**Supporting Information for
a New Artificial Cyclase for Polyprenoids:
Enantioselective Total Synthesis of (–)-Chromazonarol, (+)-8-*epi*-Puupehedione,
and (–)-11'-Deoxytaondiol Methyl Ether**

Hideaki Ishibashi,[†] Kazuaki Ishihara,^{*,†} and Hisashi Yamamoto^{*,‡}

[†]*Graduate School of Engineering, Nagoya University, Furo-cho, Chikusa, Nagoya 464-8603, Japan,*
and [‡]*Department of Chemistry, The University of Chicago, 5735 S. Ellis Avenue, Chicago, Illinois*
60637, USA

General Methods. Infrared (IR) spectra were recorded on a JASCO FT/IR 460 plus spectrometer. ¹H NMR spectra were measured on a Varian Gemini-2000 spectrometer (300 MHz) at ambient temperature. Data were recorded as follows: chemical shift in ppm from internal tetramethylsilane on the δ scale, multiplicity (s = singlet; d = doublet; t = triplet; m = multiplet), coupling constant (Hz), integration, and assignment. ¹³C NMR spectra were measured on Varian Gemini-2000 (75 MHz) spectrometer. Chemical shifts were recorded in ppm from the solvent resonance employed as the internal standard (deuteriochloroform at 77.00 ppm). High-performance liquid chromatography (HPLC) analysis was conducted using Shimadzu LC-10 AD coupled diode array-detector SPD-MA-10A-VP and chiral column of Daicel CHIRALCEL OD-H (4.6 mm x 25 cm), OC (4.6 mm x 25 cm), or Daicel CHIRALPAK AD-H (4.6 mm x 25 cm). Purification of products by HPLC was performed with recycling preparative HPLC [LC-908, Japan Analytical Industry Co., Ltd.; two linear columns, JAIGEL 2H–JAIGEL 1H]. Optical rotations were measured on a JASCO DIP-1000 digital polarimeter. GC analysis was performed with Shimadzu 17A instruments using PEG (0.25 mm x 25 m). Low-resolution mass analysis (LRMS) was performed with a Shimadzu GC/MS instrument [GC-17A/QP-5050A; column: TC-1 (0.25 mm x 30 m)] by direct insertion for chemical ionization (CI) with isobutane. The temperature program employed was 70 °C for 5 min with an increase to 250 °C at 10 °C/min. Melting points were determined using a Yanaco MP-J3. All experiments were carried out under an atmosphere of dry nitrogen. For thin-layer chromatography (TLC) analysis throughout this work, Merck precoated TLC plates (silica gel 60 GF₂₅₄ 0.25 mm) were used. The products were purified by column chromatography on silica gel (E. Merck Art. 9385). Microanalyses were performed at the Graduate School of Engineering, Nagoya University. High resolution mass spectral analysis (HRMS) was performed at Chemical Instrument Center, Nagoya University. In experiments that required dry solvent, ether, *N,N*-dimethylformamide (DMF) and tetrahydrofuran (THF) were purchased from Aldrich or Wako as the “anhydrous” and stored over 4A molecular sieves. Benzene, hexane, toluene, and dichloromethane were freshly distilled from calcium hydride. Tin(IV) chloride was distilled under nitrogen. Other simple chemicals were analytical-grade and obtained commercially.

Preparation of Chiral Catechol Derivatives ((*S*)-2a–f) (Scheme 1).

(*R*)-2-Hydroxy-2'-trifluoromethanesulfoxy-1,1'-binaphthyl.¹ To a solution of (*R*)-1,1'-bi-2-naphthol (BINOL) (5.7 g, 20 mmol) dissolved in CH₂Cl₂ (20 mL) were added 2,4,6-collidine (2.6 mL, 20 mmol), *N,N*-dimethylaminopyridine (DMAP) (600 mg, 5.0 mmol) and PhNTf₂ (7.2 g, 20 mmol) at room temperature. The mixture was heated to reflux at 40 °C, and stirred for 1 day. The mixture was then poured into brine (30 mL), washed with H₂O (10 mL x 2) and extracted with ether (100 mL x 2). The ether extracts were dried over anhydrous MgSO₄ and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–EtOAc = 4:1) to give (*R*)-2-hydroxy-2'-trifluoromethanesulfoxy-1,1'-binaphthyl (7.5 g, 18 mmol) in 90% yield. TLC, *R*_f = 0.26 (hexane–EtOAc = 4:1); ¹H NMR (CDCl₃, 300 MHz) δ 4.84 (s, 1H, OH), 7.0 (d, *J* = 6.9 Hz, 2H), 7.22–7.40 (m, 3H), 7.44 (d, *J* = 5.4 Hz, 1H), 7.60 (d, *J* = 6.6 Hz, 2H), 7.89 (d, *J* = 9.0 Hz, 1H),

7.98 (d, $J = 9.0$ Hz, 1H), 8.02 (d, $J = 9.0$ Hz, 1H), 8.14 (d, $J = 9.0$ Hz, 1H).

(*R*)-2-Methoxymethoxy-2'-trifluoromethanesulfoxy-1,1'-binaphthyl (3).¹ To a solution of (*R*)-2-hydroxy-2'-trifluoromethanesulfoxy-1,1'-binaphthyl (16.3 g, 39.0 mmol) dissolved in CH_2Cl_2 (50 mL) was added *i*-Pr₂NEt (10.3 mL, 59.0 mmol) and chloromethylmethyl ether (MOMCl) (4.9 mL, 59 mmol) at room temperature. After stirring for 1 day at room temperature, the mixture was poured into brine (30 mL), washed with H_2O (10 mL x 2) and extracted with ether (100 mL x 2). The ether extracts were dried over anhydrous MgSO_4 and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 10:1) to give (*R*)-**3** (17.5 g, 37.8 mmol) in 97% yield. TLC, $R_f = 0.40$ (Hexane–EtOAc = 4:1); ^1H NMR (CDCl_3 , 300 MHz) δ 3.22 (s, 3H), 5.03 (d, $J = 6.9$ Hz, 1H), 5.19 (d, $J = 6.9$ Hz, 1H), 7.04 (d, $J = 9.6$ Hz, 1H), 7.24–7.38 (m, 4H), 7.55 (m, 1H), 7.57 (d, $J = 9.3$ Hz, 1H), 7.64 (d, $J = 9$ Hz, 1H), 7.89 (d, $J = 9.6$ Hz, 1H), 7.99 (d, $J = 9.6$ Hz, 2H), 8.05 (d, $J = 9.6$ Hz, 1H).

