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Synthesis of Biologically Active Nonnatural Palmarumycin Derivatives

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Dedicated to Professor Horst Kunz on the occasion of his 70th birthday

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Diels–Alder reaction of benzoquinone monoacetal **1** with 1-methoxy-1,3-butadiene (**4**) and dimethyl(1-methyl-3-vinylcyclohex-3-enyl)(phenyl)silane (**5**) gave the expected adducts **2** and **3**, whereas with siloxy-dienes such as 3-methyl-1-(trimethylsiloxy)-1,3-butadiene (**6**) a 1,2-aldol-type adduct **9** was isolated. The Diels–Alder adduct **2** was isomerized under mild basic conditions to the olefin **10** and eliminated to the diene **11** under mild acidic or thermal conditions. The olefins **2**, **10** and **11** were subjected to epoxidation with *m*-chloroperbenzoic acid and *tert*-butyl hydroperoxide under mild basic conditions to afford the epoxides **12**, **15**, and **18** under the former conditions and **13**, **14**, **16**, **17**, **19**, and **20** under the latter conditions. The olefins **1**, **2**, **10**, **11**, and **20** were also transformed into the respective *cis*-diols **21a** and **23a**–**26a**. From theses diols the corresponding diacetates (**b**) and acetonides (**c**) were prepared. The compounds were tested against the Gram-negative bacterium *Escherichia coli*, the Gram-positive bacterium *Bacillus megaterium*, and the fungus *Microbotryum violaceum*. Whereas compound **25b** was the most active of the diacetates and the epoxide **18** the most active of all substances, all of the compounds were biologically active against the three test organisms, equalling and surpassing those of the natural palmarumycins.

Introduction

Palmarumycins are a relatively new and large class of fungal metabolites, derived by coupling of two units of 1,8-dihydroxynaphthalene followed by a multitude of chemical transformations. Their interesting structure and diverse bioactivity have aroused the interest of natural-product and synthetic chemists.[1] In a preceding communication, we described the synthesis of palmarumycins CP_1, CP_2, and CJ-12.371 methyl ether (see Scheme 1).[2] In this paper, we report on the synthesis of biologically active nonnatural palmarumycin derivatives, employing the same strategy of Diels–Alder reaction of dienes to benzoquinone monoacetal **1** and subsequent chemical transformations (Scheme 1).

Results and Discussion

The addition of 1-methoxy-1,3-butadiene (**4**) to benzoquinone monoacetal **1** afforded the adduct **2**, which was transformed into the naturally occurring palmarumycins CP_1, CP_2.[2] In this communication, the diolefin **2** was the starting material for further transformations (see below). However, prior to reporting on these reactions, we wanted to test some Diels–Alder reactions of the dienophile **1** with the dienes **5**, **6**, and **7**. The first experiment was conducted with dimethyl(1-methyl-3-vinylcyclohex-3-enyl)-(phenyl)silane (**5**), previously used in our group for the synthesis of angucyclines.[3,4] Similarly, as reported for the reaction with the 1-methoxy-1,3-butadiene (**4**), the addition was performed without solvent ("neat") with a fourfold excess of the diene **5** to afford the crystalline adduct **3** in 90% yield (Scheme 1).

Next, a concentrated solution of the benzoquinone acetal **1** in dichloromethane was treated with 3-methyl-1-(trimethylsiloxy)-1,3-butadiene (**6**)[5] to yield the allyl alcohol **8** in 72% yield after acidic hydrolysis of the intermediate silyl ether. Although compound **8** is structurally very close to the palmarumycins, there is no naturally occurring bis(dioxy)spironaphthalene with a methyl group in position 7.

Interestingly, neither (buta-1,3-dien-1-yloxy)trimethylsilane nor the (4-methoxybuta-1,3-dien-2-yloxy)trimethylsilane (Danishefsky diene) gave Diels–Alder adducts under similarly mild conditions. A probable reaction mode became clearer when the reaction of **1** was tried with 1,4-di-

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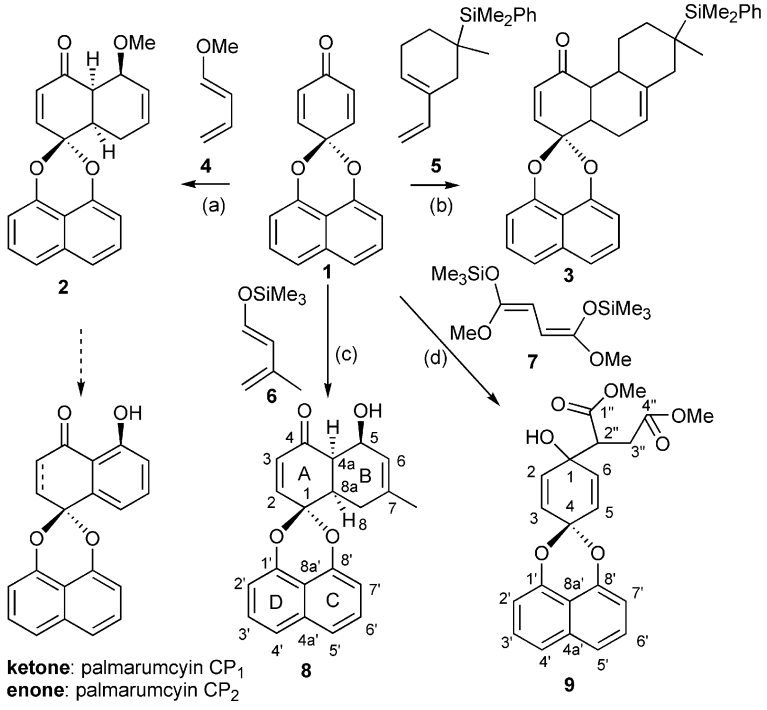
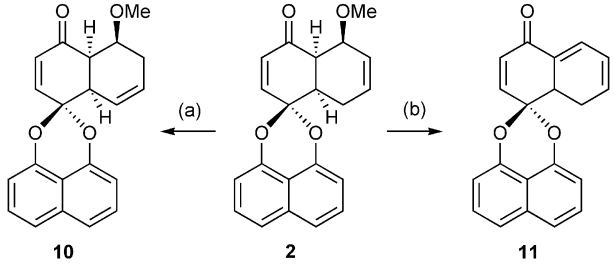


Scheme 1. Diels–Alder reaction of dienes **4**–**7** with the dienophile **1**. (a) 4–5 d, r.t, 95%; (b) 2 d, r.t., 90%; (c) 2 d, r.t., 72%; (d) 3 d, r.t., 14%.

methoxy-1,4-bis(trimethylsilyloxy)buta-1,3-diene (**7**), again under neat conditions. We hoped that this diene could introduce the two oxygen functions present in many palmarumycin derivatives. However, the only product that could be isolated was the 1,2 adduct **9** in a very low yield of 14%. This compound showed some instability on silica gel, perhaps due to β-elimination of the OH group, and could not be obtained in entirely pure form. However, the NMR spectra unambiguously confirmed the proposed structure, in particular the signals of C-1 (δ = 71.09 ppm), C-2′′ (methine) (δ = 48.02 ppm) and C-3′′ (methylene) (δ = 32.2 ppm) in the ^{13}C NMR spectrum.

The poor dienophilicity with some siloxy-dienes and the potential to prepare palmarumycin analogues suggested exploiting the synthetic options of the easily available Diels–Alder adduct **2**.[2] The idea was to obtain starting materials for further chemical transformation such as epoxidation or hydroxylation of the double bonds in adduct **2**.

The first experiment was treatment of **2** with a mild base to initiate a β-elimination of the methoxy group to give the diene **11**. However, surprisingly, no β-elimination but an isomerization to the olefin **10** took place. This base-catalyzed isomerization of **2** to **10** is surprising. However, calculations of the relative energies of absolute lowest energy minima with an MMFF-based (Merck molecular force field) conformational search and reoptimization of all minima with DFT showed that compound **10** is slightly more stable (ca. 2 kcal/mol) than the olefin **2**.[7] By contrast, the conjugated diene **11** was easily obtained by thermal isomerization (heating in xylene) in 72% yield or even almost quantitatively by treatment with dilute acid (TMSCl in moist dichloromethane) (Scheme 2). This way, the starting materials **2**, **10**, and **11** were available in sufficient amounts for further transformation to potentially biologically active palmarumycin derivatives.



Scheme 2. Base-catalyzed isomerization of diene **2** to **10** and thermal or acid-catalyzed elimination to diene **11**. (a) DMAP (0.1 mg), 2 d, r.t., 70%; (b) xylene, 2 d reflux, 72%, or TMSCl, CH_2Cl_2, 4 h, 95%.

A large number of palmarumycin derivatives carry epoxide groups, which are most probably responsible for a variety of biological activities such as cytotoxicity.[1] Therefore, the first reactions tried were epoxidations with *meta*-chloroperbenzoic acid (MCPBA) of the dienes **2**, **10**, and **11**. As expected, in all cases the most electron-rich double bond was oxidized selectively to afford the corresponding monoepoxides in 70, 63, and 88% yield, respectively. The relative configuration of the racemic epoxides **12**, **15** and **18** could be deduced from the coupling constants in the ^{1}H NMR spectra. In all cases, the oxygen atom was supposed to be introduced from the less hindered convex side of the bicycle

tetralene molecule, similarly as in **18** and structurally confirmed by X-ray analysis (Figure 1).

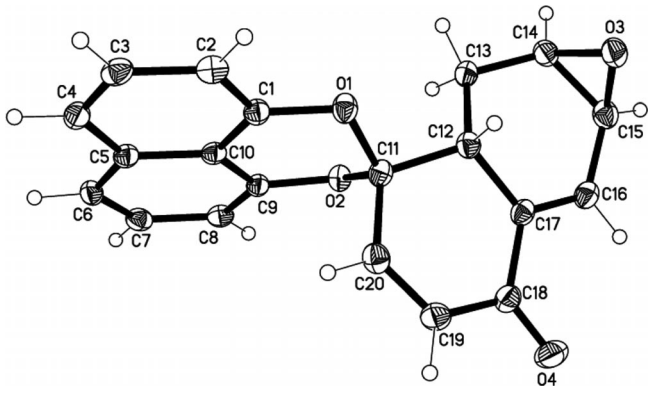


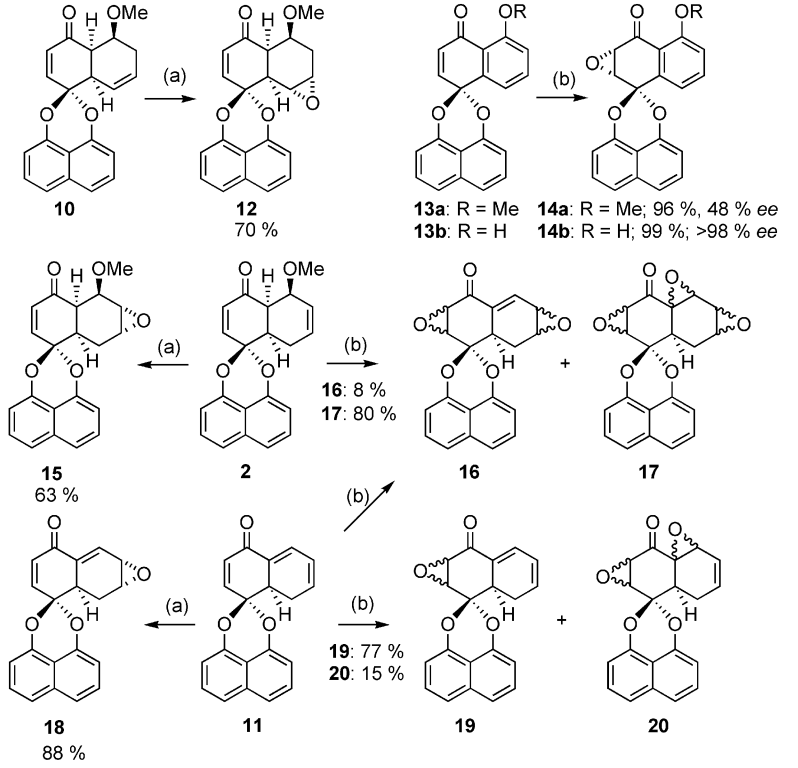
Figure 1. Molecular structure of epoxy-diene **18**. Anisotropic displacement ellipsoids are shown at the 50% probability level.

The central C-11 atom lies 0.560(2) Å above the aromatic ring moiety, and the geometry around C-11 is a slightly distorted tetrahedron with angles in the range of 104.9(1)–113.2(1)°. The epoxy moiety is almost perpendicular to the six-membered ring; the corresponding O3–C14–C13 and O3–C15–C16 angles measure 116.35(15)° and 116.01(15)°, respectively.

The other epoxidations were performed according to Weiz–Scheffer[6] in basic media (NaOH) with *N*-benzylcinchonium chloride as the phase-transfer catalyst and *tert*-butyl hydroperoxide (TBHP) as the oxygen source. This epoxidation has a different mechanism and proceeds by a Michael-type addition of the TBHP anion to the electron-deficient double bond (in our case the enone or vinylogous double bonds) followed by elimination of *tert*-butyl alcohol to form the α,β-epoxy ketone.

