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TERPENOIDS—LXXI[1]

CHEMICAL STUDIES OF MARINE INVERTEBRATES—XIV.[2] FOUR REPRESENTATIVES OF A NOVEL SESQUITERPENE CLASS—THE CAPNELLANE SKELETON

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Abstract—The isolation and complete structure determination of four marine sesquiterpenoids: $\Delta^{9(12)}$-capnellene-$8\beta,10\alpha$-diol (**1**), $\Delta^{9(12)}$-capnellene-$3\beta,8\beta,10\alpha$-triol (**3**), $\Delta^{9(12)}$-capnellene-$5\alpha,8\beta,10\alpha$-triol (**5**), $\Delta^{9(12)}$-capnellene-$2\xi,8\beta,10\alpha$-triol (**7**) from the soft coral *Capnella imbricata* is described. These alcohols are the first members of a fundamentally new sesquiterpene class consisting of three 5-membered fused rings which we have named capnellane (A).

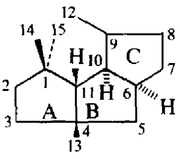
Marine sessile coelenterates of the subclass Octocorallia comprise amongst others the two colonial orders Gorgonacea (gorgonians, sea fans) and Alcyonacea (alcyonarians, soft coals), which are prominent in the biomass of many tropical reefs.[4] Most representatives of these orders live in symbiotic relationship with intracellular algae, the zooxanthellae[5,6] and it has been established that these algae play an important role in the biology of the colony.[7,8]

The ability of octocorals to ward off algal and microbial growth[9] and to prevent the settlement of larvae[7] soon suggested the presence of chemical defenses. Gorgonians have proved to be a rich source of a great variety of interesting organic compounds,[7] including sterols,[10] prostaglandins,[11] butenolides,[12] sesquiterpenoid hydrocarbons,[13] cembranolide[7,14] and other[15] diterpenoids.

The origin of these substances is intriguing, since it has been shown that the symbiotic algae in the cells of gorgonians contain significant amounts of terpenes.[16]

Recent work has confirmed the speculation that alcyonarinas might be equally productive in novel compounds: sterols,[17] sesquiterpenes[18,19] and diterpenes[2,20] have been encountered in abundance in some species. During our continuing search for novel terpenoids from marine sources we have examined sun-dried colonies of the soft coral *Capnella imbricata* (Quoy and Gaimard, 1833), collected at the islands of Leti, Lakor, Sermata, Masela and Tanimbar, all in the Province of Maluku, Indonesia, and at Laing Island, Madang District, Papua—New Guinea. The terepenoid fraction of these samples although containing structurally related compounds, was found to differ notably from population to population (Experimental).

We wish to report here the isolation and structure determination of four alcohols based upon a new sesquiterpenoid skeleton capnellane (A): $\Delta^{9(12)}$-capnellane-$8\beta,10\alpha$-diol (**1**), $\Delta^{9(12)}$-capnellane-$3\beta,8\beta,10\alpha$-triol (**3**), $\Delta^{9(12)}$-capnellene-$5\alpha,8\beta,10\alpha$-triol (**5**) and $\Delta^{9(12)}$-capnellene-$2\xi,8\beta,10\alpha$-triol (**7**). The structure of compound **3** has been already reported in a preliminary communication.[19]



A

A dichloromethane extract of the sun-dried soft coral (collection Leti) *Capnella imbricata* after repeated chromatography over silica gel furnished three sesquiterpenoids (**1**, **3** and a totrol). In order to obtain additional quantities of this tetrol, another collection of this animal was made at a different location (Lakor); no tetrol was encountered but in addition to **1**, the new sesquiterpenoids **5** and **7** were found. The structure of the tetrol will be published in a subsequent communication.

Structure of $\Delta^{9(12)}$-*capnellene*-$3\beta,8\beta,10\alpha$-*triol* (**3**). The NMR spectrum (Table 1) of compound **3** [M^+ *m/e* 252; $C_{15}H_{24}O_3$; IR 3400 cm^{-1} (OH), 1640 cm^{-1} ($C{=}CH_2$)] depicted three tertiary Me groups, one allylic secondary carbinol methine, a secondary non-allylic carbinol methine and a vinylic methylene. Acetylation of **3** furnished a diacetate **4** [$C_{19}H_{28}O_5$; IR (film) 3500 cm^{-1} (OH), 1745 cm^{-1} (C=O)] whose NMR spectrum (Experimental) depicted in addition to three tertiary Me's, a vinylic methylene and two secondary carbinol acetate methines, whose chemical shift confirm the presence of an allylic and non-allylic secondary alcohol (Experimental). Hydrogenation (PtO_2-ethyl acetate) of **3** furnished a dihydro derivative **10** [$C_{15}H_{26}O_3$] whose NMR spectrum showed the presence of a secondary Me group at 1.10 δ (d, $J = 7.0$ Hz) and the absence of vinylic methylene protons. Oxidation of **3** with manganese dioxide led to an α,β-unsaturated ketone (**12**) [$C_{15}H_{22}O_3$; UV λ_{max} 225 nm (ϵ5900); IR 1730 cm^{-1} (C=O)]. The ^{13}C NMR spectrum

Table 1. NMR[a] data of sesquiterpenoids 1, 3, 5, 7 and derivatives

Compound	CH_3-C-	CH_3-CH	CH_3-C=	CH-OH	C=C-CH-OH	$C=C{<}^{H}_{H}$
1	1.08 1.24 1.26				4.80(m)	5.31,5.33 (br s,1H each)
3	1.06 1.20 1.28			4.13 (dd,J=6,5)	4.83(m)	5.38 (d,J=1.5,2H)
5[b]	1.12 1.18 1.32			3.86 (d,J=5.5)	4.80(m)	5.20 (m,2H)
7	1.16 1.28 1.45			3.70(m)	4.70(m)	5.37 (m,2H)
11	1.00 1.20 1.30					5.53,6.20 (s,1H each)
12	0.90 1.21 1.33			4.10(m)		5 53,6.20 (s,1H each)
14	1.07 1.17 1.32			3 32 (d,J=5.5)		5.53,6.15 (s,1H each)
15	1.12 1.23 1.40			3.73 (dd,J=2.4,5.0)		5.50,6.07 (s,1H each)
16[c]	1.09 1.11	1.03 (d)				
17	1.21 1.23 1.31	1.16 (d,J=7)		4.13(m)		
18	1.15 1.20 1.28	1.02 (d,J=7.5)		3.50 (d,J=7.5)		
19	1.00 1.10 1.30	1.10 (d,J=6)		4.00 (d,d,J=8.0,6)		
20	0.90 1.20		1.66 (d,J=2.0)			
21	0.86 1.14 1.30		1.71 (d,J=2)	4.12(dd)		
22	0.90 1.23		1.67 (d,J=2)		3.23 (d,J=10)	
24	0.93 1.22 1.26		1.70 (d,J=2)		4.20 (dd,J=6,9)	
26	0.96 1.07 1.23	0.98 (d,J=6.5)				
27	0.98 1.11 1.14	1.05 (d,J=6.5)			4.00 (c)	
29	1.00 1.10 1.30	1.05 (d,J=6.5)			3.64 (d,J=9.0)	
31	1.02 1.07 1.28	1.10 (d,J=6 5)			4.0 (dd,J=6,9)	
33	1.08 1.15 1.30	1.11 (d,J=7)				
34	1.13 1.33	1.16 (d,J=6)				
35	0.96 1.01 1.23					
36	0.83 1.00 1.13					
37	0.86 1.23 1.26		1.83 (br.s)			

[a] Chemical shifts are given in δ units with tetramethylsilane as an internal standard in $CDCl_3$ (J in Hz).

