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An Approach to the Tremulane Skeleton: Synthesis of (±)-6a-*epi*-Tremulenolide B and Related Hydroazulenes

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Abstract:

An approach to the skeleton of the tremulane sesquiterpenes and the synthesis of the title compound **8** are described.

Keywords: Perhydroazulenes; Tremulane sesquiterpenes; Regioselective hydrogenation; Stereoselective reactions

Introduction

In 1993 Ayer and Cruz [1] reported on the isolation and structure determination of a new group of sesquiterpenes possessing a previously unreported perhydroazulene carbon skeleton A.

The compounds which they called tremulanes were isolated from liquid cultures of the aspen rotting fungus *Phellinus tremulae*. One example was tremulenolide B (**1**).

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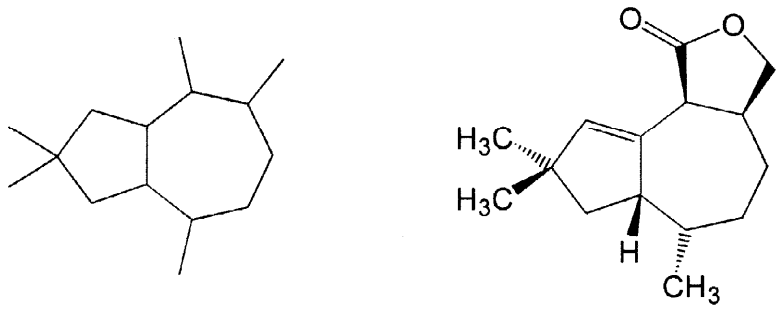
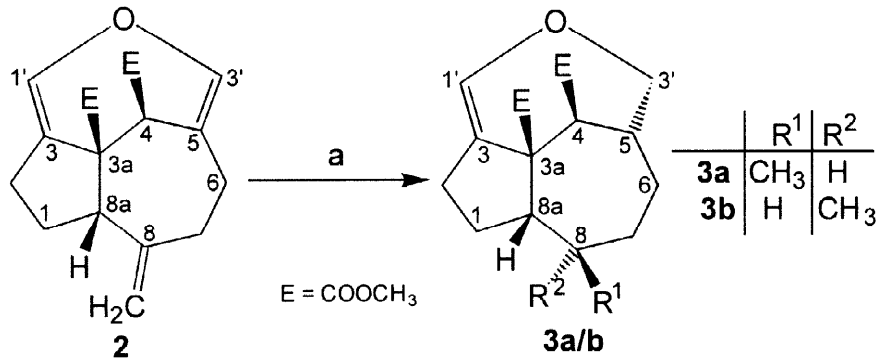


A 1

Figure 1: The tremulane skeleton **A** and the structure of tremulenolide B (**1**).

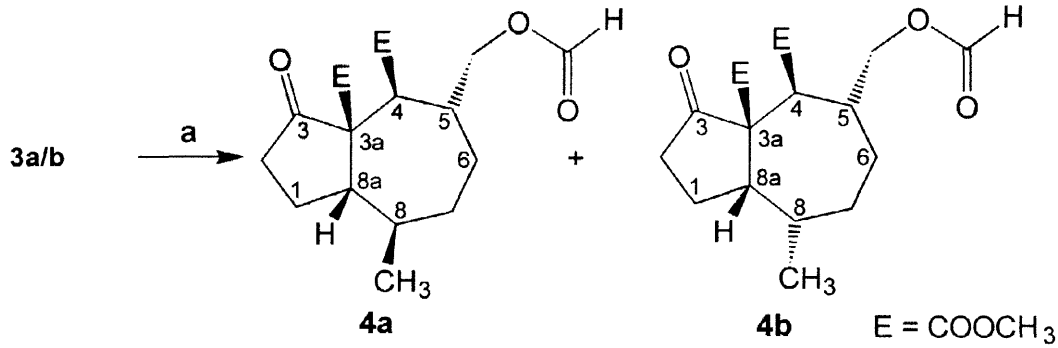
In a preliminary short communication we described an approach to the tremulane skeleton selecting (±)-**6a**-*epi*-tremulenolide B (**8**) as first example [2,3]. In this paper we report on the experimental details of our improved synthesis and on the structural assignment of three hydroazulenes by X-ray analyses. Our synthesis started with the methylene compound **2** which is readily available by a one-pot produce from a bridged ketooxepine that undergoes an intramolecular Michael addition and subsequent Wittig reaction with triphenylphosphonium methylide [4,5]. Key step of our synthesis was the regioselective hydrogenation of the C(5)-C(3') enol ether double bond and the exo methylene double bond of **2** to give a mixture of the diastereomeric hydroazulenes **3a/b** (ds **3a:3b** = 61:39, see Experimental) in 85% yield using the Wilkinson catalyst in benzene [6].

Obviously the C(1')-C(3) enol ether double bond is sterically hindered by the methoxycarbonyl group on the quarternary carbon C(3a) [4,7]. Therefore additions to this bond occur slower than to the C(3')-C(5) bond [5]. Oxidative cleavage of the C(3)-C(1') enol ether double bond in **3a/b** with ruthenium tetroxide led to the formates **4a** (54% yield) and **4b** (27% yield), which can be separated by column chromatography with ether/pentane on silica gel.*



Scheme 1: Regioselective Hydrogenation of **2**
Reagents: [a] Wilkinson catalyst, H_2, benzene.

* All compounds of this work are racemic. Only one enantiomer is drawn. **2** – **4** are numbered as azulenes.



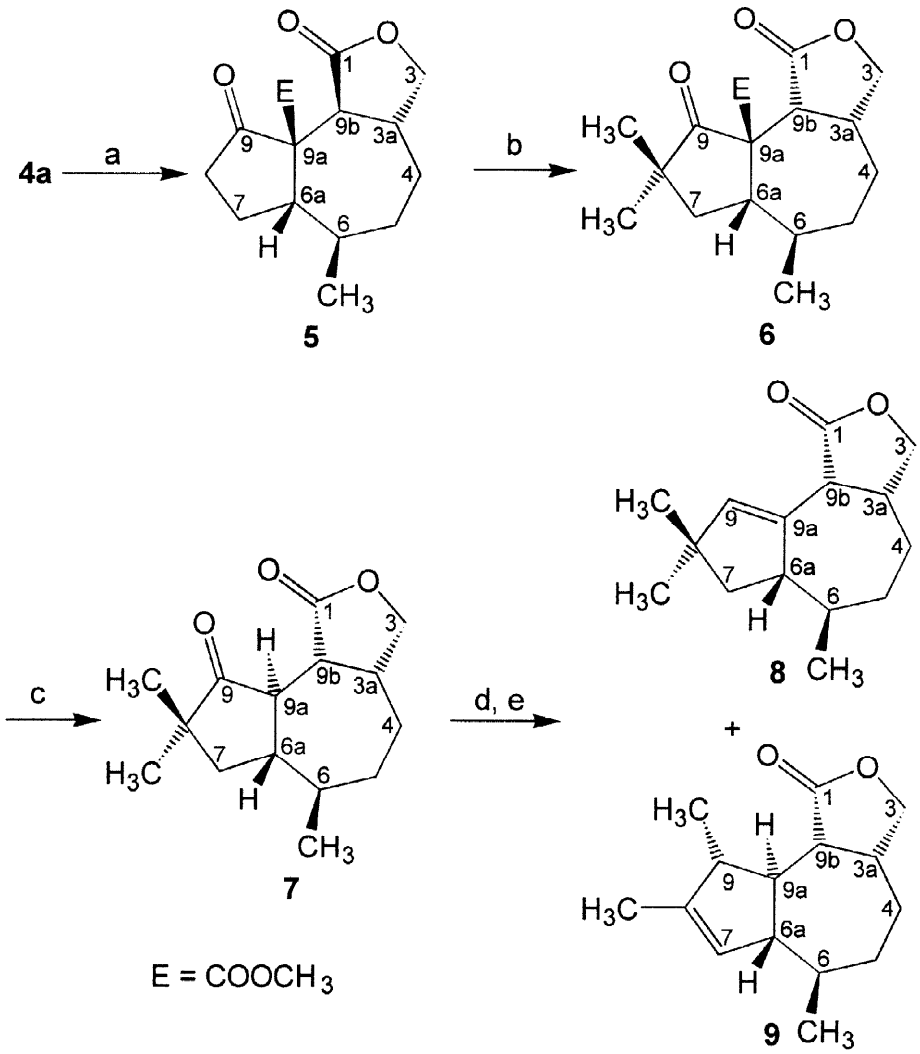
Scheme 2: Route to formates **4a** and **4b**.
Reagents: [a] $RuCl_3$ x 3 H_2O, $NaIO_4$, CCl_4, CH_3CN, H_2O.

