson, P. A. Frey, *J. Am. Chem. Soc.* **2000**, *122*, 8807−8813. [7f] B. C. Gilbert, W. Kalz, C. I. Lindsay, P. T. McGrail, A. F. Parsons, D. T. E. Whittaker, *J. Chem. Soc., Perkin Trans. 1* **2000**, 1187−1194. For preferred internal trapping, see: [7g] M. Ochiai, T. Ito, H. Takahashi, A. Nakanishi, M. Toyonari, T. Sueda, S. Goto, M. Shiro, *J. Am. Chem. Soc.* **1996**, *118*, 7716−7730.

[8] [8a] G. A. Olah, D. G. Parker, N. Yoneda, F. Pelizza, *J. Am. Chem. Soc.* **1976**, *98*, 2245−2250. [8b] K. Gollnick, A. Griesbeck, *Tetrahedron* **1984**, *40*, 3235−3250.

[9] Similar mass spectrometric results were obtained for other compounds, see: H. Schwarz, H.-M. Schiebel in *The Chemistry of Peroxides* (Ed.: S. Patai), Wiley, Chichester, **1983**, p. 105−127.

[10] Rate constants for TEMPO trapping of simple alkyl radicals decrease in the order: primary > secondary > tertiary. The rate constant for trapping of a single reported 1,3,3-trisubstituted allyl radical is around two orders of magnitude lower than those for alkyl radicals, but unfortunately, the regioselectivity of trapping was not reported: V. W. Bowry, K. U. Ingold, *J. Am. Chem. Soc.* **1992**, *114*, 4992−4996.

[11] [11a] W. Adam, O. Emmert, *J. Org. Chem.* **2000**, *65*, 4127−4130. [11b] W. Adam, O. Emmert, T. Heidenfelder, *J. Org. Chem.* **1999**, *64*, 3417−3421.

[12] D. L. Boger, R. M. Garbaccio, Q. Jin, *J. Org. Chem.* **1997**, *62*, 8875−8891.

[13] The formation of **19b** should be restricted to this malonate since a single ester functionality may not be sufficient to induce ring-opening to a ketene acetal.

[14] U. Jahn, M. Müller, S. Aussieker, *J. Am. Chem. Soc.* **2000**, *122*, 5212−5213 and cited ref.

[15] For opportunities to correct the configuration of the unnatural C-8 diastereomer, see the following review: H. Sailes, A. Whiting, *J. Chem. Soc., Perkin Trans. 1* **2000**, 1785−1805.

[16] J. Krüger, E. M. Carreira, *J. Am. Chem. Soc.* **1998**, *120*, 837−838.

[17] D. P. Curran in *Comprehensive Organic Synthesis* (Eds.: B. M. Trost, I. Fleming), Pergamon Press, Oxford, **1991**, vol. 4, p. 779−832.

[18] Reviews on enolate structures in the solid state: [18a] D. Seebach, A. K. Beck, A. Studer, *Modern Synthetic Methods*, VCH, Weinheim, **1995**, vol. 7, p. 3−178. [18b] D. Seebach, *Angew. Chem.* **1988**, *100*, 1685−1715; *Angew. Chem. Int. Ed. Engl.* **1988**, *27*, 1624. In solution: [18c] L. M. Jackman, J. Bortiatynski in *Advances in Carbanion Chemistry* (Ed.: V. Snieckus), JAI Press, Greenwich, **1992**, vol. 1, p. 45−87. [18d] L. M. Jackman, B. C. Lange, *Tetrahedron* **1977**, *33*, 2737−2769. [18e] E. Juaristi, A. K. Beck, J. Hansen, T. Matt, T. Mukhopadhyay, M. Simson, D. Seebach, *Synthesis* **1993**, 1271−1290.

[19] Precedents: K. W. Henderson, A. E. Dorigo, Q.-Y. Liu, P. G. Williard, P. von Rague-Schleyer, P. R. Bernstein, *J. Am. Chem. Soc.* **1996**, *118*, 1339−1347.

[20] This is rather surprising, but the failure to detect the C-8 diastereomers may be due to their small amounts.

[21] D. P. Curran, N. A. Porter, B. Giese, *Stereochemistry of Radical Reactions*, VCH, Weinheim, **1996**, p. 50−51.

[22] Reviews: [22a] P. Renaud, M. Gerster, *Angew. Chem.* **1998**, *110*, 2704−2722; *Angew. Chem. Int. Ed.* **1998**, *37*, 2562−2579. [22b] Y. Guindon, B. Guerin, J. Rancourt, C. Chabot, N. Mackintosh, W. W. Ogilvie, *Pure Appl. Chem.* **1996**, *68*, 89−96. [22c] Y. Guindon, G. Jung, B. Guerin, W. W. Ogilvie, *Synlett* **1998**, 213−220.

[23] P. Renaud, L. Andrau, K. Schenk, *Synlett* **1999**, 1462−1464.

[24] [24a] A. L. J. Beckwith, C. H. Schiesser, *Tetrahedron* **1985**, *41*, 3925−3941. [24b] D. C. Spellmeyer, K. N. Houk, *J. Org. Chem.* **1987**, *52*, 959−974.

[25] Y. Motoyama, H. Nishiyama in *Lewis Acids in Organic Synthesis* (Ed.: H. Yamamoto), Wiley-VCH, Weinheim, **2000**, vol. 1, p. 59−88.

[26] R. Devant, U. Mahler, M. Braun, *Chem. Ber.* **1988**, *121*, 397−406.

[27] Crystallographic data for the structure reported in this paper have been deposited with the Cambridge Crystallographic Data Centre as supplementary publication no. CCDC-167063 (**11b**) and -167064 (**23**). Copies of the data can be obtained free of charge on applicaton to CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: (internat.) + 44-1223/336-033; E-mail: deposit@ccdc.cam.ac.uk].

[28] G. M. Sheldrick, *SHELXL-97, program for crystal structure refinement*, University of Göttingen, Germany, **1997**.

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