The fist reaction performed was the epoxidation of palmarumycin CP_1 methyl ether (**13a**) and palmarumycin CP_1 (**13b**) in order to obtain optically enriched compounds for biological testing and to test the reaction conditions. We used the procedure of Barrett et al.[8] with dichloromethane instead of toluene as the solvent (Scheme 3). The products were isolated in essentially quantitative yield, and the phenol **14b** was produced in much higher enantiomeric excess (<99% *ee*) than the methyl ether **14a** (48% *ee*), thus confirming the results obtained by Barrett et al.[9] The two aromatic sidearms in the enones **13a**,**b** direct the oxidant preferentially to the *Si* face of the enone. This and the much higher *ee* values for the phenol **14b** are discussed in detail by Barret et al.[8]

The epoxidations of other olefins were performed by using the same procedure (Scheme 3). The spectrum of the epoxidation products of the triene **11** strongly depended on the reaction time. It would be expected that the most electron-deficient double bonds would be epoxidized most rapidly. In fact, in one experiment, a 77% yield of the monoepoxide **19** and a 15% yield of the diepoxide **20** were isolated. The triepoxide **17** was formed in 92% yield under prolonged reaction times. Interestingly, also the unexpected diepoxide **16** was isolated in one experiment in 8% yield together with 80% of the triepoxide **17** with the Diels–Alder adduct **2** as the starting material. We presume that this is the result of elimination of the 5-methoxy group from a 5-methoxy-2,3;6,7-diepoxide intermediate. In the diepoxide



Scheme 3. Epoxidation of olefins. (a) 1 equiv. MCPBA in CH_2Cl_2; (b) *N*-benzylcinchonium chloride, TBHP in CH_2Cl_2, NaOH, 24 h, r.t.

16, electron deficiency of the isolated 4a,5 double bond is missing, and further epoxidation under Weiz–Scheffer conditions is probably very slow. Therefore, under careful TLC monitoring, the yield of the diepoxide **16** could be optimized, and in one case a 75% yield of **16** was obtained. The formation of the triepoxide starting from the methyl ether **2** is easily explained by elimination of the methoxy group and further slow epoxidation under prolonged reaction times. The exact timing of methoxy group elimination and epoxidations is not known. With the epoxides **15**, **17** and **18** in hand, we could optimize the reaction times required for the optimum yield of these individual epoxides by TLC monitoring starting from triene **11** (see Experimental Section).

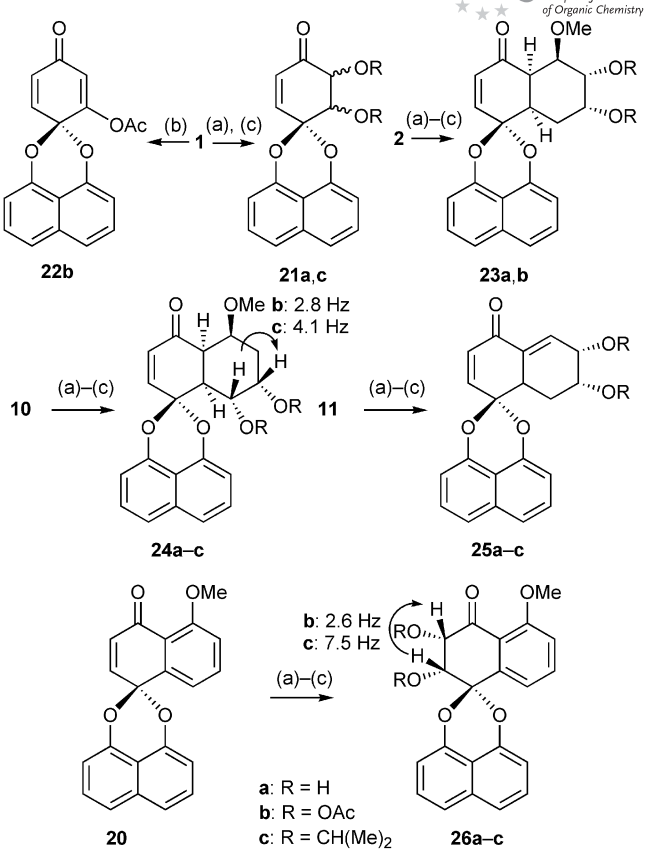
The relative and absolute stereochemistry of the epoxides **16**–**20** could not be elucidated conclusively from their NMR spectra as shown in the structures in Scheme 3. Relevant protons for analysis of the coupling constants or Overhauser effects were missing in all cases. However, they all represent compounds with only one relative stereochemistry as confirmed by analysis of their NMR spectra. Also, the individual enantiomeric excess is not known due to lack of compounds for comparison of the specific optical rotations.

In the next section, the olefins **1**, **2**, **10**, **11**, and **20** were subjected to *cis*-dihydroxylations with catalytic amounts of osmium tetroxide and *N*-methylmorpholine *N*-oxide as the oxidant in THF (Scheme 4).[10] Again, in all relevant cases (**2**, **10**, and **11**), the least electron-rich double bonds were dihydroxylized to the corresponding diols **23a**–**25a** in acceptable yields. But the osmylation was also possible at prolonged reaction times with the less reactive enones **1** and **20**, which were transformed in good yields to the *cis*-diols **21a** and **26a**. All products are racemic, and the relative stereochemistry could be deduced from the coupling constants in the ^{1}H NMR spectra.

Next, the *cis*-diols were transformed into the corresponding acetates (Scheme 4). Not surprisingly, the diol **21a** underwent β-elimination to form the stable benzoquinone acetal monacetate **22b** in 60% yield. The acetylations of all other diols **23a**–**26a** were uneventful, and the diacetates **23b**–**26b** were isolated in essentially quantitative yields. The diacetates served as valuable samples for testing for antimicrobial activity (see below), and they also provided additional NMR spectroscopic data to secure the relative stereochemistry of the diols.

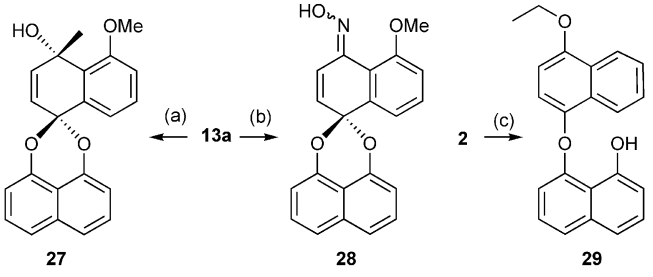
The same twofold purpose was expected from the corresponding acetonides **22c**–**26c**. With exception of **21c** (66%), they were prepared in 97–98% yield by reaction of the diols with 2,2-dimethoxypropan in acetone with perchloric acid as the catalyst. It was particularly interesting to see the increase in the coupling constants caused by the transition from the flexible acetates (gauche conformation) to the corresponding acetonides (synclinal conformation; 2.8 Hz and 2.6 Hz for **24b** and **26b** to 4.1 and 7.5 Hz for **24c** and **26c**).

To conclude the preparation of palmarumycin derivatives, the palmarumycin CP$_1$ methyl ether **13a** was treated with methylmagnesium chloride. As expected, a clean 1,2-addition to form the tertiary alcohol **27** occurred in 80%



Scheme 4. *cis*-Hydroxylation of the olefins **1**, **2**, **10**, **11**, and **20** to the diols **21a** (65%), **23a** (86%), **24a** (88%), **25a** (75%), and **26a** (**90%**) and conversion into the corresponding acetates **22b** (60%), **23b** (96%), **24b** (97%), and **25b** (95%), and **26b** (98%) and the acetonides **21c** and **23c**–**25c**. (a) Catalytic OsO_4 (0.1 equiv.) in *t*BuOH, NMO (1 equiv.), H_2O/THF, 6–48 h; (b) pyridine, Ac_2O; cat. DMAP, 6–12 h, r.t.; (c) catalytic perchloric acid (60%, 0.01 mL), acetone (10 mL), 2,2-dimethoxypropan (0.14 mmol), **21c** (66%), **24c** (98%), **25c** (97%), and **26c** (98%).

yield. As stated earlier, methyl groups on the palmarumycin ring system do not occur naturally. Next, we prepared the oxime **28** starting again from the palmarumycin CP$_1$ methyl ether **13a** (Scheme 5). The (*E*) or (*Z*) configuration of the oxime hydroxy group could not be established unambiguously. The intuitively favored (*E*) configuration requires a seven-membered ring for chelation to the neighboring methoxy group. The chemical shifts in the ^{13}C NMR spec-



Scheme 5. Formation of the tertiary alcohol **27**, the oxime **28** and the open-chain ethyl ether **29**. (a) MeMgCl (1.2 equiv.), THF, –78 °C to r.t., 80%; $(NH_2OH)HCl$, ethanol, r.t., overnight, 95%; (c) TMSCl, ethanol, 40 °C, 6 h.

tra of the methoxy carbon atoms of **13a** and **28** are virtually unchanged, and this suggests the (*Z*) configuration as shown in Scheme 5. In another reaction, the spiro acetal was opened. Under strongly acidic conditions, attained by heating the Diels–Alder adduct **2** in a mixture of TMSCl in ethanol, the acetal was opened, the methoxy group eliminated, and the resulting cation trapped by the solvent to form the ethyl ether **29**.

Biological Activity

Table 1 summarizes the test results for biological activities of the synthetic epoxide palmarumycins, which were tested in an agar diffusion assay at a concentration of 0.05 mg against the Gram-negative bacterium *Escherichia coli*, the Gram-positive bacterium *Bacillus megaterium*, and the fungus *Microbotryum violaceum*. Whereas the epoxide **18** was the most active of the substances, all of the compounds were biologically active against the three test organisms, most with quite substantial zones of inhibition. Interesting, and somewhat unusual is the fact that inhibition of the Gram-negative bacterium *E. coli*, which is often resistant to antimicrobial agents, was often more pronounced than that of the Gram-positive bacterium *B. megaterium*. In Table 1, the data for inhibition of palmarumycin CP_1 and CP_2 from the literature[11] for *E. coli* and *B. megaterium* are also included for comparison; they show much lower activity than the synthetic compounds.

After the successful synthesis of the diols **21a**, **23a**, **24a**, **25a** and **26a**, these compounds were also tested for their antibacterial and antifungal activities (Table 2). All of the diols had quite promising biological activities, in particular the diol **25a** with both antifungal and antibacterial inhibitions. The tests against the Gram-positive bacterium with some of the diols (**23a**, **24a**, and **26a**) and epoxides (**9**, **14a**, **19**) resulted in only partial inhibitions (p.i.), i.e. there was some growth within the inhibition zone, suggesting that some of the *B. megaterium* individuals were relatively resistant to these compounds.

Testing of the acetonide derivatives against the same bacterial and fungal test organisms again demonstrated excellent biological activities (Table 3). 6,7,8,8a-Pentahydrospiro[naphthalene-1,2′-naphtho[1,8-*de*][1,3]dioxin]-4-one 6,7-acetonide (**25c**) had the most pronounced activities, both against the two bacteria and against the fungus *M. violaceum*. It is quite remarkable that the acetonide **24c** also significantly inhibited *B. megaterium*. 5-Methoxyspiro-[naphthalene-1,2′-naphtho[1,8-*de*][1,3]dioxin]-4-one 2,3-acetonide (**26c**) only led to a partial inhibition of *B. megaterium*.

Synthesis of the diacetates **23b**–**26b** resulted in yields of >95% (Scheme 4). The tests for biological activities again showed that all of the compounds were biologically very active, both against the bacterial and the fungal test organisms (Table 4). Compound **25b** was the most active of the diacetates, with radii of zones of inhibition of up to 20 mm (!).

Table 1. Biological activities of the palmarumycin epoxide derivatives tested in an agar diffusion assay.[a]

Compound	*Escherichia coli*	*Bacillus megaterium*	*Microbotryum violacaeum*
29	9	p.i. 7	7
9	7	p.i. 10	9
14a	9	p.i. 15	10
18	10	15	23
16	7	12	10
19	9	p.i. 9	10
14b	10	15	13
Palmarumycin CP_1[11]	3–4	2	–
Palmarumycin CP_2[11]	0	2	–
Penicillin	28	20	0
Streptomycin	30	25	0
Acetone	12	0	0

[a] 0.05 μg of the test or control compound dissolved in acetone, applied to a filter disc and sprayed with a suspension of the respective test organism. Radii of the zones of inhibition given in mm. p.i. = partial inhibition.

Table 2. Biological activities of the palmarumycin diol derivatives tested in an agar diffusion assay.[a]

Compound	*Escherichia coli*	*Bacillus megaterium*	*Microbotryum violacaeum*
21a	10	12	10
23a	7	p.i. 9	9
25a	9	20	18
24a	7	p.i. 7	10
26a	10	p.i. 12	8
Penicillin	28	20	0
Streptomycin	30	25	0
Acetone	12	0	0

[a] See Table 1.

Table 3. Biological activities of the palmarumycin acetonide derivatives **24c**–**26c**, tested in an agar diffusion assay.[a]

Compound	*Escherichia coli*	*Bacillus megaterium*	*Microbotryum violacaeum*
25c	10	18	20
24c	7	15	10
26c	7	PI 9	10
Penicillin	28	20	0
Streptomycin	30	25	0
Acetone	12	0	0

[a] See Table 1.

Table 4. Biological activities of the palmarumycin diacetate derivatives **23b**–**26b**, tested in an agar diffusion assay.[a]

Compound	*Escherichia coli*	*Bacillus megaterium*	*Microbotryum violacaeum*
23b	9	PI 10	9
25b	10	20	16
24b	10	PI 9	10
26b	8	PI 10	10
Penicillin	28	20	0
Streptomycin	30	25	0
Acetone	12	0	0

[a] See Table 1.

Conclusion

All of the synthetic palmarumycins – epoxides, diols and diacetates – showed considerable antifungal and antibacterial activities, equaling and slightly surpassing those of the natural palmarumycins.[11,12] However, these relatively high activities are not yet sufficient for application in crop protection, and further studies are warranted. But the results suggest that the enone system of ring A is a major pharmacophore activated by oxygen substituents on ring B that may modify the lipophilicity of the compounds.

