## **Supplementary Information**

# Regiodivergent Reductive Coupling of 2-Substituted Dienes to Formaldehyde Employing Ruthenium or Nickel Catalysts: Hydrohydroxymethylation *via* Transfer Hydrogenation

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## I. General Experimental Details.

All reactions were run under an atmosphere of argon, unless otherwise indicated. Anhydrous solvents were transferred via oven-dried syringe. Reaction tubes were oven-dried and cooled under a stream of argon. Reactions tubes were purchased from Fischer Scientific (catalog number 14-959-35C). Toluene and 1,4-dioxanes were purified from sodium and benzophenone. RuHCl(CO)(PPh<sub>3</sub>)<sub>3</sub>was prepared according to literature procedure.<sup>1</sup> Ni(COD)<sub>2</sub> and all ligands were used as received from Strem Chemicals Inc. Isopropanol (99.8%, extra dry) and paraformaldehyde were obtained and used as received from Acros Organics. For nickel catalysis, paraformaldehyde was purchased and immediately taken into the drybox, where it was stored in the refrigerator. Ni(COD)<sub>2</sub>, PCy<sub>3</sub>, and Cs<sub>2</sub>CO<sub>3</sub> were purchased from Aldrich and stored in the drybox prior to use. Unless noted otherwise, 2-substituted dienes 1-14 were prepared in accordance with literature procedure.<sup>2</sup> Analytical thin-layer chromatography (TLC) was carried out using 0.25 mm commercial silica gel plates (Dynamic Adsorbents  $F_{254}$ ) and products were visualized by UV, KMnO<sub>4</sub> and/or anisaldehyde stain. Preparative column chromatography employing Silicycle silica gel (40-63 µm) was performed according to the method of Still.<sup>3</sup> Infrared spectra were recorded on a Perkin-Elmer 1600 spectrometer. High-resolution mass spectra (HRMS) were obtained on a Karatos MS9 and are reported as m/z (relative intensity). Accurate masses are reported for the molecular ion [M+H]<sup>+</sup> or a suitable fragment ion. Proton nuclear magnetic resonance (<sup>1</sup>H NMR) spectra were recorded with a Varian Gemini (400 MHz) spectrometer. Chemical shifts are reported in delta ( $\delta$ ) units, parts per million (ppm) downfield from tetramethylsilane or ppm relative to the center of the singlet at 7.26 ppm for deuteriochloroform. Coupling constants are reported in Hertz (Hz). Carbon-13 nuclear magnetic resonance (<sup>13</sup>C NMR) spectra were recorded with a Varian Gemini or 400 (100 MHz) spectrometer. Chemical shifts are reported in delta ( $\delta$ ) units, ppm relative to the center of the triplet at 77.0 ppm for deuteriochloroform. <sup>13</sup>C NMR spectra were routinely run with broadband decoupling. Fluorine-19 nuclear magnetic resonance (<sup>19</sup>F NMR) spectra were recorded with a Varian Gemini or 400 (100 MHz) spectrometer. Deuterium nuclear magnetic resonance (<sup>2</sup>H NMR) spectra were recorded in CHCl<sub>3</sub> solution with a Varian Gemini 500 (77 MHz) spectrometer (relaxation delay 2.00 s).

<sup>&</sup>lt;sup>1</sup>T. Joseph, S. S. Deshpande, S.B. Halligudi, A. Vinu, S. Ernst and M. Hartmann, *J. Mol. Catal.A.*, 2003, **206**, 13. <sup>2</sup> (a) K. Tonogaki and M. Mori, *Tetrahedron Lett.*, 2002, **43**, 2235; (b) W.Huang, Q. Shen, J. Wang, X. Zhou, *J. Org. Chem.*, 2008, **73**, 1586; (c) T. Smejkal, H. Han, B. Breit and M. J. Krische, *J. Am. Chem. Soc.*, 2009, **131**, 10366; (d) R. R. Pidaparthi, C. S. Junker, M. E. Welker, C. S. Day and M. W. Wright, *J. Org. Chem.*, 2009, **74**, 8290; (e) E. Wada, S. Kanemasa, I. Fujiwara and O. Tsuge, *Bull. Chem. Soc. Jpn.*, 1985, **58**, 1942. <sup>3</sup>W. C. Still, M. Kahn and A. Mitra, *J. Org. Chem.*, 1978, **43**, 2923.

# II. Experimental Procedures and Spectroscopic Data for Novel Dienes 1-(buta-1,3-dien-2-yl)-4-methylbenzene (2)



1-(buta-1,3-dien-2-yl)-4-methylbenzene (2) was prepared by modifying an enyne metathesis method reported by Mori.<sup>4</sup>

A 100 mL round-bottom flask was charged with Grubb's  $2^{nd}$  generation catalyst (85 mg, 0.10 mmol, 2 mol%), 4-tolylacetylene (0.63 mL, 5.0 mmol, 100 mol%), and toluene (50 mL, 0.1 M). The reaction vessel was purged with ethylene gas followed by heating to 80 °C under 1 atm of ethylene gas. The reaction mixture was allowed to stir for 6 h at 80 °C and cooled to ambient temperature. Ethyl vinyl ether (several drops) was added and the solvent was removed *in vacuo*. The residue was purified by flash column chromatography (SiO<sub>2</sub>, 2% EtOAc/hexane) to afford the title compound (0.50 g, 70%) as a colorless liquid.

<sup>1</sup><u>H NMR</u>(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.27 – 7.21 (m, 2H), 7.20 – 7.12 (m, 2H), 6.68 – 6.56 (m, 1H), 5.30 – 5.26 (m, 1H), 5.26 – 5.21 (m, 1H), 5.21 – 5.17 (m, 2H), 2.37 (s, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ148.1, 138.2, 137.2, 136.8, 128.8, 128.1, 117.0, 116.4, 21.2.

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{12}[M]^+$ : 144.0937, Found: 144.0937.

**FTIR** (in CDCl<sub>3</sub>): 3087, 3026, 2921, 1512, 1437, 1379, 1020, 991, 893, 823, 729, 695 cm<sup>-1</sup>.

<sup>&</sup>lt;sup>4</sup>K. Tonogaki and M. Mori, *Tetrahedron Lett.*, 2002, *43*, 2235.





1-(buta-1,3-dien-2-yl)-4-fluorobenzene (6)



1-(buta-1,3-dien-2-yl)-4-fluorobenzene (6) was prepared by modifying a nickel catalyzed coupling method reported by Kumada.<sup>5</sup>

To a 300 mL sealed tube (sealing was used to prevent loss of chloroprene) equipped with a was added Ni(dppe)Cl<sub>2</sub> (0.26)magnetic stir bar g, 0.50 mmol. 1 mol%), Et<sub>2</sub>O (10 ml) and then chloroprene (6.6 g, 75 mmol, 1.5 equiv.). The mixture was cooled to 0 °C and stirred for 5 min. Then 4-fluorophenylmagnesiumbromide<sup>6</sup> (100 mL, 50 mmol, 0.5 M in Et<sub>2</sub>O) was added drop-wise under inert atmosphere followed by addition of toluene (10 mL). The reaction mixture was allowed to warm to room temperature and stirred for 40 h. The reaction mixture was quenched with a saturated aqueous solution of NH<sub>4</sub>Cl (50 mL). The aqueous layer was separated and extracted with Et<sub>2</sub>O ( $3 \times 20$  mL). The combined organic phases were washed with brine (20 mL) and dried (Na<sub>2</sub>SO<sub>4</sub>). After evaporation of the solvents, the mixture was purified by distillation (5 Torr, 50 °C) to furnish the title compound (3.5 g, 47%) as a colorless liquid.