(*S*)-2-(*p*-Methoxybenzyl)-2'-methoxymethoxy-1,1'-binaphthyl (Step a in Scheme 1).^{1,2} To a mixture of activated Mg (360 mg, 15.0 mmol) in dry THF (10 mL) was added dropwise 4-methoxybenzyl chloride (1.36 mL, 10.0 mmol) with stirring over 30 min at 0 °C. After stirring for 3 h, the resulting gray solution was transferred to a mixture of (*R*)-**3** (2.31 g, 5.00 mmol) and $\text{NiCl}_2(\text{dppe})$ (100 mg) in dry THF at room temperature. The mixture was heated to reflux at 60 °C and stirred for 2 h. The mixture was then cooled to 0 °C, carefully treated with saturated aqueous NH_4Cl , extracted with ether, dried over anhydrous MgSO_4 , and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 10:1) to give (*S*)-2-(*p*-methoxybenzyl)-2'-methoxymethoxy-1,1'-binaphthyl (2.06 g, 4.75 mmol) in 95% yield. TLC, $R_f = 0.32$ (hexane–EtOAc = 4:1); ^1H NMR (CDCl_3 , 300 MHz) δ 3.12 (s, 3H), 3.69 (apparent s, 5H), 4.88 (d, $J = 6$ Hz, 1H), 4.96 (d, $J = 6$ Hz, 1H), 6.43 (d, $J = 8.4$ Hz, 2H), 6.82 (d, $J = 8.7$ Hz, 2H), 7.04 (d, $J = 9.6$ Hz, 1H), 7.08–7.24 (m, 3H), 7.28–7.48 (m, 3H), 7.60 (d, $J = 9.6$ Hz, 1H), 7.85 (d, $J = 8.4$ Hz, 3H), 7.96 (d, $J = 9.6$ Hz, 1H).

(*S*)-2'-(*p*-Methoxybenzyl)-2-methoxymethoxy-3-hydroxy-binaphthyl (Step b in Scheme 1). To a mixture of (*S*)-2-(*p*-methoxybenzyl)-2'-methoxymethoxy-1,1'-binaphthyl (2.69 g, 6.20 mmol) and *N,N,N,N*-tetramethylethylenediamine (TMEDA) (1.12 mL, 7.45 mmol) in THF (60 mL) was added a 1.6 *M* solution of BuLi in hexanes (4.65 mL, 7.45 mmol) dropwise over 30 min at –78 °C, and the mixture was allowed to warm to 0 °C. After stirring for 4 h at the same temperature, the resulting dark green mixture was cooled to –78 °C and $\text{B}(\text{OMe})_3$ (2.50 mL, 19.0 mmol) was added dropwise. The mixture was allowed to warm to room temperature and then stirred for 10 h. To the mixture was added 1 *M* aqueous HCl (10 mL) at 0 °C, and the mixture was then stirred for 30 min at room temperature, extracted with ether, dried over anhydrous MgSO_4 and concentrated. The crude boronic acid was dissolved in THF (10 mL), and 3 *M* aqueous NaOH (10 mL) was added. H_2O_2 (10 mL) was added dropwise at 0 °C, and the mixture was stirred for 2 h at the same temperature. The reaction mixture was poured into brine, washed with H_2O , extracted with ether, dried over anhydrous MgSO_4 , and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–EtOAc = 4:1) to give (*S*)-2'-(*p*-methoxybenzyl)-2-methoxymethoxy-3-hydroxy-binaphthyl (2.34 g, 5.19 mmol) in 84% yield. TLC, $R_f = 0.20$ (hexane–EtOAc = 4:1); ^1H NMR (CDCl_3 , 300 MHz) δ 3.32 (s, 3H), 3.70 (apparent s, 5H), 4.39 (d, $J = 6.3$ Hz, 1H), 4.53 (d, $J = 7.5$ Hz, 1H), 6.66 (d, $J = 8.7$ Hz, 2H), 6.84 (d, $J = 8.4$ Hz, 2H), 6.96 (d, $J = 9.6$ Hz, 1H), 7.05 (t, $J = 9.6$ Hz, 1H), 7.17 (d, $J = 9.6$ Hz, 1H), 7.20–7.46 (m, 5H), 7.50 (s, 1H), 7.76 (d, $J = 8.4$ Hz, 1H), 7.87 (d, $J = 8.4$ Hz, 2H).

(*S*)-2'-(*p*-Methoxybenzyl)-2-methoxymethoxy-3-(*o*-fluorobenzyloxy)-binaphthyl (Step c in Scheme 1). To a mixture of (*S*)-2'-(*p*-methoxybenzyl)-2-methoxymethoxy-3-hydroxy-binaphthyl (1.80 g, 4.00 mmol), triphenylphosphine (1.57 g, 6.00 mmol), and *o*-fluorobenzyl alcohol (437 μL , 6.00 mmol) in THF (10 mL) was added dropwise a toluene solution of diethylazodicarboxylate (DEAD) (40% in toluene) (2.64 mL, 6.00 mmol). After stirring for 2 h, the mixture was concentrated and the residue was purified by column chromatography on silica gel (eluent: hexane–ether = 10:1) to give (*S*)-2'-(*p*-methoxybenzyl)-2-methoxymethoxy-3-(*o*-

fluorobenzyloxy)-binaphthyl (2.21 g, 3.96 mmol) in 99% yield. TLC, R_f = 0.33 (hexane–EtOAc = 4:1); ^1H NMR (CDCl_3 , 300 MHz) δ 2.40 (s, 3H), 3.68 (d, J = 18 Hz, 1H), 3.71 (s, 3H), 3.84 (d, J = 18 Hz, 1H), 4.84 (d, J = 7.2 Hz, 1H), 4.92 (d, J = 7.2 Hz, 1H), 5.37 (s, 2H), 6.64 (d, J = 12 Hz, 2H), 6.88 (d, J = 12 Hz, 2H), 6.99 (d, J = 9.6 Hz, 1H), 7.02–7.42 (m, 9H), 7.44 (s, 1H), 7.60 (dt, J = 7.2, 1.8 Hz, 1H), 7.79 (d, J = 8.1 Hz, 2H), 7.81 (d, J = 8.1 Hz, 1H).

(S)-2'-(*p*-Methoxybenzyl)-2-hydroxy-3-(*o*-fluorobenzyloxy)-binaphthyl (2e) (Step d in Scheme 1). To a solution of (S)-2'-(*p*-methoxybenzyl)-2-methoxymethoxy-3-(*o*-fluorobenzyloxy)-binaphthyl (2.23 g, 4.00 mmol) in 1,4-dioxane (10 mL) was added 4 M aqueous HCl (10 mL). The mixture was then heated to reflux at 90 °C and stirred for 3 h. The mixture was extracted with ether, and the ether extracts were washed with brine, dried over anhydrous MgSO_4 , filtered, and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 10:1) to give (S)-2e (2.04 g, 3.96 mmol) in 99% yield. TLC, R_f = 0.26 (hexane–EtOAc = 4:1); IR (CHCl_3) 3536 (OH), 3009, 1510, 1447, 1248 cm^{-1} ; ^1H NMR (CDCl_3) δ 3.71 (s, 3H), 3.71 (dd, J = 5.0, 1.8 Hz, 2H), 5.40 (s, 2H), 5.79 (s, 1H, OH), 6.67 (dt, J = 9, 2.7 Hz, 2H), 6.89 (d, J = 9 Hz, 2H), 6.99 (d, J = 8.1 Hz, 1H), 7.12 (dd, J = 7.2, 1.8 Hz, 1H), 7.16 (dd, J = 4.5, 1.8 Hz, 1H), 7.18 (d, J = 3.6 Hz, 1H), 7.24 (apparent s, 2H), 7.31 (dt, J = 7.2, 1.4 Hz, 1H), 7.34 (d, J = 7.2 Hz, 1H), 7.38 (d, J = 3.6 Hz, 1H), 7.40 (s, 1H), 7.42 (d, J = 6.3 Hz, 1H), 7.54 (dt, J = 7.2, 1.8 Hz, 1H), 7.78 (d, J = 8.1 Hz, 1H), 7.86 (d, J = 8.1 Hz, 2H); ^{13}C NMR (75 MHz, CDCl_3) δ 38.7, 55.1, 64.9 (d, $J_{\text{C-F}}$ = 4.3 Hz), 107.4, 113.5 (2C), 115.6 (d, $J_{\text{C-F}}$ = 21 Hz), 118.6, 123.2, 124.0, 124.4 (d, $J_{\text{C-F}}$ = 3.4 Hz), 124.7, 124.8, 125.3, 126.0, 126.2, 126.9, 127.9, 128.0, 128.3, 128.8, 129.6, 130.2 (2C), 130.2, 130.4 (d, $J_{\text{C-F}}$ = 8.3 Hz), 130.8, 132.3, 132.8, 133.1, 138.9, 143.4, 146.1, 157.6, 160.7 (d, $J_{\text{C-F}}$ = 255 Hz). Anal. Calcd for $\text{C}_{35}\text{H}_{27}\text{FO}_3$: C, 81.69; H, 5.29. Found: C, 81.73; H, 5.25.