Experimental Section

General Experimental Procedures: Melting points were determined with a Gallenkamp melting point apparatus. Optical rotations were measured with a Perkin–Elmer 241 MC polarimeter. IR spectra were recorded with a Nicolet-510P spectrometer. NMR spectra were recorded with a Bruker Avance-500 NMR spectrometer with TMS as internal standard. Assignments of NMR signals are based on 2D spectra. ^{13}C notations are: s (quaternary C), d (tertiary C), t (secondary C), q (primary C). EI mass spectra were obtained with an MAT 8200 mass spectrometer. CD spectra were recorded with a J-810 spectropolarimeter. Silica gel (70–230 mesh) was used for column chromatography.

Agar Diffusion Test for Biological Activity: Compounds **1**–**11** were dissolved in acetone at a concentration of 1 mg/mL; 50 μL of the solution (0.05 μg of compound) was pipetted onto a sterile filter disc (Schleicher & Schuell, 9 mm), which was placed onto an appropriate agar growth medium for the respective test organism and subsequently sprayed with a suspension of the test organism. The test organisms were the Gram-negative bacterium *Escherichia coli*, the Gram-positive bacterium *Bacillus megaterium* (both grown on NB medium), and the fungus *Microbotryum violaceum* (MPY medium). Commencing in the middle of the filter disc, the radius of the zone of inhibition was measured in mm. These microorganisms were chosen because (a) they are non-pathogenic and (b) had in the past proved to be accurate initial test organisms for antibacterial and antifungal activities.

Diels–Alder Product 3: A suspension of ketal **1** (100 mg, 0.4 mmol) in dimethyl(1-methyl-3-vinylcyclohex-3-enyl)(phenyl)silane (**5**) (307 mg, 1.2 mmol) was stirred under argon for 2 d (TLC monitoring). The mixture was separated by column chromatography on silica gel of afford the Diels–Alder adduct **3** as a yellow solid (182 mg, 90%); m.p. 84–86 °C. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.36 (s, 3 H, $SiCH_3$), 0.39 (s, 3 H, $SiCH_3$), 0.80 (s, 3 H, CCH_3), 0.83–0.97 (m, 2 H, 5a-H, 6a-H), 1.56–1.65 (m, 2 H, 5b-H, 6b-H), 1.90–1.94 (m, 1 H, 8-H), 2.13–2.24 (m, 2 H, 10-H), 2.30–2.26 (m, 1 H, 8-H), 2.67–2.76 (m, 1 H, 4b-H), 2.79–2.83 (m, 1 H, 4a-H), 3.32–3.34 (m, 1 H, 10a-H), 5.26 (d, J = 3.2 Hz, 1 H, 9-H), 6.03 (d, J = 10.2 Hz, 1 H, 3-H), 6.56 (d, J = 10.2 Hz, 1 H, 2-H), 6.95 (m, 2 H, 2′-H, 7′-H), 7.34 (m, 3 H, Ph-H), 7.42–7.53 (m, 4 H, 3′-H, 4′-H, 5′-H, 6′-H), 7.54–7.59 (m, 2 H, Ph-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = –3.9 [q, Si(CH_3)$_2$], –3.4 [q, Si(CH_3)$_2$], 22.2 (s, C-7) 24.0 (t, C-10), 26.2 (t, C-5), 28.1 (q, CH_3), 36.7 (t, C-6), 40.9 (d, C-10a), 42.9 (t, C-8), 44.2 (d, C-4b), 46.7 (d, C-4a), 100.1 (s, C-1), 109.1 (d, C-7′), 109.7 (d, C-2′), 113.8 (s, C-8a′), 117.2 (d, C-9), 120.7 (d, C-6′), 120.9 (d, C-3′), 127.4 (d, C-5′), 127.5 (d, C-4′), 128.5, 128.6, 128.8 (d, 3C-Ph), 132.7 (d, C-3), 134.3 (s, C-4a′), 134.5, 134.6 (d, 2C-Ph), 138.0 (d, C-2), 138.4 (s, C-8a), 138.6 (s, C-Ph), 146.6, 147.4 (s, C-1′, C-8′), 199.2 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2919, 1692, 1607, 1586, 1412, 1381, 1272, 1179, 1109, 1078, 1030, 964, 823, 757, 736, 701 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 327 (3.21), 312 (3.30), 298 (3.54), 231 (4.13) nm. MS (EI, 70 eV): m/z (%) = 506 (20) [M^+], 370 (10), 279 (12), 250 (51), 197 (36), 185 (81), 135 (80), 97 (87), 55 (100), 28 (34). HRMS (EI, 70 eV): calcd. for $C_{33}H_{34}O_3Si$ 506.22772; found 447.21680.

Hydroxy-methyl Spiro Ketal 8: A solution of benzoquinone acetal **1**, (0.5 g, 1.9 mmol) in CH_2Cl_2 (2 mL) was treated with 3-methyl-1-(trimethylsiloxy)-1,3-butadiene (**6**),[5] (0.4 g, 5.9 mmol) and stirred under nitrogen at room temp. for 4 d. Excess of diene and solvent were removed under reduced pressure, and methanolic HCl (1.56 mmol/mL) was added at 0 °C until the color changed to faint yellow. The acidic solution was extracted with CH_2Cl_2 (3 × 2 mL), the combined organic phases were dried (Na_2SO_4), filtered, and

the solvent was removed under reduced pressure. The residue was purified by filtration through a pad of silica gel (CH_2Cl_2) to afford the allyl alcohol **8** as a yellow solid (510 mg, 72%); m.p. 57–58 °C. ^{1}HNMR (500 MHz, $CDCl_3$): δ = 1.67 (s, 3 H, CH_3), 2.15 (m, 2 H, 8-H), 2.97 (m, 1 H, 8a-H), 3. 59 (m, 1 H, 4a-H), 4.50 (m, 1 H, 5-H), 5.58 (d, J = 11.0 Hz, 1 H, 6-H), 6.10 (d, J = 10.0 Hz, 1 H, 3-H), 6.70 (dd, J = 3.0, J = 10.0 Hz, 1 H, 2-H), 6.88 (br. dd, 2 H, 7′-H, 2′-H), 7.46 (t, J = 8.1 Hz, 2 H, 3′-H, 6′-H), 7.53 (dd, J = 8.1, J = 1.5 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 22.8 (q, CH3), 28.1 (t, C-8), 41.9 (d, C-8a), 46.3 (d, C-4a), 69.3 (s, C-5), 99.3 (s, C-1), 109.69 (d, C-7′), 110.13 (d, C-2′), 114.17 (s, C-8a′), 121.33 (d, C-5′), 121.54 (d, C-4′), 123.26 (d, C-6), 125.45 (d, C-3), 127.95 (d, C-3′, C-6′), 134.86 (d, C-7), 134.66 (s, C-4a′), 138.78 (d, C-2), 146.76 (s, C-8′), 147.55 (s, C-1′), 202.32 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3424, 1670, 1601, 1505, 1413, 1385, 1077, 826 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 329 (1.66), 314 (2.22), 300 (2.49), 299 (2.49) nm. MS (EI, 70 eV): m/z (%) = 334 (16) [M$^+$], 160 (100), 252 (22), 77 (12). HRMS (EI, 70 eV): calcd. for $C_{21}H_{18}O_4$ 334.1205; found 334.1212.

Spiro Alcohol 9: A mixture of benzoquinone acetal **1** (100 mg, 0.38 mmol) and 1,4-dimethoxy-1,4-bis(trimethylsiloxy)-1,3-butadiene (**7**)[13] (632 mg, 1.52 mmol) was stirred under Ar at 22 °C for 3 d. Excess of diene was removed under high vacuum, and the residue purified by repeated preparative layer chromatography (1 mm; *n*-hexane/AcOEt, 95:5) to afford the crude 1-hydroxybenzoquinone acetal **9** as a slightly yellow oil (20 mg, 14%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.5 (m, 2 H, 2′′-H), 3.1 (m, 1 H, 3′-H), 3.69 (s, 3 H, OCH_3), 3.76 (s, 3 H, OCH_3), 6.01 (d, J = 11.3 Hz, 1 H, 2-H), 6.15 (d, J = 11.0 Hz, 2 H, 3-H, 5-H), 6.28 (d, J = 11.0 Hz, 2 H, 6-H), 7.02 (d, J = 8.0, Hz, 2 H, 2′-H, 7′-H), 7.46 (d, J = 8.0 Hz, 2 H, 4′-H, 5′-H) 7.56 (t, J = 8.0 Hz, 2 H, 3′-H, 6′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 32.2 (t, C-3′′), 48.02 (d, C-2′′), 51.5 (q, 2 × OCH_3), 71.09 (s, C-1), 92.03 (s, C-4), 109.7 (d, C-2′, C-7′), 113.5 (s, C-8a′), 120.6 (d, C-4′, C-5′), 126.1 (d, C-3′, C-6′), 127.4 (d, C-2, C-6), 134.1 (s, C-4a′), 135.8 (d, C-3, C-5), 147.5 (d, C-1′, C-8′), 172.6 (s, 2 × CO) ppm.

Methoxy Spiro Ketal 10: A solution of **2** (0.20 g, 0.06 mmol) in dry CH_2Cl_2 (10 mL) as treated under Ar with 4-(dimethylamino)-pyridine (DMAP) (0.02 g, 0.16 mmol). The solution was stirred at room temp. for 2 d (TLC monitoring). After completion of the reaction, the mixture was treated with water (10 mL), extracted twice with CH_2Cl_2, and the combined organic phases were dried with $MgSO_4$, filtered, and the solvent was removed under reduced pressure. Chromatography of the residue on silica gel (CH_2Cl_2) afforded the rearranged methyl ether as a white solid (0.14 g, 70%); m.p. 203–204 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.46 (m, 1 H, 6-H), 2.68 (m, 1 H, 6-H), 2.80 (m, 1 H, 8a-H), 3.17 (m, 1 H, 4a-H), 3.56 (s, 3 H, OCH_3), 4.23 (m, 1 H, 5-H), 5.94 (dd, J = 8.1, 1.5 Hz, 1 H, 8-H), 5.98 (m, 1 H, 7-H), 6.01 (d, J = 10.3 Hz, 1 H, 2-H), 6.77 (d, J = 10.3 Hz, 1 H, 3-H), 6.89 (dd, J = 7.5, 0.7 Hz, 1 H, 7′-H), 6.96 (dd, J = 7.5, 0.7 Hz, 1 H, 2′-H), 7.43 (dd, J = 8.4, 7.5 Hz, 2 H, 3′-H, 6′-H), 7.53 (dd, J = 8.4, 0.7 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 23.02 (t, C-6), 44.4 (d, C-8a), 48.1 (d, C-4a), 56.3 (q, OCH_3), 73.7 (s, C-5), 97.5 (s, C-1), 109.2 (d, C-7′), 109.9 (d, C-2′), 113.2 (s, C-8a′), 120.8 (d, C-5′), 121.1 (d, C-4′), 125.5 (d, C-7), 127.5 (d, C-3′), 127.54 (d, C-6′), 127.6 (d, C-3), 130.9 (d, C-8), 134.2 (s, C-4a′), 141.6 (d, C-2), 146.8 (s, C-8′), 147.1 (s, C-1′), 198.3 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 1682, 1600, 1408, 1377, 1274, 1268, 1087, 932, 842, 731 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.10), 312 (3.25), 298 (3.34), 233 (3.91) nm. MS (EI, 70 eV): m/z (%) = 334 (100) [M$^+$], 302 (22), 197 (55), 160 (20), 115 (42), 84 (30), 71 (10). HRMS (EI, 70 eV): calcd. for $C_{21}H_{18}O_4$ 334.1205; found 334.1212.

Spiro Ketal 11: A solution of the Diels–Alder adduct **2** (1.0 g, 2.99 mmol) in dry xylene (20 mL) was heated under Ar under reflux for 2 d (TLC monitoring, CH_2Cl_2). The solvent was removed at 50 °C under reduced pressure and the residue purified by column chromatography on silica gel (CH_2Cl_2) to afford 0.65 g of elimination product **11** as a yellow solid (72%); m.p. 130–132 °C. Alternatively, a solution of **2** (668 mg, 2 mmol) in CH_2Cl_2 (5 mL) was treated with TMSCl (0.1 mL). The solution was kept at room temp. for 10 h (TLC monitoring), the solvent was removed and the residue crystallized from diethyl ether (1 mL) to afford **11** (57 mg, 95%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.73 (m, 1 H, 8-H), 2.95 (m, 1 H, 8-H), 3.58 (m, 1 H, 8a-H), 6.18 (d, J = 10.4 Hz, 1 H, 3-H), 6.23 (m, 1 H, 7-H), 6.33 (m, 1 H, 6-H), 6.79 (d, J = 10.4 Hz, 1 H, 2-H), 6.86 (d, J = 7.5 Hz, 1 H, 7′-H), 6.98 (d, J = 7.5 Hz, 1 H, 2′-H), 7.25 (t, J = 4.6 Hz, 1 H, 5-H), 7.39 (t, J = 8.4 Hz, 1 H, 6′-H), 7.45 (t, J = 7.5 Hz, 1 H, 3′-H), 7.51 (d, J = 8.4, Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 22.6 (t, C-8), 40.7 (d, C-8a), 97.3 (s, C-1), 109.4 (d, C-2′,C-7′), 113.2 (s, C-8a′), 120.7 (d, C-4′, C-5′), 123.5 (d, C-6), 127.4 (d, C-3′, C-6′), 127.5 (d, C-7), 132.4 (d, C-3), 132.9 (d, C-4a), 134.2 (s, C-4a′), 134.3 (d, C-5), 141.9 (d, C-2), 146.4 (s, C-1′, C-8′), 185.2 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3450, 1667, 1634, 1601, 1541, 1406, 1384, 1259, 1134, 1085, 742 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.11), 312 (3.24), 296 (3.33), 232 (3.80) nm. MS (EI, 70 eV): m/z (%) = 302 (80) [M$^+$], 115 (100), 149.1 (66), 57 (62), 43 (44), 71 (41). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O$ 302.09429; found 302.09572.