<sup>1</sup><u>H</u> NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.34 – 7.23 (m, 2H), 7.09 – 6.99 (m, 2H), 6.61 (ddd, J = 17.2, 10.7, 0.6 Hz, 1H), 5.32 – 5.27 (m, 1H), 5.23 (ddd, J = 10.7, 1.2, 0.6 Hz, 1H), 5.20 – 5.11 (m, 2H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>):  $\delta$  162.3 (d, J = 245.9 Hz), 147.2, 138.1, 135.6 (d, J = 3.2 Hz, 2C), 129.9 (d, J = 8.0 Hz), 117.2, 117.1, 115.0 (d, J = 21.5 Hz, 2C).

<sup>19</sup>**F NMR** (376 MHz, CDCl<sub>3</sub>): δ -115.17 (m<sub>c</sub>).

**<u>HRMS</u>** (CI) Calcd. For  $C_{10}H_8F[M]^+$ : 148.0688, Found: 148.0689.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3091, 2970, 1738, 1604, 1507, 1366, 1317, 1296, 1220, 1158, 1095, 1037, 1014, 991, 899, 838, 818, 735, 663 cm<sup>-1</sup>.

<sup>&</sup>lt;sup>5</sup> K. Tamao, K. Sumitani, Y. Kiso, M. Zembayashi, A. Fujioka, S. Kodama, I. Nakajima, A. Minato and M. Kumada, *Bull. Chem. Soc. Japan.*, 1976, *49*, 1958.

<sup>&</sup>lt;sup>6</sup> Prepared from 1-bromo-4-fluorobenzene and Mg in Et<sub>2</sub>O.





(5-methylenehept-6-en-1-yl)benzene (9)



(5-methylenehept-6-en-1-yl)benzene (9) was prepared by modifying an iron catalyzed coupling method reported by Cossy.<sup>7</sup>

To a flame dried one neck round bottom flask equipped with a magnetic stir bar was added  $FeCl_3$ (0.49 mg, 3.0 mmol, 20 mol%) and THF (50 ml). It was cooled to 0 °C followed by addition of 1-iodo-4-phenylbutane<sup>8</sup> (3.9 g, 15 mmol, 1.0 equiv.) The resulting solution was stirred at 0 °C for 10 min and a solution of chloroprene Grignard<sup>2d</sup> (43 ml, 30 mmol, 0.7 M in THF, 2.0 equiv.) 29 TMEDA (4.3 ml, mmol. 1.9 equiv.) was added and drop-wise over 1 h. After further 2 h at 0 °C, the reaction mixture was quenched by adding an aqueous saturated NH<sub>4</sub>Cl solution. After extractive workup and evaporation of the solvent, the residue was purified by flash column chromatography (SiO<sub>2</sub>, 100% hexane) to furnish the title compound (1.5 g, 53%) as a colorless liquid.

<sup>1</sup><u>H</u> NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.29 – 7.23 (m, 2H), 7.19 – 7.13 (m, 3H), 6.35 (dd, J = 17.6, 10.8 Hz, 1H), 5.20 (ddd, J = 17.6, 1.1, 0.5 Hz, 1H), 5.07 – 4.93 (m, 3H), 2.62 (t, J = 7.7 Hz, 2H), 2.23 (t, J = 8.0 Hz, 2H), 1.70 – 1.61 (m, 2H), 1.58 – 1.49 (m, 2H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 146.2, 142.6, 138.9, 128.3, 128.2, 125.6, 115.6, 113.1, 35.8, 31.4, 31.2, 27.7.

**HRMS** (CI) Calcd. For C<sub>14</sub>H<sub>18</sub> [M<sup>+</sup>]: 186.1409, Found: 186.1405.

**FTIR** (in CDCl<sub>3</sub>): 3086, 3026, 2932, 2858, 1594, 1496, 1453, 1030, 991, 893, 744, 697 cm<sup>-1</sup>.

<sup>&</sup>lt;sup>7</sup> A. Guérinot, S. Reymond and J. Cossy, *Angew. Chem. Int. Ed.*, 2007, *46*, 6521.

<sup>&</sup>lt;sup>8</sup> Prepared in accordance with literature procedure: S. M. Smith and J. M. Takacs, *J. Am. Chem. Soc.*, **2010**, *132*, 1740.



3-methylenetridec-1-ene (11)



3-methylenetridec-1-ene (11) was prepared by applying a iron catalyzed coupling method reported by Cossy to a new substrate.<sup>9</sup>

To a flame dried one neck round bottom flask equipped with a magnetic stir bar was added FeCl<sub>3</sub> (0.49 mg, 3.0 mmol, 20 mol%) and THF (50 mL). It was cooled to 0 °C followed by addition of 1-bromodecane (3.3 g, 15 mmol, 1.0 equiv.) The resulting solution was stirred at 0 °C for 10 min and a solution of chloroprene Grignard<sup>2d</sup> (43 mL, 30 mmol, 0.7 M in THF, 2.0 equiv.) and TMEDA (4.3 mL, 29 mmol, 1.9 equiv.) was added drop wise over 2 h. After further 2 h at 0 °C, the reaction mixture was quenched by adding an aqueous saturated NH<sub>4</sub>Cl solution. After extractive workup and evaporation of the solvent, the residue was distilled (5 Torr, 85 °C) to furnish the title compound (0.4 g, 14%) as a colorless liquid.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  6.37 (dd, J = 17.6, 10.8 Hz, 1H), 5.23 (d, J = 17.5 Hz, 1H), 5.05 (d, J = 10.8 Hz, 1H), 5.01 – 4.97 (m, 2H), 2.20 (t, J = 7.7 Hz, 2H), 1.53 – 1.43 (m, 2H), 1.35 – 1.22 (m, 14H), 0.88 (t, J = 6.8 Hz, 3H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 146.8, 139.2, 115.5, 113.1, 32.0, 31.5, 29.7, 29.6, 29.4, 28.3, 22.8, 14.2.

Spectral data correspond to that reported in literature.<sup>10</sup>

<sup>&</sup>lt;sup>9</sup> A. Guérinot, S. Reymond and J. Cossy, Angew. Chem. Int. Ed., 2007, 46, 6521.

<sup>&</sup>lt;sup>10</sup> A. R. Katritzky, L. Serdyuk, D. Toader and X. Wang, J. Org. Chem., 1999, 64, 1888.

# III. Experimental Procedures and Spectroscopic Data for the Nickel Catalyzed Regioselective Couplings at the $C_1$ – position



#### General Procedure A for the coupling of 2-substituted dienes 1-11 to paraformaldehyde

An oven dried re-sealable pressure flask equipped with stir bar was charged with Ni(COD)<sub>2</sub> (14 mg, 0.050 mmol, 10 mol%), PCy<sub>3</sub> (14 mg, 0.050 mmol, 10 mol%), Cs<sub>2</sub>CO<sub>3</sub> (33 mg, 0.100 mmol, 10 mol%) and paraformaldehyde (60 mg, 2.0 mmol, 400 mol%) inside of a drybox. The flask was sealed and removed from the drybox. Under a flow of argon, toluene was added to the flask (2 mL, 0.3 M relative to diene). While stirring, the diene (0.5 mmol, 100 mol%) was added. The flask was sealed and placed in an oil bath at 75 °C for 24 h. The reaction mixture was allowed to cool to room temperature, at which point methanolic KOH (1.0 M) was added and stirred for 2 h. CH<sub>2</sub>Cl<sub>2</sub> (30 mL) was added and the mixture was washed with HCl (1.0 M). The organics were removed and the aqueous layer was extracted twice with CH<sub>2</sub>Cl<sub>2</sub> (15 mL). The combined organics were dried (Na<sub>2</sub>SO<sub>4</sub>), filtered, and evaporated to dryness. The crude residue was purified by flash column chromatography (SiO<sub>2</sub>) to furnish the title compounds.