Lactonization of **4a** with methanesulfonic acid furnished the *trans* lactone **5** ** in 84% yield. The relative *trans* configuration of the lactone moiety was derived from the ^3J coupling constant of 12.4 Hz between 9b-H and 3a-H. *Geminal* dimethylation of **5** was performed by dropping a solution of **5** and an excess MeI in THF at 72°C to KHMDS (15perc. in toluene) in THF. Under these conditions the *trans* annulated lactone ring isomerized to the *cis* isomer **6** by deprotonation on C-9b. This assignment was derived from the coupling constant of ^3J = 9.8 Hz and a NOE between 3a-H and 9b-H. Demethoxycarbonylation of **6** could be performed by treatment with NaCl in wet DMSO [8] at 150°C to give the crystalline hydroazulene **7** possessing already the tremulane skeleton. The coupling constant between 9a-H and 6a-H is ^3J = 12.3 Hz, therefore we assume a *trans* fused hydroazulene skeleton. Reduction of **7** with sodium borohydride and subsequent dehydration with phosphorus oxychloride in pyridine finally led to (±)-**6a**-*epi*-tremulenolide B (**8**) in 48% yield. Under these conditions the double bond did not migrate in conjugation to the lactone carbonyl group. As by-product (11%) an isomer **9** was isolated, in which a methyl group had migrated from C-8 to C-9 via Wagner-Meerwein rearrangement (See Experimental).

The structure of **8** was assigned by NMR spectroscopy. The chemical shifts of the geminal dimethyl groups in the cyclopentene ring of **8** (^{1}H NMR: δ = 1.07 and 1.11; ^{13}C NMR: δ = 30.0 and 30.9) are similar to those of **1** (^{1}H NMR: δ = 1.06 and 1.10; ^{13}C NMR: δ = 27.1 and 29.4) [1]. In the ^{1}H NMR spectrum of **8** only one olefinic proton (δ = 5.34) appears which exhibits ^4J couplings (1.4 Hz and 1.2 Hz). The coupling constant ^3J = 9.5 Hz between 3a-H and 9b-H and strong cross peaks in the phase-sensitive NOESY spectra reveal the relative *cis* configuration of the lactone moiety. The coupling constant ^3J = 11.4 Hz between 6-H and

** The compounds **5** – **13** are numbered as azulenofuranones.

6a-H in **8** is in agreement with the *trans* relationship of these two hydrogens. The IR spectrum of **8** indicates that the lactone group (CH_2Cl_2, 1780 cm^{-1}) is not conjugated.

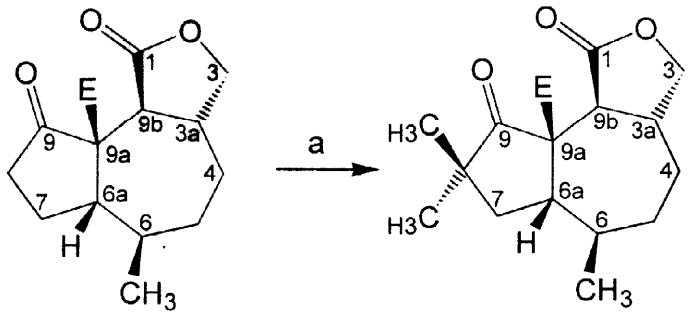


Scheme 3: Synthesis of the title compound **8**.

Reagents: [a] CH_3SO_3H, CH_2Cl_2. – [b] Addition of **5** and MeI in THF to KHMDS in THF at -78°C. – [c] NaCl, H_2O, DMSO, 150°C. – [d] $NaBH_4$, EtOH. – [e] $POCl_3$, PyH.

Additional informations concerning the structures of the hydroazulenes described here were obtained from the X-ray analyses of the related compounds **10**, **11** and **12**.

Geminal dimethylation of **5** without isomerization of the lactone moiety to give **10** could be performed by dropping the base KHMDS (15perc. in toluene) in THF to a diluted solution of **5** and an excess MeI in THF at -78°C. The *trans* annellation of the lactone ring in **10** was derived from the coupling constant ^3J = 12.4 Hz between 3a-H and 9a-H and could be finally established by X-ray analysis [9].



Scheme 4: Synthesis of the *trans* lactone **10**.
Reagents: [a] Addition of KHMDS in THF to **5** and MeI in THF at -78°C.

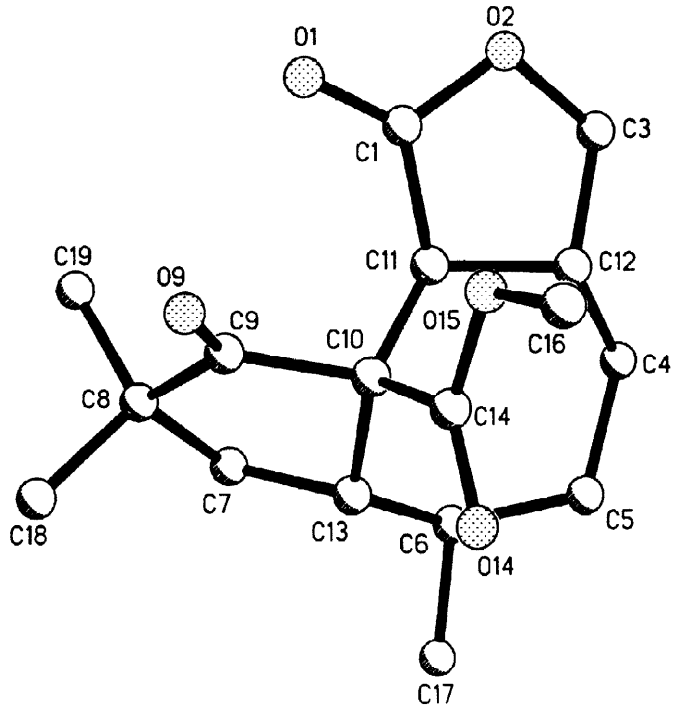
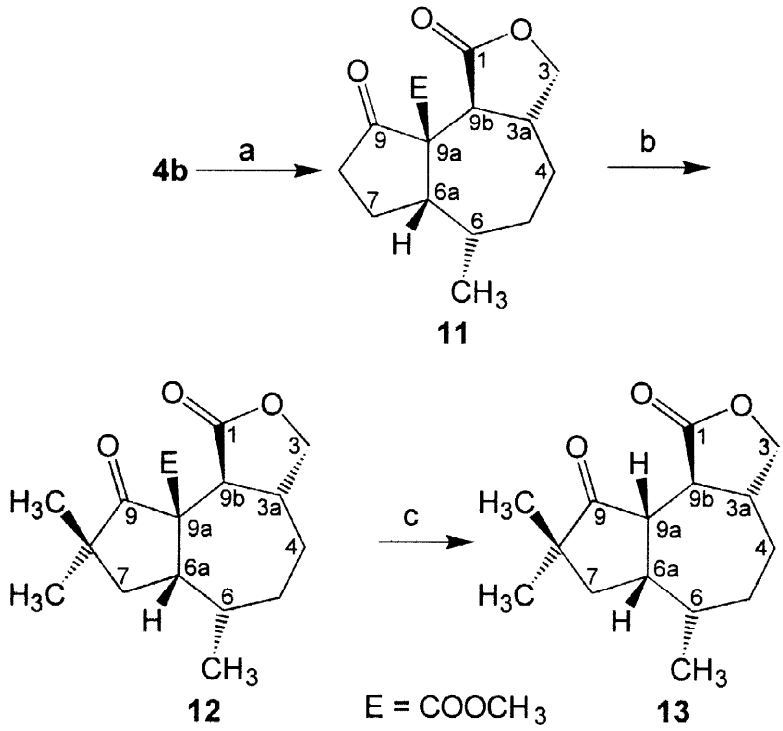


Figure 2: A molecule of **10** in the crystal; arbitrary numbering.

A reaction sequence similar to scheme 3 with the diastereomer **4b** as starting material led to the lactones **11** and **12**. Their relative (3a*R**, 6*S**, 6a*S**, 9a*R**, 9b*S**)-configuration follows from the X-ray analyses (see figures 2 and 3) [9].



Scheme 5: Synthesis of hydroazulenes from the diastereomer **4b**.

Reagents: [a] CH_3SO_3H, CH_2Cl_2. – [b] Addition of KHMDS in THF to **11** and MeI in THF at -78°C. – [c] NaCl, H_2O, DMSO, 150°C.

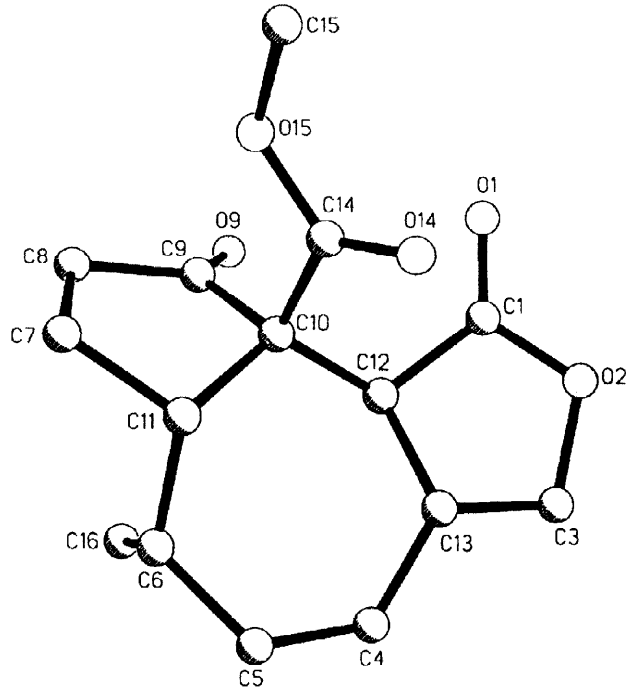


Figure 3: A molecule of **11** in the crystal; arbitrary numbering.

