232. Synthesis of (±)-Desmarestene and (±)-Viridiene, the Two Sperm Releasing and Attracting Pheromones from the Brown Algae *Desmarestia aculeata* and *Desmarestia viridis*

by **Wilhelm Boland**[1]), **Karin Jakoby** and **Lothar Jaenicke**

Institut für Biochemie der Universität, An der Bottmühle 2, D-5000 Köln 1

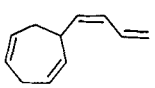
(12.VIII.82)

Summary

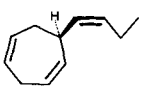
Desmarestene **1** 6-(1*Z*,3-butadienyl)-1,4-cycloheptadiene) and viridiene **3** *cis*-3-(1*Z*,3-butadienyl)-4-vinylcyclopentene) are chemical messengers for male gametes of the brown algae *Desmarestia aculeata* and *Desmarestia viridis*. Total syntheses of **1**, **3** and their stereoisomers **1a**, **3a–c** are reported. Gas-chromatographic comparison of synthetic **1** and **3** with the corresponding natural products has established their structural identity.

1. Introduction. – Gamete fusion in *Phaeophyceae* is generally mediated by hormone-like substances which are secreted by the female gametes and act on male gametes or on the gametangia [1] [2]. Mature eggs of the Northern Atlantic seaweeds *Desmarestia aculeata* and *Desmarestia viridis* discharge desmarestene **1**, ectocarpene **2** and viridiene **3** into the surroundings [3]. The chemical messengers **1** and – less pronounced – **3** first induce burst of antheridia, thus liberating the single androgamete contained therein. Subsequently, the spermatozoid is attracted to the emitting gynogamete for zygote formation[2])[3]).

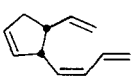
Since the thresholds of pheromone concentrations required for biological response are very low (9×10^{-11} M for gamete release; 2.8×10^{-11} M for chemotaxis) [3] it is understandable that the compounds are produced and excreted in very small amounts. Thus only microgram fractions containing **1**, **2** and **3** as major components



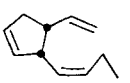
1
Desmarestene



2
Ectocarpene



3
Viridiene



4
Multifidene

[1]) Author to whom correspondence should be addressed.

[2]) Similar biological effects have been observed during the sexual cycles of the large sublitoral algae *Laminaria digitata* and *Laminaria hyperborea* [4].

[3]) Addition to the proofs: Viridiene **3** has been found in the mean time to be the gamete attractant of the atlantic seaweed *Syringoderma* [3b].

0018-019X/82/7/2355-08$01.00/0

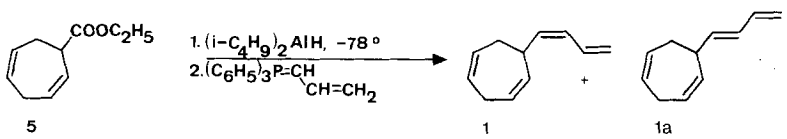
could be obtained from mass cultures of the gynogametophytes. The elemental composition of the two new hydrocarbons was determined by combined GC./MS. as $C_{11}H_{14}$ ($M^+ = 146$) in both cases. Compound **2** was readily recognized as ectocarpene **2** ($M^+ = 148$), isolated earlier as the sex attractant for male gametes of *Ectocarpus siliculosus* [5]. It is a common constituent of the pheromone bouquets of *Phaeosporales (Ectocarpales/Laminariales).*

Microhydrogenation of a sample of the *Desmarestia* pheromone mixture yielded only two products and indicated the existence of four double bonds in both molecules ($M^+ = 154$). The two saturated hydrocarbons were identical with hydrogenated samples of ectocarpene **3** and multifidene **4** by mass fragmentation and gas-chromatographic comparison (*Kováts* indices). Multifidene **4** is the lure in the hydrocarbon pattern emitted by females of the mediterranean seaweed *Cutleria multifida* [6] [7]. The close structural relationship of the new attractants to already known pheromones, together with current concepts on their biogenesis [1b,c] prompted us to synthesize butadienylcycloheptadienes and -cyclopentenes such as **1** and **3** with unambiguous configuration.

The successful syntheses and correlation of the configuration with the natural products is the subject of this paper.