#### 3-phenylpent-4-en-1-ol (1a)



The reaction was conducted in accordance with **General Procedure A** (via diene 1). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (58 mg, 72%, 3:1 r.r.) as a pale yellow oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.35 – 7.27 (m, 2H), 7.24 – 7.18 (m, 3H), 5.98 (ddd, *J* = 17.4, 10.1, 7.5 Hz, 1H), 5.15 – 5.01 (m, 2H), 3.71 – 3.55 (m, 2H), 3.48 (q, *J* = 7.6 Hz, 1H), 2.09 – 1.90 (m, 2H), 1.27 (br s, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 143.7, 141.8, 128.6, 127.6, 126.4, 114.4, 61.0, 46.3, 38.0.

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{15}O[M+H]^+$ : 163.1123, Found: 163.1126.

Spectral data corresponds to that previously reported.<sup>11</sup>

<sup>&</sup>lt;sup>11</sup> G. Zhang, L. Cui, Y. Wang and L. Zhang, J. Am. Chem. Soc., 2010, 132, 1474.





3-(4-methylphenyl)pent-4-en-1-ol (2a)



The reaction was conducted in accordance with **General Procedure A** (via diene 2). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (80 mg, 91%, 3:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.16 – 7.07 (m, 4H), 5.96 (ddd, J = 17.5, 10.2, 7.6 Hz, 1H), 5.12 – 5.00 (m, 2H), 3.69 – 3.57 (m, 2H), 3.43 (q, J = 7.6 Hz, 1H), 2.32 (s, 3H), 2.06 – 1.89 (m, 2H), 1.42 (br s, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 142.0, 140.6, 135.9, 129.3, 127.4, 114.2, 61.1, 45.9, 38.0, 21.0.

**HRMS** (CI [NH<sub>3</sub>]) Calcd. For C<sub>12</sub>H<sub>20</sub>NO [M+NH<sub>4</sub>]<sup>+</sup>: 194.1545, Found: 194.1541.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3318, 2924, 2873, 1636, 1513, 1413, 1184, 1109, 1043, 1020, 994, 912, 814, 734 cm<sup>-1</sup>.

250

200



ppm

100

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3-(4-methoxyphenyl)pent-4-en-1-ol (3a)



The reaction was conducted in accordance with **General Procedure A** (via diene **3**). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (83 mg, 86%, 7:1 r.r.) as a colorless oil.

<sup>1</sup><u>H</u> NMR (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.16 – 7.09 (m, 2H), 6.89 – 6.82 (m, 2H), 5.95 (ddd, J = 17.4, 10.2, 7.5 Hz, 1H), 5.11 – 4.99 (m, 2H), 3.79 (s, 3H), 3.67 – 3.57 (m, 2H), 3.43 (q, J = 7.7 Hz, 1H), 2.06 – 1.87 (m, 2H), 1.51 (br s, J = 7.5 Hz, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 142.3, 128.6, 114.2, 114.1, 61.2, 55.4, 45.5, 38.2.

Spectral data corresponds to that previously reported.<sup>12</sup>

<sup>&</sup>lt;sup>12</sup> O. Muraoka, B.-Z. Zheng, N. Fujiwara and G. Tanabe, J. Chem. Soc., Perkin Trans. 1, 1996, 405.





3-(3-methoxyphenyl)pent-4-en-1-ol (4a)



The reaction was conducted in accordance with **General Procedure A** (via diene 4). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (61 mg, 63%, 4:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.26 – 7.19 (m, 1H), 6.84 – 6.79 (m, 1H), 6.78 – 6.72 (m, 2H), 5.97 (ddd, J = 17.5, 10.2, 7.6 Hz, 1H), 5.15 – 5.01 (m, 2H), 3.80 (s, 3H), 3.70 – 3.56 (m, 2H), 3.45 (q, J = 7.6 Hz, 1H), 2.12 – 1.85 (m, 2H), 1.31 (br s, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 159.8, 145.4, 141.6, 129.6, 119.9, 114.5, 113.5, 111.5, 61.0, 55.2, 46.4, 37.9.

**HRMS** (EI) Calcd. For C<sub>13</sub>H<sub>19</sub>OSi [M]<sup>+</sup>: 192.1150, Found: 192.1146.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3338, 2935, 2835, 1599, 1583, 1487, 1453, 1433, 1317, 1259, 1253, 1041, 995, 915, 876, 781, 729, 700 cm<sup>-1</sup>.



3-(2-methoxyphenyl)pent-4-en-1-ol (5a)



In modification to **General Procedure A** (via diene 5), the reaction was conducted with 20 mol% of  $Ni(cod)_2$  and 20 mol% of  $PCy_3$ . After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (55 mg, 57%, 7:1 r.r.) as a colorless oil.

<sup>1</sup><u>H</u> <u>NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.26 – 7.10 (m, 2H), 7.00 – 6.84 (m, 2H), 6.06 (ddd, J = 17.3, 10.3, 7.1 Hz, 1H), 5.20 – 5.03 (m, 2H), 4.02 – 3.91 (m, 1H), 3.85 (s, 3H), 3.64 – 3.53 (m, 1H), 3.53 – 3.40 (m, 1H), 2.15 – 2.02 (m, 1H), 1.91 (br s, 1H), 1.88 – 1.76 (m, 1H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 156.8, 141.3, 131.7, 128.1, 127.3, 121.0, 114.2, 110.7, 60.9, 55.6, 38.0, 37.6.

**<u>HRMS</u>** (APCI) Calcd. For  $C_{12}H_{16}O_2$  [M]<sup>+</sup>: 192.1150, Found: 192.1151.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3350, 3075, 2938, 2836, 1636, 1598, 1585, 1491, 1463, 1438, 1288, 1239, 1181, 1099, 1050, 1028, 913, 791, 751, 672 cm<sup>-1</sup>.

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3-(4-fluorophenyl)pent-4-en-1-ol (6a)



The reaction was conducted in accordance with **General Procedure A** (via diene 6). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (67 mg, 74%, 4:1 r.r.) as a colorless oil.

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<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 161.4 (d, J = 244.3 Hz), 141.6, 139.3, 128.9 (d, J = 7.8 Hz, 2C), 115.3 (d, J = 21.1 Hz, 2C), 114.6, 60.7, 45.3, 38.0.

<sup>19</sup>**F NMR** (376 MHz, CDCl<sub>3</sub>): δ -116.9 (m<sub>c</sub>).

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{12}OF[M]^+$ : 180.0950, Found: 180.0949.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3316, 2937, 1637, 1602, 1508, 1413, 1221, 1159, 1096, 1045, 1015, 916, 832, 741 cm<sup>-1</sup>.





3-cyclohexylpent-4-en-1-ol (7a)



In modification to **General Procedure A** (via diene 7), the reaction was conducted at 0.3 mmol scale with 15 mol% of Ni(COD)<sub>2</sub> and 15 mol% of PMe<sub>3</sub> as ligand. After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (31 mg, 61%, 5.3:1.5:1:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  5.60 (ddd, J = 17.0, 9.9, 9.9 Hz, 1H), 5.07 – 4.90 (m, 2H), 3.69 – 3.54 (m, 2H), 2.01 – 1.87 (m, 1H), 1.79 – 1.43 (m, 8H), 1.31 – 0.84 (m, 5H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 141.2, 115.6, 61.7, 47.1, 42.0, 34.6, 31.0, 29.7, 26.7, 26.6.

