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# Total Synthesis of Natural Enantiomers of Heliespirones A and C *via* the Diastereoselective Intramolecular Hosomi-Sakurai Reaction

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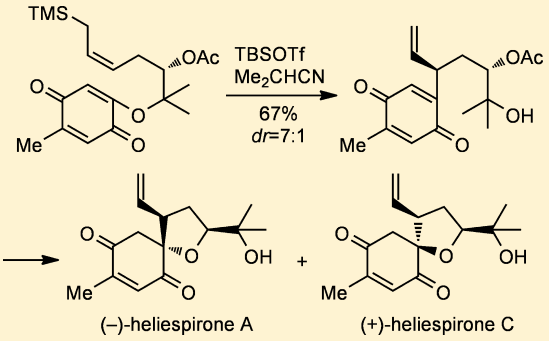
Supporting Information

**ABSTRACT:** A full account of the development of a novel type of the intramolecular Hosomi-Sakurai reactions of the substrates with a *p*-benzoquinone and an allylsilane moieties connected by an ether linkage is described. This transformation proceeds *via* an addition−elimination sequence and provides the products with two stereogenic centers through a 1,3(or 1,4)-asymmetric induction in good to excellent diastereoselectivities. A reasonable mechanistic possibility for the reaction, determination of the stereochemistry for the product, and scope and limitation of the transformation are also discussed. The methodology developed here can successfully be applied to the enantiocontrolled total synthesis of the natural enantiomers of (−)-heliespirone A and (+)-heliespirone C, which have been isolated from sunflower *Helianthus annuus* L. as allelochemicals.




## INTRODUCTION

Heliespirone A, the first member of a new class of bioactive sesquiterpenes, was isolated from cultivar sunflowers var. SH-222 (*Helianthus annuus* L.) by Macías et al.[1] Its [6.6]oxaspiro structure **1**, with (1*R*, 8*R*, 10*R*) configurations, was elucidated by a combination of extensive 2D-NMR studies, theoretical conformations and NOEDIFF data. In 2006, the same authors isolated two new sesquiterpenes from the polar bioactive fractions of the leaf extracts of *Helianthus annuus* L., which contain six- and five-membered oxaspirocyclic skeletons, heliespirones B and C (**3**), respectively.[2] The spectral properties of heliespirone C and the previously isolated heliespirone A were quite similar, suggesting that the initially assigned structure **1** should be corrected to that of **2**, the C1 epimer of **3**. Heliespirone A is therefore likely to play an important role in the allelopathic action of cultivar sunflowers,[1] since heliespirones B and C exhibited inhibitory activity in the coleoptile bioassay.[2] Because of their intriguing structural features, biological profiles, and limited availability, these natural products represent attractive targets for total synthesis. To date, two successful total syntheses of *ent*-heliespirones A (**2**) and C (**3**)[3a,4] and one racemic synthesis[3b] have been reported. Here we describe our successful total synthesis of the natural enantiomers of (−)-heliespirone A (**2**) and (+)-heliespirone C (**3**), employing an unprecedented addition−elimination, namely an intramolecular Hosomi-Sakurai reaction for the diastereoselective construction of the two tertiary stereogenic centers at C8 and C10 and an intramolecular oxy-Michael reaction promoted by cesium carbonate for assembling the five-membered oxaspirocycles as the key steps (Figure 1).

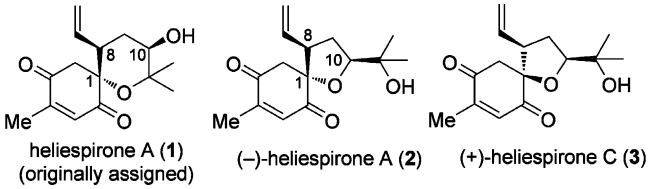
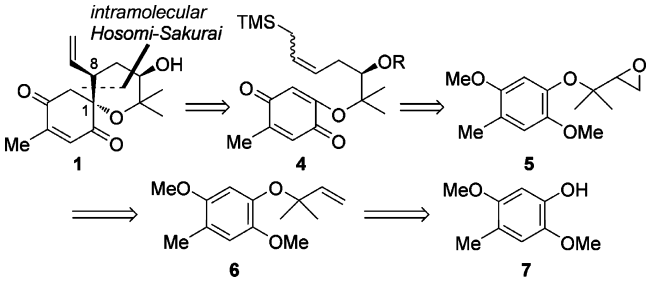



**Figure 1.** Structure of heliespirones A and C.

## RESULTS AND DISCUSSION

When we first began our synthetic studies, the structure of heliespirone A was still believed to be **1**, and so we chose it as our target molecule. Our strategy for its synthesis is illustrated in Scheme 1. We reasoned that the complete carbon framework of **1** would be constructed by an intramolecular Hosomi-

**Scheme 1. Retrosynthetic Analysis**

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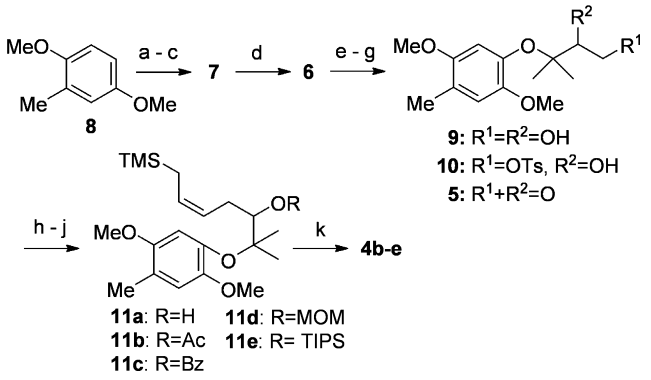
Sakurai reaction[5] of the substrate **4** possessing allylsilane and *p*-benzoquinone moieties. Since the conjugate addition cyclization[6] leading to the formation of oxaspirocycles had never been reported, the potential conversion intrigued us. We thought that the allylsilane **4** could be derived from the epoxide **5** by epoxide opening with the anion of trimethyl(prop-2-ynyl)silane followed by semihydrogenation, which would in turn be prepared from the phenol **7** *via* **6** by sequential dimethylallyl etherification[7] and epoxidation.

The phenol **7**, prepared from 2,5-dimethoxytoluene (**8**) *via* a three-step sequence, was treated with isobutyl 2-methyl-3-buten-2-yl carbonate in the presence of tetrakis(triphenylphosphine)palladium in THF to give **6** in 93% yield. Epoxidation of **6** resulted in decomposition under any of the attempted conditions (*m*CPBA, dioxirane, and methyltrifluoromethyl dioxirane, etc.). Hence, the epoxide **5** was prepared from **6** *via* a three-step sequence. Thus, dihydroxylation, selective tosylation, and basic treatment of the monotosylate produced the epoxide **5**. Nucleophilic cleavage of the epoxide with the anion of trimethyl(prop-2-ynyl)silane in the presence of $BF_3{\bullet}OEt_2$ followed by semihydrogenation with the Lindlar catalyst furnished the *Z*-alkene **11a**, the secondary hydroxyl function of which was protected to give **11b−e**. These were then oxidized with CAN to give the quinones **4b−e** (Scheme 2).

**Scheme 2. Synthesis of the Quinones (4b−e)**[a]




[a]Reagents and conditions (a) $POCl_3$, *N*-methylformanilide, 70 °C, 1 h, 86%; (b) *m*CPBA, $NaHCO_3$,$CH_2Cl_2$, −10 °C, 1 h; (c) KOH, MeOH, RT, 0.5 h, 98% (2 steps); (d) *i*BuOC(O)OC(Me)$_2$CH=CH$_2$, $(Ph_3P)_4Pd$, THF, RT, 3.5 h, 93%; (e) $OsO_4$, NMO, acetone (aq.), RT, 3.5 h, quant.; (f) TsCl, $Et_3N$, 4-DMAP, $CH_2Cl_2$, RT, 4 h, 97%; (g) $K_2CO_3$, MeOH, RT, 1 h, quant.; (h) trimethyl(prop-2-ynyl)silane, $BF_3{\cdot}OEt_2$, *n*BuLi, −78 °C, THF, 0.5 h, 75%; (i) $H_2$, Lindlar cat., quinoline, AcOEt, 50 °C, 1 h, 99%; (j) for **4b** $Ac_2O$, pyridine, 4-DMAP, RT, 2.5 h, quant.; for **4c**, benzoyl chloride, pyridine, 4-DMAP, RT, 3 h, quant.; for **4d**, MOMCl, *i*Pr$_2$NEt, 4-DMAP, RT, 16.5 h, 92%; for **4e**, TIPSOTf, $Et_3N$, RT, 2 h, 93%; (k) CAN, MeCN, $H_2O$, 0 °C, for **4b**, 97%; for **4c**, 97%; for **4d**, 84%; for **4e**, 50%.

With the substrates in hand, we next examined the intramolecular Hosomi-Sakurai reaction. Results are shown in Table 1. When the reaction was carried out with the typical Lewis acid $TiCl_4$, only the protodesilylation product **13b** was obtained, in 34% yield (entry 1). The same result was likewise obtained using $InCl_3$/TMSCl[6p,8] (entry 2). After numerous screenings of Lewis acids, silyl triflates proved to be the best choice. Treatment of **4b** with TMSOTf in acetonitrile at −10 °C resulted in not the expected acetylheliespirone A but rather in a mixture of two products, **12b** (28%, 4:1 mixture of two diastereoisomers), presumably generated through a Lewis acid mediated addition−elimination sequence, and **13b** (6%). The use of TBSOTf in acetonitrile also provided good results (entry 4), and the combined use of TBSOTf and isobutyronitrile as a solvent resulted in both improved yield (60%) and diastereoselectivity (7:1) (entry 5).[9] When the reaction was conducted with the benzoate **4c**, **12c** was the exclusive product (entries 6−8) and the best result was obtained as shown in entry 8. Attempted reactions using the substrates **4d** and **4e**, with MOM-oxy and TIPS-oxy functionalities, resulted in complex mixtures (entries 9 and 10).

The stereochemistries of the two stereogenic centers in **12b**[10] were determined by the following transformation as shown in Scheme 3. The major diastereomer **12b** was reduced with $Na_2S_2O_4$ to give the hydroquinone **14**, which was exposed to catalytic *p*-TsOH in refluxing benzene[11] to provide the chroman **15** quantitatively for the two steps. Alkaline hydrolysis produced **16**, the spectral properties of which were identical with those for 10-*epi*-heliannuol E.[12] Since the *p*-TsOH catalyzed cyclization developed by Cohen is known to proceed with retention of configuration at the tertiary alcohol bearing the carbon stereogenic center,[11a,b] the relative configuration in **12b** was therefore established to be (3*S**,5*R**).

The diastereoselectivty of this transformation may result from the preference of the transition state $T_1$ over $T_2$ due to the stereoelectronically favored antiperiplanar conformation of $T_1$ and the steric repulsion between the allylsilane and the benzoquinone moieties in $T_2$. As a result, the (3*S**,5*R**)-**12** was produced preferentially[13] (Scheme 4).

Although the initially expected spirocyclization could not be realized, an interesting reaction instead provided a promising chiral building block diastereoselectively. Since, as far as we know, this type of transformation under intramolecular Hosomi-Sakurai reaction conditions has never been reported,[14] we decided to investigate the scope and limitations of the reaction. Consequently, the substrates **17a,b** were designed to diminish the gauche-type steric interactions between C2 and C3 in the transition state ($T_1$) by removing the gem-dimethyl group at C2. They were then treated with the same conditions as for entry 5 in Table 2 to give **18a,b** with higher diastereoselectivity. In particular, **18b** was produced as a single product in moderate yields (entries 1 and 2). When the reaction was conducted using the substrates **17c,d**, exclusive formation of **18c,d** was observed in reasonable yields as we expected (entries 3 and 4). Thus, we demonstrated that this transformation could lead to the construction of quinone derivatives with two stereogenic centers, one of which is benzylic, by the 1,3- and 1,4-chirality transfers.

We further examined the effects of the substituents and the length of tether on the reaction. Treatment of the substrate **19a**, which does not have any substituents on the tether, with the same reaction conditions as for **17a−d** produced a separable mixture of the rearranged **20**, the cyclized **21** and the protodesilylation product **22** in 21, 11 and 20% yield, respectively. On the other hand, a mixture of the six-membered **23** and **24** was obtained from **19b**, bearing a one-carbon shorter tether, in 47 and 3% yield, respectively. It was revealed that the substituents on the tether and the length of tether play an important role in such types of the intramolecular Hosomi-Sakurai reactions (Table 3).

Fortunately for our purposes the major products **12b,c** that we obtained seemed to be useful for the synthesis of the revised structures of heliespirones A (**2**) and C (**3**).[2] Attempted


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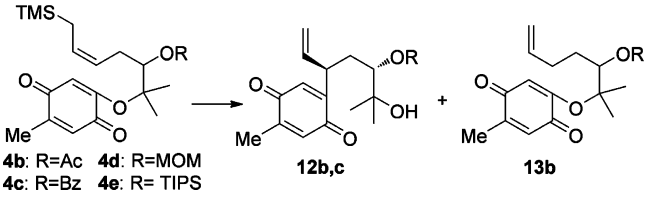
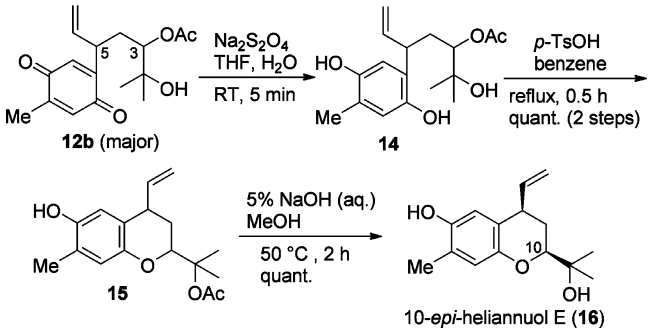
**Table 1. Intramolecular Hosomi-Sakurai Reaction of 4**



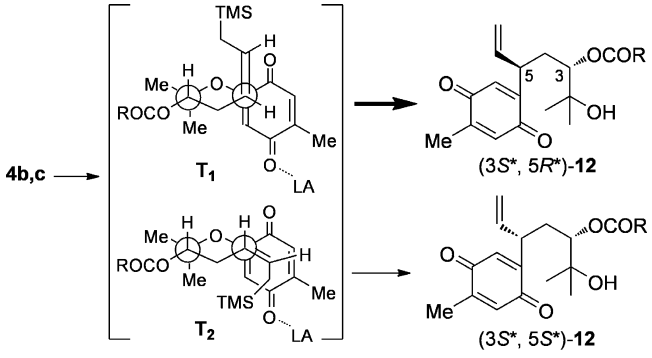

| entry | 4 | LA (equiv) | solvent | time (h) | 12 % (dr) | 13% |
|---|---|---|---|---|---|---|
| 1 | 4b | $TiCl_4$(1) | $CH_2Cl_2$[a] | 2.5 | | 34 |
| 2 | | $lnCl_3$(0.1).TMSCl(5) | $CH_2Cl_2$[b] | 0.5 | | 57 |
| 3 | | TMSOTf (2) | MeCN[c] | 0.2 | 28(4:1) | 6 |
| 4 | | TBSOTf (2) | MeCN[c] | 3.5 | 51(5:1) | 19 |
| 5 | | TBSOTf (2) | $Me_2CHCN$[c] | 1.5 | 60(7:1) | 20 |
| 6 | 4c | TMSOTf (2) | MeCN[c] | 0.2 | 49(6:1) | |
| 7 | | TBSOTf (2) | MeCN[c] | 2.5 | 59(6:1) | |
| 8 | | TBSOTf (2) | $Me_2CHCN$[c] | 6.0 | 68(8:1) | |
| 9 | 4d | TBSOTf (2) | MeCN[c] | 24 | complex mixt. | |
| 10 | 4e | TBSOTf (2) | MeCN[c] | 24 | complex mixt. | |

[a]At −78 °C. [b]At RT. [c]At −10 °C.