(S)-2a–d was prepared from (R)-3 as well as (S)-2e.

(S)-2-Hydroxy-3-methoxy-2'-methylbinaphthyl (2a): IR (CHCl_3) 3534 (OH), 3011, 1460, 1431, 1229, 1119 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 2.16 (s, 3H), 4.10 (s, 3H), 5.72 (apparent s, 1H (OH)), 6.95 (d, J = 8.1 Hz, 1H), 7.12 (t, J = 6.9 Hz, 1H), 7.21 (d, J = 1.2 Hz, 1H), 7.24 (d, J = 2.4 Hz, 1H), 7.28 (s, 1H), 7.32 (t, J = 7.7 Hz, 1H), 7.39 (dt, J = 6.9, 1.5 Hz, 1H), 7.53 (d, J = 8.1 Hz, 1H), 7.79 (d, J = 8.4 Hz, 1H), 7.89 (d, J = 7.5 Hz, 1H), 7.90 (d, J = 8.1 Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 20.2, 55.9, 105.6, 118.7, 124.0, 124.4, 124.6, 124.9, 125.6, 126.2, 126.8, 128.0, 128.1, 128.7, 128.8, 129.0, 130.4, 132.2, 132.9, 135.6, 142.8, 147.3. Anal. Calcd for $\text{C}_{22}\text{H}_{18}\text{O}_2$: C, 84.05; H, 5.77. Found: C, 84.15; H, 5.85.

(S)-2-Hydroxy-3-(*o*-fluorobenzyloxy)-2'-methylbinaphthyl (2b): IR (CHCl_3) 3538 (OH), 3010, 1495, 1445, 1381, 1231, 1115 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 2.15 (s, 3H), 5.36 (s, 2H), 5.80 (brs, 1H (OH)), 6.97 (d, J = 8.1 Hz, 1H), 7.09 (d, J = 8.7 Hz, 1H), 7.13 (t, J = 8.1 Hz, 2H), 7.21 (apparent s, 2H), 7.26–7.42 (m, 4H), 7.46–7.54 (m, 2H), 7.76 (d, J = 8.1 Hz, 1H), 7.87 (d, J = 8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl_3) δ 20.2, 64.8 (d, $J_{\text{C-F}}$ = 4.0 Hz), 107.2, 115.6 (d, $J_{\text{C-F}}$ = 21 Hz), 119.0, 123.0, 123.2, 124.0, 124.4 (d, $J_{\text{C-F}}$ = 3.5 Hz), 124.6 (d, $J_{\text{C-F}}$ = 2.8 Hz), 124.9, 125.6, 126.1, 126.9, 127.9, 128.0, 128.7, 128.8, 129.1, 130.1 (d, $J_{\text{C-F}}$ = 3.5 Hz), 130.3 (d, $J_{\text{C-F}}$ = 8.3 Hz), 130.6, 132.2, 132.8, 135.5, 143.0, 146.1, 160.7 (d, $J_{\text{C-F}}$ = 246 Hz). Anal. Calcd for $\text{C}_{28}\text{H}_{21}\text{FO}_2$: C, 82.33; H, 5.18. Found: C, 82.14; H, 5.23.

(S)-3-(*o*-Fluorobenzyloxy)-2'-(*p*-fluorobenzyl)-2-hydroxybinaphthyl (2c): IR (CHCl_3) 3534 (OH), 3010, 1509, 1447, 1383, 1231, 1157, 1115 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 3.76 (s, 2H), 5.41 (s, 2H), 5.79 (s, 1H (OH)), 6.78 (d, J = 9.6 Hz, 1H), 6.80 (d, J = 9.6 Hz, 1H), 6.82–6.92 (dd, 2H), 6.98 (d, J = 9.6 Hz, 1H), 7.08–7.47 (m, 10H), 7.52 (t, J = 7.2 Hz, 1H), 7.78 (d, J = 9.6 Hz, 1H), 7.90 (d, J = 10.8 Hz, 2H). Anal. Calcd for $\text{C}_{34}\text{H}_{24}\text{F}_2\text{O}_2$: C, 81.26; H, 4.81. Found: C, 81.29; H, 4.88.

(S)-2-Benzyl-3'-(*o*-fluorobenzyloxy)-2'-hydroxybinaphthyl (2d): IR (CHCl_3) 3538 (OH), 3011, 1495, 1447, 1383, 1342, 1231, 1150 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 3.78 (s, 2H), 5.40 (s, 2H), 5.78 (apparent s, 1H (OH)), 6.94–7.44 (m, 16H), 7.53 (t, J = 8.4 Hz, 1H), 7.77 (d, J = 8.4 Hz, 1H), 7.87 (d, J = 8.4 Hz, 2H); ^{13}C NMR (75 MHz, CDCl_3) δ 39.7, 64.9, 107.4, 115.6 (d, $J_{\text{C-F}}$ = 21 Hz), 118.5, 123.2, 124.1, 124.4, 124.7, 124.8, 125.3, 125.7, 126.0, 126.2, 126.9, 127.9, 128.0, 128.1

(2C), 128.3, 128.8, 129.3 (2C), 129.5, 130.2, 130.4 (d, $J_{\text{C-F}} = 8.0$ Hz), 131.0, 132.4, 132.9, 138.6, 140.9, 143.4, 146.1 (C-F signal was not observed). Anal. Calcd for $\text{C}_{34}\text{H}_{25}\text{FO}_2$: C, 84.28; H, 5.20. Found: C, 84.27; H, 5.22.