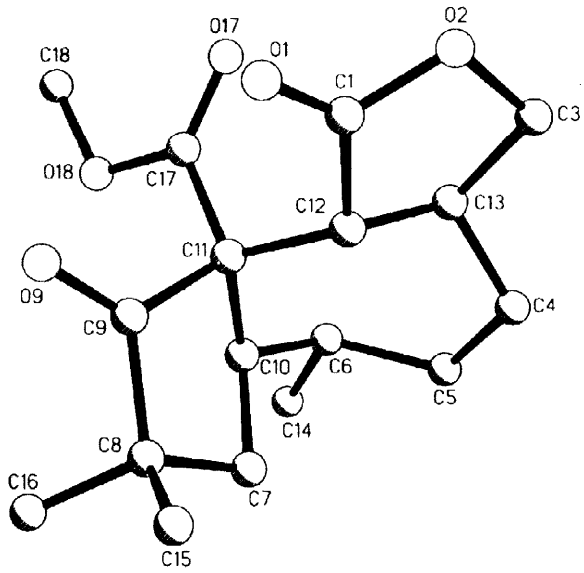


Figure 4: A molecule of **12** in the crystal; arbitrary numbering.

Demethoxycarbonylation of **12** with NaCl in wet DMSO [14] afforded an additional hydroazulene **13** with the tremulane skeleton. The relative *trans* annellation of the lactone moiety in **13** was derived from the coupling constant ^3J = 13.2 Hz between 9b-H and 3a-H and strong cross peaks in the NOESY spectra between 9b-H and the methyl group on C-6. From the coupling constant ^3J = 10.3 Hz between 9a-H and 6a-H of 10.3 Hz and a NOE between these protons a cis hydroazulene skeleton is assumed.

In summary, the above reaction sequences lead to various stereoisomeric hydroazulenes. The compounds **7**, **8** and **13** have a tremulane skeleton.

Recently we succeeded in the preparative resolution and the determination of the absolute configuration of a related starting material (**2**, C(8) = O instead of C(8) = CH_2) [5]. Therefore all compounds of this work can be synthesized also in optically active form. This is of interest because Ayer and Cruz could already established the absolute stereochemistry of the tremulanes [1].

Experimental

IR: Perkin-Elmer 1600 FTIR. - ^{1}H NMR: TMS int., Bruker AC 200 P, AM 300, DRX 500.- ^{13}C NMR: TMS int., Bruker AC 200 P, AM 300, DRX 500. The assignment of signals marked with asteriks is arbitrary. - MS: Finnigan-MAT 8230; direct inlet (EI: 70 eV, CI: isobutane). – Column Chromatography (CC): Baker Silica gel 40-60 μm. - TLC: Macherey-Nagel SIL G/UV_{254}. - Melting points: Büchi 510 (uncorrected). - Elemental analyses: Mikroanalytisches Laboratorium Ilse Beetz, D-96301 Kronach. - All solvents and reagents were purified and dried according to common procedures.

(3aR,4S*,5R*,8R*,8aS*)-(±)-Dimethyl decahydro-8-methyl-3,5-(2'-oxa-3'-propan-1'-ylidene)azulene-3a,4-dicarboxylate* (**3a**) *and its (3aR*,4S*,5R*,8S*,8aS*)-(±)-epimer* (**3b**): To a solution of 1.30 g (4.28 mmol) **2** [5,7] in 55 ml of benzene 396 mg (10 mol percent) of tris(triphenylphosphine)-rhodium(I) chloride were added. After hydrogenation for 6 h at room temp., the reaction mixture was concentrated. After filtration over a small aluminium oxide column with Et_2O/pentane (1:1) the crude product was purified by CC [Et_2O/pentane (1:1)] yielding 1.12 g (85 %) of **3a/b** (R_f = 0.45) as colourless crystals besides 65 mg (5 %) of unreacted starting material **2** (R_f = 0.50). The ratio of **3a:3b** = 61:39 was determined from the ^1H NMR spectrum by integration of the enol ether signals at δ = 6.22 ppm (**3a**) and δ = 6.34 ppm (**3b**). - m. p. 63 °C (Et_2O/pentane) - IR (KBr): ν = 1730 cm^{-1} (s, ester C=O). - ^1H NMR ($CDCl_3$, 500 MHz): Signals assigned to **3a** or **3b** are marked with *a* or *b*. - 0.88 (d, ^3J = 6.7 Hz, 3H, CH_3, *b*), 0.94 (d, ^3J = 6.2 Hz, 3H, CH_3, *a*), 1.10-1.50 (m, 5H), 1.82-2.50 [m, 5H, therein at 2.48 (m, 1H, 8a-H, *a*)], 3.00 (ddddd, $^3J_{5,3'}$ = 9.8 Hz, $^3J_{5,6}$ = 8.9 Hz, $^3J_{5,3'}$ = 5.4 Hz, $^3J_{5,6}$ = 4.3 Hz, $^3J_{5,4}$ = 2.6 Hz, 1H, 5-H, *a*), 3.20 (m, 1H, 5-H, *b*), 3.54 (dd, ^2J = 11.7 Hz, $^3J_{3,5}$ = 6.6 Hz, 1H, 3'-H, *b*), 3.69 (s, 3H, $COOCH_3$), 3.70 (s, 3H, $COOCH_3$), 3.90 (dd, ^2J = 11.7 Hz, $^3J_{3,5}$ = 5.6 Hz, 1H, 3'-H, *b*), 4.09 (d, $^3J_{4,5}$ = 2.6 Hz, 1H, 4-H, *a*), 4.14 (dd, ^2J = 11.7 Hz, $^3J_{3,5}$ = 5.4 Hz, 1H, 3'-H, *a*), 4.19 (dd, ^2J = 11.7 Hz, $^3J_{3,5}$ = 9.8 Hz, 1H, 3'-H, *a*), 4.65 (d, $^3J_{4,5}$ = 3.6 Hz, 1H, 4-H, *b*), 6.22 (m, 1H, 1'-H, *a*), 6.34 (m, 1H, 1'-H, *b*). ^{13}C NMR ($CDCl_3$, 75 MHz): 21.67/24.59 (q, CH_3), 22.54/26.15 (t, CH_2), 26.78/26.93 (t, CH_2), 27.83/30.21 (t, CH_2), 30.72/31.80 (t, CH_2), 34.85/37.24 (d, C-5)*, 36.52/41.32 (d, C-8)*, 46.36/48.15 (d, C-4), 46.56/49.82 (d, C-8a), 51.82/52.53 (q, $COOCH_3$), 51.92/52.77 (q, $COOCH_3$), 60.88/61.94 (s, C-3a), 75.92/76.41 (t, C-3'), 122.56/130.71 (s, C-3), 140.06/141.73 (d, C-1'), 174.30/174.53 (s, $COOCH_3$), 174.74/174.91 (s, $COOCH_3$). The above assignments were derived from COSY, NOESY and ^1H ^{13}C shift shift correlation spectra. - MS (70 eV): *m/z* (%) = 308 (11) [M^+], 249 (100) [M^+ - $COOCH_3$]. - $C_{17}H_{24}O_5$ (308.4): calcd. C 66.21, H 7.84, found C 66.69, H 7.88.

A run with 3.82 g (12.59 mmol) **2** [5,7] in 170 ml benzene and 1.16 g (10 mol percent) catalyst yielded 3.30 g (85%) **3a/3b**.

(3aR,4S*,5R*,8R*,8aS*)-(±)-Dimethyl 5-[(formyloxy)methyl]-decahydro-8-methyl-3-oxoazulene-3a,4-dicarboxylate* (**4a**) *and its (3aR*,4S*,5R*,8S*,8aS*)-(±)-epimer* (**4b**): To a solution of 1.53 g (4.95 mmol) **3a/b** in 9 ml of CCl_4, 6 ml of CH_3CN and 9 ml of water 50 mg (0.222 mmol) of $RuCl_3 \times 3\ H_2O$ and 8.20 g (38.4 mmol) of $NaIO_4$ were added. After stirring for 3 h at room temp. the reaction mixture was acidified with 10 ml of 5N H_2SO_4 and diluted with 80 ml of CH_2Cl_2 and 80 ml of water. The organic layer was separated and the aqueous one was extracted with CH_2Cl_2. The combined organic layers were washed with water, dried and concentrated. The crude product was purified by CC [Et_2O/pentane (3:1)] yielding 448 mg (27 %) of **4b** (R_f = 0.46) as a colourless oil and 912 mg (54 %) of **4a** (R_f = 0.35) as colourless crystals; m. p. 95-96 °C (Et_2O/pentane).

