**Studies on Highly Stereoselective Addition-Elimination Reactions of
3-(Methoxycarbonyl)-1,2-allen-4-ols with MX. An Efficient Synthesis of
3-(Methoxycarbonyl)-2-halo-1,3(Z)-dienes**

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Supporting Information

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1. Synthesis of 3-(methoxycarbonyl)-1,2-allen-4-ols

(1) 3-(Methoxycarbonyl)-1,2-hexadien-4-ol (**3a**). Typical Procedure.¹

To a solution of 3-(methoxycarbonyl)propargyl bromide (3.4806 g, 19.7 mmol)² in 30 mL of DMPU were added SnCl_2 (4.6011 g, 24.2 mmol) and NaI (3.6107 g, 24.1 mmol) at rt. The resulting yellow slurry was stirred in the absence of light (the reaction tube was wrapped with a black plastic bag) for 6 hours. A solution of propionaldehyde (0.9281 g, 16.0 mmol) in 10 mL of DMPU was then added dropwise over 15 min at 0 °C. The orange reaction mixture was allowed to warm up to room temperature and stirred in dark for an additional 24 hours. The reaction was cooled to 0 °C, diluted with Et_2O , and quenched with 30 mL of saturated aqueous NH_4Cl . The organic phase was separated and the aqueous phase was extracted with Et_2O (4 x 30 mL). The combined organic layer was washed with brine and dried over *anhydrous* Na_2SO_4 . Evaporation and column chromatography on silica gel (petroleum ether/ethyl acetate = 5:1) afforded **3a** (1.4606 g, 59%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 5.20 (d, J = 2.0 Hz, 2H), 4.32-4.24 (m, 1H), 3.70 (s, 3H), 3.20-2.94 (bs, 1H), 1.66-1.57 (m, 2H), 0.89 (t, J = 7.4 Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 212.4, 167.3, 102.6, 80.5, 70.4, 52.1, 28.2, 10.0; MS (m/z): 156 (M^+ , 0.12), 127 (100); IR (neat, cm^{-1}): 3490, 2965, 1964, 1935, 1713, 1266. HRMS calcd for $\text{C}_8\text{H}_{12}\text{NaO}_3$ ($\text{M}^+ + \text{Na}$): 179.0679, Found: 179.0676.

(2) 3-(Methoxycarbonyl)-1,2-heptadien-4-ol (3b)

The reaction of 1.7901 g (10.1 mmol) of 3-(methoxycarbonyl)propargyl bromide, 2.2896 g (12.1 mmol) of SnCl_2 , 1.8112 g (12.1 mmol) of NaI, and 0.5702 g of *n*-butanal (7.9 mmol) in 22 mL of DMPU afforded 0.8223 g (61%) of **3b**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 5.22 (d, $J = 2.0$ Hz, 2H), 4.41-4.36 (m, 1H), 3.73 (s, 3H), 3.00-2.68 (bs, 1H), 1.63-1.55 (m, 2H), 1.48-1.36 (m, 1H), 1.35-1.23 (m, 1H), 0.89 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 212.4, 167.4, 102.9, 80.5, 68.8, 52.1, 37.3, 18.9, 13.7; MS (m/z): 170 (M^+ , 0.12), 127 (100); IR (neat, cm^{-1}): 3479, 2958, 1964, 1939, 1713, 1259. HRMS calcd for $\text{C}_9\text{H}_{14}\text{NaO}_3$ ($\text{M}^+ + \text{Na}$): 193.0835, Found: 193.0837.

(3) 3-(Methoxycarbonyl)-5-methyl-1,2-hexdien-4-ol (3c)

The reaction of 1.0721 g (6.1 mmol) of 3-(methoxycarbonyl)propargyl bromide, 1.3764 g (7.3 mmol) of SnCl_2 , 1.0797 g (7.2 mmol) of NaI, and 0.3564 g of isobutanal (5.0 mmol) in 15 mL of DMPU afforded 0.7017 g (83%) of **3c**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 5.23 (d, $J = 1.2$ Hz, 2H), 4.04 (dt, $J_1 = 7.6$ Hz, $J_2 = 1.2$ Hz, 1H), 3.74 (s, 3H), 2.97-2.69 (bs, 1H), 1.97-1.88 (m, 1H), 0.98 (d, $J = 6.4$ Hz, 3H),

0.88 (d, $J = 6.4$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 213.0, 167.3, 101.7, 80.2, 75.3, 52.2, 32.8, 19.5, 17.9; MS (m/z): 170 (M^+ , 0.17), 127 (100); IR (neat, cm^{-1}): 3499, 2960, 1964, 1939, 1714, 1258. Elemental analysis: Calcd for $\text{C}_9\text{H}_{14}\text{O}_3$: C, 63.51; H, 8.29; Found: C, 63.50; H, 8.29.