(S)-2-Hydroxy-3-(*o*-fluorobenzyloxy)-2'-(2,4,6-trimethylphenyl)binaphthyl (2f): IR (CHCl_3) 3536 (OH), 3009, 1495, 1442, 1381, 1340, 1248 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 1.70 (s, 3H), 2.10 (s, 3H), 2.15 (s, 3H), 5.25 (d, $J = 10.6$ Hz, 1H), 5.32 (d, $J = 10.6$ Hz, 1H), 5.77 (s, 1H (OH)), 6.50 (s, 1H), 6.74 (s, 1H), 7.02–7.28 (m, 8H), 7.33 (d, $J = 3.5$ Hz, 1H), 7.37 (t, $J = 7.0$ Hz), 7.42 (d, $J = 8.7$ Hz, 1H), 7.46 (dt, $J = 8.8, 3.5$ Hz, 1H), 7.63 (d, $J = 8.1$ Hz, 1H), 7.97 (d, $J = 8.1$ Hz), 8.00 (d, $J = 8.4$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 20.9, 21.0, 21.0, 64.8, 107.3, 115.6 (d, $J_{\text{C-F}} = 20.8$ Hz), 118.5, 123.2, 123.5, 123.6, 124.3 (d, $J_{\text{C-F}} = 3.7$ Hz), 125.5, 126.2, 126.4, 126.7, 126.8, 127.3, 127.7, 127.9, 128.0, 128.3, 129.4, 129.6, 130.0 (d, $J_{\text{C-F}} = 3.5$ Hz), 130.3 (d, $J_{\text{C-F}} = 8.0$ Hz), 132.2, 132.6, 133.3, 135.5, 136.0, 137.3, 137.6, 139.9, 143, 7, 145.6 (C-F signal was not observed). Anal. Calcd for $\text{C}_{36}\text{H}_{29}\text{FO}_2$: C, 84.35; H, 5.70. Found: C, 84.14; H, 5.77.

(E)-4-Homogeranyltoluene (4). This compound was synthesized by reaction of 4-methylbenzyl magnesium chloride with (*E*)-geranyl diethyl phosphate according to Butsugan's method.³ LRMS (CI) $t_{\text{R}} = 15.9$ min, m/z $\text{M}^+ + 1$, 243; GC (100 kPa, column temp. 150 °C, inj. temp. 170 °C) $t_{\text{R}} = 12.1$ min.; IR (film) 2923, 1516, 1449, 1377, 806 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 1.56 (s, 3H), 1.60 (s, 3H), 1.68 (s, 3H), 1.93–2.12 (m, 4H), 2.27 (q, $J = 7.8$ Hz, 2H), 2.31 (s, 3H), 2.59 (t, $J = 8.1$ Hz, 2H), 5.09 (brt, 1H), 5.18 (t, $J = 6.9$ Hz, 1H), 7.08 (apparent s, 4H); ^{13}C NMR (75 MHz, CDCl_3) δ 16.0, 17.7, 21.0, 25.7, 26.7, 30.1, 35.7, 39.7, 123.7, 124.3, 128.3 (2C), 128.7 (2C), 131.3, 135.0, 135.6, 139.3. Anal. Calcd for $\text{C}_{18}\text{H}_{26}$: C, 89.19; H, 10.81. Found: C, 89.32; H, 10.83.

General Procedure for the Enantio- and Diastereoselective Cyclization of (*E*)-4 Induced by Chiral LBA (Table 1). To a solution of chiral catechol **2** (0.10 mmol) in toluene (2 mL) was added a 1 M solution of tin(IV) chloride in hexane (0.10 mL, 0.10 mmol) at room temperature, and the mixture was stirred for 5 min. After the solution was cooled to –78 °C, (*E*)-**4** (24.2 mg, 0.10 mmol) was added dropwise. The reaction mixture was stirred for 1 day, quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. The crude product was purified to remove chiral catechol by column chromatography on silica gel (eluent: hexane–ether). The resulting mixture of **5**, endo-**6** and exo-**6** was used for the next cyclization without further separation to determine the enantiomeric excess. To a solution of a mixture of **5**, endo-**6** and exo-**6**, which were obtained in the above reaction, in *i*-PrNO₂ (2 mL) was added dropwise ClSO_3H (50 μL) at –78 °C. After stirring for 2 h, the reaction mixture was quenched with saturated aqueous NaHCO_3 , washed with H_2O , and extracted with ether. The ether extracts were dried over anhydrous MgSO_4 , filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether) to give **6**.

(–)-(5R,10R)-12-Methylpodocarpa-8,11,13-triene (5): LRMS (CI) $t_{\text{R}} = 16.7$ min, m/z $\text{M}^+ + 1$, 243; HPLC (two linear Daicel OD-H columns, hexane-*i*-PrOH = 400:1, flow rate = 0.3 mL/min) $t_{\text{R}} = 31.4$ ((–)-enantiomer), 33.3 ((+)-enantiomer) min; IR (film) 2900, 1497, 1474, 1375, 1040, 814 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.92 (s, 3H), 0.94 (s, 3H), 1.18 (s, 3H), 1.14–1.92 (m, 8H), 2.24–2.32 (m, 1H), 2.29 (s, 3H), 2.72–2.95 (m, 2H), 6.88 (dd, $J = 7.7, 1.9$ Hz, 1H), 6.93 (d, $J = 7.7$ Hz, 1H), 7.06 (brs, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 19.1, 19.3, 21.3, 21.7, 24.8, 30.0, 33.3, 33.4, 37.7, 38.8, 41.7, 50.4, 124.9, 126.0, 128.9, 132.0, 134.7, 149.9; $[\alpha]_{\text{D}}^{20.0} = -24.3$ (c 1.25, CHCl_3) for 72% ee. Anal. Calcd for $\text{C}_{18}\text{H}_{26}$: C, 89.19; H, 10.81. Found: C, 89.25; H, 10.78.

6-(*p*-Tolylethyl)-1,5,5-trimethylcyclohexene (endo-6) and 3,3-Dimethyl-1-methylene-2-(*p*-tolylethyl)cyclohexane (exo-6): Compounds **5**, endo-**6**, and exo-**6** could not be separated by column chromatography on silica gel. GC (column temp. 150 °C, inj. temp. 170 °C) $t_{\text{R}} = 6.9$ (exo-**6**), 7.3 (endo-**6**), 12.1 (**5**) min; ^1H NMR (300 MHz, CDCl_3) δ 0.82 (s, 3H (exo-**6**)), 0.88 (s, 3H

(endo-**6**)), 0.91 (s, 3H (exo-**6**)), 0.97 (s, 3H (endo-**6**)), 4.60 (s, 1H (exo-**6**)), 4.82 (s, 1H (exo-**6**)), 5.30 (brs, 1H (endo-**6**)).

Enantioselective Total Synthesis of (–)-Chromazonarol (**9**) (Scheme 2).

(*E,E*)-2-Farnesyl-4-methoxyphenol (7a**).** To a solution of 4-methoxyphenol (248 mg, 2.00 mmol) in 1,4-dioxane (6 mL) was added $\text{BF}_3 \cdot \text{Et}_2\text{O}$ (126 μL , 1.00 mmol) at room temperature, and then a solution of (*E,E*)-farnesol (253 μL , 1.00 mmol) in 1,4-dioxane (1 mL) was added dropwise over 5 h at the same temperature. After stirring for 20 h, the reaction mixture was quenched with saturated aqueous NaHCO_3 and extracted with ether. The combined organic layers were dried over anhydrous MgSO_4 , filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 20:1 to 10:1) to give **7a** (93 mg, 0.25 mmol) in 25% yield. IR (film) 3700–3100 (OH), 2914, 1505, 1435, 1202, 1044, 803 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 1.60 (s, 6H), 1.67 (s, 3H), 1.77 (s, 3H), 1.95–2.22 (m, 8H), 3.33 (d, $J = 7.2$ Hz, 2H), 3.75 (s, 3H), 4.79 (brs, 1H (OH)), 5.09 (brt, 2H), 5.31 (t, $J = 6.3$ Hz, 1H), 6.66 (dd, $J = 8.4, 2.7$ Hz, 1H), 6.67 (d, $J = 2.7$ Hz, 1H), 6.74 (d, $J = 8.4$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 16.0, 16.2, 17.7, 25.7, 26.4, 26.6, 30.0, 39.6, 55.6, 112.0, 115.6, 116.2, 116.3, 121.3, 123.6, 124.3, 128.0, 131.3, 135.5, 138.7, 148.3, 153.6. Anal. Calcd for $\text{C}_{22}\text{H}_{32}\text{O}_2$: C, 80.44; H, 9.82. Found: C, 80.50; H, 9.84.