2. Synthesis of desmarestene *1*. – Reductive alkenylation [8] of the cycloheptadiene ester **5**, readily available in bulk quantities [9], with diisobutylaluminium hydride and propenylidenetriphenylphosphorane gave a (1:1)-mixture of (*Z*)- and (*E*)-desmarestenes **1** and **1a**. After removal of the (*E*)-isomer **1a** by *Diels-Alder* reaction using 4-phenyl-1,2,4-triazoline-3,5-dione or tetracyanoethylene as selective dienophiles almost pure desmarestene **1** was obtained in two steps and in an overall yield of 26% based on **5** *(Scheme 1).* Capillary gas-chromatography on two different columns and quantitative bioassay proved identity of natural and synthetic material *(cf. Table).*

Scheme 1



5 1 1a

1/1a + 4-Phenyl-1,2,4-triazoline-3,5-dione → **1**

3. Synthesis of viridiene (*3*). – Synthesis of viridiene **3** and its (*E*)-isomer **3a** started from the isomerically pure dibromo ester **6** [10] from which two routes, **A** and **B**, led to the desired cyclopentene derivative **3** *(Scheme 2).*

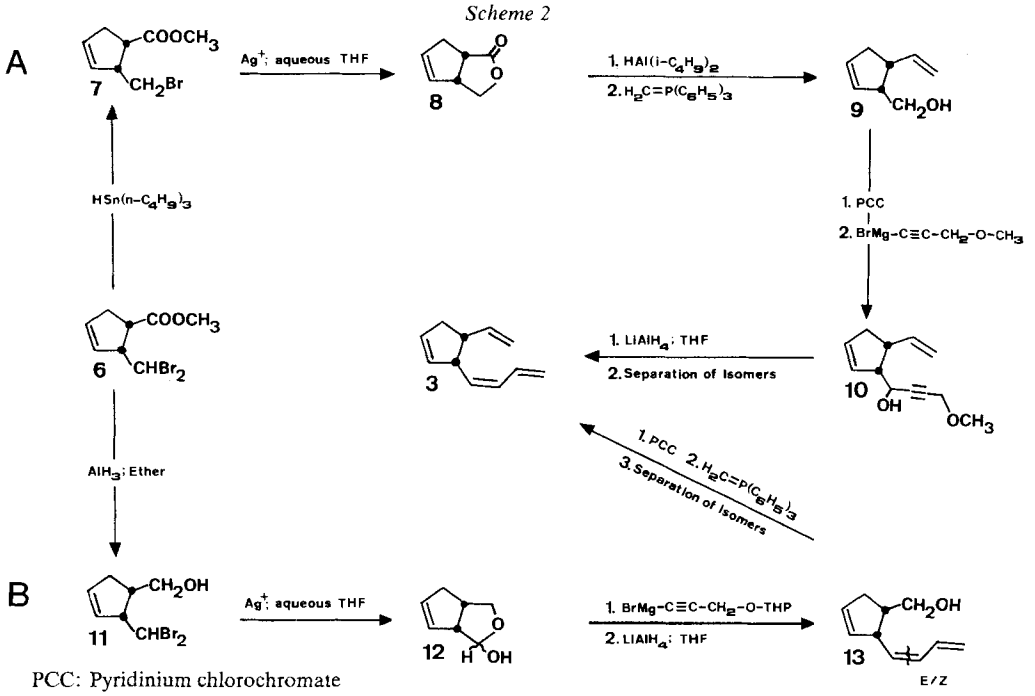
A. Reduction of the $CHBr_2$-moiety of **6** with tri-*n*-butyltin hydride afforded the monobromide **7** which, on treatment with silver nitrate in aqueous tetrahydrofuran, easily underwent neighbouring-group assisted ring closure to the bicyclic lactone **8**. Introduction of the vinyl group by reductive alkenylation [8] produced the alcohol **9**. Though this compound could be oxidized to the appropriate aldehyde, attempts to convert the latter into an alkene by the classical *Wittig* approach (butenyl and

Table. Kováts *indices of synthetic and natural products*

Compound	Column-temp. °C	Retention index OV 73	OV 1701
Viridiene (natural)	60	1085.6±0.2	1125.6±0.3
3	60	1085.6±0.3	1124.9±0.8
3a	60	1081.4±0.3	1120.0±0.9
3b	60	1059.1±0.6	1096.3±0.4
3c	60	1066.3±0.5	1105.9±0.5
3d	60	1085.5±0.3	1124.8±0.4
Desmarestene (natural)	70	1178.6±0.1	1227.8±0.1
1	70	1178.5±0.1	1227.8±0.2
1a	70	1189.3±0.1	1241.7±0.3

butadienyl substituents were tried) gave only very low yields (>7%) and impure products. An alternative alkylation/reduction procedure, however, as originally described by *Claesson* [11], proved more successful. Alkylation of the aldehyde with 3-methoxypropynylmagnesium bromide to **10** followed by $LiAlH_4$ reduction immediately led to the viridiene stereoisomers **3** and **3a** (*Z*/*E* 2:3). Again, the unwanted isomer **3a** was quantitatively removed by treatment with 4-phenyl-1,2,4-triazoline-3,5-dione, whereas tetracyanoethylene this time failed completely, attack of the ring double bond of the viridiene system being apparently preferred.