**Scheme 3. Structure Determination of the Major Diastereomer**

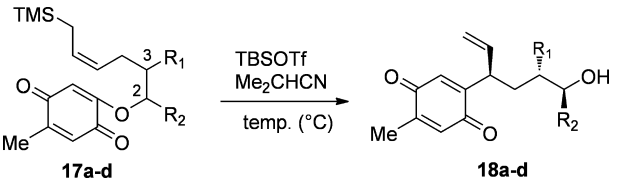



**Scheme 4. Plausible Transition State for Diastereoselection**




hydrolysis of **12b**[10] to **27** under basic and neutral chemoenzymatic (PPL, PLE-A, Lipase AK, etc.)[15] conditions led to decomposition and recovered **12b**, respectively. Therefore, a three-step sequence was chosen. Reduction of the benzoquinone moiety of **12b** followed by reduction with DIBAH gave **26**, which was oxidized with CAN to afford the quinone diol **27** in good overall yield. Exposure of **27** to $Cs_2CO_3$ in $CH_2Cl_2$[16,4] at room temperature for 20 min provided a chromatographically separable mixture of (±)-heliespirone A (**2**) and (±)-heliespirone C (**3**) in 40 and 38% yield, respectively (Scheme 5). The spectral properties of the synthetic **2** and **3** were identical to those reported for the natural products and

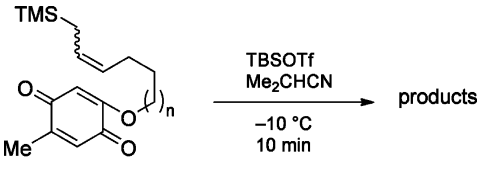
**Table 2. Intramolecular Hosomi-Sakurai Reaction of 17**




| entry | 17 | $R_1$ | $R_2$ | T, °C | product | yield, % | dr |
|---|---|---|---|---|---|---|---|
| 1 | a[a] | OAc | H | −10[c] | 18a[d] | 62 | 13:1 |
| 2 | b[a] | Me | H | −60 | 18b | 43 | >20:1 |
| 3 | c[b] | H | $CH_2OBn$ | −60 | 18c | 73 | >20:1 |
| 4 | d | H | Me | −60 | 18d | 62 | >20:1 |

[a]Mixture of *Z* and *E* isomers (1:1). [b]Mixture of *Z* and *E* isomers (1:1.5). [c]Starting **17a** was recovered at −60 °C. [d](2*S**,4*R**)-2-Hydroxy-4-(4- methyl-3,6-dioxocyclohexa-1,4-dienyl)hex-5-enyl acetate was obtained in 17% yield.

**Table 3. Intramolecular Hosomi-Sakurai Reactions of 19a,b**




| entry | 19 | n | product (yield, %) |
|---|---|---|---|
| 1 | a | 1 | 20 (21%) + 21 (11%) + 22 (20%) |
| 2 | b | 0 | 23 (47%) + 24 (3%) |

both structures were firmly established by X-ray crystallographic analysis[17] (see Supporting Information).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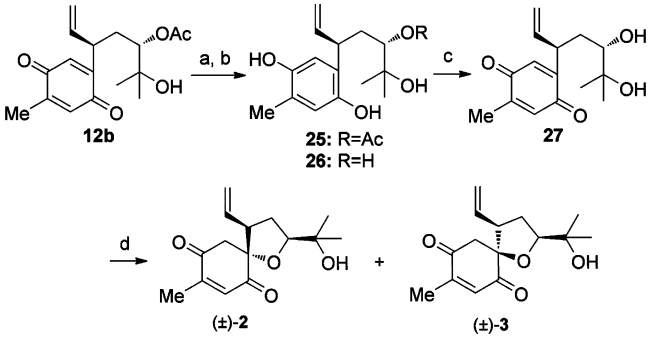
**Scheme 5. Synthesis of (±)-Heliespirones A and C[a]**




[a]Reagents and conditions: (a) $Na_2S_2O_4$, THF, $H_2O$, RT, 2.5 h, 99%; (b) DIBAH, THF, 0 °C, 1.5 h, 80%; (c) CAN, MeCN, $H_2O$, 0 °C, 10 min, 91%; (d) $Cs_2CO_3$, $CH_2Cl_2$, RT, 20 min, 40% for **2**, 38% for **3**.

For the synthesis of the optically active natural products, **6** was treated with the protocol of Sharpless[18] to give the optically active diol **9** with the *S*-configuration, confirmed by the Kusumi-Mosher method,[19] in 92% yield and 79% ee,[20] which was raised to 97% ee after two recrystallizations from ethyl acetate/hexane. It was converted to the epoxide (*S*)-**5**, which was sequentially subjected to the nucleophilic epoxide opening with trimethyl(prop-2-ynyl)silane, Lindlar reduction, and acetylation to give (*S*)-**11b**. Oxidation with CAN gave the quinone (*S*)-**4b**, which was treated with TBSOTf in isobutyronitrile at −10 °C to give the (3*S*, 5*R*)-**12b** (67% yield, dr = 7:1). It was then transformed, *via* a three-step sequence, to (3*S*, 5*R*)-**27** which was exposed to $Cs_2CO_3$ in $CH_2Cl_2$ at room temperature for 20 min to give (−)-heliespirone A (**2**) and (+)-heliespirone C (**3**) in 34% and 42% yield, respectively. Thus, an enantioselective total synthesis of the natural enantiomers of heliespirones A and C was successfully accomplished (Scheme 6).

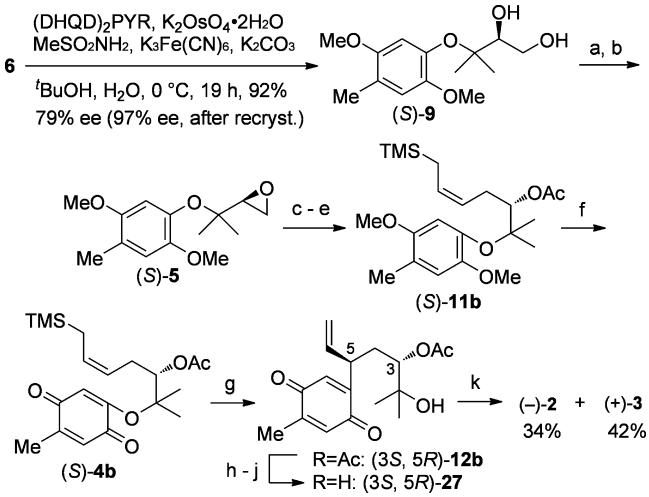
## CONCLUSION

In summary, a new strategy for the efficient and diastereoselective construction of chiral building blocks during the course of a synthetic study on the assigned structure of heliespirone A (**1**) has been realized. The methodology thus developed features a Lewis acid promoted migration of a readily accessible C−O bond to a C−C bond in a diastereoselective fashion. The building block thus obtained was successfully converted to the natural enantiomers of heliespirones A (**2**) and C (**3**) *via* the oxy-Michael reaction. The synthetic route developed here is general and efficient and could also be applied to the syntheses of related natural products with more complex structures and interesting biological profiles.

## EXPERIMENTAL SECTION

**General Procedure.** All nonaqueous reactions were carried out under a positive atmosphere of argon in dried glassware unless otherwise indicated. Materials were obtained from commercial suppliers and used without further purification expect when otherwise noted. Solvents were dried and distilled according to standard protocols. The phase "residue upon workup" refers to the residue obtained when the organic layer was separated and dried over anhydrous $MgSO_4$ and the solvent was evaporated under reduced pressure. Column chromatography was performed on silica gel 60N (70−230 mesh) using indicated solvent. Thin layer chromatography was performed on precoated plates (0.25 mm, silica gel Merck Kieselgel $60F_{245}$), and compounds were visualized with UV light and

**Scheme 6. Synthesis of the Natural Enantiomers of Heliespirones A and C[a]**




[a]Reagents and Conditions: (a) TsCl, $Et_3N$, $CH_2Cl_2$, RT, 3 h, 85%; (b) $K_2CO_3$, MeOH, RT, 1 h, quant.; (c) trimethyl(prop-2-ynyl)silane, $BF_3$•$OEt_2$, *n*BuLi, THF, −78 °C, 1 h, 97%; (d) $H_2$, Lindlar cat., AcOEt, 50 °C, 1 h, 96%; (e) $Ac_2O$, pyridine, 4-DMAP, $CH_2Cl_2$, RT, 5.5 h, 95%; (f) CAN, MeCN, $H_2O$, 0 °C, 5 min, 97%; (g) TBSOTf, $Me_2CHCN$, −10 °C, 0.5 h, 67%, dr = 7.1:1; (h) $Na_2S_2O_4$, THF, $H_2O$, RT, 2.5 h, quant.; (i) DIBAH, THF, 0 °C, 1.5 h, 67%; (j) CAN, MeCN, $H_2O$, 0 °C, 5 min, 39%; (k) $Cs_2CO_3$, $CH_2Cl_2$, RT, 0.5 h, 34% for (−)-**2**, 42% for (+)-**3**.

*p*-anisaldehyde stain. NMR spectra were recorded on 400 and 500 MHz NMR instrument. $^1$H NMR were measured in $CDCl_3$ solution and referenced to TMS (0.00 ppm) or in $CD_3COCD_3$ solution and referenced to $CD_2HCOCD_3$ (2.05 ppm). $^{13}$C NMR were measured in $CDCl_3$ solution and referenced to $CDCl_3$ (77.0 ppm) or in $CD_3COCD_3$ solution and referenced to $CD_3COCD_3$ (29.2 ppm). Chemical shifts are reported in ppm (from TMS). When peak multiplicities are reported, the following abbreviations are used: s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; sext, sextet; m, multiplet; br, broadened. High resolution mass spectra were recorded in positive ion mode using electrospray ionization and a time-of-flight mass analyzer.

**2,5-Dimethoxy-4-methylbenzaldehyde (28).** A mixture of $POCl_3$ (13.4 mL, 144 mmol) and *N*-methylformanilide (15.3 mL, 124 mmol) was stirred at rt for 50 min. 2,5-dimethoxytoluene **8** (1.56 g, 33.9 mmol) was added all at once and the solution was warmed to 70 °C. After the mixture was stirred for 1 h, the hot reaction mixture was poured into ice water and extract with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give benzaldehyde **28** (5.27 g, 86%) as colorless crystals. Mp 83.1−83.6 °C (hexane); IR (KBr) 2918, 1160, 1612, 1500, 1270, 1215 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 10.39 (1H, s), 7.24 (1H, s), 6.80 (1H, s), 3.87 (3H, s), 3.82 (3H, s), 2.27 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.7 (CH), 156.3 (C), 151.6 (C), 136.2 (C), 122.5 (C), 114.3 (CH), 107.1 (CH), 55.7 ($CH_3$), 55.3 ($CH_3$), 16.9 ($CH_3$); HRMS (ESI) calcd for $C_{10}H_{13}O_3$ 181.0865 ($M^+$ + H), found 181.0862.

**2,5-Dimethoxy-4-methylphenol (7).** To a stirred solution of benzaldehyde **28** (9.49 g, 58.7 mmol) and $NaHCO_3$ (13.4 g, 158 mmol) in $CH_2Cl_2$ (200 mL) was added *m*CPBA (16.8 g, 63.2 mmol) at −10 °C and stirring was continued for 1 h at the same temperature. The reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous $NaHCO_3$ and saturated aqueous NaCl. The residue upon workup was dissolved in MeOH, basified with 10% methanolic solution of KOH and mixture was stirred at rt for 30 min. After evaporation of solvent *in*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*vacuo*, the residue was dissolved in $H_2O$ and acidified with 10% aqueous solution of HCl, followed by dilution with $H_2O$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give phenol **7** (8.71 g, 98%) as colorless crystals. Mp 78.3−78.9 °C (hexane); IR (KBr) 3321, 2937, 1600, 1522, 1313, 1200 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.67 (1H, s), 6.53 (1H, s), 5.47 (1H, s, $D_2O$ exchangeable), 3.83 (3H, s), 3.76 (3H, s), 2.15 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 152.1 (C), 144.0 (C), 139.9 (C), 117.0 (C), 114.0 (CH), 99.1 (CH), 56.7 ($CH_3$), 55.9 ($CH_3$), 15.6 ($CH_3$); HRMS (ESI) calcd for $C_9H_{13}O_3$ 169.0865 ($M^+$ + H), found 169.0860.

**1,4-Dimethoxy-2-methyl-5-(2-methylbut-3-en-2-yloxy)-benzene (6).** To a stirred solution of phenol **7** (0.52 g, 3.09 mmol) in THF (5 mL) were added isobutyl-2-methyl-3-butene-2-ylcarbonate (0.86 g, 4.63 mmol) and $(PPh_3)_4Pd$ (36.0 mg, 0.03 mmol) at rt. After stirring was continued for 3.5 h at the same temperature, the reaction mixture was quenched with *m*CPBA (0.25 g, 0.93 mmol) at 0 °C and stirred for 10 min at rt. The resulting solution was extracted with $Et_2O$. The combined extracts were washed with $H_2O$ and saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (95:5 v/v) as eluent to give dimethylallyl ether **6** (0.68 g, 93%) as a colorless oil. IR (neat) 3398, 2980, 1509, 1385, 1216 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.69 (1H, s), 6.60 (1H, s), 6.19 (1H, dd, $J$ = 17.6 and 10.8 Hz), 5.14 (1H, dd, $J$ = 17.6 and 1.2 Hz), 5.09 (1H, dd, $J$ = 10.8 and 1.2 Hz), 3.77 (3H, s), 3.71 (3H, s), 2.16 (3H, s), 1.45 (6H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.0 (C), 146.8 (C), 144.5 (CH), 143.1 (C), 121.0 (C), 115.7 (CH), 112.9 ($CH_2$), 108.3 (CH), 80.6 (C), 56.6 ($CH_3$), 55.9 ($CH_3$), 26.3 ($CH_3$ × 2), 15.7 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{21}O_3$ 237.1491 ($M^+$ + H), found 237.1484.

**3-(2,5-Dimethoxy-4-methylphenoxy)-3-methylbutane-1,2-diol (9).** To a stirred solution of dimethylallylether **6** (12.4 mg, 0.05 mmol) in acetone/$H_2O$ (9:1 v/v, 0.3 mL) were added *N*-methylmorpholine-*N*-oxide (9.26 mg, 0.08 mmol), and 2.0 w/v solution of $OsO_4$ in water (0.06 mL, 0.5 $\mu$mol) at rt. After stirring was continued for 3.5 h at the same temperature, the reaction mixture was quenched with saturated aqueous $Na_2SO_3$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (1:1 v/v) as eluent to give diol **9** (14.3 mg, quant.) as colorless crystals. Mp 84.7−85.3 °C (AcOEt/hexane); IR (KBr) 3292, 2978, 1512, 1468 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.72 (1H, s), 6.53 (1H, s), 4.18 (1H, d, $J$ = 5.6 Hz, $D_2O$ exchangeable), 3.81 (3H, s), 3.80−3.66 (2H, m), 3.76 (3H, s), 3.63−3.58 (1H, m), 2.63 (1H, brs, $D_2O$ exchangeable), 2.19 (3H, s), 1.32 (3H, s), 1.28 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.5 (C), 146.8 (C), 141.1 (C), 122.7 (C), 114.8 (CH), 108.8 (CH), 83.9 (C), 77.1 (CH), 63.0 ($CH_2$), 56.4 ($CH_3$), 56.1 ($CH_3$), 24.2 ($CH_3$), 22.2 ($CH_3$), 15.9 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{23}O_5$ 271.1514 ($M^+$ + H), found 271.1535.

**(*S*)-3-(2,5-Dimethoxy-4-methylphenoxy)-3-methylbutane-1,2-diol (*S*)-9.** To a stirred solution of dimethylallylether **6** (6.11 g, 25.9 mmol) in $^t$BuOH/$H_2O$ (1:1 v/v, 100 mL) were added $K_3Fe(CN)_6$ (25.6 g, 77.7 mmol), $K_2CO_3$ (10.7 g, 77.7 mmol), $(DHQD)_2PYR$ (0.23 g, 0.26 mmol), $K_2OsO_4{\cdot}H_2O$ (38.0 mg, 0.10 mmol) and $CH_3SO_2NH_2$ (2.46 g, 25.9 mmol) at 0 °C. After stirring was continued for 19 h at the same temperature, the reaction mixture was quenched with saturated aqueous $Na_2SO_3$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (1:1 v/v) as eluent to give diol (*S*)-**9** (6.43 g, 23.8 mmol, 92%, 79% ee) as colorless crystals. Further recrystallization from AcOEt/hexane was carried out (1.72 g, 25%, 97% ee). Enantiomeric excess was determined by HPLC analysis [CHIRALCEL AD−H column, 8% isopropanol−hexane, 1.0 mL/min, retention times 13.6 (*R*) and 15.2 (*S*)]. [$\alpha$] +0.44 (*c* 0.88 $CHCl_3$). Other spectral data were consistent with those of the racemic diol **9**.