(–)-Chromazonarol Methyl Ether (8**):** To a solution of (*S*)-**2e** (100 mg, 0.20 mmol) in toluene (2 mL) was added a 1.0 *M* solution of tin(IV) chloride in hexane (0.10 mL, 0.10 mmol) at room temperature, and the mixture was stirred for 5 min. After the solution was cooled to -78°C , (*E*)-**7a** (37 mg, 0.10 mmol) was added dropwise. The reaction mixture was stirred for 2 days, quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. (*S*)-**2e** was removed from crude products by column chromatography on silica gel (eluent: hexane–ether). A mixture of cyclic products was dissolved in *i*-PrNO₂ (2 mL), and a 1.0 *M* solution of tin(IV) chloride in hexane (0.20 mL, 0.20 mmol) and $\text{CF}_3\text{CO}_2\text{H}$ (77 μL , 1.0 mmol) were added at -78°C . After stirring for 1 day, the reaction mixture was quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. The crude product was purified by column chromatography on silica gel (eluent: hexane–ether) to give **8** (15 mg, 0.04 mmol) in 40% yield. LRMS (CI) $t_R = 23.0$ min, m/z $\text{M}^+ + 1$, 328; GC (100 kPa, column temp. 230°C , inj. temp. 300°C) $t_R = 14.2$ min, other isomers $t_R = 8.8, 9.1, 10.3, 11.7, 11.9, 15.1$ min; HPLC (two linear Daicel OD-H columns, hexane–*i*-PrOH = 20:1, 0.15 mL/min) $t_R = 71.2$ ((+)-enantiomer), 81.4 ((–)-enantiomer) min; IR (CHCl_3) 2940, 1496, 1228, 1040, 939 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.84 (s, 3H), 0.88 (s, 3H), 0.91 (s, 3H), 1.18 (s, 3H), 0.92–1.80 (m, 11H), 2.05 (dd, $J = 12, 3.4$ Hz, 1H), 2.61 (d, $J = 9$ Hz, 2H), 3.74 (s, 3H), 6.64 (d, $J = 18$ Hz, 2H), 6.67 (s, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 14.8, 18.5, 19.7, 20.7, 21.6, 22.6, 33.2, 33.4, 36.7, 39.2, 41.1, 41.8, 52.0, 55.6, 56.1, 76.6, 113.0, 114.3, 117.4, 122.9, 147.1, 152.8; $[\alpha]_D^{20.0} = -23.4$ (*c* 0.63, CHCl_3) for 88% ee. Anal. Calcd for $\text{C}_{22}\text{H}_{32}\text{O}_2$: C, 80.44; H, 9.82. Found: C, 80.48; H, 9.83.

(–)-Chromazonarol (9**).**⁵ To a solution of (–)-**8** (15 mg, 0.040 mmol) in hexane (0.5 mL) was added a 0.2 *M* solution of $\text{B}(\text{C}_6\text{F}_5)_3$ in toluene (10 μL , 0.002 mmol) and HSiEt_3 (8 μL , 0.05 mmol) at room temperature.⁴ After stirring for 1 day, the reaction mixture was poured into brine and extracted with ether. The ether extracts were dried over MgSO_4 and concentrated to obtain chromazonarol triethylsilyl ether as a crude product, which was used in the next step without further purification. To a solution of chromazonarol triethylsilyl ether (ca. 0.04 mmol) in THF (0.4 mL) was added a 1 *M* solution of tetrabutyl ammonium fluoride (TBAF) in THF (0.04 mL, 0.04 mmol) at 0°C . After stirring for 30 min, THF was removed in vacuo and the residue was purified by column chromatography on silica gel (eluent: hexane–ether = 10:1) to give (–)-**9** (12 mg, 0.039 mmol) in 97% yield from (–)-**8** over two steps. HPLC (OD-H column, hexane–*i*-PrOH = 9:1, 0.5 mL/min) $t_R = 14.1$ ((+)-enantiomer), 16.4 ((–)-enantiomer) min; IR (CHCl_3) 3600–3100, 2929, 1495, 1447, 1379, 1221 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.84 (s, 3H), 0.87 (s, 3H), 0.90 (s, 3H), 1.17

(s, 3H), 2.05 (d, $J = 12.0$ Hz, 1H), 2.55 (d, $J = 9.0$ Hz, 2 H), 5.00 (br, 1H), 6.55 (s, 1H), 6.59 (d, $J = 18.0$ Hz, 2H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 14.8, 18.5, 20.6, 21.6, 22.4, 33.1, 33.4, 36.7, 39.0, 41.0, 41.7, 52.0, 56.0, 76.8, 114.2, 115.8, 117.4, 123.3, 146.9, 148.5; $[\alpha]^{20.0}_{\text{D}} = -33.5$ (c 0.37, CHCl_3) for 88% ee.

Enantioselective Total Synthesis of (+)-8-*epi*-Puupehedione (Scheme 3)

(*E,E*)-2-Farnesyl-4,5-methylenedioxyphenol (7b). To a solution of sesamol (3,4-methylenedioxyphenol, 2.1 g, 15 mmol) in toluene (50 mL) was added $\text{Sc}(\text{OTf})_3$ (2.2 g, 4.5 mmol) at room temperature, and then a solution of (*E,E*)-farnesol (5.3 g, 23 mmol) in toluene (50 mL) was added dropwise over a period of 7 h at 0 °C. After stirring for 1 day at the same temperature, the reaction was quenched with saturated aqueous NaHCO_3 and extracted with ether. The combined organic layers were dried over anhydrous MgSO_4 , filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 20:1 to 10:1) to give **7b** (3.87 g, 11.3 mmol) in 75% yield. IR (film) 3600–3100 (OH), 2915, 1505, 1488, 1441, 1169, 1040, 939, 852 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 1.60 (s, 6H), 1.67 (s, 3H), 1.76 (s, 3H), 1.96–2.22 (m, 8H), 3.26 (d, $J = 7.5$ Hz), 4.87 (s, 1H (OH)), 5.08 (brt, 2H), 5.23 (t, $J = 6$ Hz), 5.87 (s, 2H), 6.42 (s, 1H), 6.58 (s, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 16.0, 16.2, 17.7, 25.7, 26.3, 26.6, 29.6, 39.6 (2C), 98.6, 100.8, 109.1, 118.4, 121.7, 123.5, 124.3, 131.3, 135.6, 138.7, 141.2, 146.3, 148.8. Anal. Calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$: C, 77.16; H, 8.83. Found: C, 77.02; H, 8.87.

