*Tetrahedron* Vol. 48, No. 29, pp. 6021-6032, 1992
Printed in Great Britain

0040-4020/92 $5.00+.00
Pergamon Press Ltd

# Synthesis of Nonenolizable 6-Hydroxy-2,4-cycloheptadien-1-ones

**Ingo Stohrer and H. Martin R. Hoffmann***

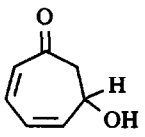
Department of Organic Chemistry, University of Hannover,
Schneiderberg 1 B, 3000 Hannover, Germany

(*Received in Germany* 24 *April* 1992)

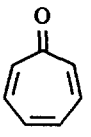
**Abstract** - 8-Oxabicyclo[3.2.1]oct-6-en-3-ones **3** with a quaternary centre adjacent to the carbonyl group have been converted into 6-hydroxy-2,4-cycloheptadien-1-ones **1** with zirconium tetrachloride/piperidine (1:1).

The title compounds have hitherto hardly been known. Only 6-hydroxy-2,4-cycloheptadien-1-one (**1a**) was obtained by [6+2] cycloaddition of singlet oxygen to cycloheptatriene followed by careful chromatography.[1a-c] The more stable complex **1a**-$Fe(CO)_3$ has also been described.[2]

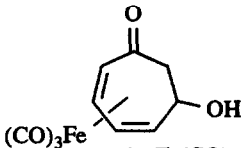
Compound **1a** has been reported to suffer rapid loss of water with formation of tropone (**1a** → **2a**).[1]




**1a**

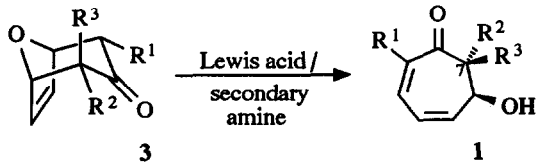



**2a**




**1a**-$Fe(CO)_3$

We here describe a variety of 7,7-dialkylated 6-hydroxy-2,4-cycloheptadien-1-ones (**1**) which were prepared in one step from 8-oxabicyclo[3.2.1]oct-6-en-3-ones (**3**).[3]



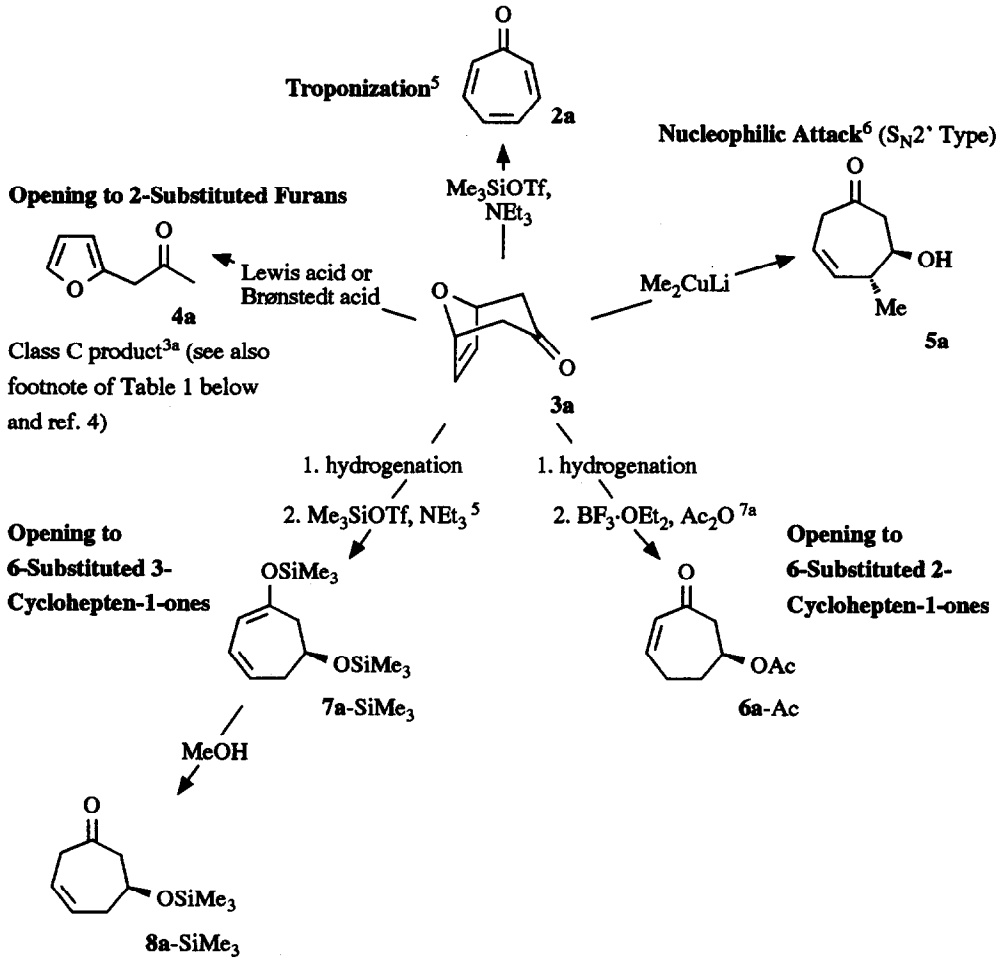

**3** **1**

| Conversion[a] | Substituents $R^1$, $R^2$, and $R^3$ |
|---|---|
| **3b** → **1b** | $R^1 = R^2 = R^3 = CH_3$ |
| **3e** → **1e** | $R^1 \frown R^2 = -(CH_2)_9-$, $R^3 = CH_3$ |
| **3g** → **1g** | $R^1 = H$, $R^2 = R^3 = CH_3$ |
| **3h** → **1h** | $R^1 = H$, $R^2 \frown R^3 = -(CH_2)_5-$ |
| **3i** → **1i** | $R^1 = H$, $R^2 \frown R^3 = -(CH_2)_4-$ |

[a] For reactions of **3a, c, d** and **f** see text.

**Scheme 1**

**Results and Discussion.** Bicyclic compounds **3** are known to enter into a variety of useful transformations, which are briefly summarized as follows.

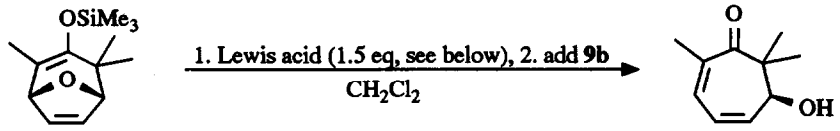



**Scheme 2**: Reaction Modes of Oxabicyclic Compound **3a**.

Thus, the direct transformation of **3** into **1** has to contend with a number of competing reactions, especially the facile heteroaromatization (e.g. **3a** → **4a**).[3a] The opening of the ether bridge in **3** to simple hydroxyketones (**3** → **6** and **8**) requires hydrogenation of bicyclic compounds **3** in the first step. As an alternative to Noyori's approach[7a] (**3a** → **6a**-Ac), a combination of $Me_3SiI$ and NaI[7b] or KI[7c] was reported to yield unprotected 6-hydroxy-2-cyclohepten-1-ones. The same result has been obtained if $BBr_3$[7d] or a stepwise procedure ($Me_3SiI$ followed by the addition of DBU)[7c] was chosen to cleave the oxygen bridge. However, the hitherto unknown products **1** proved to be quite sensitive and had never been observed in reactions of bicyclic compounds **3**. For example, dialkyl cuprates do not induce enolization and opening of the ether bridge. Instead, **3a** is converted into monocyclic **5a**.[6b]

We found that treatment of vinylogous trimethysilyl lactol ether **9b** with $TiCl_4/Me_2CO$ (Mukaiyama conditions[8]) gave **1b** (55%) after aqueous work up. Systematic variation of the Lewis acid showed that $TiCl_4$ and especially $ZrCl_4$ were most efficient for the ether cleavage of **9b** (Table 1).