Scheme 2



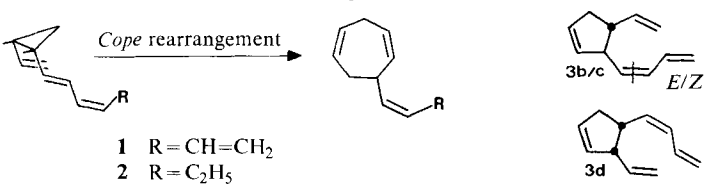
PCC: Pyridinium chlorochromate
THF: Tetrahydrofuran
THP: Tetrahydropyran

B. In a second approach the ester group of **6** was first reduced with aluminium hydride and the resulting alcohol **11** treated with silver ion in aqueous tetrahydrofuran. If the hemiacetal **12** thus obtained was subjected to the above alkylation/reduction procedure using 3-(tetrahydro-2-pyranyloxy)propynylmagnesium bromide and, subsequently, $LiAlH_4$ the butadienyl element is introduced without formation of by-products in an overall yield of 36% based on **6** (*Z*/*E* 2:3). Obviously, the internal hydride transfer and alkoxide-elimination from the intermediate allenic aluminium-organic species are highly synchronous in accordance with a six-membered transition state as proposed earlier [11]. Interaction with other hydroxyl groups within the same molecule are therefore very unlikely[3]), even if they are arranged in the vicinity of the reactive acetylenic unit (*cf.* conversion **12** → **13**).

A final oxidation of **13** with pyridinium chlorochromate (PCC) and *Wittig* reaction with methylidenephosphorane made the two pheromone isomers **3** and **3a** readily accessible. Purification was carried out as described above.

Reaction sequence **B** proved to be more useful, since the alcohol **13** also makes possible the synthesis of *trans*-disubstituted cyclopentenes after oxidation to the aldehyde. To achieve this isomerization, the latter was treated briefly with 0.02 N methanolic potassium hydroxide. The viridienes **3b/c** were obtained after *Wittig* reaction with methylidenephosphorane. In addition, **13** was easily resolved into the pure enantiomers by simple column chromatography on silica gel after appropriate chiral derivatization. This, together with the biological activity of the compounds, will be reported elsewhere [12].

Scheme 3



1 R = CH=CH$_2$
2 R = C_2H_5

4. Identification of natural products. – According to current biogenetic concepts [1b,c] the cycloheptadiene moiety of ectocarpene **2** is formed by a concerted *Cope* rearrangement of an intermediate dictyopterene (*cis*-1-vinyl-2-(1*E*,3*Z*-hexadienyl)-cyclopropane) [13] [14] *(Scheme 3)*. The same mechanism is assumed to be an essential step in the biosynthesis of desmarestene **1**.

Consequently, the ring double bonds necessarily have to be arranged in the assigned positions which reduces the possible isomers to **1** or **1a**. This is different in the case of viridiene. Though the same concept [1b,c] would also fit for its biogenesis, there is as yet no experimental proof available. The very close structural relationship to multifidene **4**, however, suggested compound **3** to be identical with the natural messenger. Therefore the other three viridiene isomers **3b/c** and **3d** [15] were included in all comparative GC. analyses and bioassays to

[3]) Allylic positions are, of course, excepted, since they are directly involved in the mechanism.

allow unambiguous positioning of the ring double bond and the substitution pattern[4]). *Kováts* indices were determined by co-injection of a suitable *n*-alkane marker together with the sample at a properly selected isothermal temperature level *(Table)*.

Whereas the coincidence of natural and synthetic desmarestene **1** was perfect, no final decision for one of the viridiene stereoisomers **3** or **3d** could be made on this basis. However, if dilutions of **3** and **3d** are used as chemical signals for gamete release from antheridia of *Desmarestia viridis* [3], a positive response was obtained down to 6.4×10^{-10} mol/l sea water with compound **3** only. Since **3d** showed no biological activity even at ten-fold concentration [16], it is clear that the structure of viridiene **3** corresponds to *cis*-4-vinyl-3-(1*Z*,3-butadienyl)cyclopentene as originally assigned by analogy to multifidene **4**.

