19. New Dienophiles: 1-Acetylvinyl Arenecarboxylates. Reactivity toward Cyclopentadiene and Exocyclic Dienes

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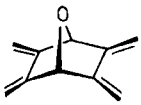
Summary

The preparations of 1-acetylvinyl arenecarboxylates $H_2C{=}C(COCH_3)OCOR$ with R = phenyl, *p*-nitrophenyl, 2,4-dinitrophenyl, *α*- and *β*-naphthyl are described (**3**). The *Diels-Alder* reactivity of these dienophiles toward cyclopentadiene is evaluated and compared with that of methyl vinylketone, 3-trimethylsilyloxy-, 3-ethoxy- and 3-acetoxy-3-buten-2-ones. The stereoselectivity of the cycloadditions of these dienophiles with 2,3,5,6-tetramethylidene-7-oxanorbornane (**1**) and 5,8-dimethoxy-1,4-epoxy-2,3-dimethylidene-1,2,3,4-tetrahydroanthracene (**2**) is studied. In principle, the dienophiles **3** allow direct functionalization of the position C(9) of the A-ring of daunomycinone analogs by *Diels-Alder* additions to exocyclic dienes such as **1** and **2**.

Introduction. – Anthracyclinones are aglycones of very important antibiotics and anti-tumor drugs [1]. They can be prepared readily [2] [3] by two successive



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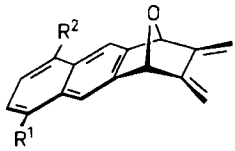

2a $R^1 = R^2 = OCH_3$
b $R^1 = R^2 = H$
c $R^1 = OCH_3$, $R^2 = H$

3a–i

R = **a**	Me_3Si	**f**	2,4-$(NO_2)_2$-C_6H_3CO
b	Et	**g**	*α*-naphthyl-CO
c	CH_3CO	**h**	*β*-naphthyl-CO
d	C_6H_5CO	**i**	CH_3
e	4-(NO_2)-C_6H_4CO	**j**	H

Diels-Alder additions [4] to 2,3,5,6-tetramethylidene-7-oxanorbornane (**1**) [5]. The A-ring of daunomycinone (**4**) [6] bears a hydroxy group at C(9), adjacent to the carbonyl function of the side-chain. This OH group can be introduced, in principle

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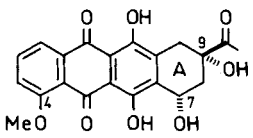
[7], by a suitable oxidation [8] of the corresponding 9-deoxy derivative obtained by cycloaddition of methyl vinyl ketone (MVK) to dienes of type **2** [2] [3]. In a more versatile and direct approach, a 3-oxy-3-buten-2-one derivative **3** could be used as a dienophile to generate ring A of the anthracyclinone.



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Agosta [9] and *Quick* [10] have shown that α-alkoxy-α,β-unsaturated carbonyl compounds **3b** and **3i** are less reactive toward nucleophiles and dienes than the unsubstituted analogs, as anticipated on electronic [4b] [11] and steric [4b] [12] grounds. The yields of the *Diels-Alder* additions (at 160–190°!) to the relatively reactive cyclopentadiene [4b] [13] were modest. *Wharton* and *Aw* [14] have shown that methyl α-acetoxyvinyl ketone (**3c**) adds with good regioselectivity to 1-isopropenylcyclohexene and the easy dimerization of methyl α-trimethylsilyloxyvinyl ketone (**3a**) has been reported by *Murai et al.* [15] [16].

In order to improve the thermal stability and to enhance the *Diels-Alder* reactivity of the dienophiles **3** we planned to protect the enol by R substituents having a larger electron-withdrawing ability than alkyl [9] [10], trimethylsilyl [15] [16] or acetyl [14] [17] groups. We report a general technique for the preparation of the oxy-substituted methyl vinyl ketones **3** from biacetyl and show that the arenecarboxylates (**3d–h**) give better yields in their cycloadditions with dienes **1** and **2a** than the known derivatives **3a–c**.

Results and discussion. – The dienophiles **3a, c–h** were prepared by trapping the monoenolate of biacetyl with the corresponding chloride (R-Cl) in THF containing Et_3N and, sometimes, 10% of hexamethylphosphortriamide (HMPTA) in order to retard C-acylations [18].

5 **6**

Table 1 summarizes our kinetic data on the *Diels-Alder* additions of **3a–h** and methyl vinyl ketone to cyclopentadiene in CH_2Cl_2 at 50°. The reactions were followed for *ca.* 2 half-lives and were found to obey the following rate law [19]:

$$-\frac{1}{B_0-D-A_0}\ln\frac{A}{A_0}+\frac{1}{B_0-D-A_0}\ln\frac{B_0-D-A_0-A}{B_0-D}=k^{II}t \quad (r>0.99)$$

where A = conc. of 3 at t (A_0 at t = 0), B_0 = initial conc. of cyclopentadiene (> 30-fold excess) and D = conc. of dicyclopentadiene formed competitively at t.

All the kinetic measurements were repeated 2 to 5 times and were found to be reproducible within a 5% error.