**(*S*)-3-(2,5-Dimethoxy-4-methylphenoxy)-2-hydroxy-3-methylbutyl-4-methylbenzenesulfonate (*S*)-10.** To a stirred solution of diol (*S*)-**9** (0.64 g, 2.37 mmol) in $CH_2Cl_2$ (10 mL) were added $Et_3N$ (0.50 mL, 3.56 mol), TsCl (0.45 g, 2.37 mmol) and catalytic amount of 4-DMAP at 0 °C. After stirring was continued for 3 h at rt, the reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (7:3 v/v) as eluent to give tosylate (*S*)-**10** (0.85 g, 85%) as colorless crystals. mp 92.2−93.3 °C (hexane); [$\alpha$] −17.2 (*c* 0.94 $CHCl_3$); IR (KBr) 3456, 2937, 1509, 1385, 1175 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 7.82 (2H, d, $J$ = 8.0 Hz), 7.34 (2H, d, $J$ = 8.0 Hz), 6.69 (1H, s), 6.48 (1H, s), 4.37 (1H, dd, $J$ = 10.4 and 4.0 Hz), 4.09 (1H, dd, $J$ = 10.4 and 6.8 Hz), 4.01 (1H, d, $J$ = 5.2 Hz, $D_2O$ exchangeable), 3.78 (1H, ddd, $J$ = 6.8, 5.2, and 4.0 Hz), 3.75 (3H, s), 3.74 (3H, s), 2.45 (3H, s), 2.18 (3H, s), 1.26 (3H, s), 1.25 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.5 (C), 146.8 (C), 144.7 (C), 141.0 (C), 133.0 (C), 129.8 (CH × 2), 128.0 (CH × 2), 122.8 (C), 114.9 (CH), 108.8 (CH), 83.0 (C), 75.3 (CH), 71.1 ($CH_2$), 56.3 ($CH_3$), 56.0 ($CH_3$), 23.5 ($CH_3$), 22.5 ($CH_3$), 21.5 ($CH_3$), 15.9 ($CH_3$); HRMS (ESI) calcd for $C_{21}H_{29}O_7S$ 425.1634 ($M^+$ + H), found 425.1649.

**(*S*)-2-[2-(2,5-Dimethoxy-4-methylphenoxy)propan-2-yl]-oxirane (*S*)-5.** To a stirred solution of tosylate (*S*)-**10** (4.35 g, 10.3 mmol) in MeOH (60 mL) was added $K_2CO_3$ (7.09 g, 51.3 mmol) at rt, and stirring was continued for 1 h at the same temperature. After evaporation of the solvent *in vacuo*, the residue was dissolved in $H_2O$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (8:2 v/v) as eluent to give epoxide (*S*)-**5** (2.52 g, quant.) as a colorless oil. [$\alpha$] −0.17 (*c* 0.46 $CHCl_3$); IR (neat) 2984, 1509, 1385 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.70 (1H, s), 6.65 (1H, s), 3.77 (3H, s), 3.76 (3H, s), 3.24 (1H, t, $J$ = 3.2 Hz), 2.76 (1H, dd, $J$ = 4.4 and 3.2 Hz), 2.70 (1H, dd, $J$ = 4.4 and 3.2 Hz), 2.18 (3H, s), 1.30 (3H, s), 1.27 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.2 (C), 147.1 (C), 142.1 (C), 121.9 (C), 115.5 (CH), 109.0 (CH), 79.6 (C), 57.2 (CH), 56.5 ($CH_3$), 55.9 ($CH_3$), 44.3 ($CH_2$), 22.8 ($CH_3$), 22.6 ($CH_3$), 15.8 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{20}O_4Na$ 275.1259 ($M^+$ + Na), found 275.1257.

**(*S*)-2-(2,5-Dimethoxy-4-methylphenoxy)-2-methyl-7-(trimethylsilyl)hept-5-yn-3-ol (29).** To a stirred solution of trimethyl(prop-2-ynyl)silane (0.14 mL, 0.95 mmol) in THF (0.2 mL) was added dropwise a 1.23 M solution of $^n$BuLi (0.39 mL, 0.48 mmol) in hexane at −78 °C. After stirring was continued for 1 h at the same temperature, $BF_3{\cdot}OEt_2$ (0.04 mL, 0.32 mmol) was added dropwise. After further stirring was continued for 10 min, epoxide (*S*)-**5** (79.7 mg, 0.32 mmol) in THF (0.8 mL) was added dropwise and stirring was continued for 1 h at the same temperature. The reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with $Et_2O$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give alkyne **29** (113 mg, 97%) as a colorless oil. [$\alpha$] −10.0 (*c* 0.51 $CHCl_3$); IR (neat) 3453, 2952, 1510, 1466 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.75 (1H, s), 6.59 (1H, s), 4.07 (1H, d, $J$ = 3.6 Hz, $D_2O$ exchangeable), 3.84 (3H, s), 3.81 (3H, s), 3.75−3.60 (1H, m), 2.58−2.41 (2H, m), 2.24 (3H, s), 1.52 (2H, t, $J$ = 2.4 Hz), 1.37 (3H, s), 1.28 (3H, s), 0.15 (9H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.3 (C), 147.1 (C), 141.4 (C), 122.3 (C), 114.8 (CH), 108.9 (CH), 84.6 (C), 79.1 (C), 76.5 (CH), 76.0 (C), 56.3 ($CH_3$), 56.0 ($CH_3$), 24.0 ($CH_3$), 22.6 ($CH_2$), 20.7 ($CH_3$ × 2), 15.9 ($CH_3$ × 3), 7.0 ($CH_2$); HRMS (ESI) calcd for $C_{20}H_{32}O_4NaSi$ 387.1968 ($M^+$ + Na), found 387.1985.

**(*S*,*Z*)-2-(2,5-Dimethoxy-4-methylphenoxy)-2-methyl-7-(trimethylsilyl)hept-5-en-3-ol (11a).** The mixture of alkyne **29** (0.28 g, 0.77 mmol), quinoline (4 $\mu$L, 0.04 mmol) and Lindlar catalyst (56 mg, 20%) in AcOEt (3 mL) was stirred under a hydrogen atmosphere at 50 °C for 1 h. The reaction mixture was filtered through a Celite pad, and solvents were removed under vacuum. The residue was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give *Z*-alkene (*S*)-**11a** (0.28 g, quant.) as a colorless oil. [$\alpha$] −7.3 (*c* 0.73 $CHCl_3$); IR (neat) 3491, 2952, 1509, 1466, 1385 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.70 (1H, s), 6.55 (1H, s), 5.57−5.45 (2H, m), 4.10 (1H, d, $J$ = 3.2 Hz, $D_2O$ exchangeable), 3.78 (3H, s), 3.76 (3H, s), 3.62 (1H, dt, $J$ = 9.6 and 3.2 Hz), 2.18 (3H, s), 2.21−


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2.07 (2H, m), 1.53 (1H, dd, $J$ = 13.2 and 7.2 Hz), 1.45 (1H, dd, $J$ = 13.2 and 7.2 Hz), 1.32 (3H, s), 1.22 (3H, s), 0.00 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.3 (C), 147.1 (C), 141.5 (C), 126.9 (CH), 124.5 (CH), 122.2 (C), 114.8 (CH), 108.9 (CH), 85.3 (C), 77.3 (CH), 56.3 ($CH_3$), 56.0 ($CH_3$), 29.3 ($CH_2$), 24.5 ($CH_3$ × 2), 20.0 ($CH_3$), 18.6 ($CH_2$), 15.9 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{20}H_{35}O_4Si$ 367.2305 ($M^+$ + H), found 367.2318.

**(*S*,*Z*)-2-(2,5-Dimethoxy-4-methylphenoxy)-2-methyl-7-(trimethylsilyl)hept-5-en-3-yl Acetate (11b).** To a stirred solution of *Z*-alkene **11a** (111 mg, 0.30 mmol) in $CH_2Cl_2$ (0.5 mL) were added pyridine (0.05 mL, 0.60 mol), $Ac_2O$ (0.06 mL, 0.60 mmol) and catalytic amount of 4-DMAP at rt. After stirring was continued for 5.5 h at the same temperature, the reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give acetate **11b** (116 mg, 95%) as a colorless oil. [$\alpha$] +24.5 ($c$ 0.51 $CHCl_3$); IR (neat) 2952, 1741, 1509, 1384, 1215 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.68 (1H, s), 6.59 (1H, s), 5.49 (1H, dt, $J$ = 10.0 and 9.2 Hz), 5.27 (1H, m), 5.15 (1H, dd, $J$ = 10.0 and 2.4 Hz), 3.74 (6H, s), 2.58 (1H, m), 2.46 (1H, m), 2.16 (3H, s), 2.07 (3H, s), 1.56 (1H, dd, $J$ = 12.8 and 9.2 Hz), 1.45 (1H, dd, $J$ = 12.8 and 9.2 Hz), 1.25 (3H, s), 1.22 (3H, s), 0.00 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 170.7 (C), 151.4 (C), 147.6 (C), 142.1 (C), 127.8 (CH), 123.2 (CH), 122.1 (C), 115.7 (CH), 109.4 (CH), 81.9 (C), 78.7 (CH), 56.6 ($CH_3$), 56.0 ($CH_3$), 27.4 ($CH_2$), 23.4 ($CH_3$), 22.3 ($CH_3$), 21.2 ($CH_3$), 18.6 ($CH_2$), 15.9 ($CH_3$), −1.8 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{22}H_{37}O_5Si$ 409.2410 ($M^+$ + H), found 409.2412.

**(*Z*)-2-(2,5-Dimethoxy-4-methylphenoxy)-2-methyl-7-(trimethylsilyl)hept-5-en-3-yl Benzoate (11c).** To a stirred solution of *Z*-alkene **11a** (14.3 mg, 0.04 mmol) in $CH_2Cl_2$ (0.5 mL) was added pyridine (0.09 mL, 0.17 mmol), BzCl (0.07 mL, 0.60 mmol) and catalytic amount of 4-DMAP at 0 °C. After stirring was continued for 3 h at rt, the reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (95:5 v/v) as eluent to give benzoate **11c** (18.3 mg, quant.) as a colorless oil. IR (neat) 2953, 1721, 1508, 1385 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 8.10 (2H, d, $J$ = 8.4 Hz), 7.45 (1H, t, $J$ = 7.6 Hz), 7.45 (2H, dd, $J$ = 8.4 and 7.6 Hz), 6.70 (1H, s), 6.60 (1H, s), 5.51−5.45 (1H, m), 5.45 (1H, dd, $J$ = 10.0 and 2.8 Hz), 5.40−5.34 (1H, m), 3.74 (3H, s), 3.70 (3H, s), 2.82−2.73 (1H, m), 2.65−2.57 (1H, m), 2.18 (3H, s), 1.43 (1H, dd, $J$ = 13.2 and 8.0 Hz), 1.36 (3H, s), 1.35 (3H, s), 1.34 (1H, dd, $J$ = 13.2 and 5.2 Hz), −0.01 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 166.2 (C), 151.3 (C), 147.6 (C), 142.2 (C), 132.8 (CH), 130.6 (C), 129.8 (CH × 2), 128.3 (CH × 2), 127.9 (CH), 123.1 (CH), 122.1 (C), 115.6 (CH), 109.5 (CH), 82.3 (C), 79.2 (CH), 56.5 ($CH_3$), 55.9 ($CH_3$), 27.6 ($CH_2$), 23.4 ($CH_3$), 22.5 ($CH_3$), 18.6 ($CH_2$), 15.9 ($CH_3$), −1.8 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{27}H_{39}O_5Si$ 471.2567 ($M^+$ + H), found 471.2585.

**(*Z*)-(6-(2,5-Dimethoxy-4-methylphenoxy)-5-(methoxymethoxy)-6-methylhept-2-enyl)trimethylsilane (11d).** To a stirred solution of *Z*-alkene **11a** (100 mg, 0.27 mmol) in $CH_2Cl_2$ (1 mL) were added $^i$Pr$_2$NEt (0.24 mL, 1.37 mmol), MOMCl (0.06 mL, 0.82 mmol) and catalytic amount of 4-DMAP at 0 °C. After stirring was continued for 16.5 h at rt, the reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous $NH_4Cl$ and saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give MOM ether **11d** (104 mg, 92%) as a colorless oil. IR (neat) 2952, 1508, 1385, 1215, 1044 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.68 (1H, s), 6.56 (1H, s), 5.54−5.45 (2H, m), 4.78 (2H, s), 3.73 (6H, s), 3.68 (1H, dd, $J$ = 3.2 and 8.8 Hz), 3.40 (3H, s), 2.63 (1H, dt, $J$ = 14.8 and 3.2 Hz), 2.29 (1H, ddd, $J$ = 14.8, 8.8, and 3.1 Hz), 2.16 (3H, s), 1.56 (1H, dd, $J$ = 13.2 and 7.2 Hz), 1.48 (1H, dd, $J$ = 13.2 and 6.8 Hz), 1.25 (3H, s), 1.23 (3H, s), 0.02 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.2 (C), 147.8 (C), 142.3 (C), 126.6 (CH), 125.2 (CH), 121.8 (C), 115.7 (CH), 109.6 (CH), 97.7 ($CH_2$), 84.5 (CH), 83.9 (C), 56.6 ($CH_3$), 56.0 ($CH_3$), 28.8 ($CH_2$), 23.0 ($CH_3$ × 2), 22.3 ($CH_3$), 18.6 ($CH_2$), 15.9 ($CH_3$), −1.7 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{22}H_{39}O_5Si$ 411.2567 ($M^+$ + H), found 411.2572.

**(*Z*)-(2-(2,5-Dimethoxy-4-methylphenoxy)-2-methyl-7-(trimethylsilyl)hept-5-en-3-yloxy)triisopropylsilane (11e).** To a stirred solution of *Z*-alkene **11a** (355 mg, 0.97 mmol) in $CH_2Cl_2$ (5 mL) were added $Et_3N$ (0.68 mL, 4.85 mmol) and TIPSOTf (0.39 mL, 1.45 mmol) at 0 °C. After stirring was continued for 2 h at rt, the reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (95:5 v/v) as eluent to give silyl ether **11e** (472 mg, 93%) as a colorless oil. IR (neat) 2946, 2360, 1385 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.69 (1H, s), 6.51 (1H, s), 5.58 (1H, dt, $J$ = 10.0 and 6.8 Hz), 5.45 (1H, dt, $J$ = 10.0 and 8.4 Hz), 4.05 (1H, dd, $J$ = 6.4 and 4.4 Hz), 3.73 (6H, s), 2.76−2.67 (1H, m), 2.28 (1H, dt, $J$ = 14.0 and 6.4 Hz), 2.17 (3H, s), 1.51 (2H, dd, $J$ = 8.4 and 8.0 Hz), 1.26 (3H, s), 1.20 (3H, s), 1.20−1.02 (21H, m), 0.00 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.1 (C), 147.8 (C), 142.5 (C), 125.9 (CH), 125.7 (CH), 121.5 (C), 115.7 (CH), 109.7 (CH), 84.6 (C), 79.3 (CH), 56.6 ($CH_3$), 55.9 ($CH_3$), 31.1 ($CH_2$), 23.6 ($CH_3$), 21.1 ($CH_3$), 18.7 ($CH_2$), 18.4 ($CH_3$ × 6), 15.9 ($CH_3$), 13.3 (CH × 3), −1.7 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{29}H_{55}O_4Si_2$ 523.3639 ($M^+$ + H), found 523.3619.

**(*S*,*Z*)-2-Methyl-2-(4-methyl-3,6-dioxocyclohexa-1,4-dienyloxy)-7-(trimethylsilyl)hept-5-en-3-yl Acetate (*S*)-4b.** To a stirred solution of acetate (*S*)-**11b** (130 mg, 0.32 mmol) in $CH_3CN/H_2O$ (4: 1 v/v, 1 mL) was added CAN (348 mg, 0.64 mmol) at 0 °C. After stirring was continued for 5 min at the same temperature, the reaction mixture was diluted with water and extracted with $Et_2O$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give quinone (*S*)-**4b** (118 mg, 97%) as yellow crystals. Mp 100−102 °C (hexane); [$\alpha$] +12.7 ($c$ 0.60 $CHCl_3$); IR (neat) 2953, 2360, 1740, 1652, 1601, 1385 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.52 (1H, d, $J$ = 1.6 Hz), 6.15 (1H, s), 5.51 (1H, dt, $J$ = 10.4 and 8.4 Hz), 5.24−5.18 (1H, m), 5.19 (1H, dd, $J$ = 8.8 and 4.0 Hz), 2.45−2.35 (2H, m), 2.07 (3H, s), 2.03 (3H, d, $J$ = 1.6 Hz), 1.47 (6H, s), 1.51−1.39 (2H, m), 0.00 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.1 (C), 182.7 (C), 170.4 (C), 154.8 (C), 145.9 (C), 131.8 (CH), 128.8 (CH), 121.8 (CH), 112.9 (CH), 84.6 (C), 77.1 (CH), 26.9 ($CH_2$), 22.5 ($CH_3$), 21.6 ($CH_3$), 21.0 ($CH_3$), 18.6 ($CH_2$), 15.6 ($CH_3$), −1.8 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{20}H_{30}O_5NaSi$ 401.1760 ($M^+$ + Na), found 401.1757.