Methoxy-epoxy Spiro Ketal 12: Olefin **10** (0.020 g, 0.054 mmol) in dry CH_2Cl_2 (5 mL) was treated with a stoichiometric amount of *m*-CPBA (0.005 g, 0.029 mmol). The mixture was stirred at room temp. under nitrogen for 1 d, the solution was diluted by addition of CH_2Cl_2 (5 mL), shaken with an aqueous $Na_2S_2O_4$ solution (0.2 N, 1 mL), and subsequently with a solution of $NaHCO_3$ (0.2 N, 2 mL) and water (2 mL). The organic phase was dried (Na_2SO_4), the solvent removed under reduced pressure, and the residue purified by column chromatography on silica gel to afford epoxide **12** as a white solid (0.012 g, 63%); m.p. 115–117 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.41 (m, 2 H, 6-H), 2.73 (m, 1 H, 8a-H), 2.88 (m, 1 H, 4a-H), 3.25 (dd, J = 10.0, 4.5 Hz, 1 H, 8-H), 3.45 (dd, J = 10.0, 4.5 Hz, 1 H, 7-H), 3.70 (s, 3 H, OCH_3), 4.23 (m, 1 H, 5-H), 6.03 (d, J = 10.0 Hz, 1 H, 2-H), 6.79 (d, J = 10.0 Hz, 1 H, 3-H), 6.87 (dd, J = 10.0, 3.0 Hz, 1 H, 7′-H), 6.98 (dd, J = 8.1, 1.5 Hz, 1 H, 2′-H), 7.54 (t, J = 8.1 Hz, 2 H, 3′-H, 6′-H), 7.53 (dd, J = 8.1, 1.5 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 22.6 (d, C-8a), 29.6 (t, C-6), 37.8 (d, C-4a), 47.64 (d, C-8), 52.4 (d, C-7), 57.8 (q, OCH_3), 72.7 (s, C-5), 97.4 (s, C-1), 109.2 (d, C-7′), 109.8 (d, C-2′), 113.3 (s, C-8a′), 120.8 (d, C-5′), 121.0 (d, C-4′), 127.5 (d, C-6′), 127.5 (d C-3′), 131.6 (d, C-3), 134.2 (s, C-4a′), 141.8 (d, C-2), 146.7 (s, C-8′), 147.1 (s, C-1′), 197.3 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3467, 2906, 2852, 1656, 1409, 1370, 1274, 1087, 932, 730 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.10), 312 (3.23), 297 (3.32), 233 (3.92) nm. MS (EI, 70 eV): m/z (%) = 350 (100) [M$^+$], 332 (60), 77 (20), 27 (10). HRMS (EI, 70 eV): calcd. for $C_{21}H_{18}O_5$ 350.1154; found 350.11539.

Methoxy-epoxy Spiro Ketal 15: The Diels–Alder adduct **2** (20.0 mg, 0.06 mmol) in dry CH_2Cl_2 (10 mL) was treated *m*-CPBA (10.4 mg, 0.06 mmol) and stirred at room temp. for 2 d. Workup proceeded as described for **12** to afford epoxide **15** as a white solid (13.2 mg. 63%); m.p. 115–117 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.88 (ddd, J = 16.0, 11.4, 2.9 Hz, 1 H, 8-H), 2.41 (m, 1 H, 8-H), 2.62 (m, 1 H, 8a-H), 3.26 (m, 1 H, 4a-H), 3.33 (d, J = 4.9 Hz, 1 H, 5-H), 3.38 (d, J = 4.0 Hz, 1 H, 6-H), 3.54 (s, 3 H, OCH_3), 3.57 (m, 1 H, 7-H), 6.12 (d, J = 10.3 Hz, 1 H, 3-H), 6.79 (d, J = 10.3 Hz, 1 H, 2-H), 6.94 (d, J = 7.5 Hz, 2 H, 2′-H, 7′-H), 7.44 (t, J = 8.1 Hz,

2 H, 3′-H, 6′-H), 7.52 (dd, *J* = 8.1, 1.5 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 22.4 (t, C-8), 39.2 (d, C-8a), 45.8 (d, C-7), 52.7 (d, C-4a), 54.5 (d, C-6), 58.4 (q, OCH_3), 77.7 (d, C-5), 99.9 (s, C-1), 109.2 (d, C-7′), 109.6 (d, C-2′), 113.6 (s, C-8a′), 121.1 (d, C-5′), 121.3 (d, C-4′), 127.9 (d, C-3′, C-6′), 132.4 (d, C-3), 134.3 (s, C-4a′), 138.5 (d, C-2), 146.1 (s, C-8′), 146.9 (s, C-1′), 197.2 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3434, 1629, 1411, 1384, 1272, 1074, 1123, 821, 794 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 328 (3.10), 312 (3.22), 297 (3.32), 233 (3.92) nm. MS (EI, 70 eV): *m*/*z* (%) = 350 (48) [M$^+$], 322 (42), 256 (20), 162 (100), 134 (52), 84 (85), 43 (28). HRMS (EI, 70 eV): calcd. for $C_{21}H_{18}O_5$ 350.11542; found 350.11522.

Epoxy Spiro Ketal 18: A solution of the diene **11** (50.0 mg, 0.16 mmol) in dry CH_2Cl_2 (20 mL) was treated with *m*-CPBA (27.6 mg, 0.16 mmol) and stirred at room temp. for 4 h (TLC monitoring). Workup was performed as described for **12** to afford the epoxide **18** as a yellow solid (46.3 mg, 88%); m.p. 85–87 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.44 (ddd, *J* = 15.0, 11.3, 1.0 Hz, 1 H, 8-H), 2.81 (ddd, *J* = 15.0, 7.5, 2.5 Hz 1 H, 8-H), 3.50 (m, 1 H, 8a-H), 3.58 (t, *J* = 4.1 Hz, 1 H, 6-H), 3.79 (m, 1 H, 7-H), 6.18 (d, *J* = 10.5 Hz, 1 H, 3-H), 6.83 (dd, *J* = 7.5, 0.7 Hz, 1 H, 7′-H), 6.88 (d, *J* = 10.5 Hz, 1 H, 2-H), 7.03 (dd, *J* = 7.5, 0.7 Hz, 1 H, 2′-H), 7.42 (d, *J* = 10.0 Hz, 1 H, 5-H), 7.62 (t, *J* = 8.1 Hz, 2 H, 3′-H, 6′-H), 8.05 (dd, *J* = 8.1, 1.5 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 20.8 (t, C-8), 40.3 (d, C-8a), 46.2 (d, C-6), 55.7 (d, C-7), 96.9 (s, C-1), 109.3 (d, C-2′,C-7′), 113.5 (s, C-8a′), 120.9 (d, C-4′, C-5′), 127.4 (d, C-3′, C-6′), 132.1 (d, C-3), 133.7 (d, C-4a), 134.2 (s, C-4a′), 134.3 (d, C-5), 141.9 (d, C-2), 146.4 (s, C-1′, C-8′), 183.4 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3059, 2977, 1677, 1607, 1411, 1373, 1270, 894, 753, 715 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.06), 312 (3.18), 297 (3.28), 233 (3.88) nm. MS (EI, 70 eV): *m*/*z* (%) = 318 (40) [M$^+$], 223 (21), 197 (30), 149 (62), 139 (100), 113 (51), 57 (53), 43 (32). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O_4$ 318.0892; found 318.0891.

Methoxy-epoxy Spiro Ketal 14a: A solution of diene **2** (100 mg, 0.30 mmol) in dry CH_2Cl_2 (10 mL) was treated with *N*-benzylcinchonium chloride (10 mg, 0.025 mmol), H_2O (2 mL) und TBHP in CH_2Cl_2 (3.17 M; 1.40 mL, 4.5 mmol). An aqueous solution of NaOH (0.10 M, 1.50 mL, 50 mol-%) was then added, and the mixture was stirred under Ar at room temp. for 24 h (TLC monitoring). The reaction mixture was acidified by addition of HCl (1 M, 0.8 mL), water was added (10 mL), and the mixture was extracted twice with CH_2Cl_2 (20 mL). The organic phase was dried (Na_2SO_4), the solvent removed under reduced pressure, and the residue purified by column chromatography on silica gel to afford the epoxide **14a** as a yellow solid (97 mg, 96%); m.p. 188–190 °C. [*a*]$_D$ = –140.35 (*c* = 0.28, CH_2Cl_2) (48% *ee*); ref.[9] [*a*]$_D$ = –291.3 (*c* = 0.28, CH_2Cl_2). The spectroscopic data are identical with those in the literature.[8]

Epoxy-hydroxy Spiro Ketal 14b: A solution of **13b** (200 mg, 0.63 mmol) in dry CH_2Cl_2 (25 mL) was epoxidized as described for **14a** to afford **14b** as a yellow solid (207 mg, 0.62 mmol, 99%; m.p. 219–221 °C. [*a*]$_D$ = –340 (*c* = 1, $CHCl_3$), (99.7% *ee*); ref. [*a*]$_D$[9] –341 (*c* = 1, $CHCl_3$). The spectroscopic data are identical with those in the literature).[8]

Diepoxy Spiro Ketal 16: A solution of diene **2** (50.0 mg, 0.16 mmol) in dry CH_2Cl_2 (10 mL) was treated with *N*-benzylcinchonium chloride (10 mg, 0.025 mmol), H_2O (2 mL) und TBHP in CH_2Cl_2 (3.17 M; 0.30 mL, 0.96 mmol). An aqueous solution of NaOH (0.10 M, 1.50 mL, 50 mol-%) was then added, and the mixture was stirred for 12 h (TLC monitoring). Workup proceeded as described for **14a** to afford **16** (40.1 mg, 75%); m.p. 215–217 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.05 (ddd, *J* = 14.7, 11.9, 0.7 Hz, 1 H, 8-H), 2.70 (ddd, *J* = 14.7, 7.0, 3.2 Hz, 1 H, 8-H), 3.44 (d, *J* = 4.3 Hz, 1 H, 3-H), 3.45 (ddd, *J* = 15.6, 7.0, 2.7 Hz, 1 H, 8a-H), 3.51 (t, *J* = 4.1 Hz, 1 H, 6-H), 3.68 (m, 1 H, 7-H), 3.81 (d, *J* = 4.3 Hz, 1 H, 2-H), 6.86 (dd, *J* = 7.6, 0.8 Hz, 1 H, 7′-H), 7.07 (dd, *J* = 7.6, 0.8 Hz, 1 H, 2′-H), 7.27 (dd, *J* = 4.1, 3.3 Hz, 1 H, 5-H) 7.40 (t, *J* = 7.6, Hz, 1 H, 6′-H), 7.48 (t, *J* = 7.6, Hz, 1 H, 3′-H), 7.52 (dd, *J* = 8.4, 0.9 Hz, 1 H, 5′-H), 7.54 (dd, *J* = 8.4, 0.9 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 20.1 (t, C-8), 35.1 (d, C-8a), 45.8 (d, C-6), 53.6 (d, C-7), 55.4 (d, C-3) 55.6 (d, C-2) 99.5 (s, C-1), 109.1 (d, C-7′), 110.1 (d, C-2′), 112.6 (s, C-8a′), 121.1 (d, C-4′, C-5′), 127.5 (d, C-6′), 127.7 (d, C-3′), 133.8 (s, C-4a′), 134.9 (d, C-5), 146.4 (s, C-8′), 146.8 (s, C-1′), 190.7 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3446, 3033, 1701, 1629, 1607, 1413, 1380, 1270, 1145, 1121, 1083, 1051, 1023, 984, 971, 888, 819, 770, 758, 644, 625 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.08), 312 (3.20), 297 (3.30), 231 (3.90) nm. MS (EI, 70 eV): *m*/*z* (%) = 334 (100) [M$^+$], 305 (10), 171 (19), 167 (21), 160 (30), 149 (58), 115 (25), 71 (24), 57 (38). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O_5$ 334.08411; found 334.08418.

Triepoxy Spiro Ketal 17: A solution of the triene **11** (50.0 mg, 0.16 mmol) in dry CH_2Cl_2 (10 mL) was treated with *N*-benzylcinchonium chloride (10 mg, 0.025 mmol), H_2O (2 mL) and TBHP in CH_2Cl_2 (3.17 M; 0.75 mL, 2.4 mmol). NaOH (0.10 M, 1.50 mL, 50 mol-%) was added, and the mixture was stirred under Ar at room temp. for 2 d. Workup was performed as described for **14a** to afford the triepoxide **17** as a colorless solid (51.5 mg, 92%); m.p. 195–197 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.26 (ddd, *J* = 14.7, 11.8, 0.7 Hz, 1 H, 8-H), 2.45 (ddd, *J* = 14.7, 5.8, 3.8 Hz, 1 H, 8-H), 3.34 (m, 1 H, 7-H), 3.47 (dd, *J* = 3.8, 2.5 Hz, 1 H, 6-H), 3.48 (d, *J* = 4.0 Hz, 1 H, 2-H), 3.54 (dd, *J* = 11.8, 5.8 Hz, 1 H, 8a-H), 3.83 (d, *J* = 4.0 Hz, 1 H, 3-H), 3.92 (d, *J* = 2.5 Hz, 1 H, 5-H), 7.00 (dd, *J* = 7.0, 0.7 Hz, 1 H, 7′-H), 7.06 (d, *J* = 7.0, 0.7 Hz, 1 H, 2′-H), 7.43 (t, *J* = 8.2 Hz, 1 H, 6′-H), 7.47 (t, *J* = 8.2 Hz, 1 H, 3′-H) 7.53 (br. d, *J* = 8.2 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 19.2 (t, C-8), 33.0 (d, 8a-H), 49.8 (d, C-2), 52.7 (d, C-7), 54.8 (d, C-3), 54.9 (d, C-5), 55.6 (d, C-6), 57.3 (d, C-4a), 99.2 (s, C-1), 109.5 (d, C-7′), 109.9 (d, C-2′), 112.6 (s, C-8a′), 121.1 (d, C-5′), 121.2 (d, C-4′), 127.6 (d, C-6′), 127.7 (d, C-3′), 134.2 (s, C-4a′), 146.3 (s, C-8′), 146.6 (s, C-1′), 197.5 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3430, 1726, 1609, 1589, 1415, 1380, 1275, 1204, 1129, 1088, 1054, 1023, 987, 879, 819, 799, 762, 735, 625 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.10), 312 (3.22), 297 (3.32), 232 (3.92) nm. MS (EI, 70 eV): *m*/*z* (%) = 350 (100) [M$^+$], 251 (11), 211 (8), 160 (19), 115 (18), 77 (10). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O_6$ 350.07904; found 350.07908.