[b] In 1:1 deuteriomethanol and perdeuterioacetone.

[c] In perdeuteriobenzene.

(Table 2) of **3** indicated the presence of two sp^2 C atoms (161.5 ppm, *C*=; 109.1 ppm, *CH*$_2$=) one secondary carbinol (81·4 ppm) but most importantly the presence of an allylic quaternary carbon bearing a OH group (89.8 ppm). All these data showed that **3** contains one secondary and one tertiary OH group and three rings, one of which is 5-membered (see IR and UV of **12**), and that it carries an exocyclic methylene and one allylic secondary OH group. Lithium/ammonia reduction of **12** gave the β-hydroxy ketone **17** [$C_{15}H_{24}O_3$] possessing (Table 1) the expected three tertiary Me groups and an additional secondary Me function. Base treatment of **17** provided an oily α,β-unsaturated ketone **21** [$C_{15}H_{22}O_2$; UV λ_{max} 242.5 nm (ϵ 12,200); IR 3450 cm^{-1} (OH), 1695 cm^{-1} (C=O), 1655 cm^{-1}

Table 2. ^{13}C chemical shift data[a]

Carbon atom	1	3	5
1	43.3	38.6	43.7
2	42.7*	51.7	42.4
3	41.4*	81.4	32.9
4	49.3	52 6	53.2
5	45.6	45.3	82.8
6	48.7	49.8	56.1
7	36.8	38.1	34.6
8	72.4	73.8	72.4
9	160.3	161.5	159.9
10	88.8	89.8	86.0
11	64.6	65.5	64.0
12	107.5	109.1	108.4
13	31.5*	25.0*	30.8*
14	30.3*	32.9	31.4*
15	23.2	26.1*	24.1

[a] $CDCl_3$ solution, in ppm relative to TMS. * The assignment of chemical shift for closely lying peaks marked with an aster may be reversed.

(C=C)] whose NMR spectrum (Table 1) was relatively uninformative. However, as reported in our preliminary communication addition of $Eu(DPM)_3$ shift reagent resulted in complete resolution of the signals of the NMR spectrum which became nearly first order so that the interrelationship of all hydrogens could be established by decoupling experiments. Repeated Li/NH_3 reduction of the α,β-unsaturated ketone **21** provide tthe hydroxy ketone **27** which represents a key compound for subsequent correlation to the other capnellanes. Indeed the other compounds **1**, **5** and **7** will be related to the hydroxy ketone **27** whose stereochemistry (except at C-9) is known, since the structure, stereochemistry and absolute configuration of **3** have been independently established by X-ray diffraction analysis.[19]

Structure of $\Delta^{9(12)}$*-capnellene-8β,10α-diol* (**1**). The NMR spectrum (Table 1) of compound **1** [M^+ m/e 236; $C_{15}H_{24}O_2$] differed from that of **3** by the absence of the non-allylic carbinol methine (4.13 δ). This was further substantiated by the absence of an 81.4 ppm (non-allylic CH–OH) signal in the ^{13}C NMR spectrum (Table 2) of compound **1**. Compound **1** furnished a monoacetate **2**, a dihydro derivative **9** and upon manganese dioxide oxidation the α,β-unsaturated ketone **11**. Lithium ammonia reduction gave the expected β-hydroxy ketone **16** and upon base-catalyzed dehydration the α,β-unsaturated ketone **20**, which in turn when reduced with Li/NH_3 yielded the saturated ketone **26**. The CD spectrum of **26** ($[\theta]_{298}+5198$) had the same sign as the 3β-hydroxy ketone **27** thus indicating the identical B/C stereochemistry in both ketones. The identity of the skeleton of **1** with that of **3** was confirmed by conversion of the hydroxy ketone **27** to its tosylate **28** which on subsequent reduction with LAH followed by Jones oxidation gave ketone **26** identical with the specimen derived from **1**. Therefore **1** and **3** are based on the identical capnellane system, the only difference being the absence of a secondary alcohol at position 3 in compound **1**.

Structure of $\Delta^{9(12)}$*-capnellene-5α,8β,10α-triol* (**5**). The most diagnostic feature of the NMR spectrum (Table 1) of compound **5** [M^+ m/e 252; $C_{15}H_{24}O_3$; IR (KBr) 3380 (OH), 1670 ($C{=}CH_2$) cm^{-1}] were the exocyclic methylene δ 5.10 (2H), the allylic secondary carbinol methine δ 4.6 (m) and the non-allylic secondary carbinol methine δ 3.2 (d, $J = 7$ Hz) signals. Assuming that compound **5** has the same skeleton and identical ene-diol moiety on ring C as **1** and **3**, then the most likely position for the non-allylic secondary OH group (note doublet at δ 3.2) is position 5. This supposition was verified by oxidation of **5** to the α,β-unsaturated ketone **14**, reduction to the β-hydroxy ketone **18**, dehydration to the α,β-unsaturated ketone **22** and reduction to the hydroxy ketone **29**. Conversion of the latter to its tosylate **30** followed successively by LAH reduction and Jones oxidation furnished a ketone **26** which proved to be identical with those derived from **1** and **3**. The presence of the non-allylic carbinol at position 5 in ring B and its stereochemistry (α) was proved as follows: compound **22** was very resistant to dehydration (TSOH, $SOCl_2$/Py gave no reaction) and the corresponding tosylate **23** was recovered unchanged after heating at 100° for 3 hr in DMSO. However, when a methanolic solution of **23** and potassium hydroxide was refluxed for 3 hr, the conjugated dienone $\Delta^{5,9}$-capnelladien-8-one (**37**) [IR 1705, 1630 cm^{-1}, UV λ_{max} 289 nm (ϵ 12,188)] was obtained. The generation of the dienone establishes the C-5 attachment of the OH group; the difficulty in the elimination step is only consistent with a *cis* relationship between the C-5 hydroxyl and the C-6 hydrogen which is known[19] to be α-oriented from the earlier X-ray analysis of **3**.

Structure of $\Delta^{9(12)}$*-capnellene-2ξ,8β,10α-triol* (**7**). Compound **7** was obtained as an oil [M^+ m/e 252; $C_{15}H_{24}O_3$; IR (film) 3400 (OH), 1660 ($C{=}CH_2$) cm^{-1}] with NMR signals (Table 1) corresponding to three tertiary methyls, one allylic carbinol methine proton and one non allylic-carbinol methine proton. In the corresponding oily diacetate **8** the two carbinol methine signals were shifted to 4.83 (dd, $J = 5$, 5.5 Hz, 1H) and 5.76 (m, 1H) thus suggesting the presence of one non-allylic secondary carbinol methine. A choice in favor of ring *A* (positions 2 or 3) was made because of an intense mass spectral fragmentation peak at m/e 149 [$M^+ - C_5H_9O + H_2O$; 63%] corresponding to loss of ring *A* (fission of 1–11 and 3–4 bonds) in addition to water elimination in ring *C*.