4a: - IR (KBr): ν = 1750 cm^{-1} (s, ketone C=O), 1730 cm^{-1} (s, ester and formyl C=O). - ^1H NMR ($CDCl_3$, 300 MHz): 0.98 (d, ^3J = 6.5 Hz, 3H, CH_3), 1.33-1.53 (m, 3H, CH_2 and 8-H), 1.84-2.16 (m, 5H, 2 CH_2 and 8a-H), 2.41-2.55 (m, 2H, CH_2), 2.63 (d, $^3J_{4,5}$ = 9.5 Hz, 1H, 4-H), 2.91 (ddddd, $^3J_{5,4}$ = 9.5 Hz, $^3J_{5,6}$ = 8.2 Hz, ^3J = 6.5 Hz, ^3J = 5.1 Hz, $^3J_{5,6}$ = 4.0 Hz, 1H, 5-H), 3.71 (s, 3H, $COOCH_3$), 3.77 (s, 3H, $COOCH_3$), 4.01 (ddd, ^2J = 11.2 Hz, ^3J = 5.1 Hz, ^4J = 1.0 Hz, 1H, CH_2O), 4.10 (ddd, ^2J = 11.2 Hz, ^3J = 6.5 Hz, ^4J = 1.0 Hz, 1H, CH_2O), 8.03 (ddd, ^4J = 1.0 Hz, ^4J = 1.0 Hz, ^5J = 0.7 Hz, 1H, formyl H). - ^{13}C NMR ($CDCl_3$, 75 MHz): 21.84 (t, CH_2), 23.48 (q, CH_3), 30.99 (t, CH_2), 31.56 (d, C-8)*, 34.53 (t, CH_2), 35.69 (t, CH_2), 35.99 (d, C-5)*, 49.25 (d, C-8a)**, 50.97 (d, C-4)**, 51.83 (q, $COOCH_3$), 52.41 (q, $COOCH_3$), 65.76 (s, C-3a), 66.17 (t, CH_2O), 160.61 (d, formyl C), 172.58 (s, $COOCH_3$), 172.94 (s, $COOCH_3$), 213.67 (s, C-3). The above assignments were derived from COSY and NOESY spectra and selective irradiation experiments ({^1H}-homodecoupling). - MS (70 eV): *m/z* (%) = 340 (29) [M^+], 308 (100) [M^+ - CH_3OH]. - $C_{17}H_{24}O_7$ (340.4): calcd. C 59.99, H 7.11, found C 59.64, H 7.00.

4b: - IR (KBr): ν = 1730 cm^{-1} (br., ketone, ester and formyl C=O). - ^1H NMR ($CDCl_3$, 300 MHz): 0.97 (d, ^3J = 6.9 Hz, 3H, CH_3), 1.09 (dddd, ^2J = 15.0 Hz, $^3J_{6,7}$ = 10.5 Hz, $^3J_{6,5}$ = 10.5 Hz, $^3J_{6,7}$ = 5.8 Hz, 1H, 6-H), 1.43 (dddd, ^2J = 14.1 Hz, $^3J_{7,8}$ = 10.8 Hz, $^3J_{7,6}$ = 5.8 Hz, $^3J_{7,6}$ = 4.0 Hz, 1H, 7-H), 1.52 (dddd, ^2J = 14.1 Hz, $^3J_{7,6}$ = 10.5 Hz, $^3J_{7,6}$ = 6.2 Hz, $^3J_{7,8}$ = 4.7 Hz, 1H, 7-H), 1.66 (dddd, ^2J = 15.0 Hz, $^3J_{6,7}$ = 6.2Hz, $^3J_{6,7}$ = 4.0 Hz, $^3J_{6,5}$ = 2.9 Hz, 1H, 6-H), 1.81 (dddd, ^2J = 13.6 Hz, $^3J_{1,2}$ = 9.9 Hz, $^3J_{1,2}$ = 6.4 Hz, $^3J_{1,8a}$ = 4.9 Hz, 1H, 1-H), 2.02 (dqdd, $^3J_{8,7}$ = 10.8 Hz, ^3J = 6.9 Hz (q), $^3J_{8,7}$ = 4.7 Hz, $^3J_{8,8a}$ = 3.4 Hz, 1H, 8-H), 2.23 (dddd, ^2J = 13.6 Hz, $^3J_{1,2}$ = 11.1 Hz, $^3J_{1,8}$ = 9.3 Hz, $^3J_{1,2}$ = 6.5 Hz, 1H, 1-H), 2.41 (m, therein ^2J = 19.6 Hz, $^3J_{2,1}$ = 9.9 Hz, $^3J_{2,1}$ = 6.5 Hz, 1H, 2-H), 2.45 (m, 1H, 5-H), 2.53 (ddd, ^2J = 19.6 Hz, $^3J_{2,1}$ = 11.1 Hz, $^3J_{2,1}$ = 6.4 Hz, 1H, 2-H), 3.25 (ddd, $^3J_{8a,1}$ = 9.3 Hz, $^3J_{8a,1}$ = 4.9 Hz, $^3J_{8a,8}$ = 3.4 Hz, 1H, 8a-H), 3.45 (d, $^3J_{4,5}$ = 7.0 Hz, 1H, 4-H), 3.69 (s, 3H, $COOCH_3$), 3.71 (s, 3H, $COOCH_3$),4.08 (ddd, ^2J = 10.9 Hz, ^3J = 7.7 Hz, ^4J = 0.8 Hz, 1H, CH_2O), 4.18 (ddd, ^2J = 10.9 Hz, ^3J = 5.5 Hz, ^4J = 0.8 Hz, 1H, CH_2O), 8.06 (m, therein ^4J = 0.8 Hz, ^4J = 0.8 Hz, 1H, formyl H). - ^{13}C NMR ($CDCl_3$, 50 MHz): 19.35 (t, CH_2), 19.77 (q, CH_3), 26.87 (t, CH_2), 30.06 (t, CH_2), 32.88 (d, C-8)*, 35.83 (t, CH_2), 37.20 (d, C-5)*, 46.47 (d, C-8a)**, 48.24 (d, C-4)**, 52.22 (q, $COOCH_3$), 53.03 (q, $COOCH_3$), 66.43 (s, C-3a), 67.33 (t, CH_2O), 160.80 (d, formyl C), 170.80 (s, $COOCH_3$), 174.09 (s, $COOCH_3$), 214.01 (s, C-3). The above assignments were derived from COSY and NOESY spectra and selective irradiation experiments ({^1H}-homodecoupling). - MS (70 eV): *m/z* (%) = 340 (12) [M^+], 308 (58) [M^+ - CH_3OH]. - $C_{17}H_{24}O_7$ (340.4): calcd. C 59.99, H 7.11, found C 59.69, H 7.30.

(3aR,6R*,6aS*,9aR*,9bS*)-(±)-Decahydro-9a-methoxycarbonyl-6-methyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**5**): 912 mg (2.68 mmol) of **4a** and 10 drops of CH_3SO_3H in 50 ml of CH_2Cl_2 were stirred for 2 h at room temp. The mixture was washed with water, dried and concentrated. The crude product was recrystallized (acetone/pentane) to afford 628 mg (84 %)

as colourless crystals; m. p. 146 °C. - IR (KBr): ν = 1775 cm^{-1} (s, lactone C=O), 1750 cm^{-1} (s, ketone C=O), 1720 cm^{-1} (s, ester C=O). - ^1H NMR ($CDCl_3$, 300 MHz): 1.00 (d, ^3J = 6.7 Hz, 3H, CH_3), 1.27 (m, 1H, 4-H), 1.28 (m, 1H, 6-H), 1.39 (m, 1H, 5-H), 1.90 (m, 1H, 5-H), 1.93 (m, 1H, 4-H), 1.98 (m, 1H, 7-H), 2.07 (m, 1H, 8-H), 2.15 (m, 1H, 7-H), 2.36 (m, 1H, 6a-H), 2.61 (m, 1H, 8-H), 2.74 (d, $^3J_{9b,\,3a}$ = 12.4 Hz, 1H, 9b-H),), 3.00 (ddddd, $^3J_{3a,\,9b}$ = 12.4 Hz, $^3J_{3a,\,4}$ = 11.4 Hz, $^3J_{3a,\,3}$ = 10.5 Hz, $^3J_{3a,\,3}$ = 7.9 Hz, $^3J_{3a,\,4}$ = 2.4 Hz, 1H, 3a-H), 3.73 (s, 3H, $COOCH_3$), 3.74 (dd, $^3J_{3,\,3a}$ = 10.5 Hz, ^2J = 8.8 Hz, 1H, 3-H), 4.41 (dd, ^2J = 8.8 Hz, $^3J_{3,\,3a}$ = 7.9 Hz, 1H, 3-H). - ^{13}C NMR ($CDCl_3$, 75 MHz): 21.99 (q, CH_3), 23.56 (t, C-7), 32.26 (t, C-4)*, 33.27 (d, C-6), 33.95 (t, C-5)*, 39.21 (t, C-8)*, 40.29 (d, C-3a), 48.37 (d, C-9b), 52.06 (d, C-6a), 52.61 (q, $COOCH_3$), 65.06 (s, C-9a), 71.36 (t, C-3), 172.74 (s, $COOCH_3$), 176.41 (s, C-1), 211.65 (s, C-9). - MS (CI): *m/z* (%) = 281 (100) [M^+ + 1]. - $C_{15}H_{20}O_5$ (280.3): calcd. C 64.27, H 7.19, found C 63.95, H 6.97.