Experiments to establish the absolute configuration of **3** and **4** are under investigation.

The authors thank the *Deutsche Forschungsgemeinschaft* and the *Fonds der Chemischen Industrie* for support. Thanks are also due to Dr. *G. Gassmann* (Biologische Anstalt, Helgoland) for GC. facilities and Prof. Dr. *D. G. Müller* (Universität Konstanz) for the bioassays.

Experimental Part

All melting (m.p.) and boiling (b.p.) points are uncorrected. Analytical GC.: *Carlo Erba* gas chromatograph, Series *4200* equipped with *Duran* glass capillaries 50 m × 0.32 mm coated with *SE 54* or *Ucon 75 H 90000*. Analytical HPLC.: *Altex 420* HPLC. system combined with a *Kratos SF 770* variable wavelength UV. monitor. UV. spectra: *Cary 14*. IR. spectra (cm^{-1}) were recorded on a *Pye Unicam SP3-200* spectrophotometer. ^{1}H-NMR. spectra were run on a *Varian EM-390* 90-MHz-spectrometer in CCl_4 with TMS as internal standard. MS. were obtained with a *Finnigan 4500* GC./MS. system. Elemental analyses were performed by *I. Beetz*, D-8640 Kronach, FRG.

All solvents and reagents were purified prior to use. Reactions were carried out under an inert atmosphere if not stated otherwise.

6-(1Z,3-Butadienyl)-1,4-cycloheptadiene (**1**) *and its isomer* **1a**. A 1.0M solution (7.0 ml) of diisobutylaluminium hydride in hexane (7.0 mmol) was added dropwise at −78° to a well-stirred solution of 1.0 g **5** (6.5 mmol) in 20 ml dry toluene. Stirring was continued at −78°, until GC. control indicated complete reduction of starting material (*ca.* 30 min). Excess diisobutylaluminium hydride was decomposed by injection of 0.1 ml absolute methanol, and the whole solution was then quickly poured into a freshly prepared solution of propenylidenetriphenylphosphorane (10.0 mmol) in 50 ml of dry THF (butyllithium as base). After 1 h stirring at 0° the mixture was hydrolyzed by addition of 50 ml 2.0N HCl. The organic layer was separated and the aq. phase was extracted with pentane (2 × 50 ml). The combined org. phases were successively washed with 2.0N HCl, saturated $NaHCO_3$-solution and water. After removing the solvent under reduced pressure the crude residue was triturated with pentane, to precipitate the triphenylphosphine oxide. The clear filtrate was concentrated *in vacuo* and the product purified by CC. on silica gel with pentane. After vacuum evaporation of solvent 0.50 g (53% yield) of (*Z*)- and (*E*)-desmarestenes **1/1a** 1:1 were obtained.

Separation of isomers by Diels-Alder *reaction*. To a solution of 0.5 g (3.42 mmol) desmarestene **1/1a** in 5 ml of dry THF was added gradually with stirring 4-phenyl-1,2,4-triazoline-3,5-dione (*ca.* 0.3 g) until the red colour of the triazoline just persisted. The solution was concentrated at reduced pressure to about 2 ml, and pure desmarestene (**1**) was obtained by CC. on silica gel with pentane. Concentration

---

[4]) Microhydrogenation of a natural sample yielded a 60:40 mixture of *cis* and *trans* disubstituted cyclopentanes. Treatment of synthetic **3** under identical conditions gave similar results thus indicating, that there is massive scrambling of double bonds during hydrogenation (Pt/H_2).

in vacuo yielded 0.21 g (1.43 mmol, 84% recovery) of pure pheromone **1**. – UV. (MeOH): $\lambda_{max} = 230$ nm ($\varepsilon = 21000$). – IR. (neat): 3080, 3005, 2960, 2930, 2900, 1650, 995, 905, 790 and 765. – ^{1}H-NMR. (CCl_4): 2.15–2.40 (*m*, 2 H); 2.75–3.05 (*m*, 2 H); 3.35–3.70 (*m*, 1 H); 5.10 (*d*×*d*, *J* = 10 and 2, 1 H); 5.17 (*d*×*d*, *J* = 17 and 2, 1 H); 5.30–6.15 (*m*, 6 H); 6.65 (*d*×*d*×*d*, *J* = 17, 10 and 10, 1 H). – MS. (70 eV): 146 (2, M^+), 145 (1), 131 (12), 117 (23), 105 (40), 91 (97), 79 (100), 77 (52), 68 (31), 65 (37), 53 (24), 51 (32), 41 (66), 39 (100).