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{21}O[M+H]^+$ : 169.1592, Found: 169.1590.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3288, 2922, 2852, 2360, 2340, 1448, 1055, 911, 667 cm<sup>-1</sup>.



7-methyl-3-vinyloct-6-en-1-ol (8a)



The reaction was conducted in accordance with **General Procedure A** (via diene 8). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (57 mg, 68%, 10:1 r.r.) as a colorless oil.

 $\begin{array}{c} {}^{1}\underline{H} \ \underline{NMR} \\ 5.01 \ - \ 4.97 \ (m, \ 1H), \ 5.71 \ - \ 5.05 \ (m, \ 1H), \ 5.03 \ (s, \ 1H), \\ 5.01 \ - \ 4.97 \ (m, \ 1H), \ 3.71 \ - \ 3.57 \ (m, \ 2H), \ 2.20 \ - \ 2.07 \ (m, \ 1H), \ 2.05 \ - \ 1.85 \ (m, \ 2H), \\ 1.74 \ - \ 1.62 \ (m, \ 4H), \ 1.58 \ (s, \ 3H), \ 1.55 \ - \ 1.24 \ (m, \ 4H). \end{array}$ 

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 142.7, 131.5, 124.4, 115.0, 61.3, 40.8, 37.8, 35.3, 25.7, 25.6, 17.7.

**<u>HRMS</u>** (APCI) Calcd. For  $C_{11}H_{20}O[M+H]^+$ : 169.1587, Found: 169.1588.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3321, 3076, 2965, 2916, 2856, 1639, 1449, 1419, 1376, 1053, 995, 911, 832, 735, 682 cm<sup>-1</sup>.





7-phenyl-3-vinylheptan-1-ol (9a)



The reaction was conducted in accordance with **General Procedure A** (via diene 9). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (82 mg, 75%, 7:1 r.r.) as a colorless oil.

 $\frac{^{1}\text{H NMR}}{5.05 - 5.01} (400 \text{ MHz, CDCl}_{3}): \delta 7.32 - 7.25 (m, 2H), 7.22 - 7.15 (m, 3H), 5.64 - 5.49 (m, 1H), 5.05 - 5.01 (m, 1H), 5.01 - 4.97 (m, 1H), 3.71 - 3.58 (m, 2H), 2.67 - 2.55 (m, 2H), 2.19 - 2.05 (m, 1H), 1.76 - 1.25 (m, 9H).$ 

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 142.8, 142.7, 128.3, 128.2, 125.6, 114.8, 61.3, 41.1, 37.8, 35.9, 35.0, 31.5, 26.8.

**<u>HRMS</u>** (APCI) Calcd. For  $C_{15}H_{23}O[M+H]^+$ : 219.1743, Found: 219.1744.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3319, 3063, 3026, 2928, 2856, 1640, 1604, 1496, 1453, 1418, 1050, 1029, 995, 910, 745, 697 cm<sup>-1</sup>.



### 3-(((triisopropylsilyl)oxy)methyl)pent-4-en-1-ol (10a)



In modification to **General Procedure A** (via diene 10), the reaction was conducted with 20 mol% of  $Ni(cod)_2$  and 20 mol% of  $PCy_3$ . After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (41 mg, 50%, 2:1 r.r (to all other isomers)) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  5.73 (ddd, J = 17.3, 10.3, 8.4 Hz, 1H), 5.14 – 5.00 (m, 2H), 3.78 – 3.56 (m, 4H), 2.47 – 2.34 (m, 1H), 1.71 – 1.61 (m, 2H), 1.13 – 1.02 (m, 21H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 139.7, 115.6, 67.0, 61.3, 44.4, 35.1, 18.0, 18.0, 11.9.

**HRMS** (CI) Calcd. For C<sub>15</sub>H<sub>33</sub>O<sub>2</sub>Si [M+H]<sup>+</sup>: 273.2250, Found: 273.2250.

**FTIR** (in CDCl<sub>3</sub>): 3345, 2942, 2892, 2865, 1641, 1463, 1383, 1247, 1106, 1055, 1013, 995, 915, 881, 795, 680, 658 cm<sup>-1</sup>.



#### 3-decylpent-4-en-1-ol (11a)



The reaction was conducted in accordance with **General Procedure A** (via diene 11). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (78 mg, 69%, 11:1 r.r.) as a colorless oil.

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<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 143.0, 114.7, 61.4, 41.2, 37.9, 35.2, 31.9, 29.7, 29.7, 29.6, 29.3, 27.1, 22.7, 14.1.

**<u>HRMS</u>** (APCI) Calcd. For  $C_{15}H_{31}O[M+H]^+$ : 227.2369, Found: 227.2373.

**FTIR** (in CDCl<sub>3</sub>): 3329, 2922, 2853, 1639, 1465, 1418, 1378, 1051, 995, 911, 721, 682 cm<sup>-1</sup>.



# IV. Experimental Procedures and Spectroscopic Data for the Ruthenium Catalyzed Regioselective Couplings at the $C_2$ – position



# General Procedure B for the coupling of 2-substituted dienes 1-11 to paraformaldehyde<sup>2c</sup>

To a pressure tube equipped with a magnetic stir bar was added  $RuH_2(CO)(PPh_3)_3$  (13.8 mg, 0.015 mmol, 5 mol%) and 1,4-bis(diphenylphosphino)butane (DPPB) (6.4 mg, 0.030 mmol, 5 mol%), and pentadecafluorooctanoic acid (6.2 mg, 0.015 mmol, 5 mol%). Paraformaldehyde (27.0 mg, 0.60 mmol, 300 mol%) was added. The tube was sealed with a rubber septum, purged with argon and 2-propanol (0.3 mL, 1.0 M with respect to diene) and diene (0.30 mmol, 100 mol%) were added. The rubber septum was quickly replaced with a screw cap and the reaction was heated to the indicated temperature for 20 hours. The reaction mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>) under the conditions noted to furnish the all-carbon quaternary center containing homoallylic alcohols.

2-methyl-2-phenylbut-3-en-1-ol (1b)



In modification to **General Procedure B**, the reaction was conducted using 1:1 acetone : isopropanol [1M] as solvent (via diene 1). After heating the reaction at 80°C for 20 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (26.9 mg, 55%, >20:1 r.r., 7:1 (product: over-reduced product)) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.40 – 7.15 (m, 5H), 6.08 (dd, J = 17.6, 10.8 Hz, 1H), 5.27 (d, J = 10.8 Hz, 1H), 5.16 (d, J = 17.6 Hz, 1H), 3.79 (d, J = 6.4 Hz, 2H), 1.43 (s, 3H), 1.37 (t, J = 6.6 Hz, 1H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 144.4, 143.5, 128.5, 128.4, 126.9, 126.8, 126.5, 114.6, 69.9, 47.0, 22.6.

Spectral data correspond to that reported in literature.<sup>13</sup>

<sup>&</sup>lt;sup>13</sup> M.-Y. Ngai, E. Skucas and M. J. Krische, Org. Lett., 2008, 10, 2705.




2-methyl-2-(p-tolyl)but-3-en-1-ol (3b)



In modification to **General Procedure B**, the reaction was conducted using 1:1 acetone : isopropanol [1M] as solvent (via diene 3). After heating the reaction at 80°C for 20 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 15% EtOAc/hexane) to furnish the title compound (32.1 mg, 61%, >20:1 r.r., 4:1 (product: over-reduced product)) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.28 – 7.20 (m, 2H), 7.15 (d, J = 8.0 Hz, 2H), 6.06 (dd, J = 17.6, 10.8 Hz, 1H), 5.25 (dd, J = 10.8, 1.2 Hz, 1H), 5.14 (dd, J = 17.6, 1.2 Hz, 1H), 3.80 – 3.72 (m, 2H), 2.33 (s, 3H), 1.44 – 1.35 (m, 4H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 143.7, 141.4, 136.1, 129.2, 126.7, 114.4, 70.0, 46.6, 22.6, 20.9.