The location (C-2) of the non-allylic OH group in **7** was established as follows. Compound **7** was subjected to the usual reaction sequence of manganese dioxide oxidation to **15**, Li/NH_3 reduction to **19**, base-catalyzed dehydration to **24**, and finally Li/NH_3 reduction to the hydroxy ketone **31**. The mass spectral fragmentation (Table 3) of this ketol **31** strongly resembled that of its isomer **27** but differed greatly from that of **29** in which the OH group is located in ring *B* rather than ring *A*. Jones oxidation of **27** and **31** furnished two different diketones **32** and **34** thus clearly establishing that the OH groups in ring *A* are located on different carbons rather than being stereoisomers in position 3. Since the OH group of **3** (and hence of **27**) is known[19] to be attached to C-3, it follows that the one of **31** (and hence **7**) must be at C-2.

The ^{13}C NMR spectra of compounds **1**, **3** and **5** (Table 2) were a valuable aid in elucidation of the structure of the capnellanes. In particular, the multiplicity of the signals in the off-resonance decoupled spectra allowed the assignment of all resonances to either primary, secondary, tertiary, or quaternary C atoms, thus providing a count of the different types of C atoms present in each compound. Furthermore, signals from carbinol and olefinic C atoms

Table 3. Mass spectral fragmentation[a] of hydroxyketones **27**, **29** and **31**

m/e	27	31	29
236	56	21	59
221	-	-	18
218	-	-	26
203	-	-	10
192	42	15	-
179	-	-	15
167	-	-	11
165	-	-	26
162	15	13	17
152	23	10	11
151	22	12	100
150	35	28	14
149	-	17	-
148	-	-	15
135	17	10	-
123	-	-	67
122	-	-	22
121	23	15	16
119	-	-	16
109	100	100	59
108	11	-	-
107	24	17	47
105	11	7	19
97	-	-	21
96	13	-	23
95	12	6	97
94	19	12	12
93	29	22	40
91	19	10	26
85	54	29	-
81	24	12	42
79	29	12	27
77	11	8	25
71	66	33	-
70	-	-	36
69	26	13	52
68	-	-	10
67	15	8	36
65	-	4	13
57	30	10	36
56	-	-	11
55	26	11	67
53	15	9	19

[a] All peaks higher than 50 mass units and which are at least >10% relative intensity in one of the three compounds are listed.

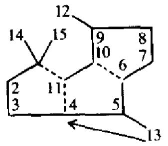
were easily recognizable by their characteristic shieldings. Having established the structure and stereochemistry of **1**, **3** and **5** it has been possible to complete the assignment of their ^{13}C NMR spectra as shown in Table 2. In addition to information obtained from off-resonance decoupled spectra the final assignment has been done by consideration of the substituent effects to be expected of the OH group in cyclic systems[21,22] and by application of several chemical shift rules. Thus, the C-9 and C-12 olefinic resonances were readily identified as the two lowest field signals in the spectra of all three compounds and differentiated by their multiplicity in the off-resonance decoupled spectra. Of the remaining three singlets in these spectra the low field one must arise from the carbinyl carbon, C-10. The C-4 resonance may be identified by comparison of the spectrum of **1** with those of **3** and **5**, since introduction of a OH group next to a quaternary C atom is expected[21] to produce a downfield shift of 2–5 ppm at this atom. The assignment for C-1 follows by exclusion.

The signals for the methine carbon atoims were assigned in the following way. Introduction of an OH group at C-3 or C-5 is expected not to influence the C-8 carbinyl resonance and the peak at 72–73 ppm may thus be assigned to C-8 in all three spectra. The assignment for the carbinyl carbons C-3 in **3** and C-5 in **5** is self-evident, since these low field signal at 81–83 ppm appear in **3** and **5** but not in **1**. The signal at ~49 ppm in **1** and **3** and at 56 ppm in **5** may be assigned to C-6, since this carbon atom in **5** is β to a OH group and a downfield shift of about that magnitude is expected to result. The remaining signal around 65 ppm appearing in the spectra of all three compounds must then arise from C-11.

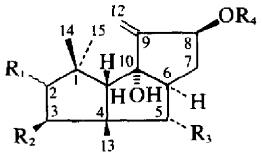
Of the saturated methylene C atoms, the C-2 resonance should be shifted downfield (10–15 ppm) in **3** relative to **1** and **5**, because of the β relationship to the C-3 OH group in the former compound. In **5**, C-3 is almost eclipsed to the C-5 OH group and large upfield shift of the C-3 resonance should result in **5** compared to **1**, whereas in **3** the dihedral angle between C-5 and the C-3 OH group is about −120° and a very small or no upfield shift is expected for C-5 upon introduction of the C-3 OH group.[23] Furthermore, for the same reason, C-7 should be only slightly more shielded in **5** than in **1** and **3**, in which two compounds the signals are expected to be very similar. On the basis of these considerations the assignment for C-3, C-5 and C-7 were done.

The three methyl carbon resonances (C-13, C-14 and C-15) are expected to be essentially unshifted in **1** compared to **5**, while C-13 should experience an upfield shift in **3**, since this C atom is almost eclipsed to the C-3 OH group; also, in **1**, the chemical shift value for C-14 is expected to be close to that for C-13, since C-13 and C-14 have very similar geometrical environments. This reasoning leads to the assignement of the Me group resonances given in Table 2, but the data did not allow differentiation between the C-13 and C-14 resonances in **1** and **5** nor between C-13 and C-15 in **3**.

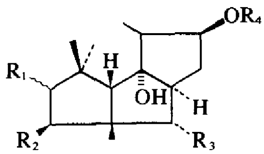
Sesquiterpenes **1**, **3**, **5** and **7** belong to a hitherto undescribed skeleton which we have named capnellane (**A**). This skeleton could possibly arise by biocyclization of a hypothetical 3,7,11-trimethyl-2,7,10-dodecatrien-1-ol pyrophosphate precursor (double bond isomer of farnesol pyrophosphate) according to the presentation shown in **B** with concomitant transfer of C-13 from position 5 to position 4.