(3aR,6R*,6aS*,9aR*,9bR*)-(±)-Decahydro-9a-methoxycarbonyl-6,8,8-trimethyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**6**): To 1.20 ml (0.790 mmol) of potassium bis(trimethylsilyl)amide (15perc. in toluene) in 5 ml of THF 100 mg (0.360 mmol) of **5** and 0.350 ml (5.62 mmol) of CH_3I in 2 ml of THF were added at -72 °C under nitrogen. After 2 h no further reaction occurred [TLC control (**5**: R_f = 0.30, Et_2O)]. The mixture was warmed to -60 °C and 0.55 ml (0.36 mmol) of potassium bis(trimethylsilyl)amide (15perc. in toluene) were added. After stirring for 30 min at the same temp. 0.55 ml (0.36 mmol) of potassium bis(trimethylsilyl)amide (15perc. in toluene) were added and stirring was continued for 30 min at -60 °C. The mixture was warmed to room temp., hydrolyzed with 2 ml of 2N HCl and diluted with 20 ml Et_2O and 20 ml of water. The aqueous layer was extracted with Et_2O. The combined organic fractions were dried and concentrated. The crude product was purified by CC (Et_2O) to give 52.0 mg (47 %) of **6** (R_f = 0.46) as a colourless oil. Crystallization (Et_2O/pentane) provided colourless needles; m. p. 111-112 °C (Et_2O/pentane). - IR (KBr): ν = 1760 cm^{-1} (lactone C=O), 1745 cm^{-1} (ketone C=O), 1720 cm^{-1} (ester C=O). - ^1H NMR (300 MHz, $CDCl_3$): 1.00 (d, ^3J = 6.2 Hz, 3H, CH_3 at C-6), 1.14 (d, ^4J = 0.6 Hz, 3H, CH_3 at C-8), 1.25-1.62 [m, 5H, therein 1.26 (s, 3H, CH_3)], 1.69 (ddd, ^2J = 12.4 Hz, $^3J_{7,\,6a}$ = 11.5 Hz, ^4J = 0.6 Hz, 1H, 7-H), 2.05 (dd, ^2J = 12.4 Hz, $^3J_{7,\,6a}$ = 8.0 Hz, 1H, 7-H), 2.99 (ddddd, $^3J_{3a,9b}$ = 9.8 Hz, $^3J_{3a,3}$ = 7.5 Hz, $^3J_{3a,4}$ = 7.1 Hz, $^3J_{3a,4}$ = 5.1 Hz, $^3J_{3a,3}$ = 2.5 Hz, 1H, 3a-H), 3.08 (ddd, $^3J_{6a,7}$ = 11.5 Hz, $^3J_{6a,6}$ = 11.0 Hz, $^3J_{6a,7}$ = 8.0 Hz, 1H, 6a-H), 3.76 (s, 3H, $COOCH_3$), 4.03 (d, $^3J_{9b,\,3a}$ = 9.8 Hz, 1H, 9b-H), 4.10 (dd, ^2J = 9.2 Hz, $^3J_{3,\,3a}$ = 2.5 Hz, 1H, 3-H), 4.40 (dd, ^2J = 9.2 Hz, $^3J_{3,\,3a}$ = 7.5 Hz, 1H, 3-H). - ^{13}C NMR (75 MHz, $CDCl_3$): 21.50 (q, CH_3 at C-6), 23.67 (q, CH_3 at C-8), 26.05 (q, CH_3 at C-8), 28.42 (t, C-4), 31.76 (t, C-5), 35.27 (d, C-3a), 36.75 (d, C-6), 43.30 (t, C-7), 44.65 (d, C-6a), 47.51 (s, C-8), 48.78 (d, C-9b), 53.40 (q, $COOCH_3$), 62.48 (s, C-9a), 71.50 (t, C-3), 171.35 (s, $COOCH_3$), 176.79 (s, C-1), 216.17 (s, C-9). The above assignments were derived from COSY, NOESY and ^1H ^{13}C shift shift correlation spectra. - MS (CI): *m/z* (%) = 309 (100) [M^+ + H]. – HRMS: $C_{17}H_{24}O_5$: calcd. 308.1624, found 308.1624.

(3aR,6R*,6aS*,9aR*,9bR)-(±)-Decahydro-6,8,8-trimethyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**7**): 100 mg (0.330 mmol) of **6**, 22.0 mg (1.22 mmol) of water and 30.0 mg (0.510 mmol) of NaCl in 6 ml DMSO were stirred for 6 h at 150 °C. After cooling to room temp. the reaction mixture was diluted with 20 ml of Et_2O and 20 ml of water. The aqueous layer was extracted with Et_2O. The combined organic fractions were washed with water, dried and concentrated. The crude product was purified by CC [Et_2O/pentane (3:1)] yielding 49.0 mg (60 %) of **7** (R_f = 0.31) as colourless crystals, m. p. 104-105 °C (Et_2O/pentane). - IR (KBr): ν = 1755 cm^{-1} (lactone C=O), 1745 cm^{-1} (ketone C=O). - ^1H NMR (300 MHz, $CDCl_3$): 0.98 (d, ^2J = 6.5 Hz, 3H, CH_3 at C-6), 1.01 (d, ^4J = 0.4 Hz, 3H, CH_3 at C-8), 1.15 (s, 3H, CH_3 at C-8), 1.17 (dddd, ^2J = 14.1 Hz, $^3J_{5,4}$ = 12.0 Hz, $^3J_{5,6}$ = 11.5 Hz, $^3J_{5,4}$ = 2.2 Hz, 1H, 5-H), 1.41 (ddqd, $^3J_{6,5}$ = 11.5 Hz, $^3J_{6,6a}$ = 9.6 Hz, ^3J = 6.5 Hz (q), $^3J_{6,5}$ = 3.4 Hz, 1H, 6-H), 1.44 (dd, ^2J = 12.4 Hz, $^3J_{7,6a}$ = 11.4 Hz, 1H, 7-H), 1.60 (m, 1H, 4-H), 1.61 (m, therein $^3J_{6a,9a}$ = 12.3 Hz, $^3J_{6a,7}$ = 11.4 Hz, $^3J_{6a,6}$ = 9.6 Hz, $^3J_{6a,7}$ = 5.6 Hz, 1H, 6a-H), 1.75 (dddd, ^2J = 14.1 Hz, $^3J_{4,5}$ = 6.0 Hz, $^3J_{4,3a}$ = 2.2 Hz, $^3J_{4,5}$ = 2.2 Hz, 1H, 4-H), 1.93 (dddd, ^2J = 14.1 Hz, $^3J_{5,4}$ = 6.0 Hz, $^3J_{5,6}$ = 3.4 Hz, $^3J_{5,4}$ = 2.2 Hz, 1H, 5-H), 2.04 (dd, ^2J = 12.5 Hz, $^3J_{7,6a}$ = 5.6 Hz, 1H, 7-H), 2.43 (ddddd, $^3J_{3a,4}$ = 12.1 Hz, $^3J_{3a,9b}$ = 7.2 Hz, $^3J_{3a,3}$ = 5.5 Hz, $^3J_{3a,4}$ = 2.2 Hz, $^3J_{3a,3}$ = 0.5 Hz, 1H, 3a-H), 2.47 (dd, $^3J_{9a,6a}$ = 12.3 Hz, $^3J_{9a,9b}$ = 8.4 Hz, 1H, 9a-H), 2.99 (m, therein $^3J_{9b,9a}$ = 8.4 Hz, $^3J_{9b,3a}$ = 7.2 Hz, 1H, 9b-H), 4.04 (dd, ^2J = 9.0 Hz, $^3J_{3,3a}$ = 0.5 Hz, 1H, 3-H), 4.36 (dd, ^2J = 9.0 Hz, $^3J_{3,3a}$ = 5.0 Hz, 1H, 3-H). - ^{13}C NMR (50 MHz, $CDCl_3$): 20.32 (q, CH_3 at C-6), 25.12 (q, CH_3 at C-8),25.83 (q, CH_3 at C-8), 31.50 (t, C-4)*, 38.60 (t, C-5)*, 41.13 (d, C-3a)**, 42.11 (d, C-6)**, 43.33 (s, C-8), 43.39 (t, C-7), 44.01 (d, C-6a)**, 44.21 (d, C-9b)**, 52.81 (d, C-9a), 74.47 (t, C-3), 177.93 (s, C-1), 221.21 (s, C-9). - MS (70 eV): *m/z* (%) = 250 (100) [M^+], 235 (45) [M^+ - CH_3]. - $C_{15}H_{22}O_3$ (250.4): calcd. C 71.97, H 8.86, found C 72.15, H 8.67.

(3aR,6R*,6aS*,9R*S*,9aR*,9bR)-(±)-Decahydro-9-hydroxy-6,8,8-trimethyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**7**, CHOH instead of C=O): 55 mg (0.220 mmol) of **7** and 10.0 mg (0.260 mmol) $NaBH_4$ in 3 ml ethanol were stirred for 2 ½ h at room temp. The solvent was removed in vacuo and the residue was resolved in 20 ml of Et_2O and 20 ml of water. The aqueous layer was extracted with Et_2O. The combined organic fractions were dried and concentrated. After filtration over a silica gel column with Et_2O the solvent was removed in vacuo yielding 40 mg (71 %) of the hydroxy compound as a colourless oil. - IR (film): ν = 3480 cm^{-1} (br., OH), 1750 cm^{-1} (lactone C=O).