$C_{11}H_{14}$ (146.23) Calc. C 90.35 H 9.65% Found C 90.27 H 9.71%

Methyl cis-*2-bromomethyl-3-cyclopentenyl-1-carboxylate* (**7**). To 17.0 g (60.0 mmol) ester **6** was added gradually with stirring a total amount of 19.0 g (65.0 mmol) tributyltin hydride. The internal temp. of the reaction flask was kept around 25° by intermittant cooling with a water bath until the moderately exothermic reaction ceased. Stirring was continued for another 2 h at RT. followed by vacuum distillation over a short *Vigreux* column (10 cm) which gave 10.5 g (86% yield) of a colourless liquid, b.p. 56°/0.04 Torr. – IR. (neat): 3060, 3020, 3000, 2950, 2860, 1730, 1435, 1200, 1030 and 715. – ^{1}H-NMR. (CCl_4): 2.30–3.60 (*m*, 5 H); 3.70 (*s*, 3 H); 5.65–6.03 (*m*, 2 H). – MS. (70 eV): 218/220 (2, M^+), 187/189 (4), 159/161 (5), 139 (47), 125 (12), 107 (28), 93 (38), 79 (100), 65 (30), 59 (79), 53 (49), 39 (84).

$C_8H_{11}BrO_2$ (219.09) Calc. C 43.86 H 5.06% Found C 43.72 H 4.98%

cis-*2-Methylcyclopent-3-ene-1,2'-carbolactone* (**8**). To a well-stirred solution of 10.0 g (46.0 mmol) ester **7** in 100 ml THF/water 9:1 (*v*/*v*) were added 12.2 g silver nitrate when an immediate precipitation of the insoluble AgBr was observed. Stirring was continued for 1 h at RT. when the excess of silver salts was removed by addition of 50 ml sat. NaCl-solution. Water (100 ml) was added and the precipitate was filtered off by suction. The clear filtrate was extracted with ether (3× 100 ml) and the combined org. layers were thoroughly washed with water (4× 50 ml). After drying and evaporation of solvent *in vacuo* distillation over a short *Vigreux* column afforded 5.4 g (90% yield) of pure lactone **8**, b.p. 60°/0.04 Torr. – IR. (neat): 3060, 2975, 2910, 2860, 1760, 1610, 1375, 1175, 1140, 1055, 995, 935, 790, 730 and 680. – ^{1}H-NMR. (CCl_4): 2.68 (*d*×*d*, *J* = 2.4 and 4.5, 2 H); 2.92–3.30 (*m*, 1 H); 3.42–3.85 (*m*, 1 H); 4.18 (*d*×*d*, *J* = 2.4 and 9, 1 H); 4.40 (*d*×*d*, *J* = 6.3 and 9.0, 1 H); 5.60–6.00 (*m*, 2 H). – MS. (70 eV): 124 (8, M^+), 96 (13), 79 (73), 66 (100), 51 (17), 39 (91).

$C_7H_8O_2$ (124.14) Calc. C 67.73 H 6.50% Found C 67.55 H 6.48%

cis-*(5-Vinyl-2-cyclopenten-1-yl)methanol* (**9**). Lactone **8** (5.0 g, 40.3 mmol) was treated with diisobutylaluminium hydride (45.0 mmol) and methylidenephosphorane (48.0 mmol in 100 ml dry THF; BuLi as base) as described for the preparation of desmarestene **1**. After CC. on silica gel using hexane/ether (80:20) 2.3 g (42% yield) of a colourless viscous oil were obtained. – IR. (neat): 3340, 3070, 3050, 2980, 2920, 2840, 1635, 1610, 1030, 1000, 910, 730 and 710. – ^{1}H-NMR. (CCl_4): 2.15 (*s*, 1 H); 2.05–3.15 (*m*, 2 H); 3.30–3.70 (*m*, *ABX*, 2 H); 4.95–5.25 (*m*, 2 H); 5.55–6.27 (*m*, 3 H). – MS. (70 eV): 124 (0.4, M^+), 106 (16), 93 (46), 91 (100), 77 (72), 65 (21), 39 (31).