Table 1. *Kinetic data of the cycloadditions of the dienophiles* **3a–h**, *methyl vinyl ketone (MVK) and cyclopentadiene (CP) to cyclopentadiene in* CH_2Cl_2 *at* $50° \pm 0.5$.

Dienophile	**3a**	**3b**	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**	MVK	CP
k^{II} 10^5 [$lmol^{-1}s^{-1}$]	1.05	0.18	1.5	1.9	3.9	8.5	3.9	4.4	10.6[a])	0.22[b])
k^{II}_{rel}	5.8	(1.0)	8.3	10.5	22	47	22	24	59	1.2

a) A rate constant $k^{II} = 12.1 \cdot 10^{-5}$ $lmol^{-1}s^{-1}$ was reported for MVK + CP in BuCl at 35° [30].

b) A rate constant $k^{II} = 1.67 \cdot 10^{-5}$ $lmol^{-1}s^{-1}$ was reported for the dimerization of CP in CCl_4 at 55° [31].

The stronger the electron withdrawing ability of the enol protecting group R in **3**, the more reactive is the oxy-substituted methyl vinyl ketone. Considering the *remote substituent effect* involved here and the various sizes of the R groups investigated, our results are significant. They confirm the hypothesis that electronic factors determine the *Diels-Alder* reactivity of **3**. Interestingly, the 2,4-dinitrobenzoate **3f** is almost as reactive as MVK, whereas the ethoxy derivative **3b** is not a better dienophile than cyclopentadiene.

The expected adducts **5** and **6** were the sole products formed, with the more reactive dienophiles **3** giving higher yields. In general, the stereoselectivity of these additions is not good *(Table 2)*. In most cases it tends to be the reverse of that of MVK + cyclopentadiene (*endo/exo* adduct ratio = 83:17 [20]). The structures of **5** and **6** were deduced from their ^{1}H-NMR. spectra with the help of double irradiation experiments, the use of Eu(thd)$_3$ induced shift reagent [21] (the preferred site of coordination being the oxygen atom of the acetyl group, see *e.g.* **5f** and **6f**, exper. part) and by comparison with the data reported for other norbornene derivatives [22].

With strong dienophiles such as benzoquinone and MVK [2] [3] the reaction of **1** to give the corresponding mono-adducts is at least 100 times faster than its cycloaddition to yield the 'symmetrical' bis-adducts. Furthermore, these *Diels-Alder* additions are highly stereoselective (attack of the dienophiles on the dienes along 4 different paths affords 2 different adducts (*cf.* [23] [24a]). We found that the

Table 2. *Stereoselectivity of the* Diels-Alder *additions of* **3a–i** *to cyclopentadiene (CP)*

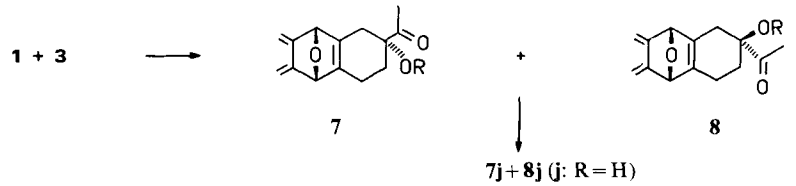
Dienophile	**3a**	**3b** [10]	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**	**3i** [9]
Solvent	–	–	–	–	CH_2Cl_2 (9 mol-equiv.)	CH_2Cl_2 (5 mol-equiv.)	–	–	C_6H_6 (10 mol-equiv.)
Temperature	50°	160°	25°	25°	25°	50°	50°	50°	120°
Time of reaction	11 h	40 h	24 h	48 h	26 h	5 h	13 h	10 h	48 h
Mol-equiv. of CP	9	13	3	3	6	10	9	8	1.4
Isolated yield of the adducts	a)	61%	90%	80%	83%	90%	77%	82%	58%
Adduct ratio **5**/**6**	68:32[b])	66:34	47:53[c])	61:39[c])	67:33[c])	58:42[d])	60:40[d])	58:42[d])	37:63

a) The adducts were decomposed under our condition of purification (column chromatography, florisil, hexane:AcOEt).

b) Ratio evaluated by GC. (5% *Carbowax* 20M).

c) Ratio evaluated by ^{1}H-NMR. and GC. (10% SE-30).

d) Ratio evaluated by ^{1}H-NMR. only.



formation of the mono-adducts **7**+**8** from **3** and **1** (CCl_4, 100–140°) is at least 50 times faster than the formation of the corresponding bis-adducts. The best yield was obtained with **3d**, determined after isolation and separation of the alcoholic derivatives **7j** and **8j** (62%) (from saponification of the mixture of **7d**+**8d**). Unfortunately, as in the case of the cycloadditions of **3** to cyclopentadiene, no stereoselectivity was observed either in the reaction of **1** with **3d**, or of **1**+**3c** (50% yield of **7j**/**8j**, 50:50); with **3a**, an unsatisfactory ratio of 66:34 or 34:66 was obtained for **7j**/**8j** (11% yield).

The presence of *Lewis* acid catalysts such as $ZnCl_2$, $SnCl_4$, $TiCl_4$ or $Et_2O \cdot BF_3$ [25] caused the decomposition of **1** and **3** without improving the yields and stereoselectivities of their cycloadditions.