(+)-Formaldehyde Acetal of 8-*epi*-puupehenol (10).⁶ To a solution of (*S*)-**2e** (100 mg, 0.20 mmol) in toluene (2 mL) was added a 1.0 *M* solution of tin(IV) chloride in hexane (0.10 mL, 0.10 mmol) at room temperature, and the mixture was stirred for 5 min. After the solution was cooled to –78 °C, (*E*)-**7b** (34 mg, 0.10 mmol) was added dropwise. The reaction mixture was stirred for 2 days, quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. (*S*)-**2e** was removed from crude product by column chromatography on silica gel (eluent: hexane–ether). A mixture of cyclic products was dissolved in *i*-PrNO₂ (2 mL), and a 1.0 *M* solution of tin(IV) chloride in hexane (0.20 mL, 0.20 mmol) and $\text{CF}_3\text{CO}_2\text{H}$ (77 μL , 1.0 mmol) were added at –78 °C. After stirring for 1 day, the reaction mixture was quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. The crude product was purified by column chromatography on silica gel (eluent: hexane–ether) to give (+)-**10** (21 mg, 0.062 mmol) in 62% yield. ^1H NMR, ^{13}C NMR, and IR spectroscopic properties were identical to those reported in the literature.⁶ LRMS (CI) $t_{\text{R}} = 24.3$ min, m/z $\text{M}^+ + 1$, 342; GC (100 kPa, column temp. 230 °C, inj. temp. 300 °C) $t_{\text{R}} = 24.2$ min, other isomers $t_{\text{R}} = 14.7, 17.5, 19.7, 20.1, 25.9$ min; HPLC (two linear Daicel AD-H columns, hexane–*i*-PrOH = 50:1, 0.25 mL/min) $t_{\text{R}} = 42.2$ ((–)-enantiomer), 44.6 ((+)-enantiomer) min; IR (CHCl_3) 3032, 1503, 1436, 1040, 939, 858 cm^{-1} ; ^1H NMR (CDCl_3 , 300 MHz) δ 0.83 (s, 3H), 0.86 (s, 3H), 0.90 (s, 3H), 1.16 (s, 3H), 2.50 (d, $J = 9.0$ Hz, 2 H), 5.83 (dd, $J = 1.8, 2.4$ Hz, 2H), 6.31 (s, 1H), 6.49 (s, 1H); ^{13}C NMR (CDCl_3 , 75 MHz) δ 14.8, 18.5, 19.7, 20.5, 21.5, 22.3, 33.1, 33.4, 36.7, 39.1, 40.9, 41.7, 52.0, 56.0, 76.6, 98.7, 100.5, 108.3, 113.5, 140.8, 146.1, 147.5; $[\alpha]^{20.0}_{\text{D}} = +15.7$ (c 5.86, CHCl_3) for 89% ee.

Formaldehyde Acetal of 9,15-Dehydro-8-*epi*-puupehenol.⁶ To a solution of (+)-**10** (130 mg, 0.40 mmol) in 1,4-dioxane (8 mL) was added DDQ (108 mg, 0.48 mmol) at room temperature. The mixture was then warmed to 60 °C and stirred for 3 h. The solvent was removed in vacuo and the residue was purified by column chromatography on silica gel to give formaldehyde acetal of 9,15-dehydro-8-*epi*-puupehenol (127 mg, 0.39 mmol) in 97 % yield. LRMS (CI) $t_{\text{R}} = 23.8$ min, m/z $\text{M}^+ + 1$, 340; GC (100 kPa, column temp. 230 °C, inj. temp. 300 °C) $t_{\text{R}} = 49.4$ min, other isomers $t_{\text{R}} = 28.7, 36.1$ min; HPLC (OD-H column, hexane–EtOAc = 20:1, 0.20 mL/min) $t_{\text{R}} = 42.9$ ((–)-enantiomer), 65.5 ((+)-enantiomer) min; ^1H NMR (300 MHz, CDCl_3) δ 0.86 (s, 3H), 0.91 (s, 3H), 1.13 (s, 3H), 1.38 (s, 3H), 5.87 (s, 2H), 6.01 (s, 1H), 6.38 (s, 1H), 6.47 (s, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 18.2, 19.2, 21.6, 22.6, 23.4, 25.8, 31.6, 33.3, 33.5, 37.9, 38.8, 41.5, 52.0, 78.0, 98.6, 100.7, 105.4, 114.2, 116.2, 141.4, 146.6, 149.5.

(+)-8-*epi*-Puupehedione (11).⁶ To a solution of formaldehyde acetal of 9,15-dehydro-8-*epi*-puupehenol (65 mg, 0.20 mmol) in hexane (1 mL) was added a 0.2 M solution of B(C₆F₅)₃ in toluene (100 μ L, 0.02 mmol) and HSiEt₃ (96 μ L, 0.6 mmol) at room temperature.⁴ After stirring for 20 h, the reaction mixture was poured into brine and extracted with ether. The ether extracts were dried over MgSO₄, concentrated to obtain bis(triethylsilyl) ether of 9,15-dehydro-8-*epi*-puupehenol as a crude product, which was used in the next step without further purification. To a solution of bis(triethylsilyl) ether of 9,15-dehydro-8-*epi*-puupehenol (ca. 0.20 mmol) in 1,4-dioxane (4 mL) was added DDQ (55 mg, 0.24 mmol) and H₂O (0.5 mL) at room temperature. The mixture was stirred for 3 h at the same temperature. The solvent was removed in vacuo and the residue was purified by column chromatography on silica gel (eluent: hexane–EtOAc = 4 : 1) to give (+)-**11** (61 mg, 0.19 mmol) in 94 % yield from formaldehyde acetal of 9,15-dehydro-8-*epi*-puupehenol. TLC, *R*_f = 0.25 (hexane–EtOAc = 2 : 1); IR (CHCl₃) 3016, 2953, 1643, 1601, 1565, 1402, 1240 cm⁻¹; ¹H NMR (CDCl₃, 300 MHz) δ 0.88 (s, 3H), 0.92 (s, 3H), 1.17 (s, 3H), 1.58 (s, 3H), 1.09 (dd, *J* = 1.8, 12.0 Hz, 1H), 2.20 (m, 1H), 5.92 (s, 1H), 6.11 (s, 1H), 6.26 (s, 1H); ¹³C NMR (CDCl₃, 75 MHz) δ 18.6, 19.2, 21.6, 21.9, 30.6, 33.1, 34.0, 37.6, 40.2, 41.0, 41.1, 53.0, 83.0, 107.9, 114.3, 122.1, 137.7, 164.2, 166.2, 179.5, 181.0; [α]_D^{20.0} = +96.5 (c 0.63, CHCl₃) for 89% ee.