**Table 1.** Opening of Bisallylically Activated Ether Bridge in **9b**.



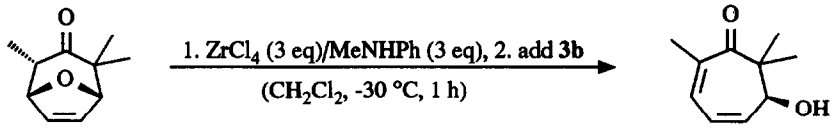

**9b** **1b**

| Lewis acid | Reaction conditions | Yield [%] | Lewis acid | Reaction conditions | Yield [%] |
|---|---|---|---|---|---|
| $BF_3{\cdot}OEt_2$ | -30 °C, 4 h | 48 | $SnCl_4$ | -95 °C, 30 min | 63 (22)[a] |
| $AlCl_3$ | -78 °C, 30 min | 42 (43)[a] | $NbCl_5$ | -78 °C, 30 min | 43 (27)[a] |
| $CeCl_3$ | r.t., 16 h | 2 [b] | $WCl_6$ | -95 °C, 15 min | 53 (19)[a] |
| $TiCl_4$ | -95 °C, 30 min | 81 (7)[a] | $ZnCl_2{\cdot}OEt_2$ | r.t., 10 h | 17 (21)[a] |
| $Ti(O\text{-}iPr)_2Cl_2$ | r.t., 16 h | 8 [b] | CuCl | r.t., 16 h | --- |
| $ZrCl_4$ | -78 °C, 30 min | 93 | $FeCl_3$ | r.t., 4 h | 16 [b] |

[a] Figure in brackets refers to yield of **4b** and **4b'** (**4b** : **4b'** ~ 2.5 : 1). [b] Mainly starting material recovered.


**4b** **4b'**

In contrast, the precursor of vinylogous acetal **9b**, i.e. bicyclic keto ether **3b**, reacted with $ZrCl_4$ to **4b** and **4b'** (class C products[3a]). Clearly, enolization is necessary to facilitate cleavage of the ether bridge. We therefore treated a 1:1 complex of N-methylaniline and $ZrCl_4$ [9] with **3b** in dichloromethane. Under these conditions (1 h, -30 °C) **1b** was generated in 71% yield. For the axial epimer **3bβ** of **3b**, enolization is stereoelectronically unfavourable and **1b** was obtained in only 6%.

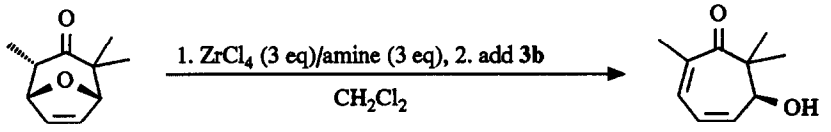



**Scheme 3** **3b** **1b**

Because of the obvious importance of enolization we investigated a variety of tertiary, secondary and primary amines in combination with $ZrCl_4$ (Table 2). Secondary amines gave best results. They showed the best compromise of basicity to abstract the acidic proton in **3b** and reactivity of the $ZrCl_4$/amine complex formed. The amines tried included aromatic and heteroaromatic systems, which enter into charge transfer

interactions. 4-Dimethylaminopyridine (DMAP) and 1,4-diazabicyclo[2.2.2]octane (DABCO) have also nucleophilic properties. Piperidine and N-methylaniline proved optimum.

**Table 2.** Effect of Amine on Ether Cleavage.

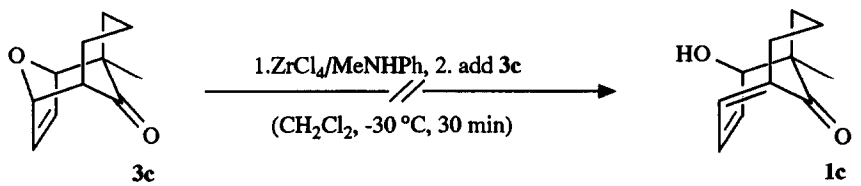



**3b** **1b**

| Amine | Amine type | Reaction conditions | Yield [%] |
|---|---|---|---|
| triethylamine | tertiary | -78 °C, 30 min | 43 |
| N-ethyl-di-*iso*-propylamine | tertiary | -30 °C, 30 min | 22 |
| pyridine | tertiary | 0 °C, 30 min | 10 |
| DMAP | tertiary | r.t., 16 h | --- |
| DABCO | tertiary | r.t., 2.5 h | 30 |
| 2,6-di-*tert*-butyl-4-methylpyridine | tertiary | r.t., 4 h | 2 |
| $Me_2NCH_2CH_2NMe_2$ (TMEDA) | tertiary (1.5 eq) | r.t., 16 h | 2 (28)[a] |
| diethylamine | secondary | -30 °C, 40 min | 64 |
| di-*iso*-propylamine | secondary | -30 °C, 1 h | 40 |
| piperidine | secondary | -30 °C, 1.5 h | 79 |
| pyrrolidine | secondary | -30 °C, 2 h | 48 |
| N-methylaniline | secondary | -30 °C, 1 h | 71 |
| piperazine | secondary (1.5 eq) | r.t., 16 h | 37 |
| *n*-butylamine | primary | r.t., 2 h | 39 |
| aniline | primary | 0 °C, 1 h | 46 |
| DBU | amidine | r.t., 16 h | 13 |
| imidazole | | r.t., 16 h | --- (44)[a] |

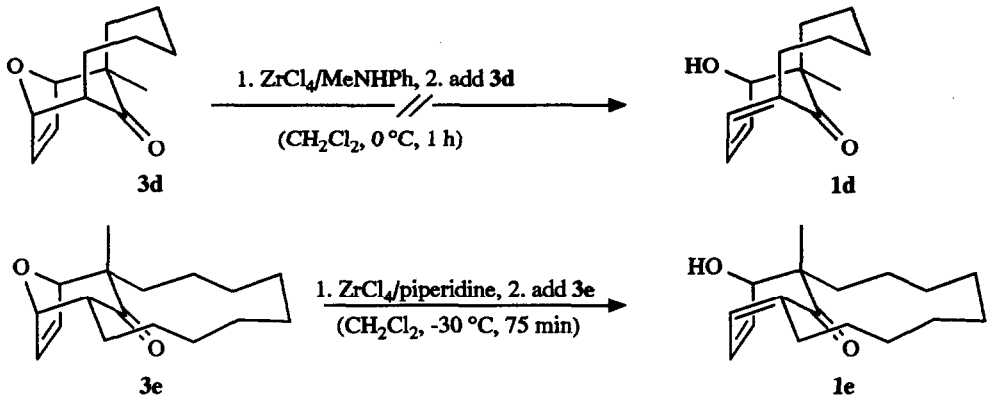
[a] Figure in brackets refers to yield of substituted furans **4b** and **4b'**.

Scope and Limitations. As expected cage keto ethers **3c** and **3d** reacted unspecifically (see reaction of **3bβ** to **1b**). In the case of **3c**, the derived enolate would violate Bredt's rule. However, more flexible tricyclic ketone **3e** furnished **1e**.