Table 3 summarizes our results on the reactivities of **3a–h** toward the exocyclic diene **2a**, an intermediate in the synthesis of 1-methoxy-daunomycinone [3]. Once again, better yields were obtained with our 1-acetylvinyl arenecarboxylates **3d–h** than with the 3-trimethylsilyloxy- or 3-ethoxy-3-buten-2-one (**3a,b**). The stereoselectivity (ratio of adducts **9**/**10**) is generally low and varies within narrow limits *(Table 3)*. This loss of stereoselectivity with respect to that observed in the cycloadditions of methyl vinyl ketone to the same dienes (**1**, **2** and cyclopentadiene) confirms the hypothesis that attractive *van der Waals* [26] and dipole-dipole interactions [27] between the dienophile substituents and the dienes are responsible for the *Alder* rule [28].

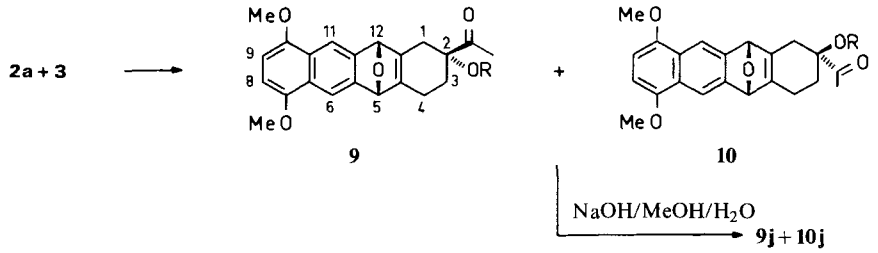
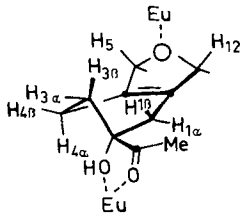


Table 3. *Yields of the adducts* **9a–h**+**10a–h** *obtained by cycloaddition of* **2a** *to the dienophiles* **3a–h** *in xylene and stereoselectivities of the hydrolyzed adducts* **9j**/**10j**

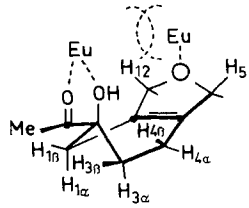
Dienophile	**3a**	**3b**	**3c**	**3d**	**3e**	**3f**	**3g**	**3h**
Temperature [°C]	160	160	160	160	140	140	140	140
Time [h]	12	5	4	3	5	3	8	8.5
Yield of **9**+**10** [%]	30	21	68	70	50	66	63	69
Product ratio **9j**/**10j**	50:50[a])	50:50[b])	65:35	60:40	60:40	40:60	38:62	50:50

[a]) Measured on **9a**/**10a**. [b]) Measured on **9b**/**10b**.

The alcohols **9j** and **10j** obtained by saponification of the esters **9(c–h)** **10(c–h)** were easily separated by chromatography. The proposed structures were deduced from their ^{1}H-NMR. (360 MHz) spectra with the help of double irradiation experiments, the use of Eu(thd)$_3$ complexing agent and by comparison with analogs [2] [24a].



9j + Eu(thd)$_3$



10j + Eu(thd)$_3$

The *'exo'* allylic protons H–C(1β,4β) are assumed to be more deshielded than the *'endo'* hydrogens H–C(1α,4α) due to the anisotropy of the 5,12-epoxide. Typical coupling constants between H_2C(1,3,4) confirm a half-chair conformation of the cyclohexene systems [29] and allow the distinction between pseudo-axial and pseudo-equatorial H-atoms *(cf. Table 4).* Interestingly, a long-range ^5J(H,H) coupling constant of *ca.* 1 Hz was measured in **9j** between the pseudo-axial

Table 4. *^{1}H-NMR. (360 MHz,* ca. *0.03*M*) of the alcohols* **9j** *and* **10j**
(δ_H in ppm, δ_{TMS} = 0.0 ppm, J(H,H) in Hz)

	H–C(1α)	(1β)	(3α)	(3β)	(4α)	(4β)	(5)	(6)
9j (in CD_2Cl_2) δ_H	1.81	2.87	1.56	1.92	2.02	2.51	5.53	7.93
relative LIS[a])	0.70	0.58	0.54	0.53	0.27	0.30	0.96	0.33
10j (in C_6D_6) δ_H	1.90	2.03	0.87	1.22	1.59	2.32	5.34	8.19
relative LIS[b])	0.6	0.47	0.65	(1.0)	0.52	0.55	0.37	0.1

	H–C(8,9)	(11)	(12)	CH_3O–C(7,10)	CH_3CO–C(2)
9j (in CD_2Cl_2), δ_H	6.75	7.90	5.50	3.92/3.93	2.20
relative LIS[a])	0	0.27	(1.0)	–	0.38
10j (in C_6D_6), δ_H	6.48	8.19	5.29	3.54	1.39
relative LIS	0	0.1	0.42	–	0.52