**(*Z*)-2-Methyl-2-(4-methyl-3,6-dioxocyclohexa-1,4-dienyloxy)-7-(trimethylsilyl)hept-5-en-3-yl Benzoate (4c).** By following the same procedure described for (*S*)-**4b**, quinone **4c** (16.6 mg, 97%) was prepared from benzoate **11c** (18.3 mg, 0.04 mmol): yield 97%; yellow oil. IR (neat) 2953, 1721, 1652, 1601 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 8.05 (2H, d, $J$ = 8.0 Hz), 7.57 (1H, t, $J$ = 7.2 Hz), 7.45 (2H, dd, $J$ = 8.0 and 7.2 Hz), 6.53 (1H, q, $J$ = 1.6 Hz), 6.22 (1H, s), 5.51−5.44 (1H, m), 5.44 (1H, dd, $J$ = 9.2 and 3.6 Hz), 5.32−5.24 (1H, m), 2.64−2.48 (2H, m), 2.04 (3H, d, $J$ = 1.6 Hz), 1.56 (6H, s), 1.60−1.51 (1H, m), 1.46−1.37 (1H, m), −0.01 (9H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.1 (C), 182.6 (C), 165.9 (C), 154.9 (C), 145.9 (C), 133.1 (CH), 131.8 (CH), 129.8 (CH × 2), 128.9 (CH), 128.4 (CH × 2), 121.7 (CH), 113.0 (CH), 84.7 (C), 77.8 (CH), 53.4 (C), 27.0 ($CH_2$), 23.0 ($CH_3$), 21.5 ($CH_3$), 18.6 ($CH_2$), 15.6 ($CH_3$), −1.8 ($CH_3$ × 3); HRMS (ESI) calcd for $C_{25}H_{33}O_5Si$ 441.2097 ($M^+$ + H), found 441.2096.

**(*Z*)-2-(3-(Methoxymethoxy)-2-methyl-7-(trimethylsilyl)hept-5-en-2-yloxy)-5-methylcyclohexa-2,5-diene-1,4-dione (4d).** By following the same procedure described for (*S*)-**4b**, quinone **4d** (79.8 mg, 84%) was prepared from MOM ether **11d** (104 mg, 0.25 mmol): yield 84%; yellow crystals. Mp 51.3−52.1 °C (hexane); IR (KBr) 2954, 1672, 1651, 1601 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.51 (1H, d, $J$ = 1.6 Hz), 6.14 (1H, s), 5.49 (1H, dt, $J$ = 10.8 and 8.0 Hz), 5.43 (1H, dt, $J$ = 10.8 and 6.8 Hz), 4.79 (1H, dd, $J$ = 8.8 and 4.0 Hz), 4.74 (1H, d, $J$ = 6.8 Hz), 3.74 (1H, dd, $J$ = 3.2 and 8.0 Hz), 3.38 (3H, s), 2.44−2.34 (1H, m), 2.22 (1H, dt, $J$ = 16.0 and 8.0 Hz), 2.03 (3H, d, $J$ = 1.6 Hz), 1.56−1.42 (2H, m), 1.52 (3H, s), 1.47 (3H, s), 0.00 (9H, s); $^{13}$C


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NMR (100 MHz, $CDCl_3$) $\delta$ 188.1 (C), 182.7 (C), 170.4 (C), 154.8 (C), 145.9 (C), 131.8 (CH), 128.8 (CH), 121.8 (CH), 112.9 (CH), 84.6 (C), 77.1 (CH), 26.9 ($CH_2$), 22.5 ($CH_3$), 21.6 ($CH_3$), 21.0 ($CH_3$), 18.6 ($CH_2$), 15.6 ($CH_3$), −1.8 ($CH_3 \times 3$); HRMS (ESI) calcd for $C_{20}H_{33}O_5Si$ 381.2097 ($M^+ + H$), found 381.2081.

**(*Z*)-2-Methyl-5-(2-methyl-3-(triisopropylsilyloxy)-7-(trimethylsilyl)hept-5-en-2-yloxy)cyclohexa-2,5-diene-1,4-dione (4e).** By the same procedure described for (*S*)-**4b**, quinone **4e** (222 mg, 50%) was prepared from silyl ether **11e** (472 mg, 0.90 mmol): yield 50%; yellow oil. IR (neat) 2946, 1599, 1385 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.51 (1H, d, *J* = 1.6 Hz), 6.15 (1H, s), 5.51−5.40 (2H, m), 4.08 (1H, t, *J* = 5.6 Hz), 2.53−2.46 (1H, m), 2.29−2.21 (1H, m), 2.04 (3H, d, *J* = 1.6 Hz), 1.54 (3H, s), 1.58−1.44 (2H, m), 1.44 (3H, s), 1.20−1.00 (21H, m), 0.00 (9H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.3 (C), 182.8 (C), 155.3 (C), 145.8 (C), 131.7 (CH), 126.9 (CH), 123.9 (CH), 112.0 (CH), 87.4 (C), 78.1 (CH), 31.1 ($CH_2$), 23.0 ($CH_3$), 20.1 ($CH_3$), 18.6 ($CH_2$), 18.3 ($CH_3 \times 6$), 17.7 ($CH_3$), 13.1 ($CH \times 3$), −1.7 ($CH_3 \times 3$); HRMS (ESI) calcd for $C_{27}H_{49}O_4Si_2$ 493.3169 ($M^+ + H$), found 493.3165.

**(3*S*,5*R*)-2-Hydroxy-2-methyl-5-(4-methyl-3,6-dioxocyclohexa-1,4-dienyl)hept-6-en-3-yl Acetate (12b).** To a stirred solution of quinone (*S*)-**4b** (103 mg, 0.27 mmol) in $(CH_3)_2CHCN$ (1 mL) was added dropwise TBSOTf (0.12 mL, 0.54 mol) at −10 °C. After stirring was continued for 0.5 h at the same temperature, the reaction mixture was quenched with saturated aqueous $NaHCO_3$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (7:3 v/v) as eluent to give quinone (3*S*,5*R*)-**12b** (55.4 mg, 67%, dr = 7:1) as a yellow oil. The diastereomixture of (3*S*,5*R*)-**12b** were partially separated with HPLC column (Mightysil, 20% AcOEt−hexane, 8 mL/min). *anti*-Quinone (3*S*,5*R*)-**12b**: [$\alpha$] −9.7 (*c* 0.49 $CHCl_3$); IR (neat) 3471, 2979, 1731, 1656, 1376, 1242 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.59 (1H, d, *J* = 0.8 Hz), 6.54 (1H, s), 5.74 (1H, ddd, *J* = 17.2, 10.0, and 4.0 Hz), 5.20 (1H, d, *J* = 10.0 Hz), 5.16 (1H, d, *J* = 17.2 Hz), 4.88 (1H, dd, *J* = 10.4 and 2.0 Hz), 3.43 (1H, dt, *J* = 9.2 and 4.0 Hz), 2.14 (3H, s), 2.04 (3H, d, *J* = 0.8 Hz), 1.93−1.77 (2H, m), 1.75 (1H, s, $D_2O$ exchangeable), 1.19 (3H, s), 1.18 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.1 (C), 186.6 (C), 171.0 (C), 150.6 (C), 145.3 (C), 136.7 (CH), 133.7 (CH), 132.0 (CH), 118.6 ($CH_2$), 77.4 (CH), 72.4 (C), 38.9 (CH), 33.6 ($CH_2$), 26.4 ($CH_3$), 25.2 ($CH_3$), 21.0 ($CH_3$), 15.3 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{23}O_5$ 307.1545 ($M^+ + H$), found 307.1553. *syn*-Quinone (3*S*, 5*S*)-**12b**: IR (neat) 3427, 2978, 1732, 1656, 1385 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, d, *J* = 1.6 Hz), 6.49 (1H, s), 5.77 (1H, ddd, *J* = 17.2, 10.0, and 7.6 Hz), 5.08 (1H, d, *J* = 17.2 Hz), 5.06 (1H, d, *J* = 10.0 Hz), 4.73 (1H, dd, *J* = 9.6 and 3.6 Hz), 3.56 (1H, dt, *J* = 7.6 and 7.2 Hz), 2.06 (3H, s), 2.04 (3H, d, *J* = 1.6 Hz), 2.02−1.96 (2H, m), 1.62 (1H, s, $D_2O$ exchangeable), 1.18 (3H, s), 1.17 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.1 (C), 186.7 (C), 170.9 (C), 149.5 (C), 145.4 (C), 138.5 (CH), 133.8 (CH), 132.3 (CH), 116.3 ($CH_2$), 77.2 (CH), 72.3 (C), 38.5 (CH), 32.8 ($CH_2$), 26.4 ($CH_3$), 25.2 ($CH_3$), 21.0 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{23}O_5$ 307.1545 ($M^+ + H$), found 307.1541.

**2-Methyl-2-(4-methyl-3,6-dioxocyclohexa-1,4-dienyloxy)-hept-6-en-3-yl Acetate (13b).** **13b** (15.7 mg, 19%) was obtained as yellow crystals; Mp 102.1−102.4 °C (hexane); IR (KBr) 2983, 1736, 1674, 1651, 1606 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.52 (1H, q, *J* = 1.6 Hz), 6.15 (1H, s), 5.80 (1H, ddt, *J* = 16.8, 10.0, and 6.8 Hz), 5.18 (1H, dd, *J* = 10.0 and 2.8 Hz), 5.04 (1H, dd, *J* = 16.8 and 1.6 Hz), 4.99 (1H, dd, *J* = 10.0 and 1.6 Hz), 2.11 (3H, s), 2.13−2.07 (2H, m), 2.04 (3H, d, *J* = 1.6 Hz), 1.85−1.68 (2H, m), 1.46 (6H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.0 (C), 182.7 (C), 170.4 (C), 154.8 (C), 145.9 (C), 137.3 (CH), 131.8 (CH), 115.4 ($CH_2$), 113.1 (CH), 84.7 (C), 76.7 (CH), 30.0 ($CH_2$), 28.5 ($CH_2$), 22.3 ($CH_3$), 21.6 ($CH_3$), 20.9 ($CH_3$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{22}O_5Na$ 329.1365 ($M^+ + Na$), found 329.1381.

**2-Hydroxy-2-methyl-5-(4-methyl-3,6-dioxocyclohexa-1,4-dienyl)hept-6-en-3-yl Benzoate (12c).** By following the same procedure described for (*S*)-**12b**, quinone **12c** (9.4 mg, 68%, dr = 8:1) was prepared from benzoate **4c** (16.6 mg, 0.04 mmol); yellow oil. The diastereomixture of **12c** were partially separated with HPLC column (Mightysil, 25% AcOEt−hexane, 10 mL/min). *anti*-Quinone **12c**: IR (neat) 3484, 2979, 1716, 1654 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 8.04 (2H, d, *J* = 8.0 Hz), 7.58 (1H, t, *J* = 8.0 Hz), 7.45 (2H, t, *J* = 8.0 Hz), 6.51 (1H, s), 6.43 (1H, d, *J* = 1.6 Hz), 5.81 (1H, ddd, *J* = 17.2, 10.0, and 8.4 Hz), 5.17 (1H, d, *J* = 17.2 Hz), 5.16 (1H, d, *J* = 10.0 Hz), 5.20−5.10 (1H, m), 3.48 (1H, dt, *J* = 5.6 and 8.4 Hz), 2.12 (1H, ddd, *J* = 14.0, 10.0, and 5.6 Hz), 2.01 (1H, ddd, *J* = 14.0, 8.4, and 1.6 Hz), 1.87 (3H, d, *J* = 1.6 Hz), 1.83 (1H, s, $D_2O$ exchangeable), 1.27 (3H, s), 1.25 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.0 (C), 186.7 (C), 166.4 (C), 150.2 (C), 145.0 (C), 137.1 (CH), 133.6 (CH), 133.2 (CH), 132.3 (CH), 129.8 (CH × 2), 129.8 (C), 128.5 (CH × 2), 118.2 ($CH_2$), 78.4 (CH), 72.6 (C), 40.4 (CH), 33.7 ($CH_2$), 26.3 ($CH_3$), 25.4 ($CH_3$), 15.2 ($CH_3$); HRMS (ESI) calcd for $C_{22}H_{25}O_5$ 369.1702 ($M^+ + H$), found 369.1707. *syn*-Quinone **12c**: IR (neat) 3503, 2979, 1717, 1655 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 7.98 (2H, d, *J* = 8.0 Hz), 7.58 (1H, t, *J* = 8.0 Hz), 7.45 (2H, t, *J* = 8.0 Hz), 6.52 (1H, q, *J* = 2.0 Hz), 6.49 (1H, s), 5.82 (1H, ddd, *J* = 17.2, 10.0, and 8.0 Hz), 5.07 (1H, d, *J* = 17.2 Hz), 5.02 (1H, dd, *J* = 10.0 and 2.8 Hz), 5.01 (1H, d, *J* = 10.0 Hz), 3.58 (1H, dt, *J* = 5.6 and 8.0 Hz), 2.20 (1H, ddd, *J* = 14.8, 8.0, and 2.8 Hz), 2.12 (1H, ddd, *J* = 14.8, 10.0, and 5.6 Hz), 1.95 (3H, d, *J* = 2.0 Hz), 1.79 (1H, brs, $D_2O$ exchangeable), 1.26 (6H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.0 (C), 186.8 (C), 166.2 (C), 149.5 (C), 145.2 (C), 138.0 (CH), 133.8 (CH), 133.1 (CH), 132.5 (CH), 129.9 (C), 129.7 (CH × 2), 128.4 (CH × 2), 116.7 ($CH_2$), 77.6 (CH), 72.6 (C), 39.4 (CH), 33.0 ($CH_2$), 26.1 ($CH_3$), 25.6 ($CH_3$), 15.3 ($CH_3$); HRMS (ESI) calcd for $C_{22}H_{25}O_5$ 369.1702 ($M^+ + H$), found 369.1713.

**(3*S*,5*R*)-5-(2,5-Dihydroxy-4-methylphenyl)-2-hydroxy-2-methylhept-6-en-3-yl Acetate (3*S*,5*R*)-25.** To a stirred solution of quinone (3*S*,5*R*)-**12b** (63.5 mg, 0.21 mmol) in THF (1 mL) was added $Na_2S_2O_4$ (108 mg, 0.62 mol) in $H_2O$ (0.1 mL) at 0 °C. After stirring was continued for 2.5 h at rt, the reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (1:1 v/v) as eluent to give hydroquinone (3*S*,5*R*)-**25** (64.7 mg, 99%) as colorless crystals. Mp 192.2−193.6 °C (MeOH); [$\alpha$] −6.4 (*c* 0.29 $CHCl_3$); IR (neat) 3379, 2979, 1712, 1418, 1384 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.59 (1H, s), 6.56 (1H, s), 5.92 (1H, ddd, *J* = 17.4, 10.4, and 7.2 Hz), 5.15 (1H, dd, *J* = 10.4 and 1.2 Hz), 5.13 (1H, dd, *J* = 17.4 and 1.2 Hz), 4.93 (1H, dd, *J* = 9.6 and 2.4 Hz), 4.71 (1H, brs, $D_2O$ exchangeable), 4.57 (1H, brs, $D_2O$ exchangeable), 3.52 (1H, dt, *J* = 7.2 and 5.6 Hz), 2.17 (3H, s), 2.12−2.02 (1H, m), 2.05−1.92 (1H, m), 1.97 (3H, s), 1.82 (1H, brs, $D_2O$ exchangeable), 1.22 (3H, s), 1.20 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 171.6 (C), 147.9 (C), 146.6 (C), 140.0 (CH), 128.0 (C), 123.0 (C), 118.9 (CH), 115.8 ($CH_2$), 114.6 (CH), 78.3 (CH), 72.8 (C), 40.3 (CH), 33.8 ($CH_2$), 26.3 ($CH_3$), 25.2 ($CH_3$), 20.9 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{25}O_5$ 309.1702 ($M^+ + H$), found 309.1695.