(±)-6a-epi-Tremulenolide B (**8**) *and (3aR*,6R*,6aS*,9S*,9aR*,9bR*)-(±)-3a,4,5,6,6a,-9,9a,9b-Octahydro-6,8,9-trimethylazuleno[4,5-c]furan-1(3H)-one* (**9**): 39.0 mg (0.160 mmol) of the above described hydroxy compound and 20.0 µl (0.215 mmol) of $POCl_3$ in 2 ml of pyridine were stirred at room temp. for 21 h. After hydrolysis with ice the mixture was diluted with 20 ml of Et_2O and 20 ml of water. The aqueous layer was extracted with Et_2O. The combined organic fractions were washed with 1N HCl and 2N aq. Na_2CO_3, dried and

concentrated. The crude product was purified by CC [Et_2O/pentane (1:2)] yielding 18.0 mg (49 %) of **8** (R_f = 0.31) as colourless crystals, m. p. 64-65.5 °C (pentane), besides 4.00 mg (11%) of **9** (R_f = 0.35) as a colourless oil.

8: IR (CH_2Cl_2): ν = 1780 cm^{-1} (lactone C=O). - ^1H NMR (300 MHz, $CDCl_3$): 0.95 (d, ^3J = 6.4 Hz, 3H, CH_3, an C-6), 1.07 (s, 3 H, β-CH_3 an C-8), 1.11 (3H, α-CH_3 an C-8), 1.16 (m, therein ^3J = 13.5 Hz, $^3J_{5,6}$ = 12.9 Hz, 1 H, 5-Hβ), 1.24 (m, therein ^2J = 13.4 Hz, $^3J_{4,3a}$ = 9.3 Hz, 1H, 4-Hα), 1.39 (ddqd, $^3J_{6,5}$ = 12.9 Hz, $^3J_{6,6a}$ = 11.4 Hz, ^3J = 6.4 Hz (q), $^3J_{6,5}$ = 2.9 Hz, 1H, 6-Hα), 1.55 (dd, ^2J = 12.8 Hz, $^3J_{7,6a}$ = 2.2 Hz, 1H, 7-Hα), 1.72 (dddd, ^2J = 13.5 Hz, $^3J_{5,4}$ = 9.3 Hz, $^3J_{5,4}$ = 9.0 Hz, $^3J_{5,6}$ = 2.9 Hz, 1H, 5-Hα), 1.89 (m, therein ^2J = 13.4 Hz, $^3J_{4,5}$ = 9.0 Hz, $^3J_{4,3a}$ = 6.0 Hz, 1H, 4-Hβ), 2.04 (dd, ^2J = 12.8 Hz, $^3J_{7,6a}$ = 9.2 Hz, 1H, 7-Hβ), 2.15 (ddddd, $^3J_{6a,6}$ = 11.4 Hz, $^3J_{6a,7}$ = 9.2 Hz, $^3J_{6a,7}$ = 2.2 Hz, $^4J_{6a,9}$ = 1.4 Hz, $^4J_{6a,9b}$ = 1.2 Hz, 1H, 6a-H), 2.77 (ddddd, $^3J_{3a,4}$ = 11.3 Hz, $^3J_{3a,3}$ = 9.9 Hz, $^3J_{3a,9b}$ = 9.5 Hz, $^3J_{3a,3}$ = 7.8 Hz, $^3J_{3a,4}$ = 6.0 Hz, 1H, 3a-H), 3.31 (ddd, $^3J_{9b,3a}$ = 9.5 Hz, $^4J_{9b,9}$ = 1.2 Hz, $^4J_{9b,6a}$ = 1.2 Hz, 1H, 9b-H), 3.81 (dd, ^2J = 8.7 Hz, $^3J_{3,3a}$ = 9.9 Hz, 1H, 3-Hα), 4.39 (dd ^2J = 8.7 Hz, $^3J_{3,3a}$ = 7.8 Hz, 1H, 3-Hβ), 5.43 (dd, $^4J_{9,6a}$ = 1.4 Hz, $^4J_{9,9b}$ = 1.2 Hz, 1H, 9-H). – ^{13}C NMR (75 MHz, $CDCl_3$): 22.48 (q, CH_3 an C-6), 28.87 (t, C-4), 30.01 (q, CH_3 on C-8), 30.87 (q, CH_3 on C-8), 33.73 (t, C-5), 40.22 (d, C-6), 44.38 (d, C-3a), 44.55 (s, C-8), 45.54 (d, C-6a), 46.34 (t, C-7), 56.92 (d, C-9b), 72.63 (t, C-3), 135.50 (s, C-9a), 139.59 (d, C-9), 177.81 (s, C-1). – HRMS: $C_{15}H_{22}O_2$: calcd: 234.1620, found: 234.1618. The above assignments were derived from COSY and NOESY and selective irradiation experiments.

9: - IR (CH_2Cl_2): ν = 1760 cm^{-1} (lactone C=O). - ^1H NMR (300 MHz, $CDCl_3$): 0.94 (d, ^3J = 7.0 Hz, 3H, CH_3 at C-9), 0.98 (d, ^3J = 7.0 Hz, 3H, CH_3 at C-6), 1.10 (dddd, ^2J = 13.5 Hz, $^3J_{5,4}$ = 12.3 Hz, $^3J_{5,6}$ = 11.3 Hz, $^3J_{5,4}$ = 1.9 Hz, 1H, 5-H), 1.23 (m, 1H, 6-H), 1.57 (dddd, ^2J = 14.4 Hz, $^3J_{4,5}$ = 6.0 Hz, $^3J_{4,5}$ = 1.9 Hz, $^3J_{4,3a}$ = 1.8 Hz, 1H, 4-H), 1.72 (ddd, ^4J = 1.6 Hz, ^5J = 2.4 Hz, ^4J = 0.8 Hz, 3H, CH_3 at C-8), 1.81 (dddd, ^2J = 14.2 Hz, $^3J_{4,3a}$ = 12.3 Hz, $^3J_{4,5}$ = 12.3 Hz, $^3J_{4,5}$ = 1.8 Hz, 1H, 4-H), 1.90 (dddd, ^2J = 13.5 Hz, $^3J_{5,4}$ = 6.0 Hz, $^3J_{5,6}$ = 3.8 Hz, $^3J_{5,4}$ = 1.8 Hz, 1H, 5-H), 2.14 (dddq, $^3J_{6a,6}$ = 11.5 Hz, $^3J_{6a,9a}$ = 9.2 Hz, $^3J_{6a,7}$ = 1.6 Hz, ^5J = 2.4 Hz (q), 1H, 6a-H), 2.26 (ddd, $^3J_{9a,9b}$ = 11.6 Hz, $^3J_{9a,6a}$ = 9.2 Hz, $^3J_{9a,9}$ = 8.0 Hz, 1H, 9a-H), 2.53 (ddddd, $^3J_{3a,4}$ = 12.3 Hz, $^3J_{3a,9b}$ = 8.6 Hz, $^3J_{3a,3}$ = 6.4 Hz, $^3J_{3a,4}$ = 1.8 Hz, $^3J_{3a,3}$ = 1.1 Hz, 1H, 3a-H), 2.97 (m, therein $^3J_{9,9a}$ = 7.8 Hz, ^3J = 7.0 Hz (q), 1H, 9-H), 3.01 (dd, $^3J_{9b,9a}$ = 11.6 Hz, $^3J_{9b,3a}$ = 8.6 Hz, 1H, 9b-H), 4.00 (dd, ^2J = 9.2 Hz, $^3J_{3,3a}$ = 1.1 Hz, 1H, 3-H), 4.38 (m, therein ^2J = 9.2 Hz, $^3J_{3,3a}$ = 6.4 Hz, 1H, 3-H), 5.29 (m, therein $^3J_{7,6a}$ = 1.6 Hz, ^4J = 1.6 Hz (q), 1H, 7-H). - ^{13}C NMR (75 MHz, $CDCl_3$): 14.54 (q, CH_3), 15.27 (q, CH_3), 21.72 (q, CH_3), 30.58 (t, C-4)*, 39.53 (t, C-5)*, 41.67 (d, C-6)**, 41.91 (d, C-9a)**, 43.16 (d, C-3a)**, 45.10 (d, C-9)**, 47.05 (d, C-6a)**, 54.22 (d, C-9b)**, 74.00 (t, C-3), 125.36 (d, C-7), 145.86 (s, C-8), 179.08 (s, C-1). The above assignments were derived from COSY spectra and selective irradiation experiments ({^1H}-homodecoupling). – HRMS: $C_{15}H_{22}O_2$: calcd. 234.1620, found 234.1618.