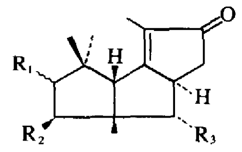


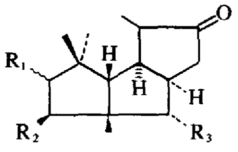
B

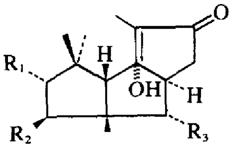


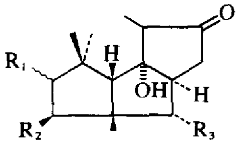
1: $R_1 = R_2 = R_3 = R_4 = H$
2: $R_1 = R_2 = R_3 = H$; $R_4 = Ac$
3: $R_1 = R_3 = R_4 = H$; $R_2 = OH$
4: $R_1 = R_3 = H$; $R_2 = OAc$; $R_4 = Ac$
5: $R_1 = R_2 = H$; $R_3 = OH$
6: $R_1 = R_2 = H$; $R_3 = OAc$; $R_4 = Ac$
7: $R_2 = R_3 = R_4 = H$; $R_1 = OH$
8: $R_2 = R_3 = H$; $R_1 = OAc$; $R_4 = Ac$


9: $R_1 = R_2 = R_3 = R_4 = H$
10: $R_1 = R_3 = R_4 = H;\ R_2 = OH$


11: $R_1 = R_2 = R_3 = H$
12: $R_1 = R_3 = H; R_2 = OH$
13: $R_1 = R_3 = H;\ R_2 = OAc$
14: $R_1 = R_2 = H;\ R_3 = OH$
15: $R_2 = R_3 = H;\ R_1 = OAc$


16: $R_1 = R_2 = R_3 = H$
17: $R_1 = R_3 = H;\ R_2 = OH$
18: $R_1 = R_2 = H;\ R_3 = OH$
19: $R_2 = R_3 = H;\ R_1 = OH$


20: $R_1 = R_2 = R_3 = H$
21: $R_1 = R_3 = H;\ R_2 = OH$
22: $R_1 = R_2 = H;\ R_3 = OH$
23: $R_1 = R_2 = H;\ R_3 = OTs$
24: $R_2 = R_3 = H;\ R_1 = OH$
25: $R_2 = R_3 = H;\ R_1 = OAc$


26: $R_1 = R_2 = R_3 = H$
27: $R_1 = R_3 = H;\ R_2 = OH$
28: $R_1 = R_3 = H;\ R_2 = OTs$
29: $R_1 = R_2 = H;\ R_3 = OH$
30: $R_1 = R_2 = H;\ R_3 = OTs$
31: $R_2 = R_3 = H;\ R_1 = OH$

EXPERIMENTAL

M.ps (Kofler) are uncorrected. All rotations and IR spectra were determined using chloroform as solvent unless otherwise mentioned. CD and UV spectra were recorded in MeOH. With the exception noted in Table 1 all NMR spectra were recorded ($CDCl_3$ with TMS as internal standard) on a Varian T-60 or XL-100 spectrometer; all chemical shifts are reported in δ values. ^{13}C NMR spectra were recorded using a Varian XL 100 spectrometer operating at 25.5 MHz. Mass spectra (direct inlet system) were obtained by Mr. R. Ross with an AEI MS-9 or an Atlas CH-4 spectrometer. All mass spectral peaks of relative intensity greater than 10% are reported. Mass spectral high resolution measurements were made by Miss Annemarie Wegmann using a Varian MAT 711 spectrometer. All GC analyses were carried out at oven temp. of 150–200° using a Hewlett-Packard hp 402 high efficiency gas chromatograph equipped with all-glass U-tube column packed with 3% OV25, OV17 and OV3 stationary phases coated over Gas-Chrom Q (100–120 mesh). All TLC was performed using Merck silica gel Hf_{254}.

Isolation of sesquiterpenoids 1, 3, 5 *and* 7

General procedure. The dried soft coral was broken into small chunks and blended with pentane, methylene chloride or ethyl acetate in a Waring blender. The solid material was filtered off, placed in a Soxhlet extractor and continuously extracted with pentane, methylene chloride or ethyl acetate for 24 hr. The combined filtrate and extractor liquids were evaporated at reduced pressure to give a dark brown oil residue.

This mixture was chromatographed (silica gel dry column chromatography) using ether as eluent. The column was cut in small portions and extracted with chloroform-methanol 1:1. The different fractions were analyzed by TLC using hexane-acetone (7:3) as eluent, the sesquiterpenoids appearing purple, pink or mauve with ceric sulfate visualization. Repeated dry column chromatography using chloroform for less polar compounds and ether for more polar ones, yielded fractions from which pure compounds **1, 3, 5** and **7** were obtained by crystallization (Table 4).

The qualitative composition of sesquiterpenoids in animals from different location is shown in Table 5.

$\Delta^{9(12)}$-*Capnellene-8β,10α-diol* (**1**). m.p. 113–114° (hexane); $[\alpha]_D^{21} + 41°$ (c = 0.15); IR 3400 (OH), 1620 cm^{-1} (C=C); NMR see Table 1; MS *m/e* 236 (M^+, 1%) 218.16716 (11, calcd for $C_{15}H_{22}O$, M^+-H_2O: 218.167056) 203 (11), 200 (12), 147 (11), 144 (11), 143 (12), 131 (26), 130 (11), 129 (15), 128 (10), 126 (30), 123 (15), 121 (10), 112 (100), 111 (16, C_8H_{15}), 111 (27, $C_6H_7O_2$), 109 (99, C_8H_{13}), 109 (11, C_7H_9O), 108 (32), 107 (10), 105 (12), 97 (11), 96 (11), 95 (20), 94 (17), 91 (23), 81 (13), 79 (16), 77 (19), 69 (39), 67 (18), 66 (13), 55 (30, C_4H_7), 55 (11, C_3H_3O), 53 (15), 43 (14), 41 (46).

Table 4.

Location of collection	Dried material	Total extract	Crystallized sesquiterpenes
Leti (II **12**)	670 g	15 g (CH_2Cl_2)	(**1**) : 540 mg (**3**) : 500 mg tetrol : 430 mg
Leti (II **12**)	700 g	34 g (AcOEt)	(**1**) : 1.7 g (**3**) : 4.0 g tetrol : 1.2 g
Lakor (VIII **117**)	200 g	4 g (pentane) 7 g (CH_2Cl_2)	(**1**) : 150 mg (**5**) : 1.25 g (**7**) : 60 mg

Table 5.

Animal identifications	Location	Composition
II **12**	Leti	**1, 3**, tetrol
VIII **117**	Lakor	**1, 5, 7**
VIII **118**	Masela	**1, 3**
VIII **119**	Sermata	**1, 5, 7** + others
VII **109**	Tanimbar	**1, 7** + others
XI **9**	Laing	**1, 5**

Acetylation (Ac_2O/Py, rt) of **1** provided an oily monoacetate **2**: NMR 1.09, 1.18, 1.27 (s, 3H each, CH_3-C), 2.08 (s, 6H, CH_3COO), 5.40 (m, 2H, $CH_2=C$) and 5.85 (m, 1H); MS *m/e* 218 (M^+-CH_3COOH).

$\Delta^{9(12)}$-*Capnellene-3β,8β,10α-triol* (**3**). m.p. 114–117° (ether) $\alpha]_D^{21} + 2°$ (*c* = 0.31) UV end absorption; IR 3400 (OH) 1640 cm^{-1} (C=C); NMR see Table 1; MS *m/e* 252 (M^+, 2%), 234.16164 (12, calcd. for $C_{15}H_{22}O_2$, M^+-H_2O: 234.16197), 219 (19), 216 (16), 201 (14), 149 (22), 139 (30), 132 (12), 131 (22), 126 (15), 125 (66, $C_8H_{13}O_1$), 125 (14, $C_7H_9O_2$), 123 (70), 122 (32), 121 (26), 120 (13), 117 (10), 112 (100), 111 (13, $C_7H_{11}O$), 111 (33, $C_6H_7O_2$), 110 (13), 109 (59, C_8H_{13}), 109 (24, C_7H_9O), 108 (15, C_8H_{12}), 108 (55, C_7H_8O), 107 (66), 105 (16), 98 (13), 97 (25), 96 (39), 95 (18, C_7H_{11}), 95 (16, C_6H_7O), 94 (15), 93 (19), 92 (11), 91 (26), 85 (11), 83 (16), 81 (29), 79 (27), 77 (21), 71 (20), 69 (11, C_5H_9), 69 (12, C_4H_5O), 67 (22), 66 (13), 55 (29, C_4H_7), 55 (18, C_3H_3O), 53 (17), 43 (15, C_3H_7), 43 (46, C_2H_3O), 41 (55).