(4) 3-(Methoxycarbonyl)-1,2-nonadien-4-ol (3d)

The reaction of 1.7810 g (10.1 mmol) of 3-(methoxycarbonyl)propargyl bromide, 2.2891 g (12.1 mmol) of SnCl_2 , 1.8052 g (12.0 mmol) of NaI, and 0.7958 g of hexanal (8.0 mmol) in 22 mL of DMPU afforded 0.9323 g (59%) of **3d**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 5.25 (d, $J = 1.2$ Hz, 2H), 4.41 (t, $J = 6.8$ Hz, 1H), 3.76 (s, 3H), 3.06-2.75 (bs, 1H), 1.66-1.61 (m, 2H), 1.49-1.40 (m, 1H), 1.40-1.20 (m, 5H), 0.87 (t, $J = 6.4$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 212.5, 167.5, 103.0, 80.6, 69.4, 52.3, 35.3, 31.6, 25.4, 22.6, 14.0; MS (m/z): 198 (M^+ , 0.10), 127 (100); IR (neat, cm^{-1}): 3519, 2954, 1964, 1939, 1715, 1259. HRMS calcd for $\text{C}_{11}\text{H}_{18}\text{NaO}_3$ ($\text{M}^+ + \text{Na}$): 221.1148, Found: 221.1145.

(5) 3-(Methoxycarbonyl)-(4-phenyl)-1,2-butadien-4-ol (3e)³

The reaction of 3.5467 g (20.0 mmol) of 3-(methoxycarbonyl)propargyl bromide, 4.5821 g (24.2 mmol) of SnCl₂, 3.6122 g (24.1 mmol) of NaI, and 1.6899 g (15.9 mmol) of benzaldehyde in 55 mL of DMPU afforded 2.5247 g (78%) of **3e**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.42-7.26 (m, 5H), 5.59 (s, 1H), 5.25-5.15 (m, 2H), 3.75 (s, 3H), 3.60-3.33 (bs, 1H); ¹³C NMR (100 MHz, CDCl₃): δ 213.0, 166.8, 141.2, 128.0, 127.5, 126.1, 103.6, 81.0, 71.3, 52.1; MS (m/z): 204 (M⁺, 4.01), 203 (M⁺-1, 22.99), 107 (100); IR (neat, cm⁻¹): 3471, 1965, 1713, 1262. HRMS calcd for C₁₂H₁₁O₃ (M⁺-H): 203.0703, Found: 203.0711.

(6) 3-(Methoxycarbonyl)- 4-(*p*-tolyl)-1,2-butadien-4-ol (3f)

The reaction of 1.7689 g (10.0 mmol) of 3-(methoxycarbonyl)propargyl bromide, 2.2812 g (12.0 mmol) of SnCl₂, 1.7998 g (12.0 mmol) of NaI, and 0.9500 g of *p*-methylbenzaldehyde (7.9 mmol) in 22 mL of DMPU afforded 1.1740 g (68%) of **3f**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.28 (d, *J* = 8.0 Hz, 2H), 7.15 (d, *J* = 8.0 Hz, 2H), 5.54 (s, 1H), 5.26-5.17 (m, 2H), 3.74 (s, 3H), 2.34 (s, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 213.0, 167.1, 138.4, 137.4, 128.9, 126.1, 103.6, 81.1, 71.6, 52.3, 21.1; MS (m/z): 218 (M⁺, 0.88), 217 (M⁺-1, 4.39), 121 (100); IR (neat, cm⁻¹): 3482, 1964, 1931, 1714, 1260. HRMS calcd for C₁₃H₁₃O₃ (M⁺-H): 217.0859, Found: 217.0862.

2. The Addition-Elimination Reactions of 3-(Methoxycarbonyl)-1,2-allen-4-ols with MX.

(1) Preparation of methyl 2-(1'-iodovinyl)pent-2(Z)-enoate (4aa). Typical Procedure.