Epoxy Spiro Ketal 19: A Solution of triene **11** (50.0 mg, 0.16 mmol) was treated as described for **14a** and the mixture stirred for 6 h (TLC monitoring) to yield the monoepoxides **19** as a white solid (39.2 mg, 77%); m.p. 160–162 °C. From the less polar fraction 15% of diepoxide **20** (8.0 mg, 0.024 mmol) was obtained. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.49 (m, 1 H, 8-H), 2.61 (m, 1 H, 8-H), 3.36 (d, *J* = 4.3 Hz, 3-H), 3.71 (m, 1 H, 8a-H), 3.75 (d, *J* = 4.3 Hz, 2-H), 6.10 (m, 1 H, 7-H), 6.28 (m, 1 H, 6-H), 6.87 (dd, *J* = 7.5, 0.7 Hz, 7′-H), 6.97 (dd, *J* = 7.5, 0.7 Hz, 2′-H), 7.06 (m, 1 H, 5-H), 7.33–7.46 (m, 4 H, 3′-H, 4′-H, 5′-H, 6′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.8 (t, C-8), 37.9 (d, C-8a), 56.0 (d, C-3), 57.3 (d, C-2), 99.3 (s, C-1), 109.2 (d, C-7′), 109.8 (d, C-2′), 113.4 (s, C-8a′), 120.9 (d, C-5′), 121.0 (d, C-4′), 123.5 (d, C-6), 127.0 (d, C-4a), 127.5 (d, C-6′), 127.6 (d, C-3′), 133.2 (d, C-7), 134.2 (s, C-4a′), 135.8 (d, C-5), 146.7 (s, C-8′), 147.1 (s, C-1′), 191.9 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3436, 3069, 1684, 1609, 1554, 1412, 1379, 1272, 1212, 1132, 978, 869, 818, 756, 715, 627, 529 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.06), 312 (3.18), 298 (3.28), 233 (3.88) nm. MS

(EI, 70 eV): *m/z* (%) = 318 (79) [M$^+$], 300 (30), 184 (52), 149 (23), 131 (42), 86 (62), 84 (93), 49 (100). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O_6$ 350.07904; found 350.07908.

Diepoxy Spiro Ketal 20: A solution of the triene **11** (50.0 mg, 0.16 mmol) in dry CH_2Cl_2 (20 mL) was treated as described for **14a**. Stirring was continued for 24 h, and the diepoxide **20** was isolated as a colorless solid (38.5 mg, 72%); m.p. 206–208 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.34 (m, 1 H, 8-H), 2.74 (ddd, J = 18.7, 6.1, 1.1 Hz, 1 H, 8-H), 3.43 (br. d, J = 9.6 Hz, 1 H, 8a-H), 3.48 (d, J = 3.8 Hz, 1 H, 3-H), 3.56 (m, 1 H, 5-H), 3.79 (d, J = 3.8 Hz, 1 H, 2-H), 5.93–6.00 (m, 2 H, 6-H, 7-H), 6.85 (dd, J = 7.6, 0.6 Hz, 1 H, 7′-H), 7.09 (dd, J = 7.6, 0.9 Hz, 1 H, 2′-H), 7.41 (t, J = 7.6 Hz, 6′-H), 7.49 (t, J = 7.6 Hz, 3′-H), 7.51 (dd, J = 7.6, 0.9 Hz, 1 H, 5′-H), 7.53 (dd, J = 7.6, 0.9 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 22.9 (t, C-8), 33.1 (d, C-8a), 53.9 (d, C-2), 55.4 (d, C-3), 56.3 (d, C-5), 59.6 (s, C-4a), 100.8 (s, C-1), 109.1 (d, C-7′), 109.9 (d, C-2′), 112.5 (s, C-8a′), 120.3 (d, C-7), 121.1 (d, C-5′), 121.2 (d, C-4′), 127.4 (d, C-6′), 127.8 (d, C-3′), 133.2 (d, C-6), 134.2 (s, C-4a′), 146.3 (s, C-8′), 146.5 (s, C-1′), 198.4 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3057, 1725, 1607, 1412, 1380, 1271, 1126, 1043, 986, 881, 817, 754, 609 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 326 (3.08), 312 (3.20), 298 (3.30), 231 (3.90) nm. MS (EI, 70 eV): *m/z* (%) = 334 (30) [M$^+$], 197 (12), 111 (18), 97 (28), 86 (62), 84 (100), 49 (82). HRMS (EI, 70 eV): calcd. for $C_{20}H_{14}O_5$ 334.08411; found 334.08306.

General Procedure 1 for *cis*-Dihydroxylation:[10] A solution of the olefin in THF (10 mL) was treated with *N*-methylmorpholine *N*-oxide (24 mg, 0.18 mmol), H_2O (2 mL), THF (20 mL) and OsO_4 (0.016 mmol, 0.2 mL, 2.5 wt.-% solution in *t*BuOH). The mixture was stirred at room temp. for 6–48 h (TLC monitoring), diluted with CH_2Cl_2 (50 mL) and washed with aqueous $Na_2S_2O_3$ (2 × 50 mL, 10 g/100 mL), water (50 mL) and brine (50 mL). The organic phase was dried (Na_2SO_4), the solvent removed under reduced pressure, and the residue purified by column chromatography on silica gel.

Dihydroxy Spiro Ketal 21a: Ketal **1** (200 mg, 0.8 mmol) was treated according to General Procedure 1 to afford the faint yellow diol **21a** (147 mg, 65%); m.p. 73 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 4.67 (d, J = 2.7 Hz, 1 H, 5-H), 4.82 (d, J = 2.7 Hz, 1 H, 6-H), 6.26 (d, J = 10.3 Hz, 1 H, 3-H), 6.73 (dd, J = 10.3, 2.5 Hz, 1 H, 2-H), 6.92 (d, J = 7.5 Hz, 1 H, 7′-H), 7.04 (d, J = 7.5 Hz, 1 H, 2′-H), 7.41 (t, J = 7.9 Hz, 1 H, 6′-H), 7.46 (t, J = 7.9 Hz, 1 H, 3′-H), 7.53 (d, J = 8.5 Hz, 1 H, 5′-H), 7.54 (d, J = 8.5 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 73.6 (d, C-6), 74.5 (d, C-5), 97.8 (s, C-1), 109.3 (d, C-7′), 110.1 (d, C-2′), 113.4 (s, C-8a′), 121.4 (d, C-5′), 121.6 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 129.4 (d, C-3), 134.2 (C-4a′), 140.7 (d, C-2), 145.4 (s, C-8′), 146.4 (s, C-1′), 196.8 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3417, 1702, 1608, 1412, 1380, 1102, 1073, 1033, 985, 823, 757, 621, 493 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 326 (2.82), 311 (3.14), 296 (3.27), 234 (3.86) nm. MS (EI, 70 eV): *m/z* (%) = 284 (100) [M]$^+$, 237 (10), 224 (83), 196 (70), 160 (78), 114 (20), 83 (18), 57 (10). HRMS (EI, 70 eV): calcd. for $C_{16}H_{12}O_5$ 284.06848; found 284.06830.

Dihydroxy-methoxy Spiro Ketal 23a: Diene **2** (200 mg, 0.60 mmol) was treated according to General Procedure 1 to afford **23a** as a colorless solid (190 mg, 86%); m.p. 202–204 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.51 (ddd, $J_{8\text{-ax},8\text{-eq}}$ = 15.8, $J_{8\text{-ax},7\text{-ax}}$ = 10.0, $J_{8\text{-ax},8a\text{-eq}}$ = 2.7 Hz, 1 H, 8-H_{ax}), 2.44 (m, 1 H, 8-H_{eq}), 3.15 (ddd, $J_{8a\text{-eq},8\text{-eq}}$ = 13.1, $J_{8a\text{-eq},4a\text{-ax}}$ = 6.2, $J_{8a\text{-eq},8\text{-ax}}$ = 2.7 Hz, 1 H, 8a-H_{eq}), 3.54 (m, 1 H, 5-H), 3.55 (s, 3 H, OCH_3), 3.70 (m, 1 H, 4a-H_{ax}), 3.91 (br. d, $J_{6\text{-eq},7\text{-ax}}$ = 3.1 Hz, 1 H, 6-H_{eq}), 4.18, (dd, $J_{7\text{-ax},8\text{-ax}}$ = 10.0, $J_{7\text{-ax},6\text{-eq}}$ = 3.1 Hz, 1 H, 7-H_{ax}), 6.03 (d, J = 10.3 Hz, 3-H), 6.62 (dd, J = 10.3, 2.4 Hz, 1 H, 2-H), 6.97 (dd, J = 7.5, 1.0 Hz, 2 H, 2′-H, 7′-H), 7.45 (d, J = 7.5 Hz, 2 H, 4′-H, 5′-H), 7.53 (t, J = 7.5 Hz, 2 H, 3′-H, 6′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 28.5 (t, C-8), 40.7 (d, C-8a), 44.0 (d, C-4a), 57.7 (q, OCH_3), 67.6 (d, C-7), 70.6 (d, C-6), 79.9 (d, C-5), 98.8 (s, C-1), 109.2 (d, C-7′), 109.9 (d, C-2′), 113.5 (s, C-8a′), 121.0 (d, C-5′), 121.2 (d, C-4′), 127.4 (d, C-6′), 127.6 (d, C-3′), 132.1 (d, C-3), 134.3 (s, C-4a′), 139.4 (d, C-2), 146.1 (s, C-8′), 147.0 (s, C-1′), 197.5 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3454, 1682, 1607, 1412, 1270, 1123, 1105, 1069, 973, 840, 818, 754, 677 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 327 (3.01), 312 (3.24), 298 (3.32), 233 (3.93) nm. MS (EI, 70 eV): *m/z* (%) = 368 (95) [M]$^+$, 336 (67), 318 (100), 294 (80), 266 (29), 160 (58), 159 (38), 131 (27), 84 (40), 57 (38). HRMS (EI, 70 eV): calcd. for $C_{21}H_{20}O_6$ 368.12598; found 368.12589.

Dihydroxy-methoxy Spiro Ketal 24a: Diene **10** (200 mg, 0.60 mmol) was treated according to General Procedure 1 to afford the diol **24a** as a white solid (194 mg, 88%); m.p. 221–223 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.91 (ddd, $J_{6\text{-ax},6\text{-eq}}$ = 14.2, $J_{6\text{-ax},5\text{-ax}}$ = 12.0, $J_{6\text{-ax},7\text{-eq}}$ = 3.9 Hz, 1 H, 6-H_{ax}), 2.27 (ddd, $J_{6\text{-eq},6\text{-ax}}$ = 14.2, $J_{6\text{-eq},7\text{-eq}}$ = 7.8, $J_{6\text{-eq},5\text{-ax}}$ = 3.8 Hz, 1 H, 6-H_{eq}), 2.95 (ddd, $J_{5\text{-ax},6\text{-ax}}$ = 12.0, $J_{5\text{-ax},4a\text{-eq}}$ = 8.1, $J_{5\text{-ax},6\text{-eq}}$ = 3.8 Hz, 1 H, 5-H_{ax}), 2.96 (m, 1 H, 4a-H_{eq}), 3.58 (dd, $J_{8\text{-ax},8a\text{-ax}}$ = 9.1, $J_{8\text{-ax},7\text{-eq}}$ = 2.8 Hz, 1 H, 8-H_{ax}), 3.70 (m, 1 H, 8a-H_{ax}), 3.73 (s, 1 H, OCH_3), 4.10 (m, 1 H, 7-H_{eq}), 5.90 (d, J = 10.3 Hz, 1 H, 3-H), 6.63 (d, J = 10.3 Hz, 1 H, 2-H), 6.83 (d, J = 8.2 Hz, 1 H, 7′-H), 6.87 (d, J = 8.2 Hz, 1 H, 2′-H), 7.34 (d, J = 8.2 Hz, 2 H, 3′-H, 6′-H), 7.43 (d, J = 8.2 Hz, 2 H, 4′-H, 5′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 28.2 (t, C-6), 41.5 (d, C-5), 50.0 (d, C-4a), 60.6 (q, OCH_3), 69.0 (d, C-7), 76.5 (d, C-8), 78.4 (d, C-8a), 97.8 (s, C-1), 109.1 (d, C-7′), 109.8 (d, C-2′), 113.2 (d, C-8a′), 120.8 (d, C-5′), 120.9 (d, C-4′), 127.4 (d, C-6′), 127.5 (d, C-3′), 130.9 (d, C-3), 134.2 (d, C-4a′), 140.8 (d, C-2), 146.7 (s, C-8′), 147.1 (s, C-1′), 198.3 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3411, 2934, 1678, 1605, 1413, 1381, 1276, 1265, 1133, 1092, 1080, 1067, 954, 820, 758, 626 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 327 (2.92), 313 (3.13), 298 (3.19), 228 (3.80) nm. MS (EI, 70 eV): *m/z* (%) = 368 (95) [M]$^+$, 336 (10), 318 (18), 294 (100), 266 (22), 160 (38), 155 (23), 131 (18), 57 (11). HRMS (EI, 70 eV): calcd. for $C_{21}H_{20}O_6$ 368.12598; found 368.12585.