On acetylation (Ac_2O/Py, rt) **3** furnished a diacetate **4**: m.p. 91° (hexane); IR (film) 3500 (OH) 1745 cm^{-1} (C=O); NMR 0.93, 1.21, 1.30 (s, 3H each, CH_3-C), 2.05 (s, 6H, CH_3COO), 5.10 (dd, J = 7 and 10 Hz, CH–OAc), 5.44 (d, 2H, J = 2 Hz, CH_2=C), 5.81 (m, 1H, CH–OAc); MS *m/e* 276 (M^+–CH_3COOH).

$\Delta^{9(12)}$-*Capnellene-5α,8β,10α-triol* (**5**). m.p. 132–133° (ether); $[\alpha]_D^{21}$ + 34.02 (c = 1.305); IR 3380 (OH) 1670 cm^{-1} (C=C); NMR (CD_3OD) see Table 1; MS *m/e* 252 (M^+, 1%), 234 (15), 219 (6), 216 (8), 201 (10), 181 (15), 165 (10), 147 (27), 142 (46), 141 (68), 140 (91), 139 (66), 125 (100), 124 (75), 123 (60), 122 (25), 121 (29), 119 (15), 112 (28), 111 (30), 109 (57), 107 (53), 96 (64), 95 (70), 93 (21), 91 (30), 85 (15), 84 (47), 83 (17), 81 (21), 79 (29), 78 (10), 77 (28), 69 (52), 68 (10), 67 (38), 66 (12), 65 (15), 57 (17), 56 (15), 55 (65), 53 (28), 43 (78), 41 (95).

Acetylation of **5** furnished a diacetate **6**: m.p. 55° (hexane); IR 3500 (OH) 1730 cm^{-1} (C=O); NMR 1.17, 1.20, 1.22 (s, 3H each, CH_3–C), 2.05 (s, 6H, CH_3COO), 4.63 (d, 1H, J = 7 Hz, $C\underline{H}OAc$) 5.45 (m, 2H, CH_2=C), 5.80 (m, 1H, C=C–$C\underline{H}OAc$); MS *m/e* 276 (M^+–CH_3COOH).

$\Delta^{9(12)}$-*Capnellene-2ξ,8β,10α-triol* (**7**). oil; IR 3400 (OH) 1660 cm^{-1} (CH_2=C); NMR see Table 1; MS *m/e* 252 (M^+, 3%), 234 (69), 219 (10), 216 (13), 201 (14), 160 (10), 149 (63), 131 (25), 123 (87), 122 (4), 121 (30), 120 (19), 112 (95), 109 (98), 108 (50), 107 (100), 105 (10), 96 (21), 95 (35), 94 (14), 93 (20), 91 (30), 81 (30), 79 (27), 77 (25), 71 (13), 69 (14), 67 (26), 66 (11), 65 (11), 55 (32), 53 (22), 51 (64), 43 (36), 41 (62).

Acetylation of **7** furnished an oily diacetate **8**: IR 3500 (OH) 1735 cm^{-1} (C=O); NMR 1.15, 1.27, 1.33 (s, 3H each, CH_3–C), 2.06 (s, 6H, CH_3COO), 4.83 (dd, 1H, J = 5 and 5.5 Hz, CHOAc), 5.38 (m, 2H, CH_2=C), 5.76 (m, 1H, C=CHOAc); NMR *m/e* 276 (M^+–CH_3COOH).

$\Delta^{9(12)}$-*Capnellene-10α-ol-8-one* (**11**), $\Delta^{9(12)}$-*capnellene-3β,10α-diol-8-one* (**12**), $\Delta^{9(12)}$-*capnellene-5α,10α-diol-8-one* (**14**) *and* $\Delta^{9(12)}$-*capnellene-2ξ,10α-diol-8-one* (**15**) *by maganese dioxide oxidation of sesquiterpenes* **1, 3, 5** *and* **7**

In a typical experiment 100–200 mg of **1** was dissolved in chloroform (50–100 ml) and then stirred with active manganese dioxide (1 g) at room temp. overnight. After filtration and evaporation of the solvent, the residue was purified by preparative TLC over silica gel.

Compound **11**. oil; IR 1735 cm^{-1} (C=O); UV λ_{max} 226 nm (ϵ6213); CD $[\theta]_{352}$ + 2733; $[\theta]_{255}$ + 2528; NMR see Table 1; MS *m/e* 234 (M^+, 5%), 219 (4), 147 (8), 125 (18), 124 (36), 123 (13), 111 (15), 110 (39), 109 (100), 95 (21), 83 (13), 82 (17), 81 (11), 71 (10), 69 (26), 58 (16), 57 (18), 55 (19), 43 (65), 41 (30).

Compound **12**. m.p. 187–188° (benzene), $[\alpha]_D^{21}$ + 75° (dioxane; c = 0.08); CD $[\theta]_{355}$ + 1840; $[\theta]_{250}$ + 5340; UV λ_{max} 225 nm (ϵ5900); IR 1730 cm^{-1} (C=O); NMR see Table 1; MS *m/e* 250 (M^+, 48%), 235 (15), 232 (12), 217 (22), 148 (17), 147 (26), 139 (27), 125 (83), 124 (37), 123 (57), 122 (31), 121 (29), 112 (100), 111 (22), 110 (46), 109 (37), 107 (44), 105 (14), 96 (22), 95 (15), 93 (22), 91 (17), 85 (17), 84 (14), 83 (13), 82 (20), 81 (28), 79 (15), 77 (17), 71 (29), 69 (14), 67 (18), 57 (13), 55 (26), 53 (19), 43 (39), 41 (64). Acetylation (Ac_2O/Py) of **12** furnished a monoacetate **13**; NMR 2.0 (s, CH_3COO) which was not rigorously characterized.

Compound **14**. m.p. 95–97° (benzene); IR (film) 3460 (OH) 1720 (C=O) 1640 cm^{-1} (C=C); UV λ_{max} 225 nm (ϵ5159); CD $[\theta]_{350}$ 3126, $[\theta]_{248}$ 3960; NMR see Table 1; MS *m/e* 250 (M^+, 2%), 232 (6), 217 (11), 140 (100), 125 (59), 123 (16), 122 (51), 120 (12), 112 (15), 111 (28), 110 (20), 109 (45), 107 (31), 105 (8), 95 (16), 85 (18), 84 (27), 83 (17), 81 (30), 79 (14), 77 (15), 71 (16), 69 (34), 67 (15), 57 (16), 55 (16).