**(3*S*,5*R*)-2-(2,3-Dihydroxy-2-methylhept-6-en-5-yl)-5-methylbenzene-1,4-diol (3*S*,5*R*)-26.** To a stirred solution of hydroquinone (3*S*,5*R*)-**25** (10.2 mg, 0.03 mmol) in THF (1 mL) was added dropwise 0.97 M solution of DIBAH in hexane (0.14 mL, 0.13 mmol) at 0 °C. After stirring was continued for 1.5 h at the same temperature, the reaction mixture was quenched with MeOH. After filtration through a Celite pad, the resulting solution was extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (35:65 v/v) as eluent to give tetraol (3*S*,5*R*)-**26** (5.9 mg, 67%) as a colorless oil. [$\alpha$] −48.7 (*c* 0.66 acetone); IR (neat) 3388, 2976, 1415, 1384 $cm^{-1}$; $^1H$ NMR (400 MHz, $CD_3COCD_3$) $\delta$ 7.30 (1H, s, $D_2O$ exchangeable), 7.19 (1H, s, $D_2O$ exchangeable), 6.47 (1H, s), 6.44 (1H, s), 5.85 (1H, ddd, *J* = 17.2, 10.4, and 8.4 Hz), 4.94 (1H, dd, *J* = 17.2 and 2.0 Hz), 4.86 (1H, dd, *J* = 10.4 and 2.0 Hz), 3.76 (1H, td, *J* = 8.4 and 3.6 Hz), 3.45 (1H, d, *J* = 5.2 Hz, $D_2O$ exchangeable), 3.30 (1H, ddd, *J* = 10.4, 5.2, and 2.0 Hz), 3.23 (1H, s, $D_2O$ exchangeable), 1.96 (3H, s), 1.95 (1H, ddd, *J* = 13.6, 8.4, and 2.0 Hz), 1.38 (1H, ddd,


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$J$ = 13.6, 10.4, and 3.6 Hz), 1.00 (3H, s), 0.99 (3H, s); $^{13}$C NMR (100 MHz, $CD_3COCD_3$) $\delta$ 149.1(C), 147.9 (C), 142.2 (CH), 130.5 (C), 122.9 (C), 118.6 (CH), 115.1 (CH), 114.6 ($CH_2$), 76.7 (CH), 72.8 (C), 40.6 (CH), 37.6 ($CH_2$), 25.8 ($CH_3$), 25.2 ($CH_3$), 15.8 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{23}O_4$ 267.1596 ($M^+$ + H), found 267.1601.

**(3*S*,5*R*)-2-(2,3-Dihydroxy-2-methylhept-6-en-5-yl)-5-methylcyclohexa-2,5-diene-1,4-dione (3*S*,5*R*)-27.** By following the same procedure described for (*S*)-**4b**, quinonediol (3*S*,5*R*)-**27** (2.3 mg, 39%) was prepared from tetraol (3*S*,5*R*)-**26** (5.9 mg, 0.02 mmol): yield 39%; yellow oil. [$\alpha$] −63.2 (*c* 0.38 $CHCl_3$); IR (neat) 3438, 2972, 1649, 1383 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, q, $J$ = 1.6 Hz), 6.54 (1H, s), 5.78 (1H, ddd, $J$ = 17.2, 10.0, and 9.6 Hz), 5.22 (1H, dd, $J$ = 17.2 and 1.2 Hz), 5.20 (1H, dd, $J$ = 10.0 and 1.2 Hz), 3.73 (1H, td, $J$ = 9.6 and 3.6 Hz), 3.46 (1H, ddd, $J$ = 10.8, 5.2, and 2.0 Hz), 2.24 (1H, d, $J$ = 5.2 Hz, $D_2O$ exchangeable), 2.04 (3H, d, $J$ = 1.6 Hz), 1.82 (1H, s, $D_2O$ exchangeable), 1.74 (1H, ddd, $J$ = 13.6, 9.6, and 2.0 Hz), 1.52 (1H, ddd, $J$ = 13.6, 10.8, and 3.6 Hz), 1.21 (3H, s), 1.15 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.3 (C), 187.1 (C), 151.4 (C), 145.4 (C), 137.3 (CH), 133.8 (CH), 131.9 (CH), 118.1 ($CH_2$), 75.9 (CH), 72.9 (C), 39.5 (CH), 35.7 ($CH_2$), 26.4 ($CH_3$), 23.6 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{21}O_4$ 265.1440 ($M^+$ + H), found 265.1447.

**(2*S*,4*R*,5*R*)-2-(2-Hydroxypropan-2-yl)-8-methyl-4-vinyl-1-oxaspiro[4.5]dec-7-ene-6,9-dione (2), (2*S*,4*R*,5*S*)-2-(2-Hydroxypropan-2-yl)-8-methyl-4-vinyl-1-oxaspiro[4.5]dec-7-ene-6,9-dione (3).** To a stirred solution of quinone (3*S*, 5*R*)-**21** (4.0 mg, 0.015 mmol) in $CH_2Cl_2$ (0.5 mL) was added $Cs_2CO_3$ (24.7 mg, 0.076 mmol) at 0 °C. After stirring was continued for 30 min at rt, the reaction mixture was diluted with water and extracted with $CH_2Cl_2$. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (8:2 v/v) as eluent to give heliespirone A (**2**) (1.3 mg, 34%) as colorless crystals and heliespirone C (**3**) (1.7 mg, 42%) as colorless crystals. Heliespirone A (**2**): mp 105−106 °C (isopropylether−hexane); [$\alpha$] −55.2 (*c* 0.13 $CHCl_3$); IR (KBr) 3454, 2970, 1678 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.63 (1H, d, $J$ = 1.2 Hz), 5.31 (1H, dt, $J$ = 16.8 and 9.6 Hz), 5.08 (1H, dd, $J$ = 16.8 and 1.3 Hz), 4.97 (1H, dd, $J$ = 9.6 and 1.3 Hz), 4.83 (1H, brs, $D_2O$ exchangeable), 4.04 (1H, dd, $J$ = 10.8 and 5.2 Hz), 3.25 (1H, d, $J$ = 15.6 Hz), 2.97 (1H, d, $J$ = 15.6 Hz), 2.92 (1H, ddd, $J$ = 12.8, 9.6, and 6.4 Hz), 2.15 (1H, td, $J$ = 12.8 and 6.4 Hz), 1.97 (1H, ddd, $J$ = 12.8, 10.8, and 5.2 Hz), 1.97 (3H, d, $J$ = 1.2 Hz), 1.34 (3H, s), 1.10 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 201.2 (C), 195.5 (C), 153.5 (C), 137.0 (CH), 135.3 (CH), 118.4 ($CH_2$), 87.6 (C), 86.7 (CH), 70.0 (C), 57.1 (CH), 51.8 ($CH_2$), 31.8 ($CH_2$), 28.3 ($CH_3$), 25.2 ($CH_3$), 15.9 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{21}O_4$ 265.1440 ($M^+$ + H), found 265.1434. Heliespirone C (**3**): mp 74.0−74.7 °C (isopropylether−hexane); [$\alpha$] +50.4 (*c* 0.40 $CHCl_3$); IR (KBr) 3482, 2966, 1691, 1676, 1384 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.68 (1H, d, $J$ = 1.6 Hz), 5.63 (1H, ddd, $J$ = 16.4, 10.4, and 8.4 Hz), 5.12 (1H, d, $J$ = 10.4 Hz), 5.12 (1H, d, $J$ = 16.4 Hz), 3.96 (1H, dd, $J$ = 10.8 and 5.2 Hz), 3.29 (1H, ddd, $J$ = 11.6, 8.4, and 6.8 Hz), 2.96 (1H, d, $J$ = 16.4 Hz), 2.84 (1H, d, $J$ = 16.4 Hz), 2.06 (1H, ddd, $J$ = 12.4, 6.8, and 5.2 Hz), 2.00 (3H, d, $J$ = 1.6 Hz), 1.98 (1H, ddd, $J$ = 12.4, 11.6, and 10.8 Hz), 1.82 (1H, brs, $D_2O$ exchangeable), 1.25 (3H, s), 1.13 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 196.6 (C), 196.2 (C), 151.8 (C), 137.0 (CH), 134.5 (CH), 119.7 ($CH_2$), 86.8 (C), 86.6 (CH), 70.2 (C), 48.7 ($CH_2$), 47.0 (CH), 32.3 ($CH_2$), 27.6 ($CH_3$), 24.5 ($CH_3$), 16.1 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{21}O_4$ 265.1440 ($M^+$ + H), found 265.1450.

**2-(6-Hydroxy-7-methyl-4-vinylchroman-2-yl)propan-2-yl Acetate (15).** To a stirred solution of quinone **12b** (5.9 mg, 0.02 mmol) in THF (1 mL) was added $Na_2S_2O_4$ (10.1 mg, 0.06 mmol) in $H_2O$ (0.1 mL) at 0 °C. After stirring was continued for 5 min at rt, the reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was dissolved in 2 mL of benzene and added *p*-TsOH (0.54 mg, 3.0 $\mu$mol). The resulting mixture was refluxed for 30 min, the reaction mixture was extracted with $Et_2O$. The combined extracts were washed with saturated aqueous $NaHCO_3$ and saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give acetate **15** (5.6 mg, quant. for 2 steps) as colorless crystals. Mp 125−127 °C (isopropylether−hexane); IR (KBr) 3458, 2925, 1714 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.62 (1H, s), 6.55 (1H, s), 5.68 (1H, dt, $J$ = 16.8 and 9.6 Hz), 5.26 (1H, dd, $J$ = 16.8 and 1.6 Hz), 5.20 (1H, dd, $J$ = 9.6 and 1.6 Hz), 4.27 (1H, brs, $D_2O$ exchangeable), 4.22 (1H, dd, $J$ = 12.0 and 1.2 Hz), 3.53−3.45 (1H, m), 2.18 (3H, s), 2.02 (3H, s), 2.03−1.99 (1H, m), 1.68−1.60 (1H, m), 1.58 (3H, s), 1.53 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 170.3 (C), 148.2 (C), 147.4 (C), 140.7 (CH), 123.8 (C), 122.1 (C), 118.6 (CH), 116.8 ($CH_2$), 114.4 (CH), 82.5 (CH), 78.8 (C), 41.0 (CH), 29.5 ($CH_2$), 22.8 ($CH_3$), 22.4 ($CH_3$), 21.2 ($CH_3$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{23}O_4$ 291.1596 ($M^+$ + H), found 291.1598.

**2-(2-Hydroxypropan-2-yl)-7-methyl-4-vinylchroman-6-ol (16).** To a stirred solution of chroman **15** (2.2 mg, 7.5 $\mu$mol) in MeOH (0.5 mL) was added 5% aqueous NaOH (0.1 mL) at rt. The mixture was warmed to 50 °C and stirred for 2 h. The reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (8:2 v/v) as eluent to give *epi*-heliannuol E (**16**) (1.8 mg, quant.) as colorless oil. IR (KBr) 3375, 2923, 1506, 1416, 1193, 1007 cm$^{-1}$; $^1$H NMR (500 MHz, $CDCl_3$) $\delta$ 6.64 (1H, s), 6.55 (1H, s), 5.68 (1H, dt, $J$ = 17.2 and 9.8 Hz), 5.24 (1H, dd, $J$ = 17.2 and 1.7 Hz), 5.19 (1H, dd, $J$ = 9.8 and 1.7 Hz), 4.35 (1H, brs, $D_2O$ exchangeable), 3.80 (1H, dd, $J$ = 11.4 and 1.7 Hz), 3.51−3.45 (1H, m), 2.38 (1H, brs, $D_2O$ exchangeable), 2.19 (3H, s), 2.02 (1H, ddd, $J$ = 13.8, 5.2, and 1.7 Hz), 1.64 (1H, ddd, $J$ = 13.8, 12.0, and 11.4 Hz), 1.31 (3H, s), 1.26 (3H, s); $^{13}$C NMR (125 MHz, $CDCl_3$) $\delta$ 148.0 (C), 147.5 (C), 140.7 (CH), 123.8 (C), 122.1 (C), 118.5 (CH), 116.8 ($CH_2$), 114.5 (CH), 81.5 (C), 71.8 (CH), 41.0 (CH), 30.0 ($CH_2$), 25.9 ($CH_3$), 24.3 ($CH_3$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{21}O_3$ 249.1491 ($M^+$ + H), found 249.1486.

**1-Allyloxy-2,5-dimethoxy-4-methylbenzene (30).** To a stirred solution of phenol **7** (1.56 g, 9.26 mmol), $K_2CO_3$ (2.82 g, 20.4 mmol) and allylbromide (1.1 mL, 13.0 mmol) in acetone (30 mL) were refluxed for 23 h. The reaction mixture was filtered through a Celite pad, and solvents were removed under vacuum. The residue was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give alkene **30** (1.72 g, 89%) as a colorless oil. IR (neat) 1385, 1216 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.53 (1H, s), 6.08 (1H, ddt, $J$ = 17.2, 10.2, and 5.6 Hz), 5.40 (1H, d, $J$ = 17.2 Hz), 5.27 (1H, d, $J$ = 10.2 Hz), 4.59 (2H, d, $J$ = 5.6 Hz), 3.82 (3H, s), 3.77 (3H, s), 2.16 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.5 (C), 146.4 (C), 143.4 (C), 133.7 (CH), 118.7 (C), 117.5 ($CH_2$), 115.5 (CH), 100.4 (CH), 70.6 ($CH_2$), 56.7 ($CH_3$), 56.1 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{12}H_{16}O_3Na$ 231.0997 ($M^+$ + Na), found 231.0986.

**3-(2,5-Dimethoxy-4-methylphenoxy)propane-1,2-diol (31).** To a stirred solution of alkene **30** (7.70 mg, 0.04 mmol) in $^t$BuOH/$H_2O$ (2: 1 v/v, 0.5 mL) were added *N*-methylmorphrine-*N*-oxide (6.50 mg, 0.06 mmol), and 2.0 w/v solution of $OsO_4$ in water (0.05 mL, 0.4 $\mu$mol) at rt. After stirring was continued for 4 h at the same temperature, the reaction mixture was quenched with saturated aqueous $Na_2SO_3$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (2:8 v/v) as eluent to give diol **31** (10.7 mg, quant.) as colorless needles. Mp 86.9−88.2 °C (AcOEt/hexane); IR (KBr) 3446, 2935, 1525, 1215 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.54 (1H, s), 4.11 (1H, dd, $J$ = 12.8 and 6.8 Hz), 4.04 (1H, dd, $J$ = 12.8 and 6.4 Hz), 4.07−4.02 (1H, m), 3.84−3.72 (2H, m), 3.81 (3H, s), 3.77 (3H, s), 3.70−3.52 (1H, br, $D_2O$ exchangeable), 2.84−2.66 (1H, br, $D_2O$ exchangeable), 2.17 (3H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (C), 146.2 (C), 143.5 (C), 120.0 (C), 115.4 (CH), 101.3 (CH), 73.2 ($CH_2$), 70.1 (CH), 63.7 ($CH_2$), 56.7 ($CH_3$), 56.1 ($CH_3$), 15.7 ($CH_3$); HRMS (ESI) calcd for $C_{12}H_{18}O_5Na$ 265.1052 ($M^+$ + Na), found 265.1053.