J(H,H)	(1α,1β)	(1α,3α)	(1α,3β)	(1α,4α)	(1α,4β)	(1α,5)	(1β,3α)	(1β,3β)	(1β,4α)
9j	17.5	2.0	< 0.5	2.0	< 1.0	< 0.5	< 1.0	< 1.0	4.0
10j	17.5	< 0.5	< 0.5	2.5	4.0	~ 1.0	< 0.5	< 1.0	1.25

J(H,H)	(1β,4β)	(1β,5)	(3α,3β)	(3α,4α)	(3α,4β)	(4α,4β)	(4α,12)	(4β,12)	(3β,4α)
9j	3.0	1.0	13.0	5.4	2.4	17.0	1.0	< 1.0	12.3
10j	2.5	< 0.5	13.1	6.6	10.0	16.6	< 0.5	~ 1.0	2.5

[a]) LIS induced by Eu(thd)$_3$, linear LIS as function of added complex was observed for [Eu(thd)$_3$]/[**9j**] up to 0.7.

[b]) LIS induced by Eu(thd)$_3$, linear LIS as function of added complex for [Eu(thd)$_3$]/[**10j**] up to 0.4, at higher complex/substrate ratio, a significant deviation from linearity was observed for H–C(1α,1β,3α) and CH_3CO–C(2).

H–C(1β) and H–C(4a) and the bridgehead H–C(5) and H–C(12), respectively. In **10j**, a similar coupling constant was found between H–C(1a) and H–C(5) and between H–C(4β) and H–C(12). Addition of Eu(thd)$_3$ led to induced chemical shifts (LIS), suggesting a relatively strong complexation of the 5,12-epoxy function. Competitive complexation of the 2-hydroxy and 2-acetyl groups was also observed. The LIS ratios H–C(6)/CH_3CO and H–C(11)/CH_3CO are one probe for the conformation and configuration of **9j** and **10j**. In agreement with our assignments, we found these LIS ratios to be significantly larger for **9j** (*ca.* 0.85) than for **10j** (*ca.* 0.2). A further confirmation was given by the observation of linear LIS as function of the Eu(thd)$_3$ concentration for all the proton signals of **9j** *(cf. Table 4).* In the case of **10j**, remarkable deviations from linearity were observed for the CH_3CO and H–C(1a,1β,3a) chemical shifts when the concentration ratio Eu(thd)$_3$/**10j** was larger than 0.4. This suggests a change in the conformation of the cyclohexene system of **10j** upon increase of the Eu(thd)$_3$ concentration because of steric crowding in the complexes (*cf.* scheme here above).

Conclusion. – 1-Acetylvinyl arenecarboxylates are better dienophiles than 3-trimethylsilyloxy- and 3-alkoxy-3-buten-2-one. The larger the electron-withdrawing ability of the enol protecting group, the faster is the *Diels-Alder* addition with an *endo-* or *exo*cyclic diene. These new dienophiles are useful building blocks as shown by their cycloadditions to the dienes **1** and **2a**, two intermediates in our doubly-convergent approach to the synthesis of anthracyclinones.

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Experimental Part

General remarks. See [2]. TMSCl = trimethylchlorosilane.

3-Trimethylsilyloxy-3-buten-2-one (**3a**). TMSCl (15.2 ml, 0.12 mol) was added in 45 min to a stirred mixture of biacetyl (8.6 g, 0.1 mol), Et_3N (33.6 ml, 0.24 mol) in anh. THF (140 ml) at RT. After heating under reflux for 6 h, the mixture was left overnight at 0°. After filtration, the solvent was removed i.v. and ether was added (70 ml). The solution was extracted successively with 1.5N HCl (2 × 10 ml), saturated aq. $NaHCO_3$-solution (2 × 10 ml) and sat. NaCl-solution (3 × 20 ml). After drying (Na_2SO_4) and solvent removal i.v., the residue was distilled. Yield 9 g (57%) (the best yield obtained following *Conia*'s procedure [16] was 10% in our hands), b.p. 45°/0.1 Torr. – UV. (isooctane): 289 (166), 244 (1360), does not vary with the concentration, whereas in CH_3CN the UV. spectrum is strongly dependent upon the concentration:

	Conc. of **3a** [mol l^{-1}]					
	1.77×10^{-3}	1.64×10^{-3}	3.54×10^{-4}	3.28×10^{-4}	1.77×10^{-4}	8.2×10^{-5}
λmax	266	266	255	255	252	248
εmax	282	312	689	774	875	1024

IR. (film): 1980*s*, 1700*vs*, 1620*vs*, 850*vs*. – ^{1}H-NMR. ($CDCl_3$): 5.3 (*d*, J = 2, 1 H); 4.8 (*d*, J = 2, 1 H); 2.2 (*s*, 3 H); 0.2 (*s*, 9 H). – ^{13}C-NMR. ($CDCl_3$): 196.1 (*m*); 153.7 (*m*); 101.5 (*d* × *d*, 158.8, 162.5); 25.3 (*qa*, 128); –4.0 (*qa* × *m*, 118). – MS. (70 eV): 143 (100, $M^+ - 15$), 101 (9), 75 (55), 45 (22), 43 (55).