(3aR,6R*,6aS*,9aR*,9bS*)-(±)-Decahydro-9a-methoxycarbonyl-6,8,8-trimethyl-9-oxo-azuleno[4,5-c]furan-1(3H)-one* (**10**): At -78 °C under nitrogen 13.0 ml (8.56 mmol) of potassium bis(trimethylsilyl)amide (15perc. in toluene) in 30 ml of THF were dropped slowly to a solution of 589 mg (0.564 mmol) of **5** and 2.80 ml (45.0 mmol) of CH_3I in 70 ml of THF. After stirring 2 h at the same temp. the mixture was warmed to -30 °C, hydrolyzed with 25 ml 2N HCl and diluted with 300 ml of CH_2Cl_2 and 300 ml of water. The aqueous layer was extracted with CH_2Cl_2. The combined organic fractions were washed with 10perc. aq. $NaHSO_3$ and water, dried and concentrated. The crude product was purified by CC (Et_2O) yielding 144 mg (22 %) of **10** (R_f = 0.38) as colourless crystals, m. p. 171-172 °C (acetone/pentane). - IR (KBr): ν = 1784 cm^{-1} (lactone C=O), 1744 cm^{-1} (ketone C=O), 1728 cm^{-1} (ester C=O). - ^{1}H-NMR (500 MHz, $CDCl_3$): 1.07 (d, ^3J = 6.8 Hz, 3H, CH_3 at C-6), 1.15 (s, 3H, CH_3 at C-8), 1.26 (s, 3H, CH_3 at C-8), 1.26 (dddd, ^2J = 13.2 Hz, $^3J_{4,5}$ = 12.9 Hz, $^3J_{4,3a}$ = 11.5 Hz, $^3J_{4,5}$ = 3.2 Hz, 1H, 4-H), 1.37 (dddd, ^2J = 14.1 Hz, $^3J_{5,4}$ = 12.9 Hz, $^3J_{5,6}$ = 10.1 Hz, $^3J_{5,4}$ = 2.9 Hz, 1H, 5-H), 1.49 (ddqd, $^3J_{6,5}$ = 10.1 Hz, $^3J_{6,6a}$ = 9.7 Hz, ^3J = 6.8 Hz (q), $^3J_{6,5}$ = 1.2 Hz, 1H, 6-H), 1.83 (dddd, ^2J = 14.1 Hz, $^3J_{5,4}$ = 4.5 Hz, $^3J_{5,4}$ = 3.2 Hz, $^3J_{5,6}$ = 1.2 Hz, 1H, 5-H), 1.91 (dddd, ^2J = 13.2 Hz, $^3J_{4,5}$ = 4,5 Hz, $^3J_{4,3a}$ = 3.1 Hz, $^3J_{4,5}$ = 2.9 Hz, 1H, 4-H), 2.03 (dd, ^2J = 14.2 Hz, $^3J_{7,6a}$ = 6.2 Hz, 1H, 7-H), 2.04 (dd, ^2J = 14.2 Hz, $^3J_{7,6a}$ = 4.7 Hz, 1H, 7-H), 2.44 (ddd, $^3J_{6a,6}$ = 9.7 Hz, $^3J_{6a,7}$ = 6.2 Hz, $^3J_{6a,7}$ = 4.7 Hz, 1H, 6a-H), 2.69 (d, $^3J_{9b,3a}$ = 12.4 Hz, 1H, 9b-H), 2.96 (ddddd, $^3J_{3a,9b}$ = 12.4 Hz, $^3J_{3a,4}$ = 11.5 Hz, $^3J_{3a,3}$ = 10.8 Hz, $^3J_{3a,3}$ = 7.8 Hz, $^3J_{3a,4}$ = 3.1 Hz, 1H, 3a-H), 3.72 (dd, $^3J_{3,3a}$ = 10.8 Hz, ^2J = 8.9 Hz, 1H, 3-H), 3.74 (s, 3H, $COOCH_3$), 4.38 (dd, ^2J = 8.9 Hz, $^3J_{3,3a}$ = 7.8 Hz, 1H, 3-H). - ^{13}C NMR (125 MHz, $CDCl_3$): 22.94 (q, CH_3 at C-6), 26.63 (q, CH_3 at C-8), 27.50 (q, CH_3 at C-8), 31.91 (t, C-4), 36.53 (d, C-6), 37.84 (t, C-5), 39.30 (t, C-7), 40.73 (d, C-3a), 43.83 (s, C-8), 47.92 (d, C-9b), 49.94 (d, C-6a), 52.54 (q, $COOCH_3$), 65.64 (s, C-9a), 71.05 (t, C-3), 172.68 (s, $COOCH_3$), 175.64 (s, C-1), 216.27 (s, C-9).). The above assignments were derived from COSY, NOESY and HSQC spectra. – HRMS: $C_{17}H_{24}O_5$: calcd. 308.1624, found 308.1624.

X-ray structure analysis of **10**[9]: The data of a crystal (acetone/pentane) with the approximate dimensions 0.20 × 0.45 × 0.65 mm were obtained with a Siemens P4-Xscans diffractometer (Mo-K_α radiation, graphite monochromator). Cell dimensions were refined from 62 reflections; a = 967.6(2), b = 1656.9(4), c = 1068.2(2) pm, β = 109.47(2) °, V = 1614.7(7) · 10^6 pm^3, monoclinic, space group $P2_1/n$, Z = 4, $\rho_{calcd.}$ = 1.268 g/cm^3, 3715 unique intensities, of which 2879 [$F_o > 3\sigma(F)$] were observed in the θ range 1.75 - 27.5 °, measured with ω-scan technique. The structure was solved by using direct-phase determination and refined on F by using SHELXTL-Plus. Positional parameters, anisotropic displacement parameters for all atoms except for hydrogen atoms, groupwise isotropic displacement parameters for all hydrogen atoms, treated as rigid groups. R = 0.055, R_w = 0.055, $w = 1/\sigma^2(F)$.

(3aR,6S*,6aS*,9aR*,9bS*)-(±)-Decahydro-9a-methoxycarbonyl-6-methyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**11**): 74 mg (2.68 mmol) of **4b** and 3 drops of CH_3SO_3H in 20 ml of CH_2Cl_2 were refluxed for 4 h. The mixture was washed with water, dried and concentrated to afford 53 mg (84 %) of **11** as colourless crystals; m. p. 151-151.5 °C (CH_2Cl_2/Et_2O/pentane). - IR (KBr): ν = 1775 cm^{-1} (lactone C=O), 1748 cm^{-1} (ketone C=O), 1721 cm^{-1} (ester C=O). - ^1H NMR (300 MHz, $CDCl_3$): 0.87 (d, ^3J = 7.4 Hz, 3H, CH_3), 1.39-1.53 (m, 1H, 4-H), 1.63 - 1.79 (m, 2H, 4-H and 5-H), 1.80 - 1.89 (m, 2H, 5-H and 7-H), 2.11 - 2.22 (m, 1H, 6-H), 2.33 - 2.49 (m, 2H, 7-H and 8-H), 2.67 - 2.82 [m, 2H, 8-H and 6a-H, therein at 2.79 (d, $^3J_{9b,\,3a}$ = 12.5 Hz, 1H, 9b-H)], 2.96 (ddddd, $^3J_{3a,\,9b}$ = 12.5 Hz, ^3J = 11.3 Hz, $^3J_{3a,\,3}$ = 10.6 Hz, $^3J_{3a,\,3}$ = 7.8 Hz, ^3J = 2.3 Hz, 1H, 3a-H), 3.73 (s, 3H, $COOCH_3$), 3.78 (dd, $^3J_{3,\,3a}$ = 10.6 Hz, ^2J = 8.8 Hz, 1H, 3-H), 4.40 (dd, ^2J = 8.8 Hz, $^3J_{3,\,3a}$ = 7.8 Hz, 1H, 3-H). - ^{13}C NMR (50 MHz, $CDCl_3$): 15.12 (q, CH_3), 25.94 (t, C-7), 27.12 (t, C-4), 35.00 (t, C-5), 35.36 (t, C-8), 39.16 (d, C-6), 40.87 (d, C-3a), 47.82 (d, C-6a), 49.73 (d, C-9b), 52.66 (q, $COOCH_3$), 63.01 (s, C-9a), 71.04 (t, C-3), 172.56 (s, $COOCH_3$), 176.27 (s, C-1), 212.34 (s, C-9). The above assignments were derived from COSY and NOESY spectra and selective irradiation experiments ({^1H}-homodecoupling). - MS (70 eV): *m/z* (%) = 280 (49) [M^+], 308 (58). - $C_{15}H_{20}O_5$ (280.3): calcd. C 64.27, H 7.19, found C 64.38, H 7.10.

X-ray structure analysis of **11**[9]: The data of a crystal (acetone/pentane) with the approximate dimensions 0.75 × 0.75 × 0.40 mm were obtained with a Siemens P4-Xscans diffractometer (Mo-K_α radiation, graphite monochromator). Cell dimensions were refined from 31 reflections; a = 898.7(2), b = 1037.00(9), c = 1479.7(1) pm, V = 1379.7(1) · 10^6 pm^3, orthorhombic, space group $P2_12_12_1$, Z = 4, $\rho_{calcd.}$ = 1.350 g/cm^3, 3168 unique intensities, of which 3024 [$F_o > 3\sigma(F)$] were observed in the θ range 1.75 - 27.5 °, measured with ω-scan technique. The structure was solved by using direct-phase determination and refined on F by using SHELXTL-Plus. Positional parameters, anisotropic displacement parameters for all atoms except for hydrogen atoms, groupwise isotropic displacement parameters for all hydrogen atoms, treated as rigid groups. R = 0.048, R_w = 0.048, $w = 1/\sigma^2(F)$.