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**3-(2,5-Dimethoxy-4-methylphenoxy)-2-hydroxypropyl 4-methylbenzenesulfonate (32).** To a stirred solution of diol **31** (0.74 g, 3.55 mmol) in $CH_2Cl_2$ (15 mL) were added $Et_3N$ (0.74 mL, 5.33 mol), TsCl (0.34 g, 1.77 mmol) and catalytic amount of DMAP at 0 °C. After stirring was continued for 1.5 h at rt, the reaction mixture was diluted with water and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (8:2 v/v) as eluent to give tosylate **32** (0.57 g, 40%) as a colorless oil and some starting material was recovered (0.40 g, 46%). IR (neat) 3434, 2936, 1518 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 7.76 (2H, d, $J$ = 8.0 Hz), 7.27 (2H, d, $J$ = 8.0 Hz), 6.68 (1H, s), 6.48 (1H, s), 4.20 (1H, dd, $J$ = 12.0 and 11.2 Hz), 4.14 (1H, dd, $J$ = 11.2 and 4.8 Hz), 4.17−4.10 (1H, m), 3.99 (2H, d, $J$ = 4.0 Hz), 3.79−3.69 (1H, m, $D_2O$ exchangeable), 3.73 (6H, s), 2.39 (3H, s), 2.15 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.7 (C), 145.9 (C), 144.8 (C), 143.3 (C), 132.3 (CH), 129.7 (CH × 2), 127.7 (CH × 2), 120.0 (C), 115.5 (CH), 101.4 (CH), 71.2 ($CH_2$), 70.1 ($CH_2$), 67.8 (CH), 56.5 ($CH_3$), 55.9 ($CH_3$), 21.4 ($CH_3$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{19}H_{24}O_7NaS$ 419.1140 ($M^+$ + Na), found 419.1144.

**2-[(2,5-Dimethoxy-4-methylphenoxy)methyl]oxirane (33).** By the same procedure described for (*S*)-**5**, epoxide **33** (0.32 g, quant.)was prepared from tosylate **32** (0.57 g, 1.44 mmol): quantitative yield; colorless needles. Mp 70.1−70.6 °C (hexane); IR (neat) 2939, 1520 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.60 (1H, s), 4.26 (1H, dd, $J$ = 11.6 and 3.2 Hz), 4.01 (1H, dd, $J$ = 11.6 and 5.6 Hz), 3.82 (3H, s), 3.78 (3H, s), 3.37 (1H, dddd, $J$ = 5.6, 4.4, 3.2, and 2.8 Hz), 2.88 (1H, dd, $J$ = 4.8 and 4.4 Hz), 2.73 (1H, dd, $J$ = 4.8 and 2.8 Hz), 2.16 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.6 (C), 146.3 (C), 143.5 (C), 119.5 (C), 115.7 (CH), 101.0 (CH), 71.3 ($CH_2$), 56.7 ($CH_3$), 56.1 ($CH_3$), 50.3 (CH), 44.8 ($CH_2$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{12}H_{16}O_4Na$ 247.0946 ($M^+$+Na), found 247.0950.

**1-(2,5-Dimethoxy-4-methylphenoxy)pent-4-en-2-ol (34).** To a stirred suspension of CuI (36.4 mg, 0.19 mmol) and 1.44 M solution of vinylmagnesium chloride (2.70 mL, 3.82 mmol) in THF was added epoxide **33** (428 mg, 1.91 mmol) in THF (5 mL) at −20 °C and stirring was continued for 40 min at the same temperature. The reaction mixture was quenched with saturated aqueous $NH_4Cl$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give alkene **34** (463 mg, 96%) as a colorless oil. IR (neat) 3465, 2933, 1518, 1217 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.54 (1H, s), 5.88 (1H, ddt, $J$ = 17.2, 10.4, and 7.2 Hz), 5.14 (1H, d, $J$ = 17.2 Hz), 5.10 (1H, d, $J$ = 10.4 Hz), 4.06−4.00 (2H, m), 3.90−3.82 (1H, m), 3.80 (3H, s), 3.76 (3H, s), 3.40 (1H, brs, $D_2O$ exchangeable), 2.34 (2H, t, $J$ = 7.2 Hz), 2.16 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.7 (C), 146.3 (C), 143.7 (C), 134.1 (CH), 120.0 ($CH_2$), 117.5 (CH), 115.5 (C), 101.7 (CH), 75.2 ($CH_2$), 69.1 (CH), 56.6 ($CH_3$), 56.0 ($CH_3$), 37.4 ($CH_2$), 15.6 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{20}O_4Na$ 275.1259 ($M^+$ + Na), found 275.1261.

**1-(2,5-Dimethoxy-4-methylphenoxy)-6-(trimethylsilyl)hex-4-en-2-ol (35).** By the same procedure described for ***E*-11a**, alkene **35** (373 mg, 60%) was prepared from alkene **34** (463 mg, 1.84 mmol): yield 60%, *E*:*Z* = 2:1; colorless oil. IR (neat) 3421, 2951, 1518, 1385 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.72 (1H, s), 6.55 (1H, s), 5.62−5.48 (1H, m), 5.40−5.26 (1H, m), 4.10−3.92 (2H, m), 3.90−3.82 (1H, m), 3.82 (3H, s), 3.78 (3H, s), 3.16 (0.33H, brs, $D_2O$ exchangeable), 3.05 (0.67H, brs, $D_2O$ exchangeable), 2.29 (2H, t, $J$ = 6.8 Hz), 2.18 (3H, s), 1.51 (0.67H, d, $J$ = 8.4 Hz), 1.46 (1.34H, d, $J$ = 7.6 Hz), 0.02 (2.97H, s), 0.00 (6.03H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.9 (C), 146.6 (C), 144.0 (C), 130.0 (CH), 128.6 (CH), 123.4 (CH), 121.9 (CH), 120.0 (C), 115.7 (CH), 102.0 (CH), 102.0 (CH), 75.5 ($CH_2$), 75.4 ($CH_2$), 70.0 (CH), 69.8 (CH), 56.8 ($CH_3$), 56.1 ($CH_3$), 36.6 ($CH_2$), 30.8 ($CH_2$), 22.9 ($CH_2$), 18.7 ($CH_2$), 15.6 ($CH_3$), −1.8 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{18}H_{30}O_4NaSi$ 361.1811 ($M^+$ + Na), found 361.1810.

**1-(2,5-Dimethoxy-4-methylphenoxy)-6-(trimethylsilyl)hex-4-en-2-yl Acetate (36).** By the same procedure described for **11b**, acetate **36** (390 mg, 93%) was prepared from alcohol **35** (373 mg, 1.10 mmol): yield 93%; colorless oil. IR (neat) 2952, 1739, 1517 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.74 (1H, s), 6.59 (0.33H, s), 6.58 (0.67H, s), 5.62−5.50 (1H, m), 5.34−5.15 (2H, m), 4.11 (0.67H, t, $J$ = 4.8 Hz), 4.10 (1.34H, d, $J$ = 5.6 Hz), 3.82 (3H, s), 3.81 (3H, s), 2.56−2.46 (1H, m), 2.41 (1H, dt, $J$ = 14.0 and 6.8 Hz), 2.18 (3H, s), 2.09 (3H, s), 1.53 (0.66H, d, $J$ = 8.8 Hz), 1.45 (1.34H, d, $J$ = 8.0 Hz), 0.02 (2.97H, s), 0.00 (6.03H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 170.6 (C), 170.5 (C), 151.8 (C), 146.8 (C), 143.8 (C), 130.4 (CH), 129.1 (CH), 122.4 (CH), 121.0 (CH), 119.6 (C), 119.5 (C), 116.5 (CH), 116.5 (CH), 101.4 (CH), 101.3 (CH), 72.3 (CH), 70.8 ($CH_2$), 70.7 ($CH_2$), 57.0 ($CH_3$), 57.1 ($CH_3$), 56.1 ($CH_3$), 34.2 ($CH_2$), 28.5 ($CH_2$), 22.9 ($CH_2$), 21.1 ($CH_3$), 18.6 ($CH_2$), 15.5 ($CH_3$), −1.9 ($CH_3$), −2.1 ($CH_3$); HRMS (ESI) calcd for $C_{20}H_{32}O_5NaSi$ 403.1917 ($M^+$ + Na), found 403.1918.

**1-(4-Methyl-3,6-dioxocyclohexa-1,4-dienyloxy)-6-(trimethylsilyl)hex-4-en-2-yl Acetate (17a).** By the same procedure described for **4b**, quinone **17a** (299 mg, 83%) was prepared from acetate **36** (390 mg, 1.03 mmol): yield 83%; yellow crystals. IR (KBr) 2952, 1743, 1674, 1651, 1608 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.57 (1H, d, $J$ = 1.6 Hz), 5.93 (1H, s), 5.66−5.50 (1H, m), 5.30−5.16 (2H, m), 4.00 (2H, d, $J$ = 4.4 Hz), 2.45 (2H, dd, $J$ = 12.0 and 6.4 Hz), 2.10 (0.99H, s), 2.09 (2.01H, s), 2.08 (3H, d, $J$ = 1.6 Hz), 1.46 (2H, d, $J$ = 8.0 Hz), 0.03 (2.97H, s), 0.00 (6.03H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.6 (C), 181.5 (C), 170.3 (C), 157.7 (C), 146.5 (C), 131.4 (CH), 131.4 (CH), 130.1 (CH), 121.4 (CH), 119.9 (CH), 108.2 (CH), 70.7 (CH), 68.9 ($CH_2$), 68.9 ($CH_2$), 34.0 ($CH_2$), 28.2 ($CH_2$), 22.9 ($CH_2$), 21.0 ($CH_3$), 18.7 ($CH_2$), 15.6 ($CH_3$), −1.9 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{18}H_{26}O_5NaSi$ 373.1447 ($M^+$ + Na), found 373.1460.

**1-Hydroxy-4-(4-methyl-3,6-dioxocyclohexa-1,4-dien-1-yl)-hex-5-en-2-yl Acetate ($18a_1$).** By the same procedure described for **12b**, quinone $\mathbf{18a_1}$ (106 mg, 45%) and $\mathbf{18a_2}$ (40 mg, 17%) was prepared from acetate **17a** (299 mg, 0.85 mmol). $\mathbf{18a_1}$: yield 45%; yellow oil. IR (KBr) 3447, 1735, 1674, 1655, 1241 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, q, $J$ = 1.2 Hz), 6.56 (1H, d, $J$ = 0.8 Hz), 5.75 (1H, ddd, $J$ = 16.8, 10.0, and 8.0 Hz), 5.17 (1H, d, $J$ = 10.0 Hz), 5.13 (1H, dd, $J$ = 16.8 and 1.2 Hz), 4.95−4.89 (1H, m), 3.74−3.60 (2H, m), 3.55 (1H, dt, $J$ = 8.8 and 6.0 Hz), 2.08 (3H, d, $J$ = 1.2 Hz), 2.08 (3H, d, $J$ = 1.2 Hz), 2.04 (3H, d, $J$ = 1.6 Hz), 1.96−1.83 (3H, one protone was $D_2O$ exchangeable, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.0 (C), 186.7 (C), 171.1 (C), 150.2 (C), 145.5 (C), 137.1 (CH), 133.7 (CH), 132.2 (CH), 118.1 ($CH_2$), 73.2 (CH), 64.7 ($CH_2$), 38.6 (CH), 34.2 ($CH_2$), 21.1 ($CH_3$) 15.3 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{18}O_5Na$ 301.1052 ($M^+$ + Na), found 301.1058.

**2-Hydroxy-4-(4-methyl-3,6-dioxocyclohexa-1,4-dien-1-yl)-hex-5-en-1-yl acetate ($18a_2$).** Yield (40 mg, 17%); yellow oil. IR (KBr) 3502, 1736, 1654, 1245 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, d, $J$ = 1.2 Hz), 6.54 (1H, s), 5.78 (1H, ddd, $J$ = 17.6, 10.0, and 8.8 Hz), 5.21 (1H, d, $J$ = 17.6 Hz), 5.19 (1H, d, $J$ = 10.0 Hz), 4.12 (1H, dd, $J$ = 11.2 and 3.2 Hz), 3.97 (1H, dd, $J$ = 11.2 and 7.2 Hz), 3.96−3.83 (1H, brm), 3.76 (1H, dt, $J$ = 8.8 and 5.2 Hz), 2.09 (3H, s), 2.11−2.06 (1H, brm, $D_2O$ exchangeable), 2.04 (3H, d, $J$ = 1.2 Hz), 1.77−1.63 (2H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.2 (C), 186.9 (C), 171.0 (C), 150.9 (C), 145.4 (C), 137.3 (CH), 133.8 (CH), 132.0 (CH), 118.1 ($CH_2$), 68.7 ($CH_2$), 67.7 (CH), 38.9 (CH), 37.1 ($CH_2$), 20.8 ($CH_3$) 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{18}O_5Na$ 301.1052 ($M^+$ + Na), found 301.1056.

**1,4-Dimethoxy-2-methyl-5-(2-methylpent-4-enyloxy)-benzene (37b).** To a stirred solution of phenol **7** (1.01 g, 5.99 mmol), 2-methylpent-4-en-1-ol (0.5 g, 4.99 mmol) and triphenylphosphine (1.57 g, 5.99 mmol) in toluene (15 mL) was added diisopropylazodicarboxylate (1.18 mL, 5.99 mmol) at 0 °C. After stirring was continued at 60 °C for 1 h, the reaction mixture was evaporated and chromatographed on silica gel hexane−AcOEt (9: 1 v/v) as eluent to give alkene **37b** (946 mg, 76%) as a colorless oil. IR (neat) 2931, 1517, 1219, 1043, 857 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.50 (1H, s), 5.83 (1H, ddt, $J$ = 16.8, 10.0, and 7.6 Hz), 5.06 (1H, ddt, $J$ = 10.0, 2.0, and 1.2 Hz), 5.03 (1H, ddt, $J$ = 16.8, 1.2, and 0.8 Hz), 3.83 (2H, dd, $J$ = 9.2 and 6.4 Hz), 3.80 (3H, s),


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3.78 (3H, s), 2.36−2.30 (1H, m), 2.16 (3H, s), 2.13−2.00 (2H, m), 1.04 (3H, d, $J$ = 6.4 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (C), 147.4 (C), 143.5 (C), 136.5 (CH), 118.5 (C), 116.4 (CH), 116.2 ($CH_2$), 100.2 (CH), 74.5 ($CH_2$), 57.2 ($CH_3$), 56.1 ($CH_3$), 37.8 ($CH_2$), 33.1 (CH), 16.6 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{23}O_3$ 251.1647 ($M^+$ + H), found 251.1654.

**[6-(2,5-Dimethoxy-4-methylphenoxy)-5-methylhex-2-enyl]-trimethylsilane (38b).** To a stirred solution of alkene **37b** (500 mg, 2.00 mmol), allyltrimethylsilane (636 $\mu$L, 4.0 mmol) and Grubbs' first catalyst (82.3 mg, 0.10 mmol) in $CH_2Cl_2$ (20 mL) were refluxed for 24 h. The solvent was removed under reduced pressure, and crude product was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give hydroquinone methyl ether **38b** (340 mg, 51%, $E/Z$ = 1:1) as a brown oil. IR (neat) 2953, 1516, 1467, 1219, 1043, 851 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.73 (1H, s), 6.51 (1H, d, $J$ = 2.4 Hz), 5.54−5.24 (2H, m), 3.92−3.74 (2H, m), 3.82 (3H, s), 3.80 (3H, s), 2.26−2.17 (1H, m), 2.17 (3H, s), 2.10−1.97 (2H, m), 1.49 (1H, d, $J$ = 8.0 Hz), 1.44 (1H, d, $J$ = 8.0 Hz), 1.06 (3H, ddd, $J$ = 11.2, 6.4, and 0.8 Hz), 0.02 (4.5H, d, $J$ = 2.4 Hz), 0.00 (4.5H, d, $J$ = 2.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.9 (C × 2), 147.6 (C × 2), 143.5 (C × 2), 128.2 (CH), 127.0 (CH), 126.1 (CH), 125.0 (CH), 118.4 (C × 2), 116.5 (CH × 2), 100.2 (CH), 100.1 (CH), 74.7 ($CH_2$ × 2), 57.3 ($CH_3$x2), 56.2 ($CH_3$ × 2), 36.8 ($CH_2$), 33.9 (CH), 33.7 (CH), 30.8 ($CH_2$), 22.8 ($CH_2$), 18.5 ($CH_2$), 17.0 ($CH_3$), 16.8 ($CH_3$), 15.5 ($CH_3$x2), −1.8 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{19}H_{32}O_3NaSi$ 359.2018 ($M^+$ + Na), found 359.2003.