3-Acetoxy-3-buten-2-one (**3c**). Acetylchloride (17.1 ml, 0.24 mol) was added dropwise to a stirred mixture of biacetyl (17.2 g, 0.2 mol), Et_3N (41 ml, 0.29 mol) and anh. THF (100 ml) maintained at –20°

under N_2. After the addition, the mixture was allowed to warm up to RT. and stirred for 8 h. After addition of Et_2O (50 ml) and filtration, the solvent was evaporated i.v. The residue was dissolved in Et_2O (60 ml) and washed successively with ice-cold 1.5N HCl (2× 10 ml), sat. $NaHCO_3$-solution (2× 10 ml) and sat. NaCl-solution (4× 30 ml). After drying (Na_2SO_4), the solvent was eliminated i.v. and the residue distilled. Yield 6.33 g (25%, *cf.* [14]), b.p. 32°/5 Torr [17]. – UV. (isooctane): 324 (37), 214 (7300) does not vary with the concentration, whereas in CH_3CN, the UV. spectrum varies strongly with the concentration:

	Conc. of **3c** [mol l^{-1}]					
	4.14×10^{-3}	2.21×10^{-3}	2.07×10^{-3}	1.105×10^{-3}	8.28×10^{-4}	2.21×10^{-4}
λmax	243	240	240	237	236	230
εmax	43	64	69.5	99.5	123	239

IR. (film): 1770*vs*, 1705*vs*, 1650*s*, 1210*vs*. – ^{1}H-NMR. ($CDCl_3$): 5.9 (*d*, *J* = 2, 1 H); 5.7 (*d*, *J* = 2, 1 H); 2.37 (*s*, 3 H); 2.25 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 191.2 (*m*); 168.4 (*m*); 151.4 (*m*); 113.4 (*t*, 162); 24.9 (*qa*, 128.3); 19.9 (*qa*, 130). – MS. (70 eV): 128 (12), 101 (6.2), 43 (100).

General procedure for the preparation of 1-acetylvinyl arenecarboxylates (**3d–3h**). The corresponding acyl chloride (R-COCl) (0.12 mol) in anh. THF (60 ml) was added dropwise (*ca.* 30 min) to a stirred solution of Et_3N (33.6 ml, 0.24 mol) in anh. THF/HMPTA 8:2 (100 ml) maintained at 0°. Then, biacetyl (8.6 g, 0.1 mol) in anh. THF (30 ml) was added dropwise (*ca.* 15 min) under N_2. After the addition, the mixture was stirred at RT. for 24 h under N_2. Light petroleum/ethyl acetate 9:1 (300 ml) was added. After vigorous stirring for 10 min, ice/water (100 ml) was added, the organic layer was collected and the water layer extracted with light petroleum (2× 100 ml). The combined organic extracts were washed successively with ice-cold 5% HCl-solution (2× 50 ml), aq. $NaHCO_3$-solution (2× 50 ml) and H_2O (4× 100 ml). After drying ($MgSO_4$), the solvent was evaporated i.v. The residue contains the crude dienophile. **3d** was purified by flash distillation, b.p. *ca.* 90°/0.001 Torr, 8.94 g (47%). – UV. (CH_3CN): 229 (16100), 274 (1100), 280 (870). – IR. (film): 3060*w*, 1740*vs*, 1700*vs*, 1690*s*, 1640*s*, 1600*s*, 1250*vs*. – ^{1}H-NMR. ($CDCl_3$): 8.22 (*m*, 2 H); 8.1 (*m*, 3 H); 6.1 (*d*, *J* = 2, 1 H); 5.7 (*d*, *J* = 2, 1 H); 2.42 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 191.6 (*m*); 164.4 (*m*); 151.1 (*m*); 133.6 (*d*× *t*, 159.3, ^3J(C,H) = 8); 130 (*d*× *t*, 161.6, ^3J(C,H) = 6.4); 128.5 (*m*); 128.4 (*d*× *d*, 162, 6.4); 113.7 (*t*, 163); 25.2 (*qa*, 128). – MS. (70 eV): 190 (1.5, M^+), 149 (3.7), 106 (18), 105 (100), 77 (99), 51 (48), 43 (28).

$C_{11}H_{10}O_3$ (190.98) Calc. C 69.46 H 5.30% Found C 69.76 H 5.30%

Compound **3e** was recrystallized from AcOEt/MeOH 7:3. Yield: 10.5 g (45%), m.p. 114.5–115.5°. – UV. (CH_3CN): 260 (14900); 209 (15000). – IR. (CH_2Cl_2): 3040*w*, 1745*vs*, 1700*vs*, 1640*s*, 1610*s*, 1350*vs*, 1120*vs*, 1090*vs*, 920*s*, 870*s*, 850*s*. – ^{1}H-NMR. ($CDCl_3$): 8.4 (*m*, 4 H); 6.13 (*d*, *J* = 3, 1 H); 5.86 (*d*, *J* = 3, 1 H); 2.46 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 190.2 (*m*); 162.2 (*m*); 151.1 (*m*, C(3)); 150.4 (*m*); 133.6 (*m*); 130.6 (*d*× *m*, 169.4); 122.8 (*d*× *m*, 172); 114.2 (*t*, 163); 25.17 (*qa*, 128). – MS. (70 eV): 235 (1.8, M^+), 150 (91), 120 (12), 104 (47), 92 (45), 76 (68), 75 (23), 74 (18), 50 (50), 43 (100), 42 (26).