Enantioselective Synthesis of (+)-**13** (Scheme 3)

Allyl 3,4-Methylenedioxyphenyl Ether.⁷ To a solution of sesamol (3.45 g, 25.0 mmol) in THF (50 mL) was added portionwise NaH (60% dispersion in mineral oil, 1.10 g, 27.5 mmol) at 0 °C, and stirred for 30 min. Allylbromide (2.38 mL, 27.5 mmol) was then added to the resulting suspension at 0 °C, and stirred for 2 h at room temperature. The reaction was quenched with saturated aqueous NH₄Cl and extracted with ether. The combined organic layers were dried over anhydrous MgSO₄, filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 20:1 to 10:1) to give allyl 3,4-methylenedioxyphenyl ether (4.24 g, 23.8 mmol) in 95% yield. ¹H NMR, ¹³C NMR, and IR spectroscopic properties were identical to those reported in the literature.⁷

Allyl (*E,E*)-2-Farnesyl-3,4-methylenedioxyphenyl Ether. To a mixture of allyl 3,4-methylenedioxyphenyl ether (4.28 g, 24.0 mmol) and TMEDA (4.38 mL, 29.0 mmol) in ether (150 mL) was added dropwise a 1.6 M solution of BuLi (18.1 mL, 29.0 mmol) in hexane at –78 °C. After stirring for 2 h, the solution was allowed to warm to 0 °C slowly and stirred for additional 2 h. To the resulting yellow solution was added CuCN (2.15 g, 24.0 mmol) in one portion and the mixture was warmed to room temperature and stirred for 30 min.⁶ A solution of diethyl (*E,E*)-farnesyl phosphate (5.38 g, 15.0 mmol) in ether (50 mL) was added to the mixture and the mixture was stirred for 3 h at room temperature. The reaction was quenched with saturated aqueous NH₄Cl and extracted with ether. The combined organic layers were dried over anhydrous MgSO₄, filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 20:1 to 10:1) to give allyl (*E,E*)-2-farnesyl-3,4-methylenedioxyphenyl ether (4.70 g, 12.8 mmol) in 85% yield. ¹H NMR (CDCl₃, 300 MHz) δ 1.59 (s, 6H), 1.67 (s, 3H), 1.74 (s, 3H), 1.92–2.16 (m, 8H), 3.32 (d, *J* = 7.2 Hz, 2H), 4.46 (d, *J* = 5.8 Hz, 2H), 5.09 (brt, 2H), 5.20–5.42 (m, 3H), 5.90 (s, 2H), 5.95–6.15 (m, 1H), 6.26 (d, *J* = 8.4 Hz, 1H), 6.56 (d, *J* = 8.4 Hz, 1H).

(*E,E*)-2-Farnesyl-3,4-methylenedioxy Phenol (7c). To a solution of allyl (*E,E*)-2-farnesyl-3,4-methylenedioxyphenyl ether (4.79 g, 13.0 mmol) and NiCl₂(dppp) (70 mg, 0.13 mmol) in ether was added dropwise a 1 M solution of DIBAH in hexane (19.5 mL, 19.5 mmol) at 0 °C under N₂.⁸ The mixture was stirred for 5 min at the same temperature and then for 2 h at room temperature. Then the mixture was diluted with ether, quenched with H₂O and extracted with ether. The ether extracts were washed with aqueous Na₂SO₄ and the combined organic layers were concentrated. The residue was purified by column chromatography on silica gel (eluent; hexane–ether 20:1) to give **7c** (3.80 g, 11.1 mmol) in 85% yield. IR (film) 3600–3100 (OH), 2915, 1459, 1384, 1263, 1167, 1056, 936, 883, 801 cm⁻¹; ¹H NMR (300 MHz, CDCl₃) δ 1.59 (s, 6H), 1.67 (s, 3H), 1.79 (s, 3H), 1.92–2.16 (m, 8H), 3.34 (d, *J* = 7.2 Hz, 2H), 4.96 (s, 1H (OH)), 5.06 (brt, 2H), 5.29 (t, *J* = 6

Hz), 5.89 (s, 2H), 6.26 (d, $J = 8.4$ Hz, 1H), 6.54 (d, $J = 8.4$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 16.0, 16.2, 17.7, 23.2, 25.7, 26.3, 26.6, 39.6 (2C), 100.9, 105.8, 107.1, 110.7, 120.6, 123.6, 124.3, 131.3, 135.5, 138.8, 140.8, 146.0, 149.8. Anal. Calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$: C, 77.16; H, 8.83. Found: C, 77.02; H, 8.87.

(+)-12. To a solution of (*R*)-**2e** (100 mg, 0.20 mmol) in toluene (2 mL) was added a 1.0 *M* solution of tin(IV) chloride in hexane (0.1 mL, 0.1 mmol) at room temperature, and the mixture was stirred for 5 min. After the solution was cooled to -78°C , (*E*)-**7c** (34 mg, 0.10 mmol) was added dropwise. The reaction mixture was stirred for 2 days, quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. (*R*)-**2e** was removed from crude products by column chromatography on silica gel (eluent: hexane–ether). A mixture of cyclic products was dissolved in *i*-PrNO₂ (2 mL), and a 1.0 *M* solution of tin(IV) chloride in hexane (0.20 mL, 0.20 mmol) and $\text{CF}_3\text{CO}_2\text{H}$ (77 μL , 1.0 mmol) were added at -78°C . After stirring for 1 day, the reaction mixture was quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. The crude product was purified by column chromatography on silica gel (eluent: hexane–ether = 100 :1) to give (+)-**12** (21 mg, 0.060 mmol) in 60% yield. LRMS (CI) $t_{\text{R}} = 24.1$ min, m/z $\text{M}^+ + 1$, 342; GC (100 kPa, column temp. 230°C , inj. temp. 300°C) $t_{\text{R}} = 52.1$ min, other isomers $t_{\text{R}} = 30.9, 35.3, 42.0, 43.5, 55.4$ min; HPLC (Daicel OD-H columns, hexane-*i*-PrOH = 20:1, 0.20 mL/min) $t_{\text{R}} = 24.2$ ((+)-enantiomer), 27.5 ((-)-enantiomer) min; IR (CHCl_3) 2928, 1459, 1380, 1220, 1055, 972, 899 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.84 (s, 3H), 0.88 (s, 3H), 0.90 (s, 3H), 1.18 (s, 3H), 2.02 (dd, $J = 12.1, 2.1$ Hz, 1H), 2.39 (dd, $J = 16.7, 12.9$ Hz, 1H), 2.63 (dd, $J = 16.8, 5.1$ Hz, 1H), 5.88 (dd, $J = 6, 0.9$ Hz, 1H), 6.21 (d, $J = 8.7$ Hz, 1H), 6.55 (d, $J = 8.4$ Hz, 1H); ^{13}C NMR (75 MHz, CDCl_3) δ 14.7, 16.9, 18.4, 19.6, 20.5, 21.5, 33.1, 33.3, 36.7, 39.0, 41.0, 41.7, 51.2, 56.0, 76.6, 100.9, 106.2, 106.6, 107.7, 139.7, 145.2, 148.4. Anal. Calcd for $\text{C}_{22}\text{H}_{30}\text{O}_3$: C, 77.16; H, 8.83. Found: C, 77.11; H, 8.85.