(3aR,6S*,6aS*,9aR*,9bS*)-(±)-Decahydro-9a-methoxycarbonyl-6,8,8-trimethyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**12**): At -78 °C under nitrogen 3.45 ml (2.27 mmol) potassium bis(trimethylsilyl)amide (15perc. in toluene) in 6 ml of THF were dropped slowly to a solution of 158 mg (0.564 mmol) of **11** and 0.74 ml (11.9 mmol) of CH_3I in 18 ml of THF. After stirring 30 min at the same temp. the mixture was warmed to -30 °C, hydrolyzed with 7 ml 2N HCl and diluted with 100 ml of CH_2Cl_2 and 100 ml of water. The aqueous layer was extracted with CH_2Cl_2. The combined organic fractions were washed with 10perc. aq. $NaHSO_3$ and water, dried and concentrated. The crude product was purified by CC (Et_2O) yielding 75 mg (43 %) of **12** (R_f = 0.26) as colourless crystals, m. p. 140 °C (acetone/pentane). - IR (KBr): ν = 1784 cm^{-1} (lactone C=O), 1720 cm^{-1} (ketone C=O, ester C=O). - ^1H NMR (500 MHz,

$CDCl_3$): 1.03 (d, ^3J = 7.0 Hz, 3H, CH_3 at C-6), 1.19 (s, 3H, CH_3 at C-8), 1.25 (s, 3H, CH_3 at C-8), 1.46 (dddd, ^2J = 14.4 Hz, $^3J_{4,3a}$ = 11.1 Hz, $^3J_{4,5}$ = 9.1 Hz, $^3J_{4,5}$ = 3.3 Hz, 1H, 4-H), 1.60 (m, 1H, 5-H), 1.67 (dddd, ^2J = 15.1 Hz, ^3J = 11.4 Hz, $^3J_{5,4}$ = 9.1 Hz, ^3J = 7.8 Hz, 1H, 5-H), 1.80 (dd, ^2J = 13.2 Hz, $^3J_{7,6a}$ = 13.3 Hz, 1H, 7-H), 1.88 (m, 1H, 4-H), 1.91 (dd, ^2J = 13.2 Hz, $^3J_{7,6a}$ = 6.4 Hz, 1H, 7-H), 2.05 (m, 1H, 6-H), 2.50 (d, $^3J_{9b,3a}$ = 10.9 Hz, 1H, 9b-H), 2.77 (ddddd, $^3J_{3a,4}$ = 11.1 Hz, $^3J_{3a,9b}$ = 10.9 Hz, $^3J_{3a,3}$ = 9.3 Hz, $^3J_{3a,3}$ = 8.8 Hz, $^3J_{3a,4}$ = 5.6 Hz, 1H, 3a-H), 2.84 (ddd, $^3J_{6a,7}$ = 13.3 Hz, $^3J_{6a,7}$ = 6.4 Hz, $^3J_{6a,6}$ = 2.2 Hz, 1H, 6a-H), 3.73 (dd, $^3J_{3,3a}$ = 9.3 Hz, ^2J = 9.1 Hz, 1H, 3-H), 3.78 (s, 3H, $COOCH_3$), 4.45 (dd, ^2J = 9.1 Hz, $^3J_{3,3a}$ = 8.8 Hz, 1H, 3-H). - ^{13}C NMR (125 MHz, $CDCl_3$): 23.07 (q, CH_3), 26.77 (q, CH_3), 26.95 (t, C-5)*, 27.44 (q, CH_3), 27.72 (t, C-4)*, 29.94 (d, C-3a), 34.35 (t, C-7)*, 37.38 (d, C-6)**, 43.40 (d, C-6a)**, 44.32 (s, C-8), 46.47 (d, C-9b)**, 52.90 (q, $COOCH_3$), 65.87 (s, C-9a), 71.25 (t, C-3), 170.85 (s, $COOCH_3$), 174.93 (s, C-1), 212.59 (s, C-9). The above assignments were derived from COSY spectra. – HRMS $C_{17}H_{24}O_5$: calcd. 308.1624, found 308.1624.

X-ray structure analysis of **12**[9]: The data of a crystal (acetone/pentane) with the approximate dimensions 0.45 × 0.55 × 0.65 mm were obtained with a Siemens P4-Xscans diffractometer (Mo-K_α radiation, graphite monochromator). Cell dimensions were refined from 60 reflections; a = 790.15, b = 1701.8(2), c = 1239.3(1) pm, β = 99.422(6) °, V = 1644.0(3) · 10^6 pm^3, monoclinic, space group $P2_1/c$, Z = 4, $\rho_{calcd.}$ = 1.246 g/cm^3, 3766 unique intensities, of which 3172 [$F_o > 3\sigma(F)$] were observed in the θ range 1.75 - 27.5 °, measured with ω-scan technique. The structure was solved by using direct-phase determination and refined on F by using SHELXTL-Plus. Positional parameters, anisotropic displacement parameters for all atoms except for hydrogen atoms, groupwise isotropic displacement parameters for all hydrogen atoms, treated as rigid groups. R = 0.057, R_w = 0.065, $w = 1/\sigma^2(F)$.

(3aR,6S*,6aS*,9aS*,9bS*)-(±)-Decahydro-6,8,8-trimethyl-9-oxoazuleno[4,5-c]furan-1(3H)-one* (**13**): 139 mg (0.451 mmol) of **12**, 150 mg (8.32 mmol) of water and 200 mg (3.40 mmol) of NaCl in 8 ml DMSO were stirred for 7.5 h at 150 °C. After cooling to room temp. the reaction mixture was diluted with 90 ml of Et_2O and 90 ml of water. The aqueous layer was extracted with Et_2O. The combined organic fractions were washed with water, dried and concentrated. The crude product was purified by CC (Et_2O) yielding 41.0 mg (36 %) of **13** (R_f = 0.42) as colourless needles, m. p. 104-105 °C (acetone/pentane) besides 46.0 mg (33 %) of unreacted starting material **12** (R_f = 0.25). - IR (KBr): ν = 1778 cm^{-1} (lactone C=O), 1735 cm^{-1} (ketone C=O). - ^{1}H NMR (500 MHz, $CDCl_3$): 0.75 (d, ^3J = 7.4 Hz, 3H, CH_3 at C-6), 1.20 (s, 3H, CH_3 at C-8), 1.22 (s, 3H, CH_3 at C-8), 1.48 (dddd, ^2J = 13.1 Hz, $^3J_{4,5}$ = 13.1 Hz, $^3J_{4,3a}$ = 11.1 Hz, $^3J_{4,5}$ = 3.0 Hz, 1H, 4-H), 1.57 (dddd, ^2J = 13.5 Hz, $^3J_{5,4}$ = 13.1 Hz, $^3J_{5,4}$ = 3.9 Hz, $^3J_{5,6}$ = 2.3 Hz, 1H, 5-H), 1.60 (dd, ^2J = 14.2 Hz, $^3J_{7,6a}$ = 2.3 Hz, 1H, 7-H), 1.71 (dddd, ^2J = 13.1 Hz, $^3J_{4,5}$ = 3.9 Hz, $^3J_{4,5}$ = 3.9 Hz, $^3J_{4,3a}$ = 2.3 Hz, 1H, 4-H), 1.78 (dddd, ^2J = 13.5 Hz, $^3J_{5,6}$ = 5.0 Hz, $^3J_{5,4}$ = 3.9 Hz, $^3J_{5,4}$ = 3.0 Hz, 1H, 5-H), 1.92 (qddd, ^3J = 7.4 Hz (q), $^3J_{6,5}$ = 5.0 Hz, $^3J_{6,5}$ = 2.3

Hz, $^3J_{6,\,6a}$ = 2.3 Hz, 1H, 6-H), 2.33 (dd, ^2J = 14.2 Hz, $^3J_{7,\,6a}$ = 10.1 Hz, 1H, 7-H), 2.37 (ddddd, $^3J_{3a,\,9b}$ = 13.2 Hz, $^3J_{3a,4}$ = 11.1 Hz, $^3J_{3a,3}$ = 11.0 Hz, $^3J_{3a,3}$ = 7.3 Hz, $^3J_{3a,\,4}$ = 2.3 Hz, 1H, 3a-H), 2.58 (dddd, $^3J_{6a,\,9a}$ = 10.3 Hz, $^3J_{6a,\,7}$ = 10.1 Hz, $^3J_{6a,\,7}$ = 2.3 Hz, $^3J_{6a,\,6}$ = 2.3 Hz, 1H, 6a-H), 2.70 (dd, $^3J_{9b,\,3a}$ = 13.2 Hz, $^3J_{9b,\,9a}$ = 9.6 Hz, 1H, 9b-H), 3.19 (dd, $^3J_{9a,\,6a}$ = 10.3 Hz, $^3J_{9a,\,9b}$ = 9.6 Hz, 1H, 9a-H), 3.80 (dd, $^3J_{3,\,3a}$ = 11.0 Hz, ^2J = 8.8 Hz,1H, 3-H), 4.30 (dd, ^2J = 8.8 Hz, $^3J_{3,\,3a}$ = 7.3 Hz, 1H, 3-H). - ^{13}C NMR (125 MHz, $CDCl_3$): 13.52 (q, CH_3 at C-6), 23.86 (q, CH_3 at C-8), 26.43 (t, C-7), 30.98 (q, CH_3 at C-8). 35.68 (t, C-4), 38.66 (d, C-6)*, 39.76 (d, C-3a)*, 42.22 (s, C-8), 42.51 (d, C-6a)**, 42.94 (t, C-5), 43.45 (d, C-9b)**, 47.69 (d, C-9a), 70.75 (t, C-3), 177.88 (s, C-1), 218.57 (s, C-9). The above assignments were derived from COSY and NOESY spectra. - MS (CI): *m/z* (%) = 251 (100) [M^+ + H]. - $C_{15}H_{22}O_3$ (250.4): calcd. C 71.97, H 8.86, found C 71.96, H 8.93.

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