**<u>HRMS</u>** (CI) Calcd. For  $C_{12}H_{16}O[M]^+$ : 176.1201, Found: 176.1201.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3385, 2967, 2923, 2876, 1634, 1513, 1454, 1412, 1378, 1192, 1116, 1037, 1017, 914, 814, 756, 725 cm<sup>-1</sup>.

Spectral data correspond to that reported in literature.<sup>14</sup>

<sup>&</sup>lt;sup>14</sup> Q. Zhang, S.-F. Zhu, Y. Cai, L.-X. Wang and Q.-L. Zhou, *Sci. China Chem.*, 2010, *53*, 1899.





#### 2-(4-fluorophenyl)-2-methylbut-3-en-1-ol (6b)



In modification to **General Procedure B**, the reaction was conducted using 1:1 acetone : isopropanol [1M] as solvent (via diene 6). After heating the reaction at 80°C for 20 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (35.3 mg, 65%, >20:1 r.r., 8:1 (product: overreduced product)) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.36 – 7.29 (m, 2H), 7.06 – 6.98 (m, 2H), 6.04 (dd, J = 17.6, 10.8 Hz, 1H), 5.27 (dd, J = 10.8, 1.1 Hz, 1H), 5.14 (dd, J = 17.6, 1.1 Hz, 1H), 3.76 (d, J = 6.4 Hz, 2H), 1.45 – 1.36 (m, 4H).

 $\frac{{}^{13}\text{C NMR}}{128.5 \text{ (d, } J = 7.8 \text{ Hz)}, 115.1 \text{ (d, } J = 20.9 \text{ Hz)}, 114.8, 69.9, 46.5, 22.8.}$ 

<sup>19</sup>**F NMR**(376 MHz, CDCl<sub>3</sub>): δ -116.67 - -116.90 (m).

Spectral data correspond to that reported in literature.<sup>13</sup>





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20	0	-20	-40	-60	-80	-100 ppm	-120	-140	-160	-180	-200	-220	

2-methyl-6-phenyl-2-vinylhexan-1-ol (9b)



The reaction was conducted in accordance with **General Procedure B** (via diene 9). After heating the reaction at 90°C for 20 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (41.4 mg, 63%, >8:1 r.r.) as a colorless oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.31 – 7.23 (m, 2H), 7.20 – 7.12 (m, 3H), 5.70 (dd, J = 17.6, 10.9 Hz, 1H), 5.16 (dd, J = 10.9, 1.3 Hz, 1H), 5.04 (dd, J = 17.6, 1.3 Hz, 1H), 3.43 – 3.27 (m, 2H), 2.66 – 2.53 (m, 2H), 1.65 – 1.53 (m, 2H), 1.40 – 1.21 (m, 5H), 1.00 (s, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 144.1, 142.7, 128.3, 128.2, 125.6, 114.6, 70.2, 42.3, 37.0, 35.9, 32.3, 23.5, 19.6.

**HRMS** (CI) Calcd. For C<sub>15</sub>H<sub>22</sub>O [M]<sup>+</sup>: 218.1671, Found: 218.1169.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3394, 2933, 2859, 1639, 1603, 1496, 1453, 1414, 1373, 1217, 1030, 908, 755, 731, 698 cm<sup>-1</sup>.





2-methyl-2-vinyldodecan-1-ol (11b)



The reaction was conducted in accordance with **General Procedure B** (via diene 11). After heating the reaction at 90°C for 20 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (39.0 mg, 57%, 8:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u>(400 MHz, CDCl<sub>3</sub>):  $\delta$  5.70 (dd, J = 17.6, 10.9 Hz, 1H), 5.16 (dd, J = 10.9, 1.4 Hz, 1H), 5.04 (dd, J = 17.6, 1.4 Hz, 1H), 3.35 (qd, J = 10.6, 6.3 Hz, 2H), 1.38 – 1.13 (m, 19H), 1.00 (s, 3H), 0.88 (t, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 144.3, 114.5, 70.2, 42.3, 37.2, 31.9, 30.5, 29.7, 29.6, 29.3, 23.76, 22.7, 19.6, 14.1.

**HRMS** (CI) Calcd. For C<sub>15</sub>H<sub>31</sub>O [M+H]<sup>+</sup>: 227.2375, Found:227.2378.

**FTIR** (in CDCl<sub>3</sub>): 3372, 2924, 2853, 1639, 1466, 1414, 1377, 1215, 1035, 909, 759, 734 cm<sup>-1</sup>.



# V. Experimental Procedures and Spectroscopic Data for the Ruthenium Catalyzed Regioselective Couplings at the $C_3$ – position



## General Procedure C for the coupling of 2-substituted dienes 1-11 to paraformaldehyde

To a pressure tube equipped with magnetic stir bar was added RuHCl(CO)(PPh<sub>3</sub>)<sub>3</sub> (14.1 mg, 0.015 mmol, 5 mol%) and 1,4-bis(diphenylphosphino)butane (DPPB) (6.4 mg, 0.030 mmol, 5 mol%). Paraformaldehyde (18.0 mg, 0.60 mmol, 200 mol%) was added. The tube was sealed with a rubber septum, purged with argon and 1,4-dioxane (0.15 mL, 2.0 M with respect to diene), diene (0.30 mmol, 100 mol%) and 2-propanol (0.11 mL, 1.5 mmol, 500 mol%) were added. The rubber septum was quickly replaced with a screw cap and the reaction was heated to the indicated temperature for 24 hours. The reaction mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>) under the conditions noted to furnish the homoallylic alcohols.

2-methyl-3-phenylbut-3-en-1-ol (1c)



The reaction was conducted in accordance with **General Procedure C** (via diene 1). After heating the reaction at 115°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 15% EtOAc/hexane) to furnish the title compound (31.6 mg, 65%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.38 – 7.26 (m, 5H), 5.34 (d, J = 1.0 Hz, 1H), 5.13 (t, J = 1.1 Hz, 1H), 3.66 (dd, J = 10.7, 6.0 Hz, 1H), 3.54 (dd, J = 10.7, 5.9 Hz, 1H), 3.01 – 2.89 (m, 1H), 1.52 (s, 1H), 1.19 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ151.2, 142.13, 128.3, 127.5, 126.6, 112.8, 66.5, 40.8, 16.7.

**<u>HRMS</u>** (CI) Calcd. For C<sub>11</sub>H<sub>14</sub>O [M]<sup>+</sup>: 162.1045, Found: 162.1044.

**<u>FTIR</u>** (neat): 3349, 3056, 2964, 2928, 2875, 1625, 1600, 1574, 1493, 1453, 1261, 1025, 979, 899, 777, 700 cm<sup>-1</sup>.





2-methyl-3-(4-methyl)but-3-en-1-ol (2c)



The reaction was conducted in accordance with **General Procedure C** (via diene 2). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 15% EtOAc/hexane) to furnish the title compound (36.8 mg, 70%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.28 – 7.23 (m, 2H), 7.13 (dd, J = 8.4, 0.5 Hz, 2H), 5.30 (d, J = 1.0 Hz, 1H), 5.07 (t, J = 1.1 Hz, 1H), 3.71 – 3.58 (m, 1H), 3.57 – 3.46 (m, 1H), 2.98 – 2.87 (m, 1H), 2.34 (s, 3H), 1.53 (t, J = 5.0 Hz, 1H), 1.17 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ151.0, 139.1, 137.2, 129.0, 126.4, 112.1, 66.5, 40.7, 21.1, 16.7.