**3c** **1c**

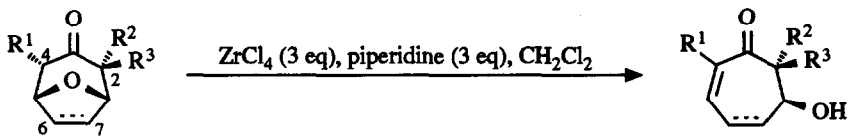
**Scheme 4**




**Scheme 5**

Enolization is feasible in the bicyclic ketone **3f** (Table 3) on either side of the carbonyl group, therefore troponization is possible and, in fact, 2,7-dimethyltropone **2f** was isolated in 54% yield. Derivatives with alkyl groups at C-4 ($R^1$ = Me, $-(CH_2)_n-$) reacted less readily than **3g** and **10g** (Table 3). The spiroannulation in **3h** and **3i** seemed to lower the yields of bicyclic products **1h** and **1i** to ca. 50%. However, in these two

**Table 3.** Summary of Results.




| Reaction | $R^1$ | $R^2$ | $R^3$ | Bond C-6/C-7 | Reaction conditions | Yield [%] |
|---|---|---|---|---|---|---|
| **3b** → **1b** | Me | Me | Me | double | -30 °C, 1.5 h | 79 |
| **3c** ↛ **1c** | $-(CH_2)_3-$[a] | Me[a] | | double | cf. Schemes 4 and 5 | -- |
| **3d** ↛ **1d** | $-(CH_2)_5-$[a] | Me[a] | | double | cf. Schemes 4 and 5 | -- |
| **3e** → **1e** | $-(CH_2)_9-$ | | Me | double | -30 °C, 1.5 h | 58 |
| **3f** → **2f** | Me | Me | H | double | -30 °C, 1.5 h | 55[b] |
| **3g** → **1g** | H | Me | Me | double | -78 °C, 1 h | 84 |
| **3h** → **1h** | H | $-(CH_2)_5-$ | | double | -30 °C, 1 h[c] | 48 |
| **3i** → **1i** | H | $-(CH_2)_4-$ | | double | -30 °C, 1 h[c] | 41 |
| **10b** → **6b** | Me | Me | Me | single | -30 °C, 1.5 h | 69 |
| **10f** → **6f** | Me | Me | H | single | -30 °C, 1.5 h | 49 |
| **10g** → **6g** | H | Me | Me | single | -30 °C, 1 h | 62 |

[a] $R^1$ and $R^2$ axial, $R^3$ equatorial. [b] Yield of 2,7-dimethyltropone (**2f**).

[c] Quality of $ZrCl_4$ was not optimal.[10]

instances, the quality of $ZrCl_4$ used was not optimal.[10] The hydrogenated bicyclic keto ethers **10** were less reactive than their unsaturated precursors **3**. Zirconium tetrachloride/piperidine mediated opening furnished conjugated 6-hydroxy-cyclohepten-1-ones **6**. Although monocycle **6f** is enolizable, consecutive loss of $H_2O$ was not observed. The conversion of **3b** into **1b** and of **3f** into **2f** was also scaled up (50 mmol) without drop in yield (80% for **3b** and 54% for **3f**).

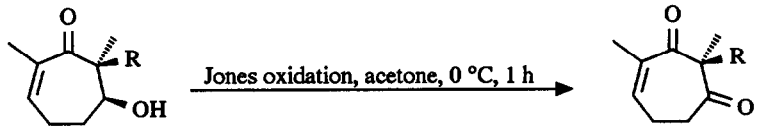
Solvent Effects. Dichloromethane and also toluene gave the highest yield of product **1b**. Because of their high melting point, benzene and $CCl_4$ were less suitable. In isopentane the initially formed $ZrCl_4$/piperidine complex turned lumpy and only a small amount of **1b** was isolable (Table 4).

**Table 4.** Solvent Effects on Opening (**3b** →**1b**).

| Solvent | Reaction conditions | Yield [%] |
|---|---|---|
| $CCl_4$ | r.t., 4 h | 39 |
| $CH_2Cl_2$ | -30 °C, 1.5 h | 79 |
| toluene | -30 °C, 1.5 h | 76 |
| benzene | 10 °C, 20 min | 68 |
| isopentane | r.t., 16 h | 5 |

Reaction Mechanism. We propose that enolization of the ketone, with $ZrCl_4$ and piperidine is crucial. Push-pull opening of the bi- or tricyclic ether furnishes a zirconium alkoxide with a strong Zr-O bond. Although a Zr-O bond is longer (2.10 - 2.15 Å) than a Ti-O bond (1.68 - 1.78 Å), it is nonetheless **stronger** (by ca. 16%).[11] The **free** 6-hydroxy-2,4-cycloheptadien-1-ones (**1**) are only released after aqueous work up (TLC monitoring).

Oxidation of 6-Hydroxy-2-cyclohepten-1-ones (**6**). Jones oxidation of **6b,f** yielded 4-cycloheptene-1,3-diones **11b,f**. Under these conditions[12], loss of $H_2O$ from **6f** with formation of the cross-conjugated dienone did not take place. Instead enedione **11f** was isolated; enolization of the 1,3-dicarbonyl system was not observed.




**6b** (R = Me) **11b** (R = Me, 83%)

**Scheme 6** **6f** (R = H) **11f** (R = H, 81%)

Conclusion. $ZrCl_4$[10]/piperidine mediated opening of 8-oxabicyclo[3.2.1]oct-6-en-3-ones (**3**) at -30 °C in $CH_2Cl_2$ represents a breakthrough in methodology to obtain the title compounds **1**. The reactions have also been scaled up in two instances. The facile 1,5-hydrogen shift in **1** is described elsewhere.[13]

## EXPERIMENTAL

*General Remarks.* Melting points are uncorrected. Infrared (IR) spectra were determined on a Perkin-Elmer FT 1710 or Bruker IFS 25. Nuclear magnetic resonance (NMR) spectra were recorded with a Bruker WP 200 SY. APT (attached proton test): Spin echo based selection of multiplicities of $^{13}C$ signals. Quaternary C and $CH_2$ carbon atoms give positive signals (↑), while CH and $CH_3$ give negative signals (↓).[14] Mass spectral data (MS) were measured on a Finnigan MAT 312 (70 eV).