$C_8H_{12}O$ (124.18) Calc. C 77.38 H 9.74% Found C 77.29 H 9.64%

cis-*1-(2-Cyclopentenyl)-4-methoxy-2-butyn-1-ol* (**10**). – a) *Oxidation.* To a suspension of 10.4 g (48.0 mmol) pyridinium chlorochromate in 70 ml CH_2Cl_2 were added with stirring 2.0 g (16.0 mmol) of the alcohol **9**. The reaction proceeded slowly, and after 1 h another portion of the oxidant (3.5 g, 16.0 mmol) was added. When GC. analysis indicated complete conversion of starting material, 100 ml pentane were added and the precipitated chromium salts removed by suction. Following evaporation of solvent under reduced pressure the crude mixture was redissolved in 50 ml pentane, dried ($MgSO_4$) and filtered. Vacuum concentration left pure aldehyde which was used without further purification in the alkylation step.

b) *Alkylation.* To a solution of 20.0 mmol 3-methoxypropynylmagnesium bromide in 50 ml dry THF was added dropwise with stirring a solution of the above aldehyde in 5.0 ml of the same solvent. The solution was stirred for 1 h at 0° and then poured onto ice/NH_4Cl (100 ml ice/water and 20 g NH_4Cl). The aq. phase was carefully extracted with ether (3× 100 ml) and the combined org. phases were washed with 2.0N HCl (50 ml) and water (50 ml). After evaporation of solvent *in vacuo* the crude product was distilled, b.p. 84°/0.03 Torr. – IR. (neat): 3420, 3070, 3050, 2980, 2920, 2840, 2820, 1685, 1635, 1100, 1000, 910, 810 and 735. – ^{1}H-NMR. (CCl_4): 1.90–3.20 (*m*, 5 H); 3.33 (*s*, 3 H); 4.10

(*d*, 2 H); 4.38 (*m*, 1 H); 5.00–5.30 (*m*, 2 H); 5.70–6.35 (*m*, 3 H). – MS. (70 eV): 192 (0.2, M^+), 159 (5), 147 (7), 131 (12), 117 (17), 106 (36), 93 (93), 91 (100), 79 (59), 77 (95), 68 (32), 65 (30), 53 (28), 41 (72), 38 (88).

$C_{12}H_{16}O_2$ (192.26) Calc. C 74.97 H 8.39% Found C 74.83 H 8.22%

cis-*3-(1Z,3-Butadienyl)-4-vinyl-cyclopentene* (**3**) *and its isomer* **3a** *(viridiene).* To a stirred, ice cooled suspension of $LiAlH_4$ (0.75 g, 15.0 mmol) in 15 ml dry THF a solution of 1.5 g (7.8 mmol) alkyne **10** in 5.0 ml of the same solvent was added dropwise. The mixture was stirred for 1 h at 40° followed by cooling with an ice bath and addition of 0.02 g $AlCl_3$ (0.15 mmol). The solution was refluxed for 1 h, cooled and *slowly* poured onto ice/dil. HCl (*ca.* 10%). The aq. phase was carefully extracted with pentane (4×50 ml), and the combined org. layers washed with water (2×50 ml). Evaporation of solvent *in vacuo* and purification of the crude product by CC. on silica gel with pentane gave 0.95 g (83% yield) of viridienes **3** and **3a** (*Z*/*E* 2:3). Separation of isomers was carried out as described for desmarestene **1**; 89% recovery of viridiene **3**. – UV. (MeOH): λ_{max} = 234 (ε = 20700), 218 (sh) (ε = 18600).– IR. (neat): 3080, 3050, 3000, 2975, 2930, 2840, 1635, 1605, 1430, 995, 905, 790 and 730. – ^{1}H-NMR. (CCl_4): 2.12–2.80 (*m*, 2 H); 3.08 (*qi*, 1 H); 3.83 (*t*, 1 H); 4.90–6.45 (*m*, 6 H); 6.72 (*d*×*d*×*d*, *J* = 16.5, 10.5 and 10.5, 1 H). – MS. (70 eV): 146 (3, M^+), 131 (13), 117 (27), 105 (47), 92 (47), 91 (77), 79 (88), 77 (51), 65 (35), 53 (23), 51 (40), 41 (62), 39 (100).