**<u>HRMS</u>** (CI) Calcd. For  $C_{12}H_{16}O[M]^+$ : 176.1201, Found: 176.1198.

**<u>FTIR</u>** (neat): 3332, 2963, 2923, 2874, 1623, 1511, 1454, 1403, 1213, 1117, 1027, 979, 896, 823, 734 cm<sup>-1</sup>.





## 3-(4-methoxyphenyl)-2-methylbut-3-en-1-ol (3c)



The reaction was conducted in accordance with **General Procedure C** (via diene 3). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (40.6 mg, 70%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.34 – 7.28 (m, 2H), 6.90 – 6.84 (m, 2H), 5.29 (d, J = 0.9 Hz, 1H), 5.04 (s, 1H), 3.81 (s, 3H), 3.70 – 3.60 (m, 1H), 3.59 – 3.48 (m, 1H), 2.98 – 2.87 (m, 1H), 1.46 (t, J = 6.1 Hz, 1H), 1.17 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ159.1, 150.5, 134.4, 127.6, 113.7, 111.5, 66.5, 55.3, 40.1, 16.8.

**<u>FTIR</u>** (neat): 3385, 2961, 2932, 2836, 1607, 1573, 1509, 1462, 1411, 1292, 1179, 1114, 1028, 978, 896, 804, 734, 696 cm<sup>-1</sup>.

Spectral data correspond to that reported in literature.<sup>15</sup>

<sup>&</sup>lt;sup>15</sup> S. Kano, Y. Yuasa, K. Asami and S. Shibuya, *Heterocycles*, 1988, 27, 1437.





#### 3-(3-methoxyphenyl)-2-methylbut-3-en-1-ol (4c)



The reaction was conducted in accordance with **General Procedure C** (via diene 4). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 25% EtOAc/hexane) to furnish the title compound (41.4 mg, 72%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.28 - 7.21 (m, 1H), 6.98 - 6.87 (m, 2H), 6.83 (ddd, J = 8.2, 2.6, 0.8 Hz, 1H), 5.33 (d, J = 0.9 Hz, 1H), 5.11 (s, 1H), 3.81 (s, 3H), 3.70 - 3.61 (m, 1H), 3.58 - 3.46 (m, 1H), 2.97 - 2.85 (m, 1H), 1.52 (s, 1H), 1.17 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 159.5, 151.1, 143.7, 129.3, 119.1, 112.9, 112.6, 112.6, 66.5, 55.2, 40.8, 16.7.

**<u>FTIR</u>** (neat): 3361, 2962, 2876, 2834, 1597, 1575, 1487, 1463, 1428, 1317, 1286, 1219, 1180, 1114, 1028, 978, 907, 881, 782, 729 cm<sup>-1</sup>.

Spectral data correspond to that reported in literature.<sup>15</sup>





## 3-(2-methoxyphenyl)-2-methylbut-3-en-1-ol (5c)



The reaction was conducted in accordance with **General Procedure C** (via diene 5). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (40.6 mg, 70%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.30 – 7.24 (m, 1H), 7.06 (dd, J = 7.4, 1.8 Hz, 1H), 6.97 – 6.87 (m, 2H), 5.32 – 5.26 (m, 1H), 5.08 (d, J = 1.7 Hz, 1H), 3.82 (s, 3H), 3.51 – 3.37 (m, 2H), 2.83 – 2.71 (m, 1H), 2.30 – 2.22 (m, 1H), 1.08 (d, J = 7.0 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 156.2, 149.0, 131.3, 130.5, 128.5, 120.6, 115.9, 110.6, 65.9, 55.5, 43.2, 16.1.

**HRMS** (CI) Calcd.For C<sub>12</sub>H<sub>16</sub>O<sub>2</sub> [M]<sup>+</sup>: 192.1150, Found: 192.1152.

**<u>FTIR</u>** (neat): 3393, 2961, 2835, 1630, 1597, 1578, 1489, 1455, 1435, 1291, 1238, 1180, 1161, 1107, 1078, 1025, 978, 905, 846, 804, 751, 733 cm<sup>-1</sup>.





#### 3-(4-fluorophenyl)-2-methylbut-3-en-1-ol (6c)



The reaction was conducted in accordance with **General Procedure C** (via diene 6). After heating the reaction at 115°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (35.1 mg, 65%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.36 - 7.27 (m, 2H), 7.06 - 6.97 (m, 2H), 5.29 (d, J = 0.8 Hz, 1H), 5.11 (t, J = 0.9 Hz, 1H), 3.65 (dd, J = 10.7, 6.1 Hz, 1H), 3.53 (dd, J = 10.7, 5.9 Hz, 1H), 2.94 - 2.83 (m, 1H), 1.45 (s, 1H), 1.16 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>):  $\delta$  162.3 (d, J = 246.2 Hz), 150.3, 138.1 (d, J = 3.2 Hz), 128.2 (d, J = 7.9 Hz), 115.1 (d, J = 21.3 Hz), 112.9, 66.4, 40.9, 16.7.

<sup>19</sup>**F NMR** (376 MHz, CDCl<sub>3</sub>): δ -115.16 - -115.38 (m).

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{13}OF[M]^+$ : 180.0950, Found: 180.0950.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3346, 2964, 2929, 1625, 1602, 1508, 1456, 1401, 1223, 1160, 1098, 1027, 979, 904, 839, 816, 735, 696 cm<sup>-1</sup>.



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20	0	-20	-40	-60	-80	-100 ppm	-120	-140	-160	-180	-200	-220	

3-cyclohexyl-2-methylbut-3-en-1-ol (7c)



The reaction was conducted in accordance with **General Procedure C** (via diene 7). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 10% EtOAc/hexane) to furnish the title compound (40.9 mg, 81%, 8:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  4.90 (s, 1H), 4.79 (s, 1H), 3.60 – 3.45 (m, 2H), 2.42 – 2.30 (m, 1H), 1.89 – 1.56 (m, 6H), 1.48 (t, J = 6.1 Hz, 1H), 1.38 – 1.08 (m, 5H), 1.04 (d, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 157.4, 107.7, 66.4, 43.9, 41.4, 33.2, 33.0, 26.9, 26.8, 26.3, 17.3.

**HRMS** (CI) Calcd. For C<sub>11</sub>H<sub>21</sub>O [M+H]<sup>+</sup>: 169.1592, Found: 169.1594.

**FTIR** (neat): 3362, 2924, 2852, 1639, 1448, 1025, 980, 886, 844, 734, 697 cm<sup>-1</sup>.



#### 2,7-dimethyl-3-methyleneoct-6-en-1-ol (8c)



The reaction was conducted in accordance with **General Procedure C** (via diene 8). After heating the reaction at 115°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 15% EtOAc/hexane) to furnish the title compound (30.8 mg, 61%, >20:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u>(400 MHz, CDCl<sub>3</sub>):  $\delta$  5.14-5.10 (m, 1H), 4.93 – 4.89 (m, 1H), 4.87 – 4.83 (m, 1H), 3.61 – 3.43 (m, 2H), 2.45 – 2.30 (m, 1H), 2.19 – 2.08 (m, 2H), 2.08 – 1.98 (m, 2H), 1.69 (d, *J* = 1.1 Hz, 3H), 1.66 – 1.58 (m, 3H), 1.45 (s, 1H), 1.05 (d, *J* = 7.0 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 150.9, 131.9, 123.9, 110.0, 65.8, 42.5, 34.0, 26.5, 16.2.