Dihydroxy Spiro Ketal 25a: Triene **11** (200 mg, 0.66 mmol) was treated according to General Procedure 1 to afford diol **25a** as a yellow solid (166 mg, 75%); m.p. 193–195 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.25 (ddd, $J_{8\text{-ax},8\text{-eq}}$ = 14.3, $J_{8\text{-ax},7\text{-ax}}$ = 10.5, $J_{8\text{-ax},8a\text{-eq}}$ = 1.7 Hz, 1 H, 8-H_{ax}), 2.53 (ddd, $J_{8\text{-eq},8\text{-ax}}$ = 14.3, $J_{8\text{-eq},8a\text{-eq}}$ = 10.0, $J_{8\text{-eq},7\text{-ax}}$ = 5.0 Hz, 1 H, 8-H_{eq}), 3.64 (m, 1 H, 8a-H_{eq}), 4.35 (m, 1 H, 7-H_{ax}), 4.53 (m, 1 H, 6-H), 6.17 (d, J = 10.4 Hz, 1 H, 3-H), 6.81 (dd, J = 7.5, 1.0 Hz, 1 H, 7′-H), 6.88 (d, J = 10.4 Hz, 1 H, 2-H), 6.94 (m, 1 H, 5-H), 7.00 (dd, J = 7.5, 1.0 Hz, 1 H, 2′-H), 7.38 (t, J = 7.5 Hz, 1 H, 6′-H), 7.46 (t, J = 7.5 Hz, 1 H, 3′-H), 7.47 (d, J = 7.5 Hz, 1 H, 5′-H), 7.53 (dd, J = 7.5, 1.0 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 26.8 (t, C-8), 39.7 (d, C-8a), 66.6 (d, C-7), 68.2 (d, C-6), 97.5 (s, C-1), 109.2 (d, C-7′), 110.0 (d, C-2′), 113.6 (s, C-8a′), 120.9 (d, C-5′), 121.1 (d, C-4′), 127.4 (d, C-6′), 127.5 (d, C-3′), 132.0 (d, C-3), 132.2 (s, C-4a), 134.2 (s, C-4a′), 137.2 (d, C-5), 144.0 (s, C-2), 146.7 (s, C-8′), 147.2 (s, C-1′), 190.0 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3459, 1670, 1608, 1413, 1381, 1274, 1245, 1135, 1080, 1063, 987, 833, 820, 756, 734, 642 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lg ε) = 327 (3.11), 312 (3.21), 297 (3.28), 232 (3.89) nm. MS (EI, 70 eV): *m/z* (%) = 336 (98) [M]$^+$, 318 (100), 289 (19), 273 (10), 197 (22), 160 (72), 131 (77), 115 (43), 114 (33), 77 (22) 57 (20). HRMS (EI, 70 eV): calcd. for $C_{20}H_{16}O_5$ 336.09976; found 336.09979.

Dihydroxy-methoxy Spiro Ketal 26a: Enone **20** (200 mg, 0.6 mmol) was treated according to General Procedure 1 to yield the diol **26a** a colorless solid (197 mg, 90%); m.p. 240–242 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 4.00 (s, 3 H, OCH_3), 4.63 (m. 1 H, 3-H), 4.83 (m, 1 H, 2-H), 6.91 (d, J = 7.2 Hz, 1 H, 7′-H), 7.11 (d, J = 7.2 Hz, 1 H, 2′-H), 7.17 (d, J = 8.1 Hz, 1 H, 6-H), 7.43 (t, J = 8.3 Hz, 1 H, 6′-H), 7.49 (t, J = 8.3 Hz, 1 H, 3′-H), 7.55 (d, J = 8.3 Hz, 1 H, 5′-H), 7.57 (d, J = 8.3 Hz, 1 H, 4′-H), 7.64 (dd, J = 8.1, 0.8 Hz, 1 H, 8-H), 7.74 (t, J = 8.1 Hz, 1 H, 7-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 56.4 (q, OCH_3), 71.5 (d, C-3), 74.0 (d, C-2), 109.1 (s, C-1), 109.1, 109.9 (d, C-7′, C-1′), 113.2 (s, C-8a′), 113.9 (d, C-6), 118.7 (s, C-4a), 120.4 (d, C-8), 121.2, 121.4 (d, C-4′, C-5′), 127.5, 127.7 (d, C-3′, C-6′), 134.2 (s, C-4a′), 136.3 (d, C-7), 140.2 (s, C-8a), 146.4, 147.4 (s, C-1′, C-8′), 159.3 (d, C-5), 194.5 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3421, 1702, 1610, 1414, 1380, 1278, 1091, 1055, 968, 822, 792, 759 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (2.94), 312 (3.08), 298 (3.34), 229 (3.92) nm. MS (EI, 70 eV): m/z (%) = 364 (100) [M]$^+$, 346 (23), 318 (19), 275 (70), 246 (19), 205 (22), 160 (60), 149 (38), 109 (32), 57 (22) 28 (41). HRMS (EI, 70 eV): calcd. for $C_{21}H_{16}O_6$ 364.09470; found 364.09433.

General Procedure 2 for Acetylation: A solution of the diol in pyridine (5 mL) was treated with acetic anhydride (0.1 mL) and DMAP (2 mg). The mixture was stirred at room temp. for 6–12 h (TLC monitoring). The solution was acidified by addition of 2 N HCl (20 mL) and extracted with diethyl ether (3 × 20 mL). The organic phase was dried (Na_2SO_4), the solvent removed under reduced pressure, and the residue purified by column chromatography on silica gel.

Acetoxy Spiro Ketal 22b: The diol **21a** (100 mg, 0.35 mmol) was treated as described in General Procedure 2 to afford the monoacetate **22b** as a yellow oil (65 mg, 60%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.25 (s, 3 H, CH_3CO_2), 6.34 (d, J = 10.3 Hz, 1 H, 3-H), 6.64 (d, J = 3.1 Hz, 1 H, 6-H), 6.96 (dd, J = 10.3, 3.1 Hz, 1 H, 2-H), 6.98 (dd, J = 8.3, 3.1 Hz, 2 H, 7′-H, 2′-H), 7.45 (t, J = 8.3 Hz, 2 H, 6′-H, 3′-H), 7.55 (d, J = 8.3 Hz, 2 H, 5′-H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 20.3 (q, CH_3CO_2), 93.8 (s C-1), 109.9 (d, C-7′, C-2′), 113.2 (s, C-8a′), 121.4 (d, C-5′,C-4′), 126.6 (d, C-6), 127.6 (d, C-6′, C-3′), 128.6 (d, C-3), 134.2 (s, C-4a′), 140.6 (d, C-2), 146.2 (s, C-5), 146.3 (s, C-8′, C-1′), 168.0 (s, CH_3CO_2), 177 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2923, 1774, 1696, 1670, 1608, 1585, 1412, 1378, 1269, 1197, 1070, 1013, 951, 823, 758 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (3.04), 312 (3.17), 296 (3.27), 232 (3.87) nm. MS (EI, 70 eV): m/z (%) = 308 (37) [M$^+$], 266 (100), 250 (75), 210 (19), 168 (23), 149 (48), 114 (41), 83 (22), 57 (35). HRMS (EI, 70 eV): calcd. for $C_{18}H_{12}O_5$ 308.06848; found 308.06816.

Diacetoxy-methoxy Spiro Ketal 23b: A solution of the diol **23a** (100 mg, 0.272 mmol) was treated according to the General Procedure 2 to yield the diacetate **23b** as a white solid (118 mg, 96%); m.p. 178–180 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.11 (s, 3 H, CH_3CO_2), 2.15 (s, 3 H, CH_3CO_2), 2.19 (ddd, $J_{8\text{-ax},8\text{-eq}}$ = 14.8, $J_{8\text{-ax},7\text{-ax}}$ = 12.4, $J_{8\text{-ax},8a\text{-eq}}$ = 2.4 Hz, 1 H, 8-H$_{ax}$), 2.32 (ddd, $J_{8\text{-eq},8\text{-ax}}$ = 14.8, $J_{8\text{-eq},8a\text{-eq}}$ = 8.4, $J_{8\text{-eq},7\text{-ax}}$ = 4.2 Hz, 1 H, 8-H$_{eq}$), 2.83 (ddd, $J_{8a\text{-eq},8\text{-eq}}$ = 8.4, $J_{8a\text{-eq},4a\text{-ax}}$ = 4.3, $J_{8a\text{-eq},8\text{-ax}}$ = 2.4 Hz, 1 H, 8a-H$_{eq}$), 3.22 (dd, $J_{4a\text{-ax},5\text{-eq}}$ = 9.8, $J_{4a\text{-ax},8a\text{-eq}}$ = 4.3 Hz, 1 H, 4a-H$_{ax}$), 3.69 (s, 3 H, OCH_3), 3.90 (t, J = 9.8 Hz, 1 H, 5-H$_{eq}$), 4.98 (dd, $J_{6\text{-eq},5\text{-eq}}$ = 9.7, $J_{6\text{-eq},7\text{-ax}}$ = 2.8 Hz, 1 H, 6-H$_{eq}$), 5.52 (m, 1 H, 7-H$_{ax}$), 6.01 (d, J = 10.3 Hz, 1 H, 3-H), 6.70 (d, J = 10.3 Hz, 1 H, 2-H), 6.91 (d, J = 7.5 Hz, 1 H, 7′-H), 6.95 (d, J = 7.5 Hz, 1 H, 2′-H), 7.42 (t, J = 7.5 Hz, 1 H, 6′-H), 7.44 (t, J = 7.5 Hz, 1 H, 3′-H), 7.51 (d, J = 7.5 Hz, 2 H, 5′-H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.0 (q, CH_3CO_2), 21.1 (q, CH_3CO_2), 26.4 (t, C-8), 42.3 (d, C-8a), 50.5 (d, C-4a), 60.6 (q, OCH_3), 68.8 (d, C-7), 75.2 (d, C-5), 76.6 (d, C-6), 97.5 (q, C-1), 109.3 (d, C-7′), 109.9 (d, C-2′), 113.2 (s, C-8a′), 121.0 (d, C-5′), 121.2 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 130.9 (d, C-3), 134.2 (s, C-4a′), 140.6 (d, C-2), 146.5 (s, C-8′), 146.9 (s, C-1′), 169.9 (s, CO), 170.3 (s, CO), 197.3 (q, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2924, 1746, 1699, 1606, 1608, 1587, 1413, 1379, 1241, 1093, 1070, 1033, 954, 819, 763, 622 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.21), 312 (3.34), 298 (3.43), 233 (4.03) nm. MS (EI, 70 eV): m/z (%) = 452 (75) [M]$^+$, 414 (12), 400 (14), 360 (26), 318 (54), 279 (20), 231 (18), 191 (31), 167 (38), 149 (79), 97 (88) 57 (100). HRMS (EI, 70 eV): calcd. for $C_{25}H_{24}O_8$ 452.14713; found 452.14756.

Diacetoxy-methoxy Spiro Ketal 24b: A solution of diol **24a** (100 mg, 0.271 mmol) was acetylated according to General Procedure 2 to afford **24b** as a white solid (191 mg; 97%); m.p. 197–199 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.10 (s, 3 H, CH_3CO_2), 2.15 (s, 3 H, CH_3CO_2), 2.19 (ddd, $J_{6\text{-ax},6\text{-eq}}$ = 14.7, $J_{6\text{-ax},5\text{-ax}}$ = 12.4, $J_{6\text{-ax},7\text{-eq}}$ = 2.2 Hz, 1 H, 6-H$_{ax}$), 2.32 (ddd, $J_{6\text{-eq},6\text{-ax}}$ = 14.7, $J_{6\text{-eq},7\text{-eq}}$ = 8.5, $J_{6\text{-eq},5\text{-ax}}$ = 4.2 Hz, 1 H, 6-H$_{eq}$), 2.83 (ddd, $J_{5\text{-ax},6\text{-ax}}$ = 12.4, $J_{5\text{-ax},4a\text{-eq}}$ = 8.4, $J_{5\text{-ax},6\text{-eq}}$ = 4.2 Hz, 1 H, 5-H$_{ax}$), 3.22 (dd, $J_{4a\text{-eq},8a\text{-ax}}$ = 13.3, $J_{4a\text{-eq},5\text{-ax}}$ = 8.4 Hz, 1 H, 4a-H$_{eq}$), 3.69 (s, 3 H, OCH_3), 3.90 (t, J = 9.7 Hz, 1 H, 8a-H$_{ax}$), 4.98 (dd, $J_{8\text{-ax},8a\text{-ax}}$ = 9.7, $J_{8\text{-ax},7\text{-eq}}$ = 2.8 Hz, 1 H, 8-H$_{ax}$), 5.52 (m, 1 H, 7-H$_{eq}$), 6.01 (d, J = 10.3 Hz, 1 H, 3-H), 6.70 (d, J = 10.3 Hz, 1 H, 2-H), 6.91 (d, J = 7.5 Hz, 1 H, 7′-H), 6.95 (d, J = 7.5, Hz, 1 H, 2′-H), 7.42 (t, J = 7.5 Hz, 1 H, 6′-H), 7.44 (t, J = 7.5 Hz, 1 H, 3′-H), 7.51 (d, J = 7.5 Hz, 2 H, 5′-H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.0 (q, CH_3CO_2), 21.1 (q, CH_3CO_2), 26.4 (t, C-6), 42.3 (d, C-5), 50.5 (d, C-4a), 60.6 (q, OCH_3), 68.8 (d, C-7), 75.2 (d, C-8a), 76.6 (d, C-8), 97.5 (s, C-1), 109.3 (d, C-7′), 109.9 (d, C-2′), 113.3 (s, C-4a′), 121.0 (d, C-5′), 121.2 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 130.9 (d, C-3), 134.2 (s, C-8a′), 140.6 (d, C-2), 146.5 (s, C-8′), 146.9 (s, C-1′), 170.0 (s, CO), 170.3 (s, CO), 197.3 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2942, 1743, 1697 1607, 1586, 1413, 1380, 1242, 1209, 1138, 1092, 1056, 955, 819, 763 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.21), 312 (3.33), 298 (3.43), 233 (4.03) nm. MS (EI, 70 eV): m/z (%) = 452 (100) [M$^+$], 448 (7), 360 (29), 318 (78), 263 (10), 240 (9), 197 (19), 160 (51), 131 (13), 91 (8), 43 (38). HRMS (EI, 70 eV): calcd. for $C_{25}H_{20}O_8$ 452.14713; found 452.14702.