*1-Methyl-13-oxatricyclo[5.4.1.1$^{8,11}$]tridec-9-en-12-one* (**3d**). A two-necked flask equipped with reflux condenser and dropping funnel with septum was charged with Cu powder (2.86 g, 45 mmol) and NaI (8.99 g, 60 mmol). The apparatus was heated externally (blow-dryer) while being flushed internally with $N_2$. After cooling to r.t. MeCN (22.5 mL) was added. 2,7-Dibromo-2-methyl-cyclooctanone (4.5 g, 15 mmol) and furan (4.08 g, 4.4 mL, 60 mmol) were filled up to 11 mL (MeCN) and added dropwise to the well-stirred suspension within 90 min. After stirring overnight, the mixture was diluted with 15 mL of $H_2O$, stirred for additional 30 min and suction-filtered through silica gel. After removal of the solvent, the residue was dissolved in $CHCl_3$ (30 mL) and washed with concd. aq. $NH_3$ (3 x 15 mL) and brine (15 mL). The organic phase was dried ($MgSO_4$), freed from solvent and chromatographed (MTBE/cyclohexane, 1:6) to give **3d**, 402 mg (13%), waxy crystals, mp 66 °C: IR ($CHCl_3$) 3000, 2932, 2864, 1700, 1452, 1380, 1116, 1096 cm$^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.32, 6.28 (2dd, $^3J$ = 6 Hz, $^3J$ = 1.5 Hz, 2H, olef H), 4.65 (dd, $^3J$ = 1.5 Hz, $^3J$ = 0.5 Hz, H-8), 4.42 (d, $^3J$ = 1.5 Hz, H-11), 2.17 - 1.98, 1.95 - 1.13 (2m, 13H, $CH_2$, H-7), 0.87 (s, $CH_3$); $^{13}C$ NMR (APT, $CDCl_3$) δ 215.24 (↑, C=O), 134.52, 133.44 (2↓, olef C), 85.34, 81.91 (2↓, C-O), 55.80 (↑, C-1), 54.26 (↓, C-7), 37.37, 31.52, 25.48, 24.82, 23.51 (5↑, $CH_2$), 19.87 (↓, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 207 (10), 206 ($M^+$, 71), 191 (6), 163 (14), 137 (45), 135 (14), 121 (33), 112 (88), 108 (31), 107 (23), 95 (77), 81 (92), 79 (32), 69 (28), 68 (21), 67 (51), 55 (41), 41 (100); exact mass calcd for $C_{13}H_{18}O_2$: 206.1307, found 206.1306.

*1-Methyl-17-oxatricyclo[9.4.1.1$^{12,15}$]heptadec-13-en-16-one (Cee 12)* (**3e**). To a solution of LDA (1.1 mmol) in THF (10 mL) was added 17-oxatricyclo[9.4.1.1$^{12,15}$]heptadec-13-en-16-one (Cee 12)[15] (248 mg, 1 mmol) in THF (5 mL) at -5 °C. The mixture was stirred for 1 h at -5 °C, then MeI (156 mg, 70 µl, 1.1 mmol) was added. After 1 h at r.t. the mixture was diluted with water (10 mL). The aqueous phase was extracted with $Et_2O$ (4 x 20 mL), the combined organic phases dried ($MgSO_4$) and evaporated. The crude product was purified by flash chromatography (MTBE/cyclohexane, 1:50) to give **3e**, 213 mg (81%), yellow oil: IR ($CHCl_3$) 3000, 2932, 2852, 1696, 1468, 1444, 1372, 1120, 1036, 916 cm$^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.47, 6.43 (2dd, $^3J$ = 6 Hz, $^3J$ = 1.5 Hz, 2H, olef H), 4.89 (dd, $^3J$ = 7.5 Hz, $^3J$ = 1.5 Hz, H-12), 4.46 (d, $^3J$ = 1.5 Hz, H-15), 2.82 - 2.67 (m, H-11), 1.63 - 0.93 (m, 18H, $CH_2$), 1.26 (s, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 263 (21), 262 ($M^+$, 100), 247 (4), 233 (4), 205 (4), 177 (4), 150 (16), 149 (11), 122 (13), 121 (25), 108 (17), 107 (15), 95 (93), 93 (17), 81 (34), 79 (22), 69 (28), 67 (31), 65 (8), 55 (46), 53 (16); exact mass calcd for $C_{17}H_{26}O_2$: 262.1933, found 262.1933.

*Spiro(8-oxabicyclo[3.2.1]oct-6-en-2,1'cyclopentan)-3-one* (**3i**). To zinc powder (3.92 g, 60 mmol), CuI (590 mg, 6 mmol) and furan (4.08 g, 4.4 mL, 60 mmol) in THF (20 mL) were added corresponding dibromoketone (5.4 g, 20 mmol) in THF (10 mL) and $Me_3SiCl$ (2.6 g, 3 mL, 24 mmol) at 0 °C. The mixture was stirred for 3 h at 0 °C and 3 h at r.t., hydrolysed with 1N HCl (5 mL) (30 min) and then filtered through silica gel. The filtrate was separated and the aqueous layer was extracted with $CHCl_3$ (30 mL). The combined organic phases were washed with sat. aq. $NaHCO_3$ solution and dried ($MgSO_4$). After removal of the solvent

purification by flash chromatography ($Et_2O$/PE, 1:3) gave **3i**, 1.5 g (42%), crystals, mp 39 - 40 °C: IR ($CHCl_3$) 3000, 2960, 2908, 2872, 1704, 1448, 1340, 1088, 1040, 968, 944, 888 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.31, 6.26 (2dd, $^3J$ = 6 Hz, $^3J$ = 1 Hz, 2H, olef H), 4.99 (ddd, $^3J$ = 5 Hz, $^3J$ = 1 Hz, $^3J$ = 1 Hz, H-5), 4.51 (d, $^3J$ = 1 Hz, H-1), 2.84 (dd, $^2J$ = 16 Hz, $^3J$ = 5 Hz, H-4β), 2.20 (dd, $^2J$ = 16 Hz, $^3J$ = 1 Hz, H-4α), 2.21 - 1.51 and 1.18 - 0.99 (2m, 7+1H, 5-ring $CH_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 209.95 (↑, C=O), 134.61, 132.70 (2↓, olef C), 85.17 (↓, C-1), 78.02 (↓, C-5), 63.34 (↑, spiro C), 43.98 (↑, $CH_2CO$), 36.50, 29.66, 26.24, 25.45 (4↑, 5-ring $CH_2$); MS (r.t.) *m/z* (rel. intensity) 179 (7), 178 ($M^+$, 61), 150 (5), 136 (2), 135 (5), 121 (7), 110 (70), 97 (51), 96 (100), 95 (24), 82 (92), 81 (45), 68 (49), 67 (45), 53 (25); exact mass calcd for $C_{11}H_{14}O_2$: 178.0994, found 178.0994.

*2,4,4-Trimethyl-3-trimethylsiloxy-8-oxabicyclo[3.2.1]octa-2,6-diene* (**9b**). Cycloadduct **3b**[16a,b] (1.5 g, 9 mmol) in THF (5 mL) was treated with LDA (9.9 mmol) in THF (10 mL) at -5 °C under $N_2$. After stirring for 1 h $Me_3SiCl$ (970 mg, 1.15 mL, 9 mmol) was added and stirring was continued for 1 h at r.t. The solvent was removed carefully (LiCl precipitate) to afford a white suspension. Kugelrohr distillation (70 °C, 0.05 torr) yielded a light-yellow, water-sensitive oil (1.80 g, 84%). $^1H$ NMR ($CD_2Cl_2$) δ 6.64 (dd, $^3J$ = 6 Hz, $^3J$ = 1.8 Hz, H-7), 5.97 (dd, $^3J$ = 6 Hz, $^3J$ = 2.3 Hz, H-6), 4.42 (d, $^3J$ = 1.8 Hz, H-1), 4.39 (d, $^3J$ = 2.3 Hz, H-5), 1.55 (s, $CH_3$), 1.20 (s, axial $CH_3$), 0.75 (s, equatorial $CH_3$), 0.16 (s, $OSi(CH_3)_3$).