$C_{11}H_9NO_5$ (235.196) Calc. C 56.17 H 3.86 N 5.96% Found C 56.29 H 3.93 N 6.1%

Compound **3f** was purified by filtration on a florisil column (60 g, light petroleum/AcOEt 8:2) and recrystallization from AcOEt/MeOH 3:2. Yield: 14.8 g (53%), colourless crystals, m.p. 108–109°. – UV. (CH_3CN): 289 (3100), 236 (15400), 208 (21100). – IR. (CH_2Cl_2): 3050*w*, 1765*vs*, 1700*vs*, 1645*s*, 1610*s*, 1540*vs*, 1350*vs*, 1240*vs*, 1120*vs*, 1100*vs*, 1050*vs*, 930*s*, 850*s*, 830*s*. – ^{1}H-NMR. ($CDCl_3$): 8.96 (*d*, *J* = 2, 1 H); 8.7 (*d*× *d*, *J* = 2, 9, 1 H); 6.21 (*d*, *J* = 3, 1 H); 6.02 (*d*, *J* = 3, 1 H); 2.47 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 190.3 (*m*); 161.5 (*d*× *m*, ^3J(C,H) = 5.5); 150.8 (*m*); 148.8 (*m*); 147.7 (*m*); 131.8 (*t*, ^3J(C,H) = 5.5); 131.6 (*d*, 174); 127.6 (*d*× *d*, 174.8, 4.5); 119.4 (*d*× *d*, 176.7, 4.5); 115.5 (*t*, 164); 24.8 (*qa*, 129). – MS. (70 eV): 223 (100), 195 (17), 188 (25), 160 (30), 115 (50), 91 (26), 77 (27). – MS. (CI, *i*-C_4H_{10}): 281 ($M^+ + 1$).

$C_{11}H_8N_2O_7$ (280.193) Calc. C 47.15 H 2.88 N 9.99% Found C 47.20 H 3.07 N 9.93%

Compound **3g** was purified by filtration on a *florisil* column (200 g, light petroleum/AcOEt 9:1) and recrystallization from MeOH. Yield: 10.33 g (43%), slightly yellow crystals, m.p. 62–63°. – UV. (CH_3CN): 320 (4300), 300 (6800), 233 (23700), 215 (46700), 211 (48800). – IR. (KBr): 3050*w*, 1740*vs*, 1700*vs*, 1640*s*, 1280*vs*, 1240*vs*, 1190*vs*, 1120*vs*, 780*vs*. – ^{1}H-NMR. ($CDCl_3$): 9.0 (*m*, 1 H); 8.45

(*d*×*d*, *J*=1.5, 6.5, 1 H); 8.21–7.33 (*m*, 5 H); 6.1 (*d*, *J*=2.3, 1 H); 5.81 (*d*, *J*=2.3, 1 H); 2.43 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 191.5 (*m*); 165.0 (*d*, ^3J(C,H)=5.0); 151.7 (*t*, ^3J(C,H)=5.5); 134.0 (*d*×*d*×*d*, 159.6, 7.3 and 4.5); 133.5 (*m*); 131.0 (*m*); 131.0 (*d*×*d*, 163, ^3J=8.3); 128.3 (*d*, 163); 127.8 (*d*, 160); 126.1 (*d*, 148); 125.3 (*d*, 162); 124.9 (*m*); 124.2 (*d*×*m*, 164); 113.7 (*t*, 162.5); 25.2 (*qa*, 128.2). – MS. (70 eV): 240 (18), 156 (5), 155 (33), 128 (8), 127 (57), 126 (22), 101 (9), 77 (15), 76 (6), 75 (13), 43 (100), 42 (29).

$C_{15}H_{12}O_3$ (240.258) Calc. C 74.99 H 5.03% Found C 75.04 H 5.16%

Compound **3h** was purified by filtration on *florisil* (200 g, light petroleum/AcOEt 9:1) and double recrystallization from MeOH. Yield: 8.5 g (35%), m.p. 84–85°. – UV. (CH_3CN): 335 (1800), 292 (6040), 281 (8600), 273 (7000), 239 (62200), 215 (29500). – IR. (CH_2Cl_2): 3060*w*, 1740*vs*, 1700*vs*, 1640*s*, 1220*vs*, 1200*vs*, 1130*vs*, 1080*vs*. – ^{1}H-NMR. ($CDCl_3$): 8.77 (br. *s*, 1 H); 8.37–7.42 (*m*, 6 H); 6.1 (*d*, *J*=2, 1 H); 5.8 (*d*, *J*=2, 1 H); 2.42 (*s*, 3 H). – ^{13}C-NMR. ($CDCl_3$): 191.4 (*m*); 164.5 (*m*); 151.8 (*t*, ^3J(C,H)=6.4); 135.6 (*m*); 132.2 (*m*); 131.8 (*m*); 129.1 (*d*×*d*, 161, ^3J=7.3); 128.4 (*d*, 160); 128.1 (*d*, 160.5); 127.5 (*d*, 160); 126.6 (*d*×*d*, 161, ^3J=7.3); 125.4 (*m*); 125.1 (*d*×*d*, 165, ^3J=7.3); 113.2 (*t*, 163); 25.2 (*qa*, 129). – MS. (70 eV): 240 (3.7), 155 (70), 127 (100), 126 (36), 101 (13), 77 (21), 75 (15), 43 (63).