Diacetoxy Spiro Ketal 25b: A solution of **25a** (100 mg, 0.297 mmol) was acetylated according to General Procedure 2 to afford **25b** as a yellow solid (120 mg, 95%); m.p. 158–160 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 2.10 (s, 3 H, CH_3CO_2), 2.11 (s, 3 H, CH_3CO_2), 2.41 (ddd, $J_{8ax,8eq}$ = 14.6, $J_{8\text{-ax},7\text{-ax}}$ = 10.4, $J_{8\text{-ax},8a\text{-eq}}$ = 1.9 Hz, 1 H, 8-H$_{ax}$), 2.50 (ddd, $J_{8\text{-eq},8\text{-ax}}$ = 14.6, $J_{8\text{-eq},8a\text{-ax}}$ = 9.3, $J_{8\text{-eq},7\text{-ax}}$ = 5.3 Hz, 1 H, 8-H$_{eq}$), 3.58 (m, 1 H, 8a-H$_{ax}$), 5.65 (m, 1 H, 7-H), 5.75 (m, 1 H, 6-H), 6.19 (d, J = 10.4 Hz, 1 H, 3-H), 6.84 (d, J = 8.2 Hz, 1 H, 7′-H), 6.87 (m, 1 H, 5-H), 6.90 (d, J = 10.4 Hz, 1 H, 2-H), 7.00 (d, J = 8.2 Hz, 1 H, 2′-H), 7.40 (t, J = 8.2 Hz, 1 H, 6′-H), 7.46 (t, J = 8.2 Hz, 1 H, 3′-H), 7.49 (d, J = 8.2 Hz, 1 H, 5′-H), 7.53 (d, J = 8.2 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 20.7 (q, CH_3CO_2), 21.0 (q, CH_3CO_2), 24.8 (t, C-8), 40.7 (d, C-8a), 66.4 (d, C-7), 68.4 (d, C-6), 97.2 (s, C-1), 109.4 (d, C-7′), 110.0 (d, C-2′), 113.5 (s, C-8a′), 121.0 (d, C-5′), 121.3 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 131.8 (d, C-3), 133.2 (s, C-4a), 134.1 (d, C-5), 134.2 (s, C-4a′), 144.2 (d, C-2), 146.5 (s, C-8′), 147.0 (s, C-1′), 170.1 (s, CO), 170.3 (s, CO), 184.5 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2929, 1750, 1688, 1641, 1610, 1424, 1382, 1238, 1201, 1124, 1098, 1056, 928, 829, 767, 627 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (3.18), 312 (3.30), 296 (3.40), 232 (4.00) nm. MS (EI, 70 eV): m/z (%) = 420 (81) [M]$^+$, 360 (36), 318 (98), 266 (40), 197 (22), 160 (100), 149 (59), 97 (68), 57 (82). HRMS (EI, 70 eV): calcd. for $C_{24}H_{20}O_7$ 420.12091; found 420.12127.

Diacetoxy-methoxy Spiro Ketal 26b: A solution of the diol **26a** (derived from palmarumycin CP_2 methyl ether **20**) (100 mg, 0.275 mmol) was treated as according to General Procedure 2 to yield a white solid of **26b** (120 mg, 98%); m.p. 85–87 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.97 (s, 3 H, CH_3CO_2), 2.09 (s, 3 H, CH_3CO_2), 3.99 (s, 3 H, OCH_3), 5.92 (d, J = 2.6 Hz, 1 H, 3-H), 6.07 (d, J = 2.6 Hz, 1 H, 2-H), 6.92 (d, J = 7.6 Hz, 1 H, 7′-H), 6.98 (d, J = 7.6 Hz, 1 H, 2′-H), 7.18 (d, J = 8.1 Hz, 1 H, 6-H), 7.44 (t, J = 7.6 Hz, 1 H, 6′-H), 7.46 (t, J = 7.6 Hz, 1 H, 3′-H), 7.57 (d, J = 7.6 Hz, 2 H, 5′-H, 4′-H), 7.59 (dd, J = 8.1, 0.8 Hz, 1 H, 8-H), 7.73 (t, J = 8.1 Hz, 1 H, 7-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 20.4 (q, CH_3CO_2), 20.4 (q, CH_3CO_2), 56.3 (q, OCH_3), 69.7 (d, C-3), 73.5 (d, C-2), 97.9 (s, C-1), 109.3 (d, C-7′),109.6 (d, C-2′), 112.9 (s, C-8a′), 114.2 (d, C-6), 119.3 (s, C-4a), 119.7 (d, C-8), 121.5 (d, C-5′), 121.7 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 134.2 (s, C-4a′), 135.8 (d, C-7), 139.8 (s, C-8a), 146.4 (s, C-8′), 146.8 (s, C-1′), 159.7 (s, C-5), 169.0 (s, CO), 169.6 (s, CO), 186.8 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2925, 1756, 1715, 1610, 1594, 1412, 1378, 1270, 1209, 1082, 1055, 1030, 950, 817, 758, 730 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (3.23), 312 (3.31), 298 (3.41), 230 (4.01) nm. MS (EI, 70 eV): m/z (%) = 448 (98) [M]$^+$, 406 (8), 364 (20), 322 (10), 275 (17), 247 (11), 205 (48) 160 (39), 131 (70), 97 (62), 57 (100). HRMS (EI, 70 eV): calcd. for $C_{25}H_{20}O_8$ 448.11581; found 448.11571.

General Procedure 3 for the Acetonide Formation: Perchloric acid (60%, 0.01 mL) was added under cooling with ice to a suspension of the diol in acetone (10 mL) und 2,2-dimethoxypropane (0.14 mmol). The mixture was stirred at 0 °C under Ar for 6–12 h. The solution was then neutralized by addition of concd. aqueous NH_4OH (1 mL). After stirring for 30 min, the organic phase was dried (Na_2SO_4), the solvent removed under reduced pressure, and the residue purified by column chromatography on silica gel.

(Dimethylmethylenedioxy) Spiro Ketal 21c: Diol **21a** (100 mg, 0.35 mmol) was treated as described in General Procedure 3 to yield a white oil of **21c** (74 mg, 66%). ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.44 (s, 3 H, CCH_3), 1.46 (s, 3 H, CCH_3), 4.65 (d, J = 5.2 Hz, 1 H, 5-H), 4.89 (dd, J = 5.2, 2.3 Hz, 1 H, 6-H), 6.22 (d, J = 10.4 Hz, 1 H, 3-H), 6.84 (dd, J = 10.4, 2.3 Hz, 1 H, 2-H), 6.88 (d, J = 7.5 Hz, 1 H, 7′-H), 7.15 (d, J = 7.5 Hz, 1 H, 2′-H), 7.42 (t, J = 7.5 Hz, 1 H, 6′-H), 7.48 (t, J = 7.5 Hz, 1 H, 3′-H), 7.53 (d, J = 7.5 Hz, 1 H, 5′-H), 7.55 (d, J = 7.5 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 26.1 (q, CCH_3), 27.5 (q, CCH_3), 75.2 (d, C-5), 77.0 (d, C-6), 96.3 (s, C-1), 109.3 (d, C-7′), 110.5 (d, C-2′), 112.4 (s, C_{acetal}), 113.6 (s, C-8a′), 121.4 (d, C-5′), 121.5 (d, C-4′), 127.4 (d, C-6′), 127.7 (d, C-3′), 131.0 (d, C-3), 134.2 (s, C-4a′), 142.7 (d, C-2), 145.7 (s, C-8′), 146.2 (s, C-1′), 194.3 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2924, 1703, 1610, 1585, 1418, 1393, 1284, 1227, 1087, 1062, 1010, 824, 762 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.07), 312 (3.19), 296 (3.29), 233 (3.89) nm. MS (EI, 70 eV): m/z (%) = 324 (13) [M]$^+$, 196 (11), 155 (7), 141 (9), 84 (100), 47 (35), 35 (12). HRMS (EI, 70 eV): calcd. for $C_{19}H_{16}O_5$ 324.09976; found 324.09976.

(Dimethylmethylenedioxy)-methoxy Spiro Ketal 24c: A solution of diene **24a** in acetone (100 mg, 0.272 mmol) was treated according to General Procedure 3 to afford a white solid of **24c** (109 mg, 98%); m.p. 168–170 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.40 (s, 3 H, CCH_3), 1.53 (s, 3 H, CCH_3), 2.08 (ddd, $J_{6\text{-ax},6\text{-eq}}$ = 15.8, $J_{6\text{-ax},5\text{-ax}}$ = 12.3, $J_{6\text{-ax},7\text{-eq}}$ = 3.5 Hz, 1 H, 6-H_{ax}), 2.38 (ddd, $J_{6\text{-eq},6\text{-ax}}$ = 14.5, $J_{6\text{-eq},7\text{-eq}}$ = 5.0, $J_{6\text{-eq},5\text{-ax}}$ = 2.6 Hz, 1 H, 6-H_{eq}), 2.86 (ddd, $J_{5\text{-ax},6\text{-ax}}$ = 12.3, $J_{5\text{-ax},4a\text{-eq}}$ = 6.1, $J_{5\text{-ax},6\text{-eq}}$ = 2.6 Hz, 1 H, 5-H_{ax}), 3.05 (dd, $J_{4a\text{-eq},5\text{-ax}}$ = 6.1, $J_{4a\text{-eq},8a\text{-ax}}$ = 4.1 Hz, 1 H, 4a-H_{eq}), 3.59 (s, 3 H, OCH_3), 4.09 (dd, $J_{8a\text{-ax},8\text{-ax}}$ = 6.1, $J_{8a\text{-ax},4a\text{-eq}}$ = 4.1 Hz, 1 H, 8a-H_{ax}), 4.35 (dd, $J_{8\text{-ax},8a\text{-ax}}$ = 6.1, $J_{8\text{-ax},7\text{-eq}}$ = 4.1 Hz, 1 H, 8-H_{ax}), 4.51 (m, 1 H, 7-H_{eq}), 6.00 (d, J = 10.3 Hz, 1 H, 3-H), 6.73 (d, J = 10.3 Hz, 1 H, 2-H), 6.90 (dd, J = 7.5, 1.0 Hz, 1 H, 7′-H), 6.97 (dd, J = 7.5, 1.0 Hz, 1 H, 2′-H), 7.41 (t, J = 7.5 Hz, 6′-H), 7.45 (t, J = 7.5 Hz, 3′-H), 7.48 (d, J = 7.5 Hz, 5′-H), 7.51 (d, J = 7.5 Hz, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 25.2 (q, CCH_3), 25.5 (t, C-6), 27.3 (q, CCH_3), 39.6 (d, C-5), 49.5 (d, C-4a), 58.1 (q, OCH_3), 72.5 (d, C-7), 76.2 (d, C-8a), 77.5 (d, C-8), 97.9 (s, C-1), 108.6 (s, C_{acetal}), 109.1 (d, C-7′), 110.0 (d, C-2′), 113.4, (s, C-8a′), 120.8 (d, C-5′), 120.9 (d, C-4′), 127.4 (d, C-6′), 127.6 (d, C-3′), 130.8 (d, C-3), 134.2 (s, 4a′), 141.2 (d, C-2), 146.8 (s, C-8′), 147.2 (s, C-1′), 197 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2991, 2934, 2893, 1703, 1615, 1413, 1393, 1279, 1227, 1155, 1098, 1041, 948, 824, 767 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 327 (3.17), 312 (3.29), 298 (3.39), 234 (3.99) nm. MS (EI, 70 eV): m/z (%) = 408 (4) [M]$^+$, 371 (30), 279 (8), 188 (44), 167 (22), 149 (60), 126 (21), 97 (20), 84 (100), 73 (61), 57 (52). HRMS (EI, 70 eV): calcd. for $C_{24}H_{24}O_6$ 408.15729; found 408.15678.