**<u>HRMS</u>** (CI) Calcd. For  $C_{11}H_{19}O[M-H]^+$ : 167.1436, Found: 167.1434.

**<u>FTIR</u>** (neat): 3329, 3076, 2966, 2924, 2876, 1642, 1452, 1376, 1220, 1107, 1028, 981, 891, 831, 734 cm<sup>-1</sup>.



## 2-methyl-3-methylene-7-phenylheptan-1-ol (9c)



The reaction was conducted in accordance with **General Procedure C** (via diene 9). After heating the reaction at 115°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (43.9 mg, 67%, 17:1 r.r.) as a yellow oil.

<sup>1</sup><u>H NMR</u>(400 MHz, CDCl<sub>3</sub>):  $\delta$  7.32 – 7.25 (m, 2H), 7.22 – 7.15 (m, 3H), 4.91 – 4.87 (m, 1H), 4.84 (s, 1H), 3.60 – 3.45 (m, 2H), 2.68 – 2.59 (m, 2H), 2.41 – 2.29 (m, 1H), 2.13 – 1.96 (m, 2H), 1.71 – 1.59 (m, 2H), 1.58 – 1.47 (m, 2H), 1.42 (s, 1H), 1.04 (d, *J* = 7.0 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 151.1, 142.5, 128.4, 128.3, 125.7, 109.8, 65.9, 42.2, 35.8, 34.2, 31.2, 27.5, 16.3.

**<u>HRMS</u>** (CI) Calcd. For  $C_{15}H_{22}O[M]^+$ : 218.1671, Found: 218.1672.

**<u>FTIR</u>** (neat): 3355, 3026, 2931, 2858, 1641, 1603, 1496, 1453, 1028, 979, 908, 890, 732, 698 cm<sup>-1</sup>.



## 2-methyl-3-(((triisopropylsilyl)oxy)methyl)but-3-en-1-ol (10c)



The reaction was conducted in accordance with **General Procedure C** (via diene 10). After heating the reaction at 95°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 10% EtOAc/hexane) to furnish the title compound (66.0 mg, 81%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H NMR</u>(400 MHz, CDCl<sub>3</sub>):  $\delta$  5.19 (q, J = 1.5 Hz, 1H), 4.96 (dd, J = 1.6, 0.8 Hz, 1H), 4.26 - 4.10 (m, 2H), 3.63 - 3.47 (m, 2H), 2.49 - 2.35 (m, 2H), 1.18 - 1.02 (m, 24H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 150.3, 111.6, 66.9, 65.6, 40.1, 18.0, 16.3, 11.9.

**<u>HRMS</u>** (CI) Calcd. For  $C_{15}H_{33}O_2Si[M+H]^+$ : 273.2250, Found: 273.2253.

**<u>FTIR</u>** (neat): 3348, 2942, 2866, 1650, 1463, 1385, 1247, 1087, 1060, 1031, 996, 899, 881, 817, 792, 734, 681, 658 cm<sup>-1</sup>.



#### 2-methyl-3-methylenetridecan-1-ol (11c)



The reaction was conducted in accordance with **General Procedure C** (via diene 11). After heating the reaction at 115°C for 24 hours, the mixture was concentrated *in vacuo* and purified by flash column chromatography (SiO<sub>2</sub>, 20% EtOAc/hexane) to furnish the title compound (42.1 mg, 62%, >20:1 r.r.) as a yellow oil.

<sup>1</sup><u>H</u> NMR(400 MHz, CDCl<sub>3</sub>):  $\delta$  4.89 (q, J = 1.4 Hz, 1H), 4.83 (dd, J = 1.4, 0.8 Hz, 1H), 3.58 – 3.46 (m, 2H), 2.41 – 2.31 (m, 1H), 2.06 – 1.94 (m, 2H), 1.50 – 1.37 (m, 1H), 1.36 – 1.17 (m, 16H), 1.04 (d, J = 7.0 Hz, 3H), 0.88 (t, J = 6.9 Hz, 3H).

<sup>13</sup>C NMR(100 MHz, CDCl<sub>3</sub>): δ 151.4, 109.7, 65.8, 42.3, 34.3, 31.9, 29.6 (s, 2C), 29.6, 29.5, 29.3, 28.0, 22.7, 16.3, 14.1.

**<u>HRMS</u>** (CI) Calcd. For  $C_{15}H_{31}O[M+H]^+$ : 227.2375, Found: 227.2373.

**FTIR** (neat): 3362, 2957, 2923, 2853, 1642, 1464, 1377, 1028, 980, 907, 890, 734 cm<sup>-1</sup>.





## VI. Experimental Procedures and Spectroscopic Data for the Nickel Catalyzed Regioselective Couplings at the $C_4$ – position



## General Procedure D for the coupling of 2-substituted dienes 12-13 to paraformaldehyde

An oven dried re-sealable pressure flask equipped with stir bar was charged with Ni(COD)<sub>2</sub> (28 mg, 0.10 mmol, 20 mol%), PCy<sub>3</sub> (28 mg, 0.10 mmol, 20 mol%) and paraformaldehyde (60 mg, 2.0 mmol, 400 mol%) inside of a drybox. The flask was sealed and removed from the drybox. Under a flow of argon, toluene was added to the flask (2 mL, 0.25 M relative to diene). While stirring, the diene (0.5 mmol, 100 mol%) was added. The flask was sealed and placed in an oil bath at 60 °C for 24 h. The reaction mixture was allowed to cool to room temperature, at which point methanolic KOH (1.0 M) was added and stirred for 2 h. CH<sub>2</sub>Cl<sub>2</sub> (30 mL) was added and the mixture was washed with HCl (1.0 M). The organics were removed and the aqueous layer was extracted twice with CH<sub>2</sub>Cl<sub>2</sub> (15 mL). The combined organics were dried (Na<sub>2</sub>SO<sub>4</sub>), filtered, and evaporated to dryness. The crude residue was purified by flash column chromatography (SiO<sub>2</sub>) to furnish the title compounds.

#### 4-(dimethyl(phenyl)silyl)pent-4-en-1-ol (12d)



The reaction was conducted in accordance with **General Procedure D** (via diene 12). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, DCM) to furnish the title compound (78 mg, 71%, 7:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.56 – 7.48 (m, 2H), 7.40 – 7.32 (m, 3H), 5.78 – 5.67 (m, 1H), 5.51 – 5.37 (m, 1H), 3.56 (t, *J* = 6.5 Hz, 2H), 2.19 (t, *J* = 7.7 Hz, 2H), 1.70 – 1.53 (m, 2H), 0.39 (s, 6H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 149.7, 138.1, 133.9, 129.0, 127.8, 127.8, 126.1, 62.6, 31.9, 31.7, -3.0.

**HRMS** (CI) Calcd. For C<sub>13</sub>H<sub>19</sub>OSi [M-H]<sup>+</sup>: 219.1205, Found: 219.1208.

**<u>FTIR</u>** (in CDCl<sub>3</sub>): 3334, 3050, 2941, 1625, 1427, 1248, 1111, 1055, 924, 832, 816, 774, 730, 699, 668 cm<sup>-1</sup>.