**2-Methyl-5-[2-methyl-6-(trimethylsilyl)hex-4-enyloxy]-cyclohexa-2,5-diene-1,4-dione (17b).** To a stirred solution of hydroquinone methyl ether **38b** (220 mg, 0.65 mmol) in $CH_3CN$/$H_2O$ (4: 1 v/v, 7 mL) was added CAN (717 mg, 1.31 mmol) at 0 °C. After stirring was continued for 10 min at the same temperature, the reaction mixture was diluted with water and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give quinone **17b** (137 mg, 68%) as a yellow oil. IR (neat) 2955, 1674, 1651, 1248, 1206, 852 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.56 (1H, m), 5.90 (1H, d, $J$ = 2.4 Hz), 5.56−5.40 (1H, m), 5.31−5.18 (1H, m), 3.82−3.77 (1H, m), 3.71−3.65 (1H, m), 2.22−1.96 (3H, m), 2.07 (3H, d, $J$ = 1.2 Hz), 1.45 (2H, dd, $J$ = 8.0 and 7.6 Hz), 1.06 (1.5H, d, $J$ = 6.4 Hz), 1.03 (1.5H, d, $J$ = 6.4 Hz), 0.02 (4.5H, s), 0.00 (4.5H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 187.7 (C × 2), 181.9 (C × 2), 158.2 (C × 2), 146.4 (C × 2), 131.2 (CH × 2), 129.0 (CH × 2), 127.7 (CH), 125.0 (CH), 123.8 (CH), 107.8 (CH), 73.5 ($CH_2$), 73.5 ($CH_2$), 36.4 ($CH_2$), 32.9 (CH), 32.7 (CH), 30.4 ($CH_2$), 22.7 ($CH_2$), 18.4 ($CH_2$), 16.8 ($CH_3$), 16.5 ($CH_3$), 15.6 ($CH_3$ × 2), −1.9 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{27}O_3Si$ 307.1729 ($M^+$ + H), found 307.1721.

**2-(6-Hydroxy-5-methylhex-1-en-3-yl)-5-methylcyclohexa-2,5-diene-1,4-dione (18b).** To a stirred solution of quinone **17b** (90 mg, 0.294 mmol) in $(CH_3)_2CHCN$ (2 mL) was added dropwise TBSOTf (67.4 $\mu$L, 0.294 mmol) at −60 °C. After stirring was continued for 1 h, the reaction mixture was quenched with saturated aqueous $NaHCO_3$ and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (9:1 v/v) as eluent to give quinone **18b** (29.9 mg, 43%) as a yellow oil. IR (neat) 3439, 2926, 1654, 1609, 913 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, q, $J$ = 1.2 Hz), 6.59 (1H, s), 5.77 (1H, ddd, $J$ = 17.6, 10.0, and 8.0 Hz), 5.13 (1H, dd, $J$ = 10.0 and 0.8 Hz), 5.13 (1H, dd, $J$ = 17.6 and 1.2 Hz), 3.64−3.46 (3H, m), 2.04 (3H, d, $J$ = 1.2 Hz), 1.94 (1H, brs, $D_2O$ exchangeable), 1.73−1.57 (2H, m,), 1.37 (1H, ddd, $J$ = 11.6, 8.0, and 6.0 Hz), 0.93 (3H, d, $J$ = 6.8 Hz); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.2 (C), 187.3 (C), 151.0 (C), 145.5 (C), 138.4 (CH), 133.7 (CH), 132.1 (CH), 116.9 ($CH_2$), 67.2 ($CH_2$), 39.2 (CH), 37.2 ($CH_2$), 33.3 (CH), 17.2 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{18}O_3Na$ 257.1154 ($M^+$ + Na), found 257.1147.

**1-[1-(Benzyloxy)hex-5-en-2-yloxy]-2,5-dimethoxy-4-methylbenzene (37c).** By following the same procedure described for **37b**, alkene **37c** (1.32 g, 89%) was prepared from phenol **7** (700 mg, 4.16 mmol) and 2-(benzyloxymethyl)pent-4-en-1-ol: yield 89%; colorless oil. IR (neat) 2935, 1640, 1611, 1514, 1454, 1216, 738, 698 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 7.34−7.28 (5H, m), 6.70 (1H, s), 6.62 (1H, s), 5.83 (1H, ddd, $J$ = 16.8, 10.0, and 6.4 Hz), 5.00 (1H, dd, $J$ = 16.8 and 1.6 Hz), 4.96 (1H, dd, $J$ = 10.0 and 0.8 Hz), 4.56 (2H, s), 4.36−4.31 (1H, m), 3.78 (3H, s), 3.68 (3H, s), 3.69−3.60 (2H, m), 2.33−2.16 (2H, m), 2.16 (3H, s), 1.93−1.76 (2H, m); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (C), 146.3 (C), 144.5 (C), 138.3 (C), 138.3 (CH), 128.3 (CH × 2), 127.6 (CH × 2), 127.5 (CH), 119.7 (C), 116.0 (CH), 114.8 ($CH_2$), 103.5 (CH), 79.5 (CH), 73.4 ($CH_2$), 72.0 ($CH_2$), 56.9 ($CH_3$), 56.6 ($CH_3$), 31.4 ($CH_2$), 29.5 ($CH_2$), 15.6 ($CH_3$) ; HRMS (ESI) calcd for $C_{22}H_{29}O_4$ 357.2066 ($M^+$ + H), found 357.2050.

**[7-Benzyloxy-6-(2,5-dimethoxy-4-methylphenoxy)hept-2-enyl]trimethylsilane (38c).** By following the same procedure described for **38b**, alkene **38c** (367 mg, 37%) was prepared from alkene **37c** (800 mg, 2.24 mmol): yield 37% ($E/Z$ = 3:2); brown oil. IR (neat) 2953, 1676, 1652, 1601, 1191, 853, 698 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 7.39−7.28 (5H, m), 6.73 (1H, s), 6.68 (1H, s), 5.48−5.24 (2H, m), 4.60 (1.2H, s), 4.60 (0.8H, s), 4.41−4.33 (1H, m), 3.82 (3H, s), 3.72 (0.8H, s), 3.72 (1.2H, s), 3.75−3.64 (2H, m), 2.20 (3H, s), 2.24−2.15 (2H, m), 1.92−1.73 (2H, m), 1.46 (0.5H, d, $J$ = 8.0 Hz), 1.41 (1.5H, d, $J$ = 8.0 Hz), 0.01 (2.4H, s), 0.00 (6.6H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 151.7 (C × 2), 146.4 (C × 2), 144.4 (C × 2), 138.3 (C × 2), 128.2 (CH), 128.0 (CH), 127.6 (CH × 2), 127.5 (CH × 2), 126.7 (CHx2), 126.1 (CHx2), 119.4 (C × 2), 115.9 (CH × 2), 103.3 (CH × 2), 79.7 (CH × 2), 73.4 ($CH_2$ × 2), 72.2 ($CH_2$), 72.1 ($CH_2$), 56.8 ($CH_3$ × 2), 56.0 ($CH_3$ × 2), 32.4 ($CH_2$), 32.1 ($CH_2$), 28.6 ($CH_2$), 22.9 ($CH_2$), 22.6 ($CH_2$), 18.3 ($CH_2$), 15.6 ($CH_3$ × 2), −1.8 ($CH_3$), −2.1 ($CH_3$); HRMS (ESI) calcd for $C_{26}H_{39}O_4Si$ 443.2618 ($M^+$ + H), found 443.2625.

**2-[1-Benzyloxy-7-(trimethylsilyl)hept-5-en-2-yloxy]-5-methylcyclohexa-2,5-diene-1,4-dione (17c).** By following the same procedure described for **17a**, quinone **17c** (166 mg, 83%) was prepared from hydroquinone methyl ether **38c** (214 mg, 0.48 mmol): yield 83% ($E/Z$ = 3:2); yellow oil. IR (neat) 2953, 1676, 1651, 1601, 1191, 854 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 7.39−7.31 (5H, m), 6.56 (1H, q, $J$ = 0.8 Hz), 6.04 (0.8H, d, $J$ = 1.2 Hz), 6.03 (1.2H, d, $J$ = 1.2 Hz), 5.51−5.37 (1H, m), 5.25−5.17 (1H, m), 4.56 (2H, s), 4.45−4.38 (1H, m), 3.71−3.61 (2H, m), 2.13−2.03 (5H, m), 1.89−1.72 (2H, m), 1.42 (2H, m), 0.03 (2.4H, s), 0.00 (6.6H, s); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.0 (C × 2), 182.3 (C × 2), 157.5 (C × 2), 146.3 (C × 2), 137.7 (C × 2), 131.3 (CH × 2), 128.4 (CH), 128.3 (CH), 127.9 (CH), 127.7 (CH), 127.6 (CH × 2), 127.3 (CH), 126.6 (CH), 125.2 (CH × 2), 108.8 (CH × 2), 78.3 (CH × 2), 73.4 ($CH_2$ × 2), 70.9 ($CH_2$ × 2), 31.0 ($CH_2$), 30.7 ($CH_2$), 28.3 ($CH_2$), 22.6 ($CH_2$), 22.5 ($CH_2$), 18.5 ($CH_2$), 15.7 ($CH_3$ × 2), −1.9 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{24}H_{33}O_4Si$ 413.2148 ($M^+$ + H), found 413.2149.

**2-(7-Benzyloxy-6-hydroxyhept-1-en-3-yl)-5-methylcyclohexa-2,5-diene-1,4-dione (18c).** By following the same procedure described for **18b**, quinone **18c** (121 mg, 73%) was prepared from quinone **17c** (200 mg, 0.485 mmol): yield 73%; yellow oil. IR (neat) 3464, 2924, 2860, 1655 cm$^{-1}$; $^1$H NMR (400 MHz, $CDCl_3$) $\delta$ 7.38−7.30 (5H, m), 6.59 (1H, m), 6.52 (1H, s), 5.82 (1H, ddd, $J$ = 17.2, 10.4, and 8.0 Hz), 5.12 (1H, dd, $J$ = 17.2 and 0.8 Hz), 5.01 (1H, d, $J$ = 10.4 Hz), 4.54 (2H, s), 3.83−3.77 (1H, m), 3.53−3.44 (2H, m), 3.30 (1H, t, $J$ = 8.4 Hz), 2.32 (1H, d, $J$ = 3.6 Hz, $D_2O$ exchangeable), 2.03 (3H, m), 1.83−1.73 (1H, m), 1.61−1.37 (3H, m); $^{13}$C NMR (100 MHz, $CDCl_3$) $\delta$ 188.2 (C), 186.9 (C), 150.8 (C), 145.2 (C), 138.1 (CH), 137.8 (C), 133.6 (CH), 132.0 (CH), 128.4 (CH), 127.8 (CH), 127.7 (CH), 117.0 ($CH_2$), 74.3 ($CH_2$), 73.3 ($CH_2$), 70.2 (CH), 41.5 (CH), 30.9 ($CH_2$), 29.5 ($CH_2$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{21}H_{25}O_4$ 341.1753 ($M^+$ + H), found 341.1754.

**1-(Hex-5-yn-2-yloxy)-2,5-dimethoxy-4-methylbenzene (39).** To a stirred solution of phenol **7** (714 mg, 4.25 mmol), hex-5-yn-2-ol (0.5 g, 5.09 mmol) and triphenylphosphine (1.34 g, 5.09 mmol) in toluene (15 mL) was added diisopropylazodicarboxylate (1.0 mL, 5.09 mmol) at 0 °C. After stirring was continued at 40 °C for 0.5 h, the reaction mixture was evaporated and chromatographed on silica gel hexane−AcOEt (9:1 v/v) as eluent to give alkyne **39** (796 mg, 75%) as


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a colorless oil. IR (neat) 3290, 2932, 1514, 1217, 1043 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.58 (1H, s), 4.43 (1H, tq, $J$ = 6.4 and 6.0 Hz), 3.79 (3H, s), 3.78 (3H, s), 2.51−2.32 (2H, m), 2.17 (3H, s), 2.04−1.97 (1H, m), 1.96 (1H, dd, $J$ = 2.8 and 2.4 Hz), 1.83−1.75 (1H, m), 1.30 (3H, d, $J$ = 6.0 Hz); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.7 (C), 145.7 (C), 144.7 (C), 119.6 (C), 116.0 (CH), 103.3 (CH), 84.2 (C), 75.3 (CH), 68.4 (CH), 56.9 ($CH_3$), 56.2 ($CH_3$), 35.3 ($CH_2$), 19.8 ($CH_3$), 15.6 ($CH_3$), 14.8 ($CH_2$); HRMS (ESI) calcd for $C_{15}H_{21}O_3$ 249.1491 ($M^+$ + H), found 249.1489.

**(*Z*)-2-Methyl-5-[7-(trimethylsilyl)hept-5-en-2-yloxy]-cyclohexa-2,5-diene-1,4-dione (17d).** To a stirred solution of alkyne **39** (799 mg, 3.22 mmol) in THF/DMPU (3:1 v/v, 20 mL) was added dropwise 2.61 M solution of $^n$BuLi (1.3 mL, 3.38 mmol) in hexane at −100 °C. After stirring was continued for 10 min at the same temperature, a solution of iodomethyltrimethylsilane (1.03 g, 4.83 mmol) in THF/DMPU (3:1 v/v, 4 mL) was added dropwise and stirring was continued for 15 min at the same temperature and further 15 min at −50 °C. The reaction mixture was diluted with water and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon evaporated *in vacuo* to give crude propargylsilane (1.08 g). The mixture of crude propargylsilane, quinoline (19 $\mu$L, 0.161 mmol), and Lindlar catalyst (215 mg) in AcOEt (50 mL) was stirred under a hydrogen atmosphere at 50 °C for 24 h. The reaction mixture was filtered and evaporated *in vacuo*. The residue was dissolved into $CH_3CN/H_2O$ (4:1 v/v, 7 mL) was added CAN (4.41 g, 8.05 mmol) at 0 °C. After stirring was continued for 10 min at the same temperature, the reaction mixture was diluted with water and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (19:1 v/v) as eluent to give quinone **17d** (578 mg, 59% for 3 steps) as a yellow oil. IR (neat) 2955, 1676, 1650, 1599, 1190, 854 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.56 (1H, s), 5.90 (1H, s), 5.46 (1H, dt, $J$ = 10.4 and 7.2 Hz), 5.23 (1H, dt, $J$ = 10.4 and 7.6 Hz), 4.38−4.25 (1H, m), 2.13−2.04 (2H, m), 2.07 (3H, d, $J$ = 1.2 Hz), 1.96−1.87 (1H, m), 1.71−1.63 (1H, m), 1.45−1.40 (2H, m), 1.37 (3H, d, $J$ = 6.0 Hz), 0.00 (9H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.9 (C), 182.4 (C), 157.1 (C), 146.3 (C), 131.3 (CH), 126.9 (CH), 125.3 (CH), 108.0 (CH), 75.2 (CH), 35.3 ($CH_2$), 22.6 ($CH_2$), 18.6 ($CH_3$), 18.4 ($CH_2$), 15.6 ($CH_3$), −1.9 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{27}O_3Si$ 307.1729 ($M^+$ + H), found 307.1728.

**2-(6-Hydroxyhept-1-en-3-yl)-5-methylcyclohexa-2,5-diene-1,4-dione (18d).** By following the same procedure described for **18b**, quinone **18d** (70.9 mg, 62%) was prepared from quinone **17d** (150 mg, 0.493 mmol): yield 62%; yellow oil. IR (neat) 3612, 3022, 1660, 1650, 1241, 913 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, q, $J$ = 1.6 Hz), 6.53 (1H, s), 5.75 (1H, ddd, $J$ = 17.6, 10.0, and 8.0 Hz), 5.13 (1H, d, $J$ = 11.2 Hz), 5.13 (1H, d, $J$ = 16.0 Hz), 3.81−3.78 (1H, brm), 3.46 (1H, dt, $J$ = 8.0 and 6.4 Hz), 2.04 (3H, d, $J$ = 2.0 Hz), 1.77−1.68 (1H, m), 1.63−1.37 (1H, m), 1.32 (1H, d, $J$ = 4.8 Hz, $D_2O$ exchangeable), 1.18 (3H, d, $J$ = 6.0 Hz); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.3 (C), 187.0 (C), 151.0 (C), 145.3 (C), 138.2 (CH), 133.7 (CH), 132.0 ($CH_2$), 117.0 ($CH_2$), 67.9 (CH), 41.5 (CH), 36.8 ($CH_2$), 29.8 ($CH_2$), 23.5 ($CH_3$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{18}O_3Na$ 257.1154 ($M^+$ + Na), found 257.1136.