*Opening of* **9b** *with various Lewis acids.* To a solution of Lewis acid (3 mmol) ($BF_3{\cdot}OEt_2$, $AlCl_3$, $CeCl_3$, $Ti(O\text{-}iPr)_2Cl_2$, $ZrCl_4$, $NbCl_5$, $ZnCl_2{\cdot}OEt_2$, CuCl or $FeCl_3$) in $CH_2Cl_2$ (5 mL) was added at -78 °C, respectively -95 °C ($TiCl_4$, $SnCl_4$, $WCl_6$), enol ether **9b** (240 mg, 1 mmol) in $CH_2Cl_2$ (5 mL) under $N_2$ atmosphere. For reaction conditions see Table 1. After complete reaction sat. aq. $NH_4Cl$ solution (5 mL) was added. Water (5 mL) was added at 0 °C to dissolve the precipitate. The aqueous layer was extracted with $CH_2Cl_2$ and the combined organic phases were dried ($MgSO_4$). After evaporation flash chromatography (MTBE/cyclohexane, 1:5) yielded 1 or 2 fractions. The first, when formed, contained **4b** and **4b'** (isomeric ratio, ca. 2.5:1), the second, more polar, the desired product **1b** (yields are indicated in Table 1).

*2-(2'-Furyl)-4-methylpentan-3-one* (**4b**) *and 2-(2'-Furyl)-2-methylpentan-3-one* (**4b'**). The furans were formed with the following Lewis acids: $AlCl_3$ (43%), $TiCl_4$ (7%), $SnCl_4$ (22%), $NbCl_5$ (27%), $WCl_6$ (19%), $ZnCl_2{\cdot}OEt_2$ (21%). Data for **4b**[17]: $^1H$ NMR ($CDCl_3$) δ 7.34 (dd, $^3J$ = 2 Hz, $^4J$ = 1 Hz, H-5'), 6.34 (m, H-4'), 6.14 (ddd, $^3J$ = 3.5 Hz, $^4J$ = 1 Hz, $^4J$ = 1 Hz, H-3'), 3.99 (dq, $^3J$ = 7 Hz, $^4J$ = 1 Hz, $CHCH_3$), 2.79 (sept, $^3J$ = 7 Hz, $CH(CH_3)_2$), 1.40 (d, $^3J$ = 7 Hz, $CHCH_3$), 1.06, 1.00 (2d, $^3J$ = 7 Hz, $CH(CH_3)_2$). Data for **4b'**: $^1H$ NMR ($CDCl_3$) δ 7.37 (dd, $^3J$ = 2.5 Hz, $^4J$ = 1 Hz, H-5'), 6.34 (m, H-4'), 6.18 (dd, $^3J$ = 3 Hz, $^4J$ = 1 Hz, H-3'), 2.28 (q, $^3J$ = 7.5 Hz, $CH_2$), 1.57, 1.45 (2s, $C(CH_3)_2$), 0.88 (t, $^3J$ = 7.5 Hz, $CH_2CH_3$).

*Axial epimer of* **3b**. *2,2,4β-Trimethyl-8-oxabicyclo[3.2.1]oct-6-en-3-one* (**3bβ**). Cycloadduct **3g**[16a,c] (6 mmol) was treated with LDA and MeI as described for the preparation of **3e**. Flash chromatography (MTBE/cyclohexane, 1:9) gave 824 mg **3bβ** (83%), colorless oil. For spectroscopic data see ref. 16a.

*General procedure for the opening of* **3** *with* $ZrCl_4$ *and piperidine.* To a suspension of $ZrCl_4$ (2.1 g, 9 mmol) in abs. $CH_2Cl_2$ (20 mL) was added piperidine (890 µl, 9 mmol) at -78 °C under $N_2$ (toluene instead of $CH_2Cl_2$ and N-methylaniline instead of piperidine can be used, if the reaction product is not a tropone). The resulting mixture was stirred for 10 min, then the cycloadduct (3 mmol) in $CH_2Cl_2$ (5 mL) was added slowly. Reaction conditions: 1 to 1.5 h, -30 °C (hydrogenated cycloadducts, α,α'-alkylated cycloadducts) or -78 °C (α- and/or α'-unsubstituted cycloadducts). After complete reaction saturated aq. $NH_4Cl$ solution was added at -20 °C followed by water (10 mL) to dissolve the precipitate. The aqueous layer was extracted with $CH_2Cl_2$

(3 x 20 mL). Drying ($MgSO_4$), removal of the solvent and chromatography or distillation (2,7-dimethyltropone **2f**, bp 50 °C, 0.05 torr) gave the pure product **1** (or **2**, if a tropone is the reaction product).

*6-Hydroxy-2,7,7-trimethylcyclohepta-2,4-dienone* (**1b**). Cycloadduct **3b**[16a,b] (500 mg, 3 mmol) was allowed to react according to the general procedure. Reaction conditions: 1.5 h, -30 °C. Flash chromatography (MTBE/cyclohexane, 1:5) afforded **1b**, 394 mg (79%) [scale up: **3b** (8.31 g, 50 mmol) → **1b** (6.66 g, 80%)]: IR (cap. film) 3480, 3032, 2976, 2934, 2875, 1724, 1695, 1652, 1466, 1380, 1241, 1065, 1044, 1012, 743 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.38 (ddq, $^3J$ = 6 Hz, $^4J$ = 1 Hz, $^4J$ = 0.5 Hz, C*H*=C($CH_3$)CO), 6.12 (ddd, $^3J$ = 11 Hz, $^3J$ = 5 Hz, $^4J$ = 0.5 Hz, CH=C*H*CHOH), 5.94 (ddq, $^3J$ = 11 Hz, $^3J$ = 6 Hz, $^5J$ = 0.5 Hz, C*H*=CHCHOH), 4.32 (d, $^3J$ = 5 Hz, C*H*OH), 2.07 br (OH), 1.97 (dd, $^4J$ = 1 Hz, $^5J$ = 0.5 Hz, $CH_3$), 1.21, 1.15 (2s, C($CH_3$)$_2$); $^{13}C$ NMR ($CDCl_3$) δ 206.32 (s, C=O), 139.37 (s, CH=*C*($CH_3$)CO), 138.92, 131.31, 124.03 (3d, other olef C), 73.49 (d, CHOH), 56.20 (s, *C*($CH_3$)$_2$), 23.58, 21.88, 18.12 (3q, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 167 (3), 166 ($M^+$, 23), 151 (8), 138 (13), 123 (16), 96 (5), 95 (10), 81 (4), 77 (5), 70 (100), 42 (35), 41 (34); exact mass calcd for $C_{10}H_{14}O_2$: 166.0994, found 166.0994.

*r-15-Hydroxy-r-1-methylbicyclo[9.4.1]hexadeca-11,13-dien-16-one* (**1e**). Cycloadduct **3e** (787 mg, 3 mmol) was allowed to react according to the general procedure. Reaction time: 90 min. Chromatography (MTBE/cyclohexane, 1:7) afforded **1e**, 456 mg (58%), yellow oil: IR ($CHCl_3$) 3588, 3504, 2932, 2864, 1716, 1692, 1656, 1468, 1388, 1136, 1108, 1036, 996 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.27 (d, $^3J$ = 7.5 Hz, C*H*=C($CH_2$)CO), 6.15 (dd, $^3J$ = 11.5 Hz, $^3J$ = 7 Hz, CH=C*H*CHOH), 5.99 (dd, $^3J$ = 11.5 Hz, $^3J$ = 7.5 Hz, C*H*=CHCHOH), 3.91 (d, $^3J$ = 7 Hz, C*H*OH), 3.25 - 3.11, 2.09 - 1.91, 1.86 - 1.61, 1.49 - 1.06 (4m, 19H, $CH_2$, OH), 1.26 (s, $CH_3$); $^{13}C$ NMR (APT, $CDCl_3$) δ 204.60 (↑, C=O), 142.39 (↑, CH=*C*($CH_2$)CO), 133.34, 130.58, 126.29 (3↓, other olef C), 73.68 (↓, CHOH), 55.13 (↑, *C*$CH_3$), 35.13, 33.98, 27.40, 26.41, 24.55, 23.91, 23.62, 22.39, 22.09 (9↑, $CH_2$), 19.62 (↓, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 263 (4), 262 ($M^+$, 21), 244 (3), 234 (8), 219 (4), 191 (6), 163 (5), 152 (2), 135 (7), 124 (3), 121 (17), 112 (3), 107 (8), 93 (9), 85 (63), 83 (100), 67 (14); exact mass calcd for $C_{17}H_{26}O_2$: 262.1933, found, 262.1933.