(+)-13: To a solution of formaldehyde acetal of (+)-**12** (13 mg, 0.060 mmol) in hexane (1 mL) was added a 0.2 *M* solution of $\text{B}(\text{C}_6\text{F}_5)_3$ in toluene (30 μL , 0.006 mmol) and HSiEt_3 (29 μL , 0.18 mmol) at room temperature.⁴ After stirring for 20 h, the reaction mixture was poured into brine and extracted with ether. The ether extracts were dried over MgSO_4 , concentrated, and the residue was purified by column chromatography on silica gel to give (+)-**13** (25 mg, 0.059 mmol) in 98 % yield. TLC, $R_{\text{f}} = 0.29$ (hexane–ether = 20:1); ^1H NMR (300 MHz, CDCl_3) δ 0.85 (s, 3H), 0.89 (s, 3H), 0.90 (s, 3H), 1.14 (s, 3H), 2.03 (dt, $J = 13.2, 2.5$ Hz, 1H), 2.29 (dd, $J = 13.2, 17.2$ Hz, 1H), 2.67 (dd, $J = 5.1, 17.2$ Hz, 1H), 6.26 (d, $J = 9.2$ Hz, 1H), 6.57 (d, $J = 9.2$ Hz, 1H). Anal. Calcd for $\text{C}_{33}\text{H}_{58}\text{O}_3\text{Si}_2$: C, 70.91; H, 10.46. Found: C, 70.88; H, 10.54.

Enantioselective Synthesis of (+)-16 (Equation 2)

(*E,E,E*)-2-Geranylgeranyl-4-methoxy-6-methylphenol (7d).⁹ To a mixture of 4-methoxy-2-methylphenol (390 mg, 2.8 mmol) and $\text{Sc}(\text{OTf})_3$ (150 mg, 0.30 mmol) in toluene was added dropwise a 1 *M* solution of (*E,E,E*)-geranylgeraniol¹⁰ in toluene (4.5 mL, 4.5 mmol) over 3 h at room temperature. After stirring for 1 day, the reaction was quenched with saturated aqueous NaHCO_3 and extracted with ether. The combined organic layers were dried over anhydrous MgSO_4 , filtered and concentrated. The residue was purified by column chromatography on silica gel (eluent: hexane–ether = 20:1) to give **7d** (450 mg, 1.1 mmol) in 39% yield. IR (film) 3300–3650 (OH), 2920, 1605, 1483, 1196, 1148, 1059 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 1.60 (brs, 9H), 1.68 (s, 3H), 1.78 (s, 3H), 1.91–2.15 (m, 12H), 2.21 (s, 3H), 3.32 (d, $J = 7.5$ Hz, 2H), 3.37 (s, 3H), 4.79 (s, 1H (OH)), 5.09 (brt, 3H), 5.30 (t, $J = 6.1$ Hz, 1H), 6.55 (dd, $J = 14.1, 2.7$ Hz, 2H); ^{13}C NMR (75 MHz, CDCl_3) δ 15.9, 16.0, 16.1, 16.2, 17.6, 25.7, 26.3, 26.5, 26.7, 30.5, 39.62, 39.65, 39.68, 55.5, 112.8, 113.9, 121.6, 123.5, 124.2, 124.3, 125.4, 127.2, 131.2, 134.8, 135.6, 138.7, 146.7, 152.9.

(-)-11'-Deoxytaondiol Methyl Ether (16).^{9b} To a solution of (*R*)-**2e** (100 mg, 0.20 mmol) in toluene (2 mL) was added a 1.0 *M* solution of tin(IV) chloride in hexane (0.10 mL, 0.10 mmol) at

room temperature, and the mixture was stirred for 5 min. After the solution was cooled to $-78\text{ }^{\circ}\text{C}$, (*E*)-**7d** (41 mg, 0.10 mmol) was added dropwise. The reaction mixture was stirred for 2 days, quenched with saturated aqueous NaHCO_3 , and extracted with ether. The combined organic phases were dried over anhydrous MgSO_4 and concentrated. The crude product was purified by column chromatography on silica gel (eluent: hexane–ether) to give (–)-**16** (9.0 mg, 0.022 mmol) in 22% yield. HPLC (two linear Daicel OD-H columns, hexane–*i*-PrOH = 100:1, flow rate = 0.25 mL/min) t_{R} = 41.7 ((+)-enantiomer), 60.1 ((–)-enantiomer) min; IR (film) 2932, 1605, 1483, 1222, 1150, 1057, 864 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 0.82 (s, 3H), 0.85 (s, 6H), 0.87 (s, 3H), 1.13 (s, 3H), 2.12 (s, 3H), 2.58 (d, J = 8.7 Hz, 2H), 3.73 (s, 3H), 6.45 (s, 3H), 6.54 (s, 3H); ^{13}C NMR (75 MHz, CDCl_3) δ 15.9, 16.3, 16.4, 18.2, 18.6, 20.8, 21.4, 22.7, 33.28, 33.30, 37.0, 37.4, 39.9, 40.9, 41.1, 42.0, 52.5, 55.6, 56.5, 60.7, 76.1, 111.3, 114.3, 122.1, 126.9, 145.4, 152.1; $[\alpha]_{\text{D}}^{20.0}$ = -62.0 (c 0.34, CHCl_3) for 90% ee.

References and Notes

1. Hosoya, N.; Hatayama, A.; Irie, R.; Sasaki, H.; Katsuki, T. *Tetrahedron* **1994**, *50*, 4311.
2. Tamao, K.; Sumitani, K.; Kiso, Y.; Zembayashi, M.; Fujioka, A.; Kodama, S.; Nakajima, I.; Minato, A.; Kumada, M. *Bull. Chem. Soc. Jpn.* **1976**, *49*, 1958.
3. Araki, S.; Sato, T.; Butsugan, Y. *J. Chem. Soc. Chem. Commun.* **1982**, 285.
4. (a) Blackwell, J. M.; Foster, K. L.; Beck, V. H.; Piers, W. E. *J. Org. Chem.* **1999**, *64*, 4887. (b) Gevorgyan, V.; Liu, J. –X.; Rubin, M.; Benson, S.; Yamamoto, Y. *Tetrahedron Lett.* **1999**, *40*, 8919. (c) Gevorgyan, V.; Rubin, M.; Benson, S.; Liu, J. –X.; Yamamoto, Y. *J. Org. Chem.* **2000**, *65*, 6179.
5. (a) Fenical, W.; McConnel, O. *Experientia* **1975**, *31*, 1004. (b) Cimino, G.; De Stefeano, S.; Minale, L. *Experientia* **1975**, *31*, 1117. (c) Djura, P.; Stiele, D. B.; Sullivan, B.; Faulkner, J.; Arnold, E.; Clardy, J. *J. Org. Chem.* **1980**, *45*, 1435. (d) Rodriguez, J.; Quinoa, E.; Riguera, R.; Peters, B. M.; Abrell, L. M.; Crews, P. *Tetrahedron* **1992**, *48*, 6667.
6. Barrero, A. F.; Alvarez-Manzaneda, E. J.; Chahboun, R.; Cortes, M.; Armstrong, V. *Tetrahedron* **1999**, *55*, 15181.
7. Satoh, T.; Ikeda, M.; Miura, M.; Nomura, M. *J. Org. Chem.* **1997**, *62*, 4877.
8. Taniguchi, T.; Ogasawara, K. *Angew. Chem. Int. Ed.* **1998**, *37*, 1136.
9. (a) Gonzalez, A. G.; Darias, J.; Martin J. D. *Tetrahedron Lett.* **1971**, *29*, 2729. (b) Gonzalez, A. G.; Darias, J.; Martin J. D.; Pascual, C. *Tetrahedron* **1973**, *29*, 1605. (c) Begley, M. J.; Fish, P. V.; Pattenden, G. *J. Chem. Soc. Perkin Trans. 1* **1990**, 2263.
10. Eis, K.; Schmalz, H.-G. *Synthesis* **1997**, 202.