**1,4-Dimethoxy-2-methyl-5-(pent-4-enyloxy)benzene (40).** To a stirred suspension of NaH (743 mg, 18.6 mmol) in DMF (50 mL) was added phenol **7** (2.4 g, 14.3 mmol) at 0 °C. After stirring was continued at room temperature for 10 min, tetrabutylammonium iodide (517 mg, 1.4 mmol) and 4-bromo-1-pentene (2.0 mL, 17.2 mmol) were added at 0 °C. Being stirred at room temperature for 2.5 h, the reaction was quenched with water and extracted with AcOEt. The combined extracts were washed with saturated aqueous NaCl. The residue upon workup was chromatographed on silica gel with hexane−AcOEt (4:1 v/v) as eluent to give alkene **40** (2.87 g, 85%) as a colorless oil. IR (neat) 2936, 1517, 1219, 1043 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.51 (1H, s), 5.86 (1H, ddt, $J$ = 17.2, 10.4, and 6.8 Hz), 5.07 (1H, ddt, $J$ = 10.4, 1.6, and 1.2 Hz), 5.07 (1H, ddt, $J$ = 10.4, 1.6, and 1.2 Hz), 4.01 (2H, t, $J$ = 7.2 Hz), 3.81 (3H, s), 3.78 (3H, s), 2.25 (2H, m), 2.16 (3H, s), 1.96−1.89 (2H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (C), 147.0 (C), 143.5 (C), 137.9 (CH), 118.5 (C), 115.9 (CH), 115.0 ($CH_2$), 100.2 (CH), 69.1 ($CH_2$), 57.0 ($CH_3$), 56.2 ($CH_3$), 30.1 ($CH_2$), 28.5 ($CH_2$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{14}H_{20}O_3Na$ 259.1310 ($M^+$ + Na), found 259.1316.

**[6-(2,5-Dimethoxy-4-methylphenoxy)hex-2-enyl]-trimethylsilane (41).** By following the same procedure described for **38b**, hydroquinone methyl ether **41** (576 mg, 42%) was prepared from alkene (**40**) (1.0 g, 4.23 mmol): yield 42%, ($E$/$Z$ = 1:1); IR (neat) 2951, 1516, 1219, 1044, 852 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.72 (1H, s), 6.53 (1H, s), 5.52−5.42 (1H, m), 5.38−5.25 (1H, m), 4.03 (1H, t, $J$ = 6.8 Hz), 4.01 (1H, t, $J$ = 6.8 Hz), 3.83 (3H, s), 3.80 (3H, s), 2.23−2.16 (2H, m), 2.18 (3H, s), 1.93−1.86 (2H, m), 1.50 (1H, d, $J$ = 8.4 Hz), 1.43 (1H, d, $J$ = 8.4 Hz), 0.02 (4.5H, s), 0.00 (4.5H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (C × 2), 147.2 (C × 2), 143.5 (C × 2), 127.7 (CH), 127.0 (CH), 126.4 (CH × 2), 118.4 (C × 2), 116.0 (CH × 2), 100.1 (CH × 2), 69.3 ($CH_2$ × 2), 57.0 ($CH_3$ × 2), 56.3 ($CH_3$ × 2), 29.6 ($CH_2$), 29.4 ($CH_2$), 29.1 ($CH_2$) 23.4 ($CH_2$), 22.6 ($CH_2$), 18.4 ($CH_2$), 15.5 ($CH_3$ × 2), −1.8 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{18}H_{31}O_3Si$ 323.2042 ($M^+$ + H), found 323.2038.

**2-Methyl-5-[6-(trimethylsilyl)hex-4-enyloxy]cyclohexa-2,5-diene-1,4-dione (19a).** By following the same procedure described for **17b**, quinone **19a** (339 mg, 75%) was prepared from hydroquinone methyl ether (**41**) (500 mg, 1.55 mmol): yield 75%; yellow oil. IR (neat) 2953, 1675, 1652, 1248, 851 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.56 (1H, q, $J$ = 0.8 Hz), 5.92 (0.5H, s), 5.91 (0.5H, s), 5.53−5.40 (1H, m), 5.29−5.20 (1H, m), 3.96−3.90 (2H, m), 2.21−2.13 (2H, m), 2.07 (3H, d, $J$ = 1.6 Hz), 1.96−1.87 (2H, m), 1.47 (1H, d, $J$ = 8.4 Hz), 1.43 (1H, d, $J$ = 8.4 Hz), 0.02 (4.5H, s), 0.00 (4.5H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.7 (C × 2), 182.1 (C × 2), 158.1 (C × 2), 146.5 (C × 2), 131.2 (CH × 2), 127.9 (CH), 127.2 (CH), 126.6 (CH), 125.2 (CH), 107.8 (CH × 2), 68.6 ($CH_2$ × 2), 28.7 ($CH_2$), 28.2 ($CH_2$), 28.1 ($CH_2$), 23.0 ($CH_2$), 22.6 ($CH_2$), 18.4 ($CH_2$), 15.6 ($CH_3$ × 2), −1.9 ($CH_3$), −2.1 ($CH_3$); HRMS (ESI) calcd for $C_{16}H_{24}O_3NaSi$ 315.1392 ($M^+$ + Na), found 315.1388.

**2-(6-Hydroxyhex-1-ene-3-yl)-5-methylcyclohexa-2,5-diene-1,4-dione (20).** By the same procedure described for **12b**, quinones **20** (31.8 mg, 21%), **21** (17.2 mg, 11%) and **22** (30.7 mg, 20%) were prepared from quinone **19a** (200 mg, 0.684 mmol): yield 21%; yellow oil. IR (neat) 3385, 2939, 1655, 914 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.60 (1H, q, $J$ = 1.6 Hz), 6.53 (1H, d, $J$ = 0.8 Hz), 5.75 (1H, ddd, $J$ = 17.2, 10.0, and 8.0 Hz), 5.14 (1H, ddd, $J$ = 17.2, 2.4, and 1.2 Hz), 5.14 (1H, ddd, $J$ = 10.0, 2.0, and 1.2 Hz), 3.66 (2H, brs), 3.44 (1H, brm), 2.04 (3H, d, $J$ = 1.2 Hz), 1.70−1.48 (4H, m), 1.37 (1H, brs, $D_2O$ exchangeable); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 188.2 (C), 187.0 (C), 151.0 (C), 145.4 (C), 138.0 (CH), 133.7 (CH), 132.0 (CH), 117.2 ($CH_2$), 62.4 ($CH_2$), 41.2 (CH), 30.3 ($CH_2$), 29.8 ($CH_2$), 15.4 ($CH_3$); HRMS (ESI) calcd for $C_{13}H_{16}O_3Na$ 243.0997 ($M^+$ + Na), found 243.0992.

**7-Methyl-5-vinyl-2,3,4,5-tetrahydrobenxo[b]oxepine-6,9-dione (21).** Yield (17.2 mg, 11%); yellow oil. IR (neat) 2926, 1672, 1651, 1601, 1225, 1190 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.53 (1H, d, $J$ = 1.6 Hz), 6.00 (1H, ddd, $J$ = 17.2, 10.4, and 5.6 Hz), 5.15 (1H, dt, $J$ = 10.4 and 1.2 Hz), 5.02 (1H, dt, $J$ = 17.2 and 1.2 Hz), 4.49 (1H, ddd, $J$ = 12.0, 9.2, and 4.0 Hz), 4.08 (1H, ddd, $J$ = 12.0, 5.2, and 4.8 Hz), 3.99 (1H, brm), 2.06 (3H, s), 2.00−1.85 (4H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 189.8 (C), 183.2 (C), 158.0 (C), 146.4 (C), 138.7 (CH), 131.0 (CH), 127.6 (C), 116.2 ($CH_2$), 73.9 ($CH_2$), 38.1 (CH), 28.1 ($CH_2$), 25.3 ($CH_2$), 16.2 ($CH_3$); HRMS (ESI) calcd for $C_{13}H_{14}O_3Na$ 241.0841 ($M^+$ + Na), found 241.0840.

**2-(Hex-5-enyloxy)-5-methylcyclohexa-2,5-diene-1,4-dione (22).** Yield (30.7 mg, 20%); yellow oil. IR (neat) 2940, 1673, 1651, 1208, 905 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.54 (1H, d, $J$ = 1.2 Hz), 5.90 (1H, s), 5.80 (1H, ddt, $J$ = 16.8, 10.0, and 6.8 Hz), 5.03 (1H, dd, $J$ = 17.2 and 1.6 Hz), 4.98 (1H, dd, $J$ = 10.0 and 1.2 Hz), 3.92 (2H, dd, $J$ = 6.8 and 6.4 Hz), 2.11 (2H, dt, $J$ = 7.6 and 7.6 Hz), 2.05 (3H, s), 1.86 (2H, quint, $J$ = 6.8 Hz), 1.59−1.55 (2H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.8 (C), 182.1 (C), 158.1 (C), 146.6 (C), 138.0 (CH), 131.3 (CH), 115.1 ($CH_2$), 107.8 (CH), 69.2 ($CH_2$), 33.2


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($CH_2$), 27.6 ($CH_2$), 25.0 ($CH_2$), 15.6 ($CH_3$); HRMS (ESI) calcd for $C_{13}H_{17}O_3$ 221.1178 ($M^+$ + H), found 221.1172.

**1-(But-3-enyloxy)-2,5-dimethoxy-4-methylbenzene (42).** By following the same procedure described for **39**, alkene **42** (7.6 mg, 20%) was prepared from phenol **7** (30 mg, 0.178 mmol): yield 20%; colorless oil. IR (neat) 2933, 1516, 1219, 1201, 1042 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.52 (1H, s), 5.92 (1H, ddd, $J$ = 17.2, 10.4, and 6.8 Hz), 5.18 (1H, ddt, $J$ = 17.2, 3.6, and 1.6 Hz), 5.11 (1H, ddt, $J$ = 10.4, 3.2, and 1.6 Hz), 4.05 (2H, t, $J$ = 7.2 Hz), 3.81 (3H, s), 3.78 (3H, s), 2.59 (1H, ddt, $J$ = 7.2, 6.8, and 1.6 Hz), 2.58 (1H, ddt, $J$ = 7.2, 6.8, and 1.6 Hz), 2.16 (3H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.7 (C), 146.8 (C), 143.5 (C), 134.4 (CH), 118.8 (C), 116.9 ($CH_2$), 116.0 (CH), 100.4 (CH), 69.2 ($CH_2$), 56.9 ($CH_3$), 56.2 ($CH_3$), 33.8 ($CH_2$), 15.5 ($CH_3$); HRMS (ESI) calcd for $C_{13}H_{18}O_3Na$ 245.1154 ($M^+$ + Na), found 245.1161.

**[5-(2,5-Dimethoxy-4-methylphenoxy)pent-2-enyl]-trimethylsilane (43).** By following the same procedure described for **38b**, hydroquinone methyl ether **43** (2.8 mg, 10%) was prepared from alkene **42** (20 mg, 0.090 mmol): yield 10%, ($E/Z$ = 1:1); colorless oil. IR (neat) 2952, 1516, 1219, 1043, 853 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.71 (1H, s), 6.52 (1H, s), 5.61−5.52 (1H, m), 5.39−5.29 (1H, m), 3.99 (2H, t, $J$ = 9.2 Hz), 3.82 (1.5H, s), 3.81 (1.5H, s), 3.78 (3H, s), 2.50−2.45 (2H, m), 2.17 (3H, s), 1.54 (1H, d, $J$ = 8.4 Hz), 1.45 (1H, d, $J$ = 8.4 Hz), 0.02 (4.5H, s), 0.00 (4.5H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 151.8 (Cx2), 147.0 (C × 2), 143.6 (C), 143.4 (C), 129.2 (CH), 128.4 (C), 123.8 (CH), 121.9 (CH), 118.6 (C), 118.5 (C), 115.9 (CH), 115.8 (CH), 100.4 (CH), 100.1 (CH), 70.1 ($CH_2$), 69.3 ($CH_2$), 57.0 ($CH_3$ × 2), 56.3 ($CH_3$ × 2), 32.9 ($CH_2$), 27.5 ($CH_2$), 22.9 ($CH_2$), 18.8 ($CH_2$), 15.5 ($CH_3$ × 2), −1.8 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{17}H_{28}O_3NaSi$ 331.1705 ($M^+$ + Na), found 331.1699.

**2-Methyl-5-[5-(trimethylsilyl)pent-3-enyloxy]cyclohexa-2,5-diene-1,4-dione (19b).** By following the same procedure described for **17b**, quinone **19b** (110 mg, 61%) was prepared from hydroquinone methyl ether (**43**) (200 mg, 0.648 mmol): yield 61%; yellow oil. IR (neat) 2954, 1676, 1652, 1604, 1248, 851 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.57−6.55 (1H, m), 5.92 (0.5H, s), 5.92 (0.5H, s), 5.64−5.54 (1H, m), 5.32−5.23 (1H, m), 3.90 (2H, t, $J$ = 7.2 Hz), 2.61−2.51 (2H, m), 2.07 (3H, s), 1.53 (1H, d, $J$ = 8.0 Hz), 1.46 (1H, d, $J$ = 8.0 Hz), 0.03 (4.5H, s), 0.00 (4.5H, s); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.9 (C), 187.8 (C), 182.1 (C × 2), 158.1 (C), 158.0 (C), 146.6 (C × 2), 131.3 (CH), 130.6 (CH), 129.6 (CH), 122.1 (CH), 120.3 (CH), 107.9 (CH × 2), 69.4 ($CH_2$), 68.8 ($CH_2$), 31.6 ($CH_2$), 26.2 ($CH_2$), 23.0 ($CH_2$), 18.9 ($CH_2$), 15.7 ($CH_3$ × 2), −1.8 ($CH_3$), −2.0 ($CH_3$); HRMS (ESI) calcd for $C_{15}H_{22}O_3NaSi$ 301.1236 ($M^+$ + Na), found 301.1225.

**6-Methyl-4-vinyl-3,4-dihydro-2H-chromene-5,8-dione (23).** By the same procedure described for **12b**, quinones **23** (17.2 mg, 47%) and **24** (1.1 mg, 3%) were prepared from quinone **19b** (50 mg, 0.180 mmol): yield 47%; yellow oil. IR (neat) 1673, 1649, 1605, 1256, 1193, 1154, 928 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.51 (1H, q, $J$ = 1.6 Hz), 5.91 (1H, ddd, $J$ = 17.2, 10.4, and 6.0 Hz), 5.19 (1H, d, $J$ = 10.4 Hz), 4.97 (1H, dd, $J$ = 17.2 and 1.2 Hz), 4.47−4.42 (1H, m), 4.09 (1H, ddd, $J$ = 12.4, 11.6, and 2.8 Hz), 3.59−3.54 (1H, m), 2.06 (3H, d, $J$ = 1.6 Hz), 2.03−1.93 (1H, m), 1.91−1.85 (1H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 186.0 (C), 181.9 (C), 153.7 (C), 146.7 (C), 138.8 (CH), 130.6 (CH), 119.2 (C), 116.9 ($CH_2$), 63.6 ($CH_2$), 30.8 (CH), 25.4 ($CH_2$), 16.0 ($CH_3$); HRMS (ESI) calcd for $C_{12}H_{13}O_3$ 205.0865 ($M^+$ + H), found 205.0862.

**2-Methyl-5-(pent-4-enyloxy)cyclohexa-2,5-diene-1,4-dione (24).** Yield (1.1 mg, 3%); yellow oil. IR (neat) 1672, 1652, 1354, 1211, 924, 907, 860 $cm^{-1}$; $^1H$ NMR (400 MHz, $CDCl_3$) $\delta$ 6.54 (1H, q, $J$ = 1.6 Hz), 5.90 (1H, s), 5.80 (1H, ddd, $J$ = 17.2, 10.4, and 6.4 Hz), 5.06 (1H, dd, $J$ = 17.2 and 2.0 Hz), 5.02 (1H, d, $J$ = 10.4 Hz), 3.92 (2H, dd, $J$ = 2.8 and 2.4 Hz), 2.25−2.19 (2H, m), 2.06 (3H, d, $J$ = 1.2 Hz), 1.99−1.91 (2H, m); $^{13}C$ NMR (100 MHz, $CDCl_3$) $\delta$ 187.8 (C), 182.1 (C), 158.1 (C), 146.6 (C), 136.9 (CH), 131.3 (CH), 115.8 ($CH_2$), 107.9 (CH), 68.5 ($CH_2$), 29.7 ($CH_2$), 27.2 ($CH_2$), 15.7 ($CH_3$); HRMS (ESI) calcd for $C_{12}H_{14}O_3Na$ 229.0814 ($M^+$ + Na), found 229.0833.

## ■ ASSOCIATED CONTENT

### Supporting Information

$^1H$ and $^{13}C$ NMR spectra of all new compounds and crystal data for **2** and **3**. This material is available free of charge via the Internet at http://pubs.acs.org.

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### Notes

The authors declare no competing financial interest.

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