$C_{11}H_{14}$ (146.23) Calc. C 90.35 H 9.65% Found C 90.37 H 9.69%

cis-*(2-Dibromomethyl-3-cyclopenten-1-yl)methanol* (**11**). A solution of 2.22 g (16.0 mmol) $AlCl_3$ in 30 ml dry ether was added dropwise to a stirred suspension (0°) of 1.9 g (50.0 mmol) $LiAlH_4$ in 80 ml of the same solvent. Stirring was continued for 30 min, then a solution of 15.0 g (50.3 mmol) ester **6** in 30 ml ether was added slowly with cooling (0°). After 1 h the mixture was hydrolyzed with 2.0N HCl and the clear solution was extracted with ether (3×100 ml). The combined extracts were washed with saturated $NaHCO_3$-solution and water (2×50 ml each). After drying and evaporation of solvent *in vacuo* a crude viscous oil was obtained (12.2 g, 89% yield). During workup, temperatures above 35° should be avoided, since the dibromide easily decomposes with loss of HBr. An analytically pure sample was obtained by CC. on silica gel with hexane/ether (80:20). Because of the thermal instability of **11** HPLC. was used to follow elution of compounds (stationary phase: RP 18, mobile phase: CH_3OH/water (90:10), detection: 220 nm). – IR. (neat): 3350, 3060, 3010, 2930, 2900, 2850, 1440, 1160, 1020, 955, 785 and 650. – ^{1}H-NMR. (CCl_4): 2.15–2.55 (*m*, 2H); 2.65 (*qi*, 1 H); 3.45 (*s*, 1 H); 3.65 (*m*, 1 H); 3.87 (*qi*, 2 H); 5.80–6.25 (*m*, 2 H); 6.10 (*d*, 1 H). – MS. (70 eV): the thermally stable acetate was used instead of the free alcohol; 252 (1.8, $M^+ - CH_3COOH$), 171/173 (33), 157/159 (8), 91 (81), 79 (100), 66 (38), 51 (43), 39 (50).

$C_9H_{12}Br_2O_2$ (acetate of **11**, 312.01) Calc. C 34.65 H 3.88% Found C 33.84 H 3.87%

cis-*3,3a,6,6a-Tetrahydro-1*H*-cyclopenta[c]furan-1-ol* (**12**). To a solution of 8.0 g (30.0 mmol) of alcohol **11** in 50 ml THF, a solution of 12.0 g (70.6 mmol) silver nitrate in 20 ml distilled water was added with stirring. Formation of silver bromide occurred immediately and the reaction was usually completed within 0.5 h. Excess of silver salts was removed by addition of 50 ml sat. NaCl-solution and the precipitate removed by suction. The aq. phase was extracted with ether (3×100 ml) and the combined org. layers were thoroughly washed with water (3×50 ml). After drying ($MgSO_4$) and evaporation of solvent under reduced pressure the crude product was purified by CC. on silica gel with hexane/ether (60:40). Elution of compounds was followed as described for **11**. Removal of solvent *in vacuo* afforded 3.2 g of pure hemiacetal **12** (85% yield). – IR. (neat): 3400, 3050, 2955, 2920, 2850, 1620 (very weak), 1080, 1040, 990, 960, 910, 835, 770 and 695. – ^{1}H-NMR. (CCl_4): 2.05–4.35 (*m*, 6 H); was used; 139 (0.8, $M^+ - 1$), 109 (9), 79 (100), 77 (27), 65 (12), 51 (12), 45 (12), 41 (38), 39 (43).

$C_8H_{12}O_2$ (methyl ether of **12**, 140.18) Calc. C 68.54 H 8.63% Found C 68.47 H 8.61%

cis-*[2-(1Z,3-Butadienyl)-3-cyclopenten-1-yl]methanol* (**13**). – a) *Alkylation.* To a solution of 30 mmol 3-(tetrahydropyranyl-2-oxy)propynylmagnesium bromide in 80 ml dry THF was added dropwise with stirring a solution of 3.2 g **12** (25.4 mmol) in 10 ml of the same solvent. The solution was stirred for 1 h at 0° and then poured onto ice/NH_4Cl (100 ml ice/water and 20 g NH_4Cl). The aq. phase was

carefully extracted with ether (3× 100 ml) and the combined org. layers were washed neutral with water. After drying and evaporation of solvent the crude product (5.4 g, 84% yield) was used for reduction without further purification.

b) *Reduction.* The acetylenic intermediate was reduced to the alcohol **13** using the standard procedure given for the synthesis of **3/3a**. Following evaporation of solvent under reduced pressure the crude product was distilled. Yield 3.0 g (79% with reference to **12**), b.p. 57°/0.02 Torr. – IR. (neat): 3350, 3080, 3050, 3000, 2920, 2840, 1640, 1600, 1005, 965, 900 and 720. – ^{1}H-NMR. (CCl_4): 1.20–3.10 (*m*, 4 H); 3.20–4.00 (*m*, 3 H); 4.80–6.95 (*m*, 7 H). – MS. (70 eV): 150 (5, M^+), 131 (15), 117 (78), 104 (35), 91 (100), 77/78/79 (48), 67 (28), 65 (33), 51/53 (23), 40 (93), 38 (79).