*7,7-Dimethyl-6-hydroxycyclohepta-2,4-dienone* (**1g**). Cycloadduct **3g**[16a,c] (457 mg, 3 mmol) was allowed to react according to the general procedure. Chromatography (MTBE/cyclohexane, 1:5 → 1:3) afforded **1g**, 383 mg (84%), yellow oil: IR (cap. film) 3436, 3032, 2977, 2934, 2874, 1722, 1696, 1651, 1589, 1466, 1312, 1259, 1119, 1052, 1018, 767 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.50 (dddd, $^3J$ = 12 Hz, $^3J$ = 6.5 Hz, $^4J$ = 1 Hz, $^5J$ = 1 Hz, C*H*=CHCO), 6.32 (dddd, $^3J$ = 11 Hz, $^3J$ = 5 Hz, $^4J$ = 1 Hz, $^5J$ = 1 Hz, CH=C*H*CHOH), 6.10 (ddd, $^3J$ = 12 Hz, $^4J$ = 1 Hz, $^5J$ = 1 Hz, CH=C*H*CO), 6.05 (dddd, $^3J$ = 11 Hz, $^3J$ = 6.5 Hz, $^4J$ = 1.5 Hz, $^4J$ = 1 Hz, C*H*=CHCHOH), 4.38 br (d, $^3J$ = 5 Hz, C*H*OH), 2.33 br (OH), 1.21, 1.12 (2s, C($CH_3$)$_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 204.38 (↑, C=O), 142.28, 135.28, 131.55, 124.11 (4↓, olef C), 73.27 (↓, CHOH), 53.73 (↑, *C*($CH_3$)$_2$), 22.69, 18.36 (2↓, C(*C*$H_3$)$_2$); MS (r.t.) *m/z* (rel. intensity) 153 (5), 152 ($M^+$, 45), 137 (39), 124 (47), 123 (55), 110 (87), 95 (14), 91 (37), 82 (37), 81 (40), 70 (100), 52 (10), 42 (62), 41 (67); exact mass calcd for $C_9H_{12}O_2$: 152.0837, found 152.0837.

*12-Hydroxyspiro[5.6]dodeca-8,10-dien-7-one* (**1h**). Cycloadduct **3h**[18] (442 mg, 2.3 mmol) was allowed to react according to the general procedure[10] to give after chromatography ($Et_2O$/PE, 1:1) **1h**, 216 mg (48%), yellow oil: IR ($CHCl_3$) 3596, 3420, 3000, 2936, 2856, 1660, 1452, 1384, 1228, 1160, 1128, 1108, 1036, 996 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.39 (ddd, $^3J$ = 12.5 Hz, $^3J$ = 7 Hz, $^4J$ = 1 Hz, C*H*=CHCO), 6.29 (dddd, $^3J$ = 11.5 Hz, $^3J$ = 6.5 Hz, $^4J$ = 1 Hz, $^5J$ = 1 Hz, CH=C*H*CHOH), 6.05 (ddd, $^3J$ = 11.5 Hz, $^3J$ = 7 Hz, $^4J_{8,10}$ or $^4J_{10,12}$ = 1 Hz, C*H*=CHCHOH), 5.97 br (d, $^3J$ = 12.5 Hz, CH=C*H*CO), 4.13 br (d, $^3J$ = 6.5 Hz, C*H*OH), 2.65 br (OH),

2.34, 1.80, 1.65 - 1.14 (3m, 1+1+8H, $CH_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 204.64 (↑, C=O), 136.55, 132.50, 130.57, 126.05 (4↓, olef C), 72.03 (↓, CHOH), 53.76 (↑, spiro C), 31.61, 29.74, 25.85, 23.90, 22.66 (5↑, $CH_2$); MS (r.t.) *m/z* (rel. intensity) 193 (10), 192 ($M^+$, 76), 174 (16), 164 (47), 149 (10), 138 (13), 137 (19), 123 (27), 111 (12), 110 (93), 109 (25), 107 (46), 91 (27), 82 (49), 81 (41), 67 (100), 54 (93); exact mass calcd for $C_{12}H_{16}O_2$: 192.1150, found 192.1149.

*11-Hydroxyspiro[4.6]undeca-7,9-dien-6-one* (**1i**). Cycloadduct **3i** (535 mg, 3 mmol) was allowed to react according to the general procedure[10]. Chromatography ($Et_2O$/PE, 1:1) afforded **1i**, 217 mg (41%), yellow oil: IR ($CHCl_3$) 3592, 3420, 2956, 2872, 1652, 1594, 1448, 1428, 1380, 1272, 1148, 1092, 1024 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.46 (ddd, $^3J$ = 12 Hz, $^3J$ = 6.5 Hz, $^4J$ = 1 Hz, C*H*=CHCO), 6.33 (dddd, $^3J$ = 11.5 Hz, $^3J$ = 6 Hz, $^4J$ = 1 Hz, $^5J$ = 0.5 Hz, CH=C*H*CHOH), 6.04 br (d, $^3J$ = 12 Hz, CH=C*H*CO), 6.01 br (dd, $^3J$ = 11.5 Hz, $^3J$ = 6.5 Hz, C*H*=CHCHOH), 4.31 br (d, $^3J$ = 6 Hz, C*H*OH), 2.82 br (OH), 2.26, 2.01 - 1.47 (2m, 1+7H, $CH_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 203.90 (↑, C=O), 140.24, 134.33, 130.81, 124.78 (4↓, olef C), 72.51 (↓, CHOH), 64.14 (↑, spiro C), 33.20, 31.84, 25.77, 25.53 (4↑, $CH_2$); MS (r.t.) *m/z* (rel. intensity) 179 (7), 178 ($M^+$, 60), 160 (23), 150 (94), 137 (19), 122 (14), 121 (24), 107 (100), 96 (82), 95 (60), 91 (88), 82 (79), 81 (54), 68 (49), 67 (70), 54 (56), 53 (67); exact mass calcd for $C_{11}H_{14}O_2$: 178.0994, found 178.0994.

*2,7-Dimethyltropone* (**2f**). Cycloadduct **3f**[16] (457 mg, 3 mmol) was allowed to react according to the general procedure to give after distillation (50 °C, 0.05 torr) **2f**, 220 mg (55%) [scale up: **3f** (7.61 g, 50 mmol) → **2f** (3.66 g, 54%)]. For spectroscopic data see ref. 7a and 19.