Compound **15**. m.p. 111–112° (benzene); IR (film) 3380 (OH) 1720 (C=O) 1640 cm^{-1} (C=C); UV λ_{max} 225 nm (ϵ5500); NMR see Table 1; MS *m/e* 250 (M^+, 20%), 232 (21), 217 (15), 148 (16), 147 (32), 125 (30), 124 (26), 123 (82), 122 (66), 121 (40), 112 (31), 109 (97), 107 (100), 105 (14), 96 (19), 95 (24), 93 (20), 91 (20), 85 (11), 83 (17), 82 (14), 81 (30), 79 (16), 77 (16), 71 (16), 69 (23), 67 (21), 57 (18), 55 (42), 53 (16), 45 (59), 43 (58), 41 (66).

Capnellane-10α-ol-8-one (**16**), *capnellane-3β,10α-diol-8-one* (**17**), *capnellane-5α,10α-diol-8-one* (**18**), *capnellane-2ξ,10α-diol-8-one* (**19**) *by* Li/NH_3 *reduction of* **11, 12, 14** *and* **15**

To a soln of Li (150 mg) in 50 ml liquid ammonia was added, with a syringe, a soln of the unsaturated ketone (100 mg) in ether (15–20 ml). After 30 min, solid ammonium chloride was slowly added until the blue soln decolorized. The ammonia was allowed to evaporate, water (30 ml) and ether (30 ml) were added and the mixture stirred vigorously for 10 min. After separation of the ether layer, it was dried over Na_2SO_4 and evaporated to an oily residue. Subsequent preparative TLC furnished the appropriate β-hydroxy ketone.

Compound **16**. oil; IR 1725 cm^{-1} (C=O); NMR see Table 1; MS *m/e* 236 (M^+, 22%), 221 (3), 179 (100), 167 (13), 147 (11), 135 (10), 123 (12), 121 (10), 111 (11), 109 (36), 95 (17), 69 (32), 57 (23), 55 (25), 43 (16), 41 (33).

Compound **17**. m.p. 160–162°. CD $[\theta]_{295}$ + 1062; NMR see Table 1; MS *m/e* 252 (M^+).

Compounds **18** and **19** were directly dehydrated to **22** and **24** without rigorous purification and characterization.

Δ^9-*Capnellene-8-one* (**20**), Δ^9-*capnellene-3β-ol-8-one* (**21**), Δ^9-*capnellene-5α-ol-8-one* (**22**), Δ^9-*capenllene-2ξ-ol-8-one* (**24**) *by dehydration of β-hydroxy ketones* **16, 17, 18** *and* **19**

In a typical experiment, **16** (50 mg) was dissolved in MeOH (10 ml), 3 drops of 10% KOHaq were added and the mixture stirred overnight at room temp. The soln was then poured into water (10 ml) and extracted with ether. The ether extract was washed with water, dried over $NaqSO_4$ and evaporated to a gum which was purified by preparative TLC over silica gel.

Compound **20**. oil; IR (film) 3420 (OH) 1700 (C=O) 1660 cm^{-1} (C=C); UV λ_{max} 244 nm (ϵ12500); CD $[\theta]_{305}$ + 12354, $[\theta]_{247\,5}$ + 53960; NMR see Table 1; MS *m/e* 218 (M^+, 32%), 203 (3), 148 (39), 147 (100), 105 (18), 91 (11), 79 (7), 77 (9), 69 (7), 55 (8), 41 (16).

Compound **21**. oil; IR 3450 (OH) 1695 (C=O) 1655 cm^{-1} (C=C); UV λ_{max} 242.5 (ϵ12168); CD $[\theta]_{305}$ − 11120, $[\theta]_{242}$ + 50656; NMR see Table 1; MS *m/e* 234 (M^+, 50%), 216 (15), 178 (13), 177 (13), 176 (56), 163 (53), 161 (24), 150 (33), 149 (37), 148 (20), 136 (23), 135 (34), 133 (13), 121 (16), 119 (12), 111 (15), 109 (15), 107 (14), 105 (24), 97 (20), 95 (15), 91 (18), 85 (42), 83 (22), 81 (17), 79 (14), 77 (14), 71 (61), 69 (38), 67 (13), 59 (14), 57 (100), 56 (14), 55 (45), 43 (76), 41 (60).

Compound **22**. oil; IR (film) 3420 (OH) 1700 (C=O) 1660 cm^{-1} (C=C); UV λ_{max} 244 nm (ϵ12500); CD $[\theta]_{305}$ − 12354, $[\theta]_{247\,5}$ + 53960; NMR see Table 1; MS *m/e* 234 (M^+, 100%), 219 (8), 216 (11), 206 (14), 201 (10), 198 (14), 183 (11), 166 (36), 165 (27), 164 (19), 163 (15), 148 (34), 147 (79), 146 (10), 145 (10), 137 (24), 136 (45), 135 (21), 121 (22), 119 (17), 117 (11), 110 (16), 107 (19), 105 (23), 97 (11), 95 (12), 93 (27), 91 (41), 79 (27), 77 (37), 69 (56), 67 (15), 65 (17), 57 (20), 55 (37), 53 (25), 51 (11), 43 (48), 41 (73).

Compound **24**. oil; IR (film) 3420 (OH) 1700 (C=O); 1655 cm^{-1} (C=C); UV λ_{max} 243 nm (ϵ14400); CD $[\theta]_{305}$ − 3900; $[\theta]_{241}$ + 14400; NMR see Table 1; MS *m/e* 234 (M^+, 3%), 216 (97), 201 (26), 188 (10), 174 (68), 173 (35), 161 (31), 160 (100), 149 (25), 148 (54), 147 (96), 146 (40), 145 (25), 135 (30), 133 (25), 132 (90), 131 (15), 121 (18), 119 (21), 117 (20), 115 (10), 108 (20), 107 (20), 105 (54), 103 (10), 93 (20), 91 (47), 85 (17), 79 (31), 78 (12), 77 (38), 71 (26), 69 (14), 67 (14), 65 (18), 57 (16), 55 (22), 53 (27), 51 (13), 43 (50), 41 (80).

Capnellane-8-one (**26**), *capnellane-3β-ol-8-one* (**27**), *capnellane-5α-ol-8-one* (**29**) *and capnellane-2ξ-ol-8-one* (**31**) *by* Li/NH_3 *reduction of α,β-unsaturated ketones* **20, 21, 22** *and* **24**

The procedure employed for this Li/NH_3 reduction was identical to that previously described for the preparation of **16, 17, 18** and **19**.

Compound **26**. m.p. below 40°; IR 1725 cm^{-1} (C=O); CD $[\theta]_{298}$ + 5198; NMR see Table 1; MS *m/e* 220 (M^+, 68%), 205 (15), 167 (17), 165 (23), 162 (21), 151 (51), 150 (55), 149 (58), 148 (13), 135 (18), 123 (24), 122 (17), 121 (40), 109 (88), 108 (32), 107 (68), 106 (11), 105 (20), 96 (22), 95 (61), 94 (50), 93 (100), 92 (15), 91 (38), 82 (12), 81 (60), 80 (26), 79 (50), 77 (34), 70 (36), 69 (38), 68 (18), 67 (44), 65 (14), 57 (18), 55 (60), 53 (29), 43 (43), 41 (85).