$C_{10}H_{14}O$ (150.22) Calc. C 79.96 H 9.39% Found C 79.80 H 9.39%

Viridiene (**3**) *and its isomer* **3a** via *route* **B**. The alcohol **13** (1.0 g, 6.7 mmol) was oxidized as described for **10**. The crude product thus obtained (0.7 g, 71% yield) was added to a solution of 10.0 mmol methylidenetriphenylphosphorane in 20 ml dry THF. The solution was stirred for 30 min at RT., and excess phosphorane was quenched by addition of 20 ml 2.0N HCl. Following usual workup (*cf.* compound **1**) 0.45 g (46% yield) of viridienes **3** and **3a** were obtained. For separation of isomers follow route **A**, *Scheme 2.*

trans-*3-(1Z,3-Butadienyl)-4-vinyl-cyclopentene* (**3b**) *and the isomer* **3c**. The alcohol **13** (1.0 g, 6.7 mmol) was oxidized as described for **10**. The crude product thus obtained (0.7 g, 71% yield) was dissolved in 5 ml CH_3OH and then treated with 50 mg solid KOH (0.9 mmol). The mixture immediately turned dark, and stirring was continued for 30 min. Water (10 ml) was added and the solution was extracted with pentane (3× 30 ml). The combined org. layers were washed with 20 ml each of 1.0N HCl and water. After drying and evaporation of solvent *in vacuo* the dark residue (0.45 g, 64% yield) was immediately converted into the alkene as described for viridiene (**3**) (route **B**). Purification by CC. on silica gel with pentane afforded 0.34 g (76% yield) of viridiene isomers **3b** and **3c**. Separation of isomers followed the usual procedure (*cf.* **1** and **3**). – IR. (neat): 3080, 3065, 3000, 2965, 2920, 2845, 1635, 995, 905, 790 and 720. – ^{1}H-NMR. (CCl_4): 1.90–2.78 (*m*, 3 H); 3.50 (*m*, irrad. at 2.50 reduces the broad signal to a doublet, J=9, 1 H); 4.80–6.17 (*m*, 9 H); 6.60 ($d\times d\times d$, J= 16.5, 11.4 and 10.5, 1 H). – MS. (70 eV): identical with **3**.

REFERENCES

[1] a) *D.G. Müller*, Pure Appl. Chem. *51*, 1885 (1979); b) *L. Jaenicke*, J. Sci. Ind. Res. *39*, 819 (1980); c) *L. Jaenicke & W. Boland*, Angew. Chem. *94*, 659 (1982); Int. Ed. *94*, 643 (1982).

[2] *D.G. Müller & N. Lüthe*, Br. Phycol. J. *16*, 351 (1981).

[3] a) *D.G. Müller, A. Peters, G. Gassmann, W. Boland, F.-J. Marner & L. Jaenicke*, Naturwissenschaften *69*, 290 (1982); b) *D.G. Müller, W. Boland, F.-J. Marner & G. Gassmann*, Naturwissenschaften *69*, 501 (1982).

[4] *D.G. Müller, G. Gassmann & K. Lüning*, Nature *279*, 430 (1979).

[5] *D.G. Müller, L. Jaenicke, M. Donike & T. Akintobi*, Science *171*, 815 (1971).

[6] *L. Jaenicke, D.G. Müller & R.E. Moore*, J. Am. Chem. Soc. *96*, 3324 (1974).

[7] *W. Boland & L. Jaenicke*, J. Org. Chem. *44*, 4819 (1979).

[8] *W. Boland, P. Ney & L. Jaenicke*, Synthesis *1979*, 1015.

[9] *L. Jaenicke, T. Akintobi & F.-J. Marner*, Liebigs Ann. Chem. *1973*, 1252.

[10] *W. Boland & L. Jaenicke*, Chem. Ber. *110*, 1823 (1977).

[11] *A. Claesson*, Acta Chem. Scand. *B29*, 609 (1975).

[12] *W. Boland et al.*, in preparation.

[13] *J.A. Pettus, jr. & R.E. Moore*, J. Am. Chem. Soc. *93*, 3087 (1971).

[14] *G. Ohloff & W. Pickenhagen*, Helv. Chim. Acta *52*, 880 (1969).

[15] *W. Boland, K. Jakoby & L. Jaenicke*, synthesis unpublished; details are available on request.

[16] *A. Peters & D.G. Müller*, personal communication.