*2,2,4α-Trimethyl-8-oxabicyclo[3.2.1]octan-3-one* (**10b**), *2α,4α-Dimethyl-8-oxabicyclo[3.2.1]octan-3-one* (**10f**) *and 2,2-Dimethyl-8-oxabicyclo[3.2.1]octan-3-one* (**10g**). A heterogeneous solution of the ketone (3 mmol) and catalyst (Pd/C, 10%) (75 mg) in MeOH (30 mL) was hydrogenated in an autoclave at $7.8 \cdot 10^4$ hPa for 72 h. Filtration, removal of the solvent and chromatography yielded the corresponding hydrogenated cycloadducts **10b** (908 mg, 90%), **10f** (842 mg, 91%) and **10g** (796 mg, 86%). For spectroscopic data see ref. 5 (**10b** and **10g**) and 20 (**10f**).

*6-Hydroxy-2,7,7-trimethylcyclohept-2-enone* (**6b**). Cycloadduct **10b** (504 mg, 3 mmol) was allowed to react according to the general procedure. Chromatography (MTBE/cyclohexane, 1:4) afforded **6b**, 345 mg (69%), yellowish oil: IR (cap. film) 3480, 2974, 2928, 2874, 1669, 1455, 1439, 1382, 1361, 1073, 1031, 951 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.00 (ddq, $^3J$ = 8 Hz, $^3J$ = 6 Hz, $^4J$ = 2 Hz, C*H*=C($CH_3$)CO), 3.82 - 3.71 (m, C*H*OH), 2.56 - 2.34, 2.28 - 1.81 (2m, 5H, $CH_2$, OH), 2.85 (ddd, $^4J$ = 2 Hz, $^5J$ = 1.5 Hz, $^5J$ = 1.5 Hz, $CH_3$), 1.22, 1.19 (2s, C($CH_3$)$_2$); $^{13}C$ NMR ($CDCl_3$) δ 210.44 (s, C=O), 138.13 (s, CH=*C*($CH_3$)CO), 132.11 (d, *C*H=C($CH_3$)CO), 75.91 (d, CHOH), 53.49 (s, *C*($CH_3$)$_2$), 31.31 (t, $CH_2CH_2CHOH$), 24.62 (t, $CH_2CH_2CHOH$), 24.50, 21.72, 20.43 (3q, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 169 (1), 168 ($M^+$, 7), 150 (12), 135 (9), 109 (8), 100 (26), 95 (8), 82 (19), 69 (100), 67 (22), 54 (15), 41 (59); exact mass calcd for $C_{10}H_{16}O_2$: 168.1150, found 168.1150.

*2,t-7-Dimethyl-r-6-hydroxycyclohept-2-enone* (**6f**). Cycloadduct **10f** (462 mg, 3 mmol) was allowed to react according to the general procedure. Chromatography (MTBE/cyclohexane, 1:6) afforded **6f**, 224 mg (49%), yellow oil: IR ($CHCl_3$) 3614, 3497, 2982, 2926, 2879, 2855, 1671, 1451, 1437, 1399, 1049, 992, 962 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.66 - 6.51 (m, C*H*=C($CH_3$)CO), 3.75 - 3.62 (m, C*H*OH), 2.85 (dq, $^3J$ = 8 Hz, $^3J$ = 6.5 Hz, C*H*$CH_3$), 2.96 - 2.79 br (m, OH), 2.77 - 2.54, 2.41 - 2.19, 2.10 - 1.93, 1.77 - 1.58 (4m, 4H, $CH_2$), 1.82 (ddd, $^4J$ = 2 Hz, $^5J$ = 1.5 Hz, $^5J$ = 1.5 Hz, CH=C(*C*$H_3$)CO), 1.24 (d, $^3J$ = 6.5 Hz, CHC*H*$_3$); $^{13}C$ NMR (APT, $CDCl_3$) δ 204.73 (↑, C=O), 142.43 (↓, *C*H=C($CH_3$)CO), 139.39 (↑, CH=*C*($CH_3$)CO), 72.97 (↓, CHOH), 53.52

(↓, $CHCH_3$), 36.76 (↑, $CH_2CH_2CHOH$), 24.36 (↑, $CH_2CH_2CHOH$), 19.36 (↓, $CH{=}C(CH_3)CO$), 13.69 (↓, $CHCH_3$); MS (r.t.) *m/z* (rel. intensity) 155 (3), 154 ($M^+$, 20), 136 (24), 126 (2), 121 (11), 109 (23), 100 (46), 81 (22), 68 (25), 67 (42), 55 (100), 53 (31); exact mass calcd for $C_9H_{14}O_2$: 154.0994, found 154.0994.

*7,7-Dimethyl-6-hydroxycyclohept-2-enone* (**6g**). Cycloadduct **10g** (463 mg, 3 mmol) was allowed to react according to the general procedure. Chromatography (MTBE/cyclohexane, 1:3) yielded **6g**, 288 mg (62%), yellow oil: IR ($CHCl_3$) 3616, 3480, 3016, 2932, 2875, 1661, 1457, 1399, 1125, 1065 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.33 (ddd, $^3J$ = 13 Hz, $^3J$ = 6 Hz, $^3J$ = 4 Hz, C*H*=CHCO), 5.93 (ddd, $^3J$ = 13 Hz, $^4J$ = 2 Hz, $^4J$ = 2 Hz, CH=C*H*CO), 3.83 (dd, $^3J$ = 6 Hz, $^3J$ = 2 Hz, C*H*OH), 2.71 - 2.50, 2.46 - 1.93 (2m, 5H, $CH_2$, OH), 1.25, 1.18 (2s, $C(CH_3)_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 206.86 (↑, C=O), 141.59, 130.67 (2↓, olef C), 75.41 (↓, CHOH), 53.39 (↑, $C(CH_3)_2$), 30.09 (↑, $CH_2CH_2CHOH$), 26.49 (↑, $CH_2CH_2CHOH$), 25.87, 21.57 (2↓, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 155 (1), 154 ($M^+$, 5), 139 (9), 121 (6), 95 (8), 93 (10), 83 (22), 70 (23), 69 (100), 55 (21), 42 (59); exact mass calcd for $C_9H_{14}O_2$: 154.0994, found 154.0994.

*2,2,4-Trimethylcyclohept-4-en-1,3-dione* (**11b**). Alcohol **6b** (84 mg, 0.5 mmol) was oxidized with Jones reagent (125 µL, 0.5 mmol) at 0 °C. Decantation and chromatography (MTBE/cyclohexane, 1:6) afforded **11b**, 69 mg (83%), yellowish oil: IR ($CHCl_3$) 2976, 2934, 2908, 1723, 1675, 1454, 1381, 1107, 965 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.01 (m, C*H*=C($CH_3$)CO), 2.67 (dt, $^3J$ = 6 Hz, $^4J$ = 1 Hz, $CH_2CH_2CO$), 2.56 - 2.43 (m, $CH_2CH_2CO$), 1.92 (ddd, $^4J$ = 2 Hz, $^5J$ = 1.5 Hz, $^5J$ = 1.5 Hz, CH=C($CH_3$)CO), 1.28 (s, $C(CH_3)_2$); $^{13}C$ NMR (APT, $CDCl_3$) δ 211.07, 206.94 (2↑, C=O), 137.61 (↑, CH=*C*($CH_3$)CO), 132.58 (↓, *C*H=C($CH_3$)CO), 63.60 (↑, *C*($CH_3$)$_2$), 38.99 (↑, $CH_2CH_2CO$), 27.95 (↑, $CH_2CH_2CO$), 27.32, 21.55 (2↓, 1+2C, $CH_3$); MS (r.t.) *m/z* (rel. intensity) 167 (2), 166 ($M^+$, 21), 124 (83), 109 (10), 96 (24), 82 (12), 70 (100), 67 (40), 53 (23), 42 (51); exact mass calcd for $C_{10}H_{14}O_2$: 166.0994, found 166.0994.