Compound **27**. m.p. 105–107° (hexane); IR 1730 cm^{-1} (C=O); CD $[\theta]_{300}$ + 9200; NMR see Table 1; MS see Table 3.

Compound **29**. m.p. 43–48° (hexane); IR (film) 1735 cm^{-1} (C=O); CD $[\theta]_{296}$ + 8637; NMR see Table 1; MS see Table 3.

Compound **31**. m.p. 50–52° (hexane); IR (film) 1740 cm^{-1} (C=O); CD $[\theta]_{307\,5}$ + 5616, $[\theta]_{305}$ + 6230, $[\theta]_{302\,5}$ + 6740, $[\theta]_{296\,5}$ + 7477; NMR see Table 1; MS see Table 3.

GC retention times of **27**, **29** and **31** over OV 3, 3% (oven temp. 160°) relative to compound **1** (ret. time 1.0) are as follows: **27**, 1.45; **29**, 1.49; **31**, 1.40.

Capnellane-3,8-dione (**32**), *capnellane-5,8-dione* (**33**) *and capnellane-2,8-dione* (**34**) *by Jones oxidation of* **27**, **29** *and* **31**

In a general procedure **27** (5–10 mg) was dissolved in acetone, 10 ml of Jones reagent was added dropwise to this soln with vigorous stirring, at room temp., until a yellow color persisted. Water (10 ml) was then added and the mixture extracted with chloroform. The chloroform extract after washing with water and $NaHCO_3$aq was dried over $NaSO_4$ and evaporated to a gum which was further purified by preparative TLC (silica gel) and examined by analytical GC over OV 3, 3% (oven temp. 160°, det. 270). The retention times are relative to compound **1**.

Compound **32**. oil; IR 1735 cm^{-1} (C=O); CD $[\theta]_{300}+10800$; MS *m/e* 234 (M^+, 66), 190 (20), 151 (16), 150 (100), 135 (11), 125 (23), 121 (10), 107 (16), 94 (52), 93 (46), 91 (15), 83 (36), 80 (15), 79 (23), 77 (13), 56 (34), 55 (12), 53 (10), 45 (31), 41 (23); GC retention time 1.30.

Compound **33**. m.p. 57–60° (benzene); IR (film) 1740 cm^{-1} (C=O), CD $[\theta]_{313}-2691$, $[\theta]_{277\ 5}+819$; NMR see Table 1; MS *m/e* 234 (M^+, 22%), 219 (7), 206 (7), 165 (12), 163 (11), 124 (29), 110 (76), 96 (23), 95 (100), 93(13), 91 (13), 81 (12), 79 (17), 77 (15), 69 (22), 55 (28), 53 (17), 43 (12), 41 (42); GC retention time 1.10.

Compound **34**. oil; IR ((llm) 1740 cm^{-1} (C=O); CD $[\theta]_{298}+19552$; NMR see Table 1; MS *m/e* 234 (M^+, 45%), 219 (3), 190 (16), 150 (100), 135 (12), 125 (17), 121 (11), 107 (22), 106 (15), 105 (10), 94 (62), 93 (57), 91 (19), 83 (49), 80 (22), 79 (27), 77 (17), 67 (10), 56 (54), 55 (17), 53 (14): GC retention time 1.30.

Capnellane-5α-ol (**35**) *and capnellane-5-one* (**36**)

A mixture of **40** (250 mg), ethylene glycol (4 ml) and hydrazine hydrate (5 ml) was heated at 125° for 6 hr under N_2. After addition of KOH (10 pellets), the temp. of the mixture was raised to 195° and maintained for 14 hr. After cooling, water was added and the mixture extracted with ether. The ether extract was purified by preparative TLC.

Compound **35**. oil; IR (film) 3400 cm^{-1} (OH); NMR 0.95, 1.07, 1.23; (s, 3H each, CH_3–C), 3.50 (d, 1H, J = 9 Hz, CHOH); MS *m/e* 222 (M^+, 18%), 207 (89), 204 (11), 189 (18), 151 (25), 148 (14), 135 (25), 133 (13), 123 (17), 121 (10), 119 (12), 110 (15), 109 (62), 107 (31), 105 (19), 97 (20), 95 (85), 93 (34), 91 (28), 81 (100), 77 (25), 71 (18), 70 (15), 69 (30), 67 (35), 65 (10), 57 (31), 56 (15), 55 (59), 53 (25), 43 (54). Jones oxidation of **35** according to procedure presented under preparation of **32**, **33** and **34** furnished **36**.

Compound **36**. oil; IR (film) 1730 cm^{-1} (C=O); CD $[\theta]_{302}-7610$; NMR see Table 2; MS *m/e* 220 (M^+, 23%), 205 (15), 151 (17), 138 (33), 123 (27), 121 (12), 110 (11), 109 (28), 107 (12), 96 (14), 95 (100), 93 (20), 91 (18), 81 (29), 79 (29), 77 (21), 69 (14), 67 (34), 65 (10), 55 (35), 53 (21), 43 (13), 41 (65).

$\Delta^{5,9}$*-Capnelladien-8-one* (**37**)

Compound **22** could not be dehydrated by TsOH in benzene or $SOCl_2$ in pyridine. The corresponding tosylate **23** was prepared by reaction of **22** (10 mg) with TsCl (20 mg), but is recovered unchanged after heating at 100° for 3 hr in DMSO. However, the dehydration could be effected when a soln of tosylate **23** (60 mg) in MeOH (2 ml) containing one pellet of KOH was refluxed for 3 hr. The mixture was then poured into water, extracted with ether and the ether extract purified by preparative TLC (silica gel).

Compound **37**. oil; IR (film) 1705 (C=O) 1630 cm^{-1} (C=C), UV λ_{max} 289 nm (ϵ 12188); CD $[\theta]_{315\ 5}-15428$, $[\theta]_{28715}+15430$, $[\theta]_{230-227\ 5}+12857$; NMR 0.85, 1.22, 1.27 (s, 3H each, CH_3–C), 1.8 (s, 3H, CH_3–C=C), 2.57 (s, 1H, CH–C=C), 2.85 (s, 2H, CO–CH_2–C=C), 5.65 (s, 1H, HC=C); MS *m/e* 216 (M^+, 59%), 201 (22), 173 (21), 169 (19), 159 (23), 148 (23), 147 (45), 146 (25), 145 (25), 132 (27), 131 (15), 129 (14), 128 (15), 119 (25), 118 (18), 117 (34), 116 (12), 115 (29), 105 (15), 103 (14), 91 (45), 79 (19), 77 (29), 71 (25), 69 (28), 67 (15), 65 (18), 57 (45), 55 (45), 53 (20), 51 (17), 43 (100), 41 (80).

Capnellane-8-one (**26**) *from ketols* **27**, **29** *and* **31**

In a general procedure **27** was converted to the monotosylate **28** (TsCl/Py., rt., 24 hr). The crude tosylate was reduced with LAH in ether and the product oxidized by the Jones procedure. The reaction product was purified by preparative TLC (silica gel) and examined by GC and MS. The monoketone thus obtained in all three instances had GC retention times and mass spectra identical with that derived from **1**.