## 4-(dimethyl(benzyl)silyl)pent-4-en-1-ol (13d)



The reaction was conducted in accordance with **General Procedure D** (via diene 13). After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, DCM) to furnish the title compound (82 mg, 70%, 7:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  7.23 – 7.17 (m, 2H), 7.07 (app. t, *J* = 7.4 Hz, 1H), 7.02 – 6.97 (m, 2H), 5.64 (dt, *J* = 2.9, 1.6 Hz, 1H), 5.36 – 5.33 (m, 1H), 3.64 (t, *J* = 6.5 Hz, 2H), 2.21 – 2.09 (m, 4H), 1.73 – 1.62 (m, 2H), 1.26 (br s, 1H), 0.07 (s, 6H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 150.1, 140.0, 128.3, 128.3, 128.2, 125.4, 124.1, 62.8, 32.1, 31.9, 25.6, -3.5.

**<u>HRMS</u>** (APCI) Calcd. For  $C_{14}H_{23}OSi[M-H]^+$ : 235.1518, Found: 235.1517.





4-(tributylstannyl)pent-4-en-1-ol (14d)



In modification to **General Procedure D** (via diene 14), the reaction was conducted at 75 °C. After heating the reaction for 24 hours and workup, the mixture was purified by flash column chromatography (SiO<sub>2</sub>, DCM) to furnish the title compound (105 mg, 56%, >20:1 r.r.) as a colorless oil.

<sup>1</sup><u>H NMR</u> (400 MHz, CDCl<sub>3</sub>):  $\delta$  5.71 (dt, J = 2.8, 1.5 Hz, and  $J_{Sn-H}$  = 68.7 Hz, 1H), 5.14 (m<sub>c</sub>, 1H), 3.65 (dd, J = 6.3, 4.5 Hz, and  $J_{Sn-H}$  = 31.4 Hz, 2H), 2.33 (t, J = 7.6 Hz, 2H), 1.65 (m<sub>c</sub>, 2H), 1.57 – 1.42 (m, 6H), 1.40 – 1.21 (m, 6H), 0.99 – 0.81 (m, 15H).

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 155.0, 125.3, 62.8, 37.5, 32.5, 29.2, 27.5, 13.8, 9.7.

HRMS (CI) Calcd. For C<sub>17</sub>H<sub>36</sub>OClSn [M+Cl]<sup>-</sup>: 411.1477, Found: 411.1487.

Spectral data correspond to that reported in literature.<sup>16</sup>

<sup>&</sup>lt;sup>16</sup> A. Barbero, P. Cuadrado, I. Fleming, A. M. González and F. J. Pulido, J. Chem. Soc. Perkin Trans. 1, 1992, 327.

## VII. Experimental Procedure and Spectroscopic Data for the Hiyama Coupling of the C<sub>4</sub> Product.

4-phenylpent-4-en-1-ol (12e)



The reaction was conducted by modifying a literature procedure by Denmark.<sup>17</sup>

To a dry Schlenk tube with a stir bar was added a solution of 4-(dimethyl(phenyl)silyl)pent-4-en-1-ol (12d) (77 mg, 0.33 mmol) in THF (0.66ml) under an argon atmosphere. To this was added iodobenzene (67 mg, 0.33 mmol, 1.0 equiv.) and then TBAF (0.66 ml, 1.0 M in THF, 2.0 equiv.). The resulting solution was stirred at room temperature for 5 min.  $Pd(dba)_2$  (9.5 mg, 0.017 mmol, 5 mol%) was added. The reaction mixture was stirred at room temperature for 30 min. After filtering through silica gel and washing with DCM, the solvents were removed under reduced pressure. The mixture was purified by flash column chromatography (SiO<sub>2</sub>, DCM) to furnish the title compound (42 mg, 78%) as a colorless oil.

 $\frac{^{1}\text{H NMR}}{(t, J = 5.5 \text{ Hz}, 2\text{H}), 2.61 (t, J = 7.5 \text{ Hz}, 2\text{H}), 1.80 - 1.67 (m, 2\text{H}), 5.10 (d, J = 1.2 \text{ Hz}, 1\text{H}), 3.67 (m, 2\text{H}), 1.26 (br s, 1\text{H}).}$ 

<sup>13</sup>C NMR (100 MHz, CDCl<sub>3</sub>): δ 148.1, 141.1, 128.4, 127.5, 126.2, 112.7, 62.6, 31.7, 31.3.

Spectral data correspond to that reported in literature.<sup>18</sup>

<sup>&</sup>lt;sup>17</sup> S. E. Denmark and S. A. Tymonko, *J. Am. Chem. Soc.*, 2005, *127*, 8004.

<sup>&</sup>lt;sup>18</sup> A. Takemiya and J. F. Hartwig, J. Am. Chem. Soc., 2006, **128**, 6042.



## VIII. Deuterium Labeling of Nickel Catalyzed Coupling at the C1-position



(CD <sub>2</sub> O) <sub>n</sub>							
H <sub>a</sub>	0%	$^{2}\mathrm{H}$					
$\mathbf{H}_{\mathbf{b}}$	100%	$^{2}\mathrm{H}$					
H <sub>c</sub>	0%	$^{2}\mathrm{H}$					
$\mathbf{H}_{\mathbf{d}}$	0%	$^{2}\mathrm{H}$					
H <sub>e</sub>	0%	$^{2}\mathrm{H}$					
$\mathbf{H}_{\mathbf{f}}$	100%	$^{2}\mathrm{H}$					
Yield	65%	(6:1 r.r.)					

The above values represent the average of two trials. The extent of deuterium incorporation was determined for the major regionsomer (alcohol 3a).

Diene **3** was subjected to one experiment employing *deuterio*-paraformaldehyde under otherwise the same conditions to furnish 3-(4-methoxyphenyl)pent-4-en-1-ol (**3a**). The extent of deuterium incorporation was determined in the isolated product

*deuterio*-**3-(4-methoxyphenyl)pent-4-en-1-ol** by integration of the corresponding signals in <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) and <sup>2</sup>H NMR (77 MHz, CHCl<sub>3</sub>).



(\*Inseparable regioisomer)

## IX. Deuterium Labeling of Ruthenium Catalyzed Coupling at the C3-position



	$(CD_2O)_n + i$ -PrOH		$(CH_2O)_n + i$ -PrOH- $d_8$		$(CD_2O)_n + i$ -PrOH- $d_8$	
H <sub>a</sub>	0%	<sup>2</sup> H	6%	$^{2}\mathrm{H}$	0%	$^{2}\mathrm{H}$
$H_b$	0%	<sup>2</sup> H	5%	$^{2}\mathrm{H}$	2%	$^{2}\mathrm{H}$
Hc	25%	<sup>2</sup> H	12%	$^{2}\mathrm{H}$	31%	$^{2}\mathrm{H}$
$H_d$	13%	<sup>2</sup> H	8%	$^{2}\mathrm{H}$	17%	$^{2}\mathrm{H}$
He	100%	$^{2}\mathrm{H}$	1%	$^{2}\mathrm{H}$	100%	$^{2}\mathrm{H}$
Yield	65%	(20:1 r.r.)	60%	(12:1 r.r.)	64%	(17:1 r.r)

The above values represent the average of two trials. The extent of deuterium incorporation was determined for the major regionsomer (alcohol 3c).

Diene **3** was subjected to three separate experiments employing *deuterio*-paraformaldehyde,  $d_8$ -isopropanol, and both *deuterio*-paraformaldehyde and  $d_8$ -isopropanol under otherwise the same conditions to furnish 3-(4-methoxyphenyl)-2-methylbut-3-en-1-ol (3c). The extent of deuterium incorporation was determined in the isolated product

*deuterio*-**3**-(4-methoxyphenyl)-2-methylbut-3-en-1-ol by integration of the corresponding signals in <sup>1</sup>H NMR (400 MHz, CDCl<sub>3</sub>) and <sup>2</sup>H NMR (77 MHz, CHCl<sub>3</sub>).