$C_{15}H_{12}O_3$ (240.258) Calc. C 74.99 H 5.03% Found C 75.12 H 5.06%

2,7-Dehydro-4-hydroxy-9,10-dimethylidene-11-oxa-4-tricyclo[6.2.1.0^{2,7}]undecyl methyl ketones (**7j**+**8j**). The tetraene **1** (0.1 g, 0.68 mmol [5]), the dienophile **3d** (0.258 g, 1.35 mmol) and hydroquinone (1 mg) were heated in CCl_4 (0.35 ml) to 110° for 5 h under N_2. The crude adducts **7d**+**8d** were purified by column chromatography (60 g *florisil*, hexane/AcOEt 9:1) and saponified in MeOH/H_2O/THF/1N NaOH (18:2:5:1.1 ml) (RT., 4 h). After neutralization with 5% HCl-solution and solvent distillation i.v., the aqueous residue was extracted with AcOEt (3×20 ml). The organic extract was washed with a sat. NaCl-solution (2× 10 ml). After drying (Na_2SO_4), the solvent was distilled off under normal pressure. The crude **7j**+**8j** were purified and separated by TLC. (Al_2O_3 150, F 254 Type T, *Merck*, hexane/AcOEt 6:4).

Compound **7j**, yield: 0.05 g (31.6%), oil. – UV. (EtOH): 240 (15900), 231 (21000), 223 (24500), 210 (28700). – IR. (CH_2Cl_2): 3450*w*, 3010*w*, 2930*s*, 1710*vs*, 1670*s*, 1360*s*, 1200*s*, 1100*s*. – ^{1}H-NMR. ($CDCl_3$): 5.21 (*s*, 2 H); 5.01 (*s*, 1 H); 4.96 (*s*, 1 H); 4.91 (*s*, 2 H); 3.06 (*s*, 2 H); 2.76 (*d*, *J*=17.2, 1 H); 2.25 (*s*, 4 H); 1.65–2.05 (*m*, 4 H). – MS. (70 eV): 232 (0.7, M^+), 214 (4.3), 189 (13), 185 (12), 171 (21), 161 (9.0), 143 (18), 137 (28), 128 (10), 115 (21), 91 (31), 77 (21), 55 (30), 43 (100).

$C_{14}H_{16}O_3$ (292.279) Calc. C 72.39 H 6.94% Found C 72.07 H 7.02%

Compound **8j**, yield: 0.048 g (30.4%), oil. – UV. (EtOH): 241 (13600), 231 (18200), 223 (21200), 209 (26900). – IR. (CH_2Cl_2): 3440*s*, 3005*w*, 2920*s*, 1700*vs*, 1660*s*, 1355*s*, 1190*s*, 1100*vs*. – ^{1}H-NMR. ($CDCl_3$): 5.17 (*s*, 2 H); 5.0 (*s*, 2 H); 4.92 (*s*, 1 H); 4.85 (*s*, 1 H); 3.48 (*s*, 1 H); 2.35 (*s*, 3 H); 2.15 (*s*, 4 H); 1.68 (*m*, 2 H). – MS. (70 eV): 232 (0.4, M^+), 214 (2.0), 189 (12), 185 (15), 167 (20), 149 (60), 137 (20), 91 (18), 69 (43), 57 (75), 55 (50), 43 (100).

$C_{14}H_{16}O$ (232.279) Calc. C 72.39 H 6.94% Found C 72.26 H 6.99%

5,12-Epoxy-1,2,3,4,5,12-hexahydro-2-hydroxy-7,10-dimethoxy-2-naphtacenyl methyl ketone (**9j**+**10j**). The diene **2a** [3] (0.3 g, 1.07 mmol), the dienophile **3d** (0.6 g, 3.15 mmol) and hydroquinone (5 mg) were heated in xylene (0.9 ml) at 160° for 3 h under N_2. The mixture was purified by column chromatography (*Florisil*, 25 g; hexane/AcOEt 9:1). The adducts **9d**+**10d** (0.35 g, 0.75 mmol) were saponified in MeOH/H_2O/1N NaOH 27:3:15 (32 ml, RT., 8 h, under N_2 and stirring). The mixture was neutralized with 5% HCl-solution and the solvent distilled i.v. After extraction with AcOEt (3×30 ml), the organic phase was washed with sat. NaCl-solution (2×20 ml), dried (Na_2SO_4) and concentrated i.v. The crude **9j**+**10j** mixture was purified and separated by TLC. (Al_2O_3, F-254, Type T, *Merck*, hexane/AcOEt 6:4). **9j**, yield: 0.129 g (33%), colourless crystals, m.p. 183–184.5° (dec.). – UV. (dioxane): 341 (6360), 325 (6800), 293 (9960), 262 (64500), 220 (65300). – IR. (CH_2Cl_2): 3480*s*, 3010*w*, 2900*vs*, 1710*vs*, 1620*vs*, 1460*vs*, 1380*s*, 1340*vs*, 1200*s*, 1140*vs*, 1090*vs*, 1050*vs*, 800*s*. – ^{1}H-NMR. (CD_2Cl_2): *cf. Table 4.* – MS. (70 eV): 366 (100, M^+), 351 (8.2), 323 (23), 319 (9.6), 305 (26), 295 (15), 277 (20), 265 (13), 252 (20), 237 (23), 221 (15), 165 (12), 43 (11).