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REFERENCES

[1] For paper LXX see W. L. Tan, C. Djerassi, J. Fayos and J. Clardy, *J. Org. Chem.* **40**, 466 (1975).

[2] For paper XIII see B. Tursch, J. C. Braekman and D. Daloze, *Bull. Soc. Chim. Belges*, **84**, 767 (1975).

[3][a] Postdoctoral fellow (1974) from the University of Geneva; [b] Postdoctoral research associate (NATO and Fulbright-Hays Fellowship 1972) on leave from the University of Brussels, Belgium; [c] Postdoctoral fellow (1974) from the University of Copenhagen; [d] Chercheur qualifie du Fonds National de la Recherche Scientifique.

[4] H. Mergner and H. Schuhmacher, Morphologie, Okologie and Zonierung von Korallenriffen bei Aqaba, *Helgoländer wiss. Meeresunters* **26**, 238 (1974). F. M. Bayer, The Shallow-water Octocorallia of the West Indian Region, Martinus Nijhoff (1961).

[5] P. Buchren in Endosymbiose der Tiere mit Pflanzlichen Microorganismen, Busch, Stuttgart (1953).

[6] C. M. Yonge, *The Biology of Coral Reefs.* In *Advances in Marine Biology*, Vol. 1. Academic Press, New York (1963).

[7] L. S. Ciereszko and T. K. B. Karns, *Comparative Biochemistry of Coral Reef Coelenterates*, Chap. 6 in *Biology and Geology of Coral Reefs* (Edited by O. A. Jones and R. Endean), Vol. II. Academic Press, New York (1972).

[8] L. Muscatine, *Science* **156**, 516 (1967); L. Muscatine and E. Cernichiari, *Biol. Bull.* **137**, 506 (1969); D. Smith, L. Muscatine and D. Lewis, *Biol. Rev.* **44**, 17 (1969); C. von Holt and M. von Holt, *Comp. Biochem. Physiol.* **24**, 73 and 83 (1968).

[9] L. S. Ciereszko, *Trans. N.Y. Acad. Sci.*, **24**, 502 (1962); P. R. Burkholder and L. M. Burkholder, *Science* **127**, 1174 (1958).

[10] R. L. Hale, J. Leclercq, B. Tursch, C. Djerassi, R. A. Gross, A. J. Weinheimer, K. Gupta and P. J. Scheuer, *J. Am. Chem. Soc.* **92**, 2179 (1970); N. C. Ling, R. L. Hale and C. Djerassi, *Ibid.* **92**, 5281 (1970); F. J. Schmitz and T. Pattabhiraman, *Ibid.* **92**, 6073 (1970); E. L. Enwall, D. van der Helm, I. Nan Hsu, T. Pattabhiraman, F. J. Schmitz, R. L. Spraggins and A. J. Weinheimer, *Chem. Comm.* 215 (1972).

[11] A. J. Weinheimer and R. L. Spraggins, *Tetrahedron Letters* 5185 (1969); G. L. Bundy, E. G. Daniels, F. H. Lincoln and J. E. Pike, *J. Am. Chem. Soc.* **94**, 2124 (1972); W. P. Schneider, R. D. Hamilton and L. E. Rhuland, *Ibid.* **94**, 2122 (1972); R. J. Light and B. Samuelsson, *Eur. J. Biochem.* **28**, 232 (1972).

[12] F. J. Schmitz, K. W. Kraus, L. S. Ciereszko, D. H. Sifford and A. J. Weinheimer, *Tetrahedron Letters* 97 (1966); F. J. Schmitz, E. D. Lorance and L. S. Ciereszko, *J. Org. Chem.* **34**, 1989 (1969); F. J. Schmitz and E. D. Lorance, *Ibid.* **36**, 719 (1971).

[13] A. J. Weinheimer, P. H. Washecheck, D. van der Helm and M. B. Hossain, *Chem. Comm.*, 1070 (1968); A. J. Weinheimer, W. W. Youngblood, P. H. Washecheck, T. K. B. Karns and L. S. Ciereszko, *Tetrahedron Letters* 497 (1970); A. J. Weinheimer and P. H. Washecheck, *Ibid.* 3315 (1969); P. W. Jeffs and L. T. Lytle, *Lloydia* **37**, 315 (1974).

[14] A. J. Weinheimer, R. E. Middlebrook, J. O. Bledsoe, Jr., W. E. Marsico and T. K. B. Karns, *Chem. Comm.* 384 (1968); M. B. Hossain and D. van der Helm, *J. Am. Chem. Soc.* **90**, 6607 (1968); M. B. Hossain, A. F. Nicholas and D. van der Helm, *Chem. Comm.* 385 (1968).

[15] O. Kennard, D. G. Watson, L. Riva di Sanseverino, B. Tursch, R. Bosmans and C. Djerassi, *Tetrahedron Letters* 2879 (1968).

[16] J. R. Rice, C. Papastephanou and D. Anderson, *Biol. Bull.* **138**, 334 (1970).

[17] J. P. Engelbrecht, B. Tursch and C. Djerassi, *Steroids* **20**, 121 (1972); J. M. Moldowan, B. Tursch and C. Djerassi, *Ibid.* **24**, 387 (1974); A. Kanazawa, S. Teshima, T. Ando and S. Tomita, *Bull. Jap. Soc. Sci. Fish.* **40**, 729 (1974).

[18] B. Tursch, J. C. Braekman, D. Daloze, P. Fritz, A. Kelecom, R.

Karlsson and D. Losman, *Tetrahedron Letters* 747 (1974); B. Tursch, M. Colin, D. Daloze, D. Losman and R. Karlsson, *Bull. Soc. Chim. Belges* **84**, 81 (1975).

[19] M. Kaisin, Y. M. Sheikh, L. J. Durham, C. Djerassi, B. Tursch, D. Daloze, J. C. Braekman, D. Losman and R. Karlsson, *Tetrahedron Letters* 2239 (1974).

[20] B. Tursch, J. C. Braekamn, D. Daloze, M. Herin and R. Karlsson, *Ibid.* 3769 (1974); B. Tursch, J. C. Braekman, D. Daloze, M. Herin, R. Karlsson and D. Losman, *Tetrahedron* **31**, 129 (1975); F. J. Schmitz, D. J. Vanderah and L. S. Ciereszko, *Chem. Comm.* 407 (1974); J. Bernstein, U. Shmeuli, E. Zadock, Y. Kashman and I. Néeman, *Tetrahedron* **30**, 2817 (1974); Y. Kashman, E. Zadock and I. Néeman, *Ibid.* **30**, 3615 (1974).

[21] J. D. Roberts, F. J. Weigert, J. I. Kroschwitz and H. J. Reich, *J. Am. Chem. Soc.* **92**, 1338 (1970).

[22] H. Eggert, C. L. Van Antwerp, N. S. Bhacca and C. Djerassi, *J. Org. Chem.* in press.

[23] T. Yamagishi, K. Hayashi, H. Mitsuhashi, M. Imanari and K. Matsushita, *Tetrahedron Letters* 3531 (1973).