(Dimethylmethylenedioxy) Spiro Ketal 25c: A solution **25a** (100 mg, 0.297 mmol) was treated according to General Procedure 3 to yield **25c** as a white solid (108 mg, 97%); m.p. 194–196 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.28 (s, 3 H, CCH_3), 1.35 (s, 3 H, CCH_3), 2.24 (ddd, $J_{8\text{-ax},8\text{-eq}}$ = 14.3, $J_{8\text{-ax},7\text{-ax}}$ = 11.3, $J_{8\text{-ax},8a\text{-eq}}$ = 2.2 Hz, 1 H, 8-H_{ax}), 2.59 (ddd, $J_{8\text{-eq},8\text{-ax}}$ = 14.3, $J_{8\text{-eq},8a\text{-eq}}$ = 8.5, $J_{8\text{-eq},7\text{-ax}}$ = 4.5 Hz, 1 H, 8-H_{eq}), 3.49 (m, 1 H, 8a-H_{eq}), 4.51 (m, 1 H, 7-H), 4.69 (m, 1 H, 6-H), 6.10 (d, J = 10.4 Hz, 3-H), 6.73 (dd, J = 7.5, 0.8 Hz, 1 H, 7′-H), 6.81 (d, J = 10.4 Hz, 1 H, 2-H), 6.91 (m, 1 H, 5-H), 6.92 (d, J = 7.5 Hz, 1 H, 2′-H), 7.31 (t, J = 7.5 Hz, 1 H, 6′-H), 7.38 (t, J = 7.5 Hz, 3′-H), 7.41 (d, J = 7.5 Hz, 5′-H), 7.45 (d, J = 7.5 Hz, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 23.7 (t, C-8), 26.5 (q, CCH_3), 28.1 (q, CCH_3), 38.8 (d, C-8a), 71.7 (d, C-7), 71.8 (d, C-8), 97.2 (s, C-1), 109.2 (d, C-2′), 109.3 (d, C-7′), 110.1 [s, $C(CH_3)$], 113.6 (s, C-8a′), 120.9 (d, C-5′), 121.1 (d, C-4′), 127.5 (d, C-6′), 127.6 (d, C-3′), 131.2 (s, C-4a), 132.2 (d, C-3), 134.2 (s, C-4a′), 135.4 (d, C-5), 143.8 (d, C-2), 146.7 (s, C-8′), 146.9 (s, C-1′), 184.8 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2930, 1681, 1633, 1608, 1587, 1411, 1380, 1275, 1098, 1064, 1032, 825, 754 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (3.13), 312 (3.25), 296 (3.35), 237 (3.95) nm. MS (EI, 70 eV): m/z (%) = 376 (92) [M$^+$], 361 (12), 318 (100), 300 (69), 273 (30), 197 (85), 131 (79), 103 (21), 43 (34). HRMS (EI, 70 eV): calcd. for $C_{23}H_{20}O_5$ 376.13107; found 376.13121.

(Dimethylmethylenedioxy)-methoxy Spiro Ketal 26c: A solution of diol **26a** (100 mg, 0.275 mmol) was treated according to General Procedure 3 to yield a white solid of **26c** (109 mg, 98%); m.p. 200–202 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.20 (s, 3 H, CCH_3), 1.36 (s, 3 H, CCH_3), 3.86 (q, 3 H, OCH_3), 4.80 (d, J = 7.5 Hz, 1 H, 3-H), 5.07 (d, J = 7.5 Hz, 1 H, 2-H), 6.80 (dd, J = 7.5, 0.7 Hz, 1 H, 7′-H), 6.93 (d, J = 8.2 Hz, 1 H, 6-H), 7.13 (dd, J = 7.0, 1.4 Hz, 1 H, 2′-H), 7.14 (dd, J = 7.8, 0.7 Hz, 1 H, 8-H), 7.31 (d, J = 8.2 Hz, 1 H, 7-H), 7.34 (t, J = 8.2 Hz, 1 H, 6′-H), 7.44 (d, J = 8.2 Hz, 1 H, 5′-H), 7.45 (d, J = 8.2 Hz, 1 H, 4′H) 7.47 (t, J = 8.2 Hz, 1 H, 3′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 25.4 (q, CCH_3), 26.4 (q, CCH_3), 56.3 (q, OCH_3) 77.1 (d, C-3), 78.8 (d, C-2), 98.1 (s, C-1), 108.9 (d, C-7′), 109.2 (d, C-2′), 113.0 (d, C-6), 113.6 [s, $C(CH_3)_2$], 118.2 (d, C-8), 120.9 (d, C-5′), 120.9 (d, C-4′), 121.0 (s, C-4a′, C-8a′), 127.4 (d, C-6′), 127.6 (d, C-3′), 133.3 (d, C-7), 134.0 (s, C-4a′), 139.7 (s, C-8a), 146.5 (s, C-8′), 147.1 (s, C-1′), 158.5 (s, C-5), 190.1 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 2935, 1711, 1607, 1478, 1412, 1379, 1272, 1213, 1087, 1062, 1032, 891, 817, 753 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 326 (3.16), 312 (3.29), 298 (3.38), 232 (3.98) nm. MS (EI, 70 eV): m/z (%) = 404 (40) [M]$^+$, 346 (38), 318 (23), 275 (27), 246 (10), 211 (11), 159 (17), 149 (30), 83 (58), 43 (100), 29 (23). HRMS (EI, 70 eV): calcd. for $C_{24}H_{20}O_6$ 404.12598; found 404.12607.

Methoxy Spiro Alcohol 27: In a two-necked 100 mL flask commercially available methylmagnesium chloride (0.15 mL, 3 M, 0.37 mmol) was added under Ar to THF (5 mL). After 15 min, a solution of the enone **13a** (0.10 g, 0.30 mmol) in THF (5 mL) was added, and the mixture was stirred at room temp. for 2 h. The reaction was then quenched by addition of aqueous ammonium chloride (20 mL). The phases were separated, and the aqueous phase was extracted with diethyl ether (20 mL). The combined organic phases were dried (Na_2SO_4), the solvent was removed under reduced pressure, and the residue purified by column chromatography on silica gel to yield a colorless solid of the tertiary alcohol **27** (0.08 g, 80%); m.p. 45–48 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.79 (s, 3 H, CH_3), 4.05 (s, 3 H, OCH_3), 6.08 (d, J = 10.0 Hz, 1 H, 3-H), 6.2 (d, J = 10.0 Hz, 1 H, 2-H), 6.9 (d, J = 8.2 Hz, 1 H, 6-H), 7.02 (d, J = 7.6 Hz, 1 H, 2′-H), 7.11 (d, J = 7.6 Hz, 1 H, 7′-H), 7.44 (t, J = 8.2 Hz, 1 H, 7-H), 7.47 (d, J = 7.6 Hz, 1 H, 8-H) 7.50 (t, J = 7.6 Hz, 1 H, 3′-H), 7.56 (t, J = 7.6 Hz, 1 H, 6′-H),7.65 (d, J = 7.6 Hz, 1 H, 5′-H), 7.85 (d, J = 7.6 Hz, 1 H, 4′-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 29.8 (q, CH_3), 55.8 (q, OCH_3), 69.06 (C-4), 95.04 (s, C-1), 109.23 (d, C-2′, C-7′), 113.6 (d, C-6), 114.2 (s, C-8a′), 119.3 (s, C-4a), 120.6 1 (d, C-8), 121.6 (s, C-4′, C-5′), 127.99 (d, C-3′, C-6′), 128.8 (d, C-2), 135.6 (d, C-3), 134.5 (s, C-4a′), 135.31 (d, C-7), 141.52 (s, C-8a), 147.8 (s, C-1′, C-8′), 156.26 (s, C-5) ppm. IR (KBr): $\tilde{\nu}$ = 3402, 2906, 2830, 1732, 1601, 1574, 1406, 1373, 927 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 286 (3.5), 293 (3.56), 306 (4.5), 301 (4.7) nm. MS (EI, 70 eV): m/z (%) = 346 (36) [M$^+$], 150 (100), 176 (70), 77 (30), 43 (50). HRMS (EI, 70 eV): calcd. for $C_{22}H_{18}O_4$ 346.1205; found 346.1227.

Methoxy Spiro Oxime 28: A solution of enone **13a** (0.030 g, 0.09 mmol) and $(NH_2OH)HCl$ (0.010 g, 0.10 mmol) in dry ethanol (3 mL) was stirred under Ar at room temp. overnight. The solvent was removed under reduced pressure to afford a white residue of the oxime **28** (0.026 g, 95%); m.p. 170–175 °C. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 4.05 (s, 3 H, OCH_3), 4.02 (d, J = 10.0 Hz, 1 H, 3-H), 6.31 (d, J = 10.0 Hz, 1 H, 2-H), 7.01 (dd, J = 7.6, J = 1.3 Hz, 2 H, 2′-H, 7′-H), 6. 5 (d, J = 8.2, J = 1.2 Hz, 1 H, 6-H), 6.9 (d, J = 8.2 Hz, 2 H, 8-H), 7.51 (d, J = 11.0, J = 1.3 Hz, 2 H, 4′-H, 5′-H), 7.54 (t, J = 7.4 Hz, 2 H, 3′-H, 6′-H), 7.44 (t, J = 8.2 Hz, 1 H, 7-H) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 53.4 (q, OCH_3) 94.82 (s, C-1), 110.23 (d, C-2′, C-7′), 113.50 (d, C-6), 114.2 (s, C-8a′), 115.3 (s, C-4a), 120.60 (d, C-8), 121.6 (s, C-4′, C-5′), 127.9 (d, C-3′, C-6′), 120.6 (d, C-3), 134.51 (s, C-4a′), 132.31 (d, C-7), 132.6 (d, C-2), 139.52 (s, C-8a), 147.8 (s, C-1′, C-8′), 159.03 (s, C-5), 164.4 (s, C-4) ppm. IR (KBr): $\tilde{\nu}$ = 3048, 2983, 1263, 746, 693 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 328 (2.7), 309 (4.2), 306 (4.5), 301 (5.0) nm. MS (EI, 70 eV): m/z (%) = 345.2 (74) [M$^+$], 330.2 (100), 329 (26), 300.2 (22). HRMS (EI, 70 eV): calcd. for $C_{21}H_{15}NO_4$ 345.100; found 345.098.

1′-(4′-Ethoxynaphthalen-1-yloxy)naphthalen-8′-ol (29): A solution of the Diels–Alder adduct **2** (50 mg, 0.15 mmol) in dry ethanol (20 mL) was treated with TMSCl (0.1 mL), and the solution was kept at 40 °C for 6 h (TLC monitoring, CH_2Cl_2). The solvent was removed under reduced pressure and the residue purified by column chromatography on silica gel (CH_2Cl_2) to yield a white solid of naphthol **29** (33.7 mg, 68%); m.p. 136–138 °C. ^{1}H NMR (200 MHz, $CDCl_3$): δ = 1.60 (t, J = 13.9 Hz, 3 H, CH_3), 4.25 (q, J = 13.9, 6.9 Hz, 2 H, CH_2), 6.43 (d, J = 8.2 Hz, 1 H, 7′-H), 6.80 (d, J = 8.2 Hz, 1 H, 3-H), 7.02 (dd, J = 8.2, 1.0 Hz, 1 H, 2′-H), 7.10 (t, J = 8.2 Hz, 1 H, 6′-H), 7.24 (d, J = 8.2 Hz, 1 H, 2-H), 7.39 (dd, J = 8.2, 1.0 Hz, 1 H, 5′-H), 7.42–7.49 (m, 3 H, 3′-H, 4′-H, 6-H), 7.53 (t, J = 8.2 Hz, 1 H, 7-H), 7.94 (d, J = 8.2 Hz, 1 H, 8-H), 8.38 (d, J = 8.2 Hz, 1 H, 5-H), 9.35 (s, 1 H, OH) ppm. ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.8 (q, CH_3), 64.2 (t, CH_2), 104.0 (d, C-3), 108.5 (d, C-7′), 110.7 (d, C-2′), 115.2 (s, C-4a′), 118.1 (d, C-8), 119.2 (d, C-5), 121.5 (d, C-5′), 122.7 (d, C-4′), 125.6 (d, C-6), 126.1 (d, C-7), 126.9 (s, C-8a), 127.3 (d, C-6′), 127.8 (d, C-3′), 127.9 (s, C-4a), 137.0 (s, C-4a′), 142.8 (s, C-1), 153.1 (s, C-1′), 154.3 (s, C-4), 156.6 (s, C-8′) ppm. IR (KBr): $\tilde{\nu}$ = 3426, 1630, 1607, 1581, 1460, 1427, 1388, 1267, 1237, 1147, 1083, 1060, 1029, 812, 767, 748, 699 cm^{-1}. UV (CH_2Cl_2): λ_{max} (lgε) = 332 (2.90), 318 (3.13), 304 (3.25), 232 (3.84) nm. MS (EI, 70 eV): m/z (%) = 330 (97) [M$^+$], 301 (100), 273 (50), 255 (30), 159 (18), 115 (98). HRMS (EI, 70 eV): calcd. for $C_{22}H_{18}O_3$ 330.12561; found 330.12564.

Crystal Structure Determination of Epoxy-diene 18:[14] $C_{20}H_{14}O_4$, M_r = 318.3, monoclinic, space group $P2_1/c$, a = 12.031(3), b = 14.775(3), c = 8.3997(18) Å, β = 110.43(1)°, V = 1399.1(5) Å^3, Z = 4, D_X = 1.511 g/cm^3, F(000) = 664, T = 120(2) K. Bruker-AXS SMART APEX CCD, graphite monochromator, λ(Mo-K_α) = 0.71073 Å, μ = 0.105 mm^{-1}, colorless crystal, size 0.45 × 0.42 × 0.40 mm, 12875 intensities collected 1.8° < θ < 27.9°, –15 < h < 15, –19 < k < 19, –10 < l < 11. Structure solved by direct methods,[15] full-matrix least-squares refinement[15] with 3331 independent reflections based on F^2 and 217 parameters, all but H atoms refined anisotropically, H atoms from difference Fourier maps refined with riding model in idealized positions with U = 1.2 × U_{iso}(C). Refinement converged at R_1 [I > 2σ(I)] = 0.055, wR_2 (all data) = 0.139, S = 1.02, max(δ/σ) < 0.001, min/max density in final ΔF map –0.30/0.27 e Å^{-3}. Figure 1 shows the molecular structure.

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