$C_{22}H_{22}O_5$ (366.413) Calc. C 72.11 H 6.05% Found C 72.05 H 6.11%

Compound **10j**, yield: 0.09 g (23%), oil. – UV. (dioxane): 340 (6410), 325 (6520), 294 (10000), 260 (64600), 219 (63500). – IR. (CH_2Cl_2): 3480*s*, 3020*w*, 2910*vs*, 2860*vs*, 1715*vs*, 1620*vs*, 1470*vs*, 1340*vs*, 1220*vs*, 1200*vs*, 1140*vs*, 1090*vs*, 1060*vs*, 800–700*vs*. – ^{1}H-NMR., *cf. Table 4.* – MS. (70 eV): 366 (100, M^+), 351 (12), 333 (11), 323 (21), 305 (18), 277 (27), 252 (21), 237 (28), 165 (20), 43 (32).

$C_{22}H_{22}O_5$ (366.413) Calc. C 72.11 H 6.05% Found C 72.29 H 6.14%

Cyclopentadiene adduct with **3f**. A mixture of the dienophile **3f** (0.05 g, 0.178 mmol), cyclopentadiene (0.17 g, 2.57 mmol) and hydroquinone (3 mg) was heated in CH_2Cl_2 (0.06 ml) at 50° for 5 h under N_2. The precipitate was isolated by filtration and washed with hexane (2 × 5 ml). The crude **5f**+**6f** mixture was purified by recrystallization from AcOEt/Et_2O 7:3: yield: 0.056 g (90%) colourless crystals. – UV. (dioxane): 260 (18000), 242 (25600). – IR. (KBr): 3100*w*, 1740–1710*vs*, 1600*s*, 1550–1530*vs*, 1340*vs*, 1300*vs*, 1250*vs*, 1100*vs*, 1050*vs*. – ^{1}H-NMR. ($CDCl_3$): 8.82 (*d*, *J* = 1.6, 1 H); 8.72 (*d*, *J* = 1.6, 1 H); 8.61 (*d* × *d*, *J* = 3.2 and 1.6, 1 H); 8.52 (*d* × *d*, *J* = 3.2 and 1.6, 1 H); 8.03 (*d*, *J* = 3.2, 1 H); 7.92 (*d*, *J* = 3.2, 1 H); 6.46 (*m*, 2 H); 6.05 (*d* × *d*, *J* = 6.0, 3.0, 1 H); 5.85 (*d* × *d*, *J* = 6.0, 3.0, 1 H); 3.1 (*m*, 4 H); 2.8 (*d* × *d*, *J* = 13.0, 4.0, 1 H); 2.51 (*d*, *J* = 2.6, ½ H); 2.31 (*s*, 4 H); 2.21 (*s*, 3 H); 2.08 (*d*, *J* = 3.2, ½ H); 1.35–1.96 (*m*, 4½ H); 1.3 (*d*, *J* = 3.2, ½ H). – MS. (70 eV): 195 (20), 151 (5), 149 (4), 123 (6), 91 (7.7), 77 (11), 75 (26), 66 (100), 43 (99). – MS. (CI, *i*-C_4H_{10}): 347 (M^+ + 1).

$C_{16}H_{14}N_2O_7$ (346.293) Calc. C 55.49 H 4.07 N 8.09% Found C 55.58 H 4.19 N 8.17%

Kinetic measurements. The reaction of cyclopentadiene (at least 30-fold excess, redistilled twice, 100% pure by GC.) with the dienophiles **3a–h** (redistilled or recrystallized before use, 0.18 to 0.27M) in degassed (Ar) CH_2Cl_2 was followed by GC. (*Hewlett Packard* 5710 A, catharometer, internal standard: *n*-C_{10} to *n*-C_{18}, SE-30 10%-4′ × 0.25″ or *Carbowax* 20 M 5%-4′ × 0.25″ or OV-101 10%-4′ × 0.25″, 100–200°, ~30 ml/min He). The disappearance of **3a–h** was measured (*Hewlett-Packard* integrator HP 3380 A) as a function of time. The solutions (~0.6 ml) were placed in 10 ml pyrex tubes sealed with a septum and immersed in a thermostated (50° ± 0.1°) bath (*Colora NBDS* thermostat). The concentration of the formed dicyclopentadiene was measured simultaneously with that of unreacted **3a–h**.

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