*2,4-Dimethylcyclohept-4-en-1,3-dione* (**11f**). Alcohol **6f** (80 mg, 0.52 mmol) was oxidized with Jones reagent (130 µL, 0.52 mmol) at 0 °C. Decantation and chromatography (MTBE/cyclohexane, 1:4) afforded **11f**, 64 mg (81%), yellowish oil: IR ($CHCl_3$) 2988, 2940, 1716, 1668, 1452, 1316, 1228, 948 $cm^{-1}$; $^1H$ NMR ($CDCl_3$) δ 6.88 - 6.78 (m, C*H*=C($CH_3$)CO), 4.33 (q, $^3J$ = 6.5 Hz, C*H*$CH_3$), 3.11 - 2.37 (m, 4H, $CH_2$), 1.87 (ddd, $^4J$ = 1.5 Hz, $^5J$ = 1 Hz, $^5J$ = 1 Hz, CH=C($CH_3$)CO), 1.21 (d, $^3J$ = 6.5 Hz, CH$CH_3$); $^{13}C$ NMR (APT, $CDCl_3$) δ 205.78 (↑, C=O), 194.27 (↑, CH=C($CH_3$)*C*O), 141.97 (↓, *C*H=C($CH_3$)CO), 139.68 (↑, CH=*C*($CH_3$)-CO), 60.67 (↓, *C*$HCH_3$), 40.43 (↑, $CH_2CH_2CO$), 24.09 (↑, $CH_2CH_2CO$), 19.54 (↓, CH=C(*C*$H_3$)CO), 9.74 (↓, $CHCH_3$); MS (r.t.) *m/z* (rel. intensity) 153 (4), 152 ($M^+$, 37), 124 (23), 109 (100), 96 (53), 81 (18), 68 (54), 67 (54), 53 (34), 41 (43); exact mass calcd for $C_9H_{12}O_2$: 152.0837, found 152.0837.

Acknowledgments. We thank *Ulrike Eggert* for experimental contributions, *Michael Henningsen* for discussions and the *Fonds der Chemischen Industrie* for support of this work.

## REFERENCES AND NOTES

1. a) Becker, A. M.; Rickards, R. W. *Org. Prep. Proced. Int.* **1983**, *15*, 239. b) Adam, W.; Balci, M. *Angew. Chem.* **1978**, *90*, 1014; *Angew. Chem., Int. Ed. Engl.* **1978**, *17*, 954 and Adam, W.; Balci, M. *J. Am. Chem. Soc.* **1979**, *101*, 7542. c) Asao, T.; Yagihara, M.; Kitahara, Y. *Bull. Chem. Soc. Jpn.* **1978**, *51*, 2131.
2. Hunt, D. F.; Farrant, G. C.; Rodeheaver, G. T. *J. Organometal. Chem.* **1972**, *38*, 349.
3. a) Hoffmann, H. M. R. *Angew. Chem.* **1984**, *96*, 29; *Angew. Chem., Int. Ed. Engl.* **1984**, *23*, 1.

b) Noyori, R.; Hayakawa, Y. *Org. Reactions* **1983**, *29*, 163. c) Mann, J. *Tetrahedron* **1986**, *42*, 4611.

4. Barbosa, L.-C. A.; Mann, J.; Wilde, P. D. *Tetrahedron* **1989**, *45*, 4619.
5. Föhlisch, B.; Sendelbach, S.; Bauer, H. *Liebigs Ann. Chem.* **1987**, 1; see also Murray, D. H.; Albizati, K. F. *Tetrahedron Lett.* **1990**, *31*, 4109 and ref. 4.
6. a) Lautens, M.; Abd-El-Aziz, A. S.; Lough, A. *J. Org. Chem.* **1990**, *55*, 5305. b) Lautens, M.; Di Felice, C.; Huboux, A. *Tetrahedron Lett.* **1989**, *30*, 6817; see also c) Lautens, M.; Belter, R. K.; Lough, A. J. *J. Org. Chem.* **1992**, *57*, 422.
7. a) Takaya, H.; Hayakawa, Y.; Makino, S.; Noyori, R. *J. Am. Chem. Soc.* **1978**, *100*, 1778. b) Barbosa, L.-C. A.; Mann, J. *J. Chem. Soc. Perkin Trans. I* **1990**, 177. c) Cummins, W. J.; Drew, M. G. B.; Mann, J.; Markson, A. J. *Tetrahedron* **1988**, *44*, 5151. d) Montaña, A. M.; Nicholas, K. M. *J. Org. Chem.* **1990**, *55*, 1569.
8. a) Mukaiyama, T.; Narasaka, K. *Org. Synth.* **1987**, *65*, 6. Mukaiyama, T.; Banno. K.; Narasaka, K. *J. Am. Chem. Soc.* **1974**, *96*, 7503. b) Rasmussen, J. K. *Synthesis* **1977**, 91.
9. Saito, T.; Itoh, A.; Oshima, K.; Nozaki, H. *Tetrahedron Lett.* **1979**, 3519.
10. It is essential to use high quality $ZrCl_4$. One freshly opened bottle (Fluka) gave only low yields (<5%) of monocyclic unsaturated hydroxyketone **1b**. It is likely that basic oxychlorides ($ZrOCl_2$) were present.
11. Connor, J. A. *Topics in Current Chemistry* **1977**, *71*, 71.
12. Weichert, A.; Hoffmann, H. M. R. *J. Org. Chem.* **1991**, *56*, 4098. Jones, B. in Chinn, L. J., Ed.: *Selection of Oxidants in Synthesis*; Marcel Dekker: New York, 1971.
13. Eggert, U.; Stohrer, I.; Hoffmann, H. M. R. *Tetrahedron Lett.* **1992**, *33*, 3465.
14. APT is a time saving alternative to DEPT sequence, when used with care. See Günther, H.; *NMR-Spektroskopie*; Georg Thieme Verlag: Stuttgart, 1992, p. 423. Atta-ur-Rahman; *One and Two Dimensional NMR Spectroscopy*; Elsevier: Amsterdam, 1989, p. 82.
15. Vinter, J. G.; Hoffmann, H. M. R. *J. Am. Chem. Soc.* **1974**, *96*, 5466.
16. a) Hoffmann, H. M. R.; Clemens, K. E.; Smithers, R. H. *J. Am. Chem. Soc.* **1972**, *94*, 3940. b) Ashcroft, M. R.; Hoffmann, H. M. R. *Org. Synth. Coll. Vol. 6*, **1988**, 512. c) Herter, R.; Föhlisch, B. *Synthesis* **1982**, 976.
17. For partial $^1H$ NMR data see Dana, G.; Wiemann, J. *Bull. Soc. Chim. France* **1970**, 3994.
18. Hoffmann, H. M. R.; Eggert, U.; Gibbels, U.; Giesel, K.; Koch, O.; Lies, R.; Rabe, J. *Tetrahedron* **1988**, *44*, 3899.
19. Closs, G. L.; Closs, L. E. *J. Am. Chem. Soc.* **1961**, *83*, 599.
20. Arco, M. J.; Trammell, M. H.; White, J. D. *J. Org. Chem.* **1976**, *41*, 2075.