To a mixture of NaI (151.1 mg, 1.0 mmol) and **3a** (77.0 mg, 0.49 mmol) was added 1.0 mL of TFA at room temperature. After the addition, the reaction was refluxed at 80 °C with stirring for 1 h. After the reaction was complete as monitored by TLC, it was cooled to room temperature and slowly quenched by 10 mL of water followed by neutralization with NaHCO₃ until no gas was released. The mixture was extracted with diethyl ether (3 x 25 mL) and washed with saturated aqueous solution of Na₂S₂O₃ and brine. The organic layer was dried over *anhydrous* Na₂SO₄. Evaporation and column chromatography on silica gel (30-60 °C petroleum ether/diethyl ether = 30:1) afforded **4aa** (65.4 mg, 50%): Liquid; ¹H NMR (300 MHz, CDCl₃) δ 6.75 (t, *J* = 7.8 Hz, 1H), 6.08 (d, *J* = 1.1 Hz, 1H), 6.03 (d, *J* = 1.1 Hz, 1H), 3.77 (s, 3H), 2.29-2.18 (m, 2H), 1.06 (t, *J* = 7.7 Hz, 3H); ¹³C NMR (75 MHz, CDCl₃): δ 165.3, 146.6, 135.7, 131.2, 96.3, 52.1, 22.8, 12.3; MS (*m/z*): 267 (*M*⁺+1, 100); IR (neat, cm⁻¹): 2962, 1722, 1603, 1434, 1243. HRMS calcd for C₈H₁₁IO₂ (*M*⁺): 265.9798, Found: 265.9790.

(2) Methyl 2-(1'-bromovinyl)pent-2(Z)-enoate (4ab)

The reaction of 77.1 mg (0.49 mmol) of **3a** and 105.0 mg (1.0 mmol) of LiBr·H₂O in 1 mL of TFA afforded 60.2 mg (56%) of **4ab**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.88 (t, *J* = 7.8 Hz, 1H), 5.84 (d, *J* = 2.0 Hz, 1H), 5.66 (d, *J* = 2.0 Hz, 1H), 3.79 (s, 3H), 2.32-2.26 (m, 2H), 1.07 (t, *J* = 7.6 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 165.5, 148.5, 132.9, 122.6, 122.3, 52.2, 22.9, 12.8; MS (m/z): 220 (M⁺ (⁸¹Br), 8.22), 218 (M⁺ (⁷⁹Br), 8.32), 139 (100); IR (neat, cm⁻¹): 2971, 2952, 1724, 1645, 1615, 1267, 1245. HRMS calcd for C₈H₁₁BrNaO₂ (M⁺+Na): 242.9822 (⁸¹Br), 240.9835 (⁷⁹Br), Found: 242.9811 (⁸¹Br), 240.9833 (⁷⁹Br).

(3) Methyl 2-(1'-chlorovinyl)pent-2(Z)-enoate (**4ac**)

The reaction of 78.8 mg (0.51 mmol) of **3a** and 122.1 mg (2.02 mmol) of LiCl·H₂O in 1 mL of TFA afforded 35.5 mg (40%) of **4ac** (There are some unidentified impurities in the ¹H NMR spectra. The purity by GC is 92%) : Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.94 (t, *J* = 7.8 Hz, 1H), 5.62 (d, *J* = 1.2 Hz, 1H), 5.26 (d, *J* = 1.2 Hz, 1H), 3.79 (s, 3H), 2.36-2.27 (m, 2H), 1.07 (t, *J* = 7.6 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 165.6, 149.1, 133.0, 131.4, 118.3, 52.2, 23.0, 13.0; MS (m/z): 176 (M⁺ (³⁷Cl), 3.72), 174 (M⁺ (³⁵Cl), 11.67), 139 (100); IR (neat, cm⁻¹): 2971, 2955, 1725, 1644, 1619, 1246. HRMS calcd for C₈H₁₁ClO₂ (M⁺): 174.0448 (³⁵Cl), Found: 174.0448 (³⁵Cl).

(4) Methyl 2-(1'-iodovinyl)hex-2(Z)-enoate (4ba)

The reaction of 85.2 mg (0.50 mmol) of **3b** and 150.1 mg (1.0 mmol) of NaI in 1 mL of TFA afforded 102.1 mg (73%) of **4ba**: Liquid; ^1H NMR (300 MHz, CDCl_3) δ 6.75 (t, $J = 7.7$ Hz, 1H), 6.07 (d, $J = 1.0$ Hz, 1H), 6.01 (d, $J = 1.0$ Hz, 1H), 3.75 (s, 3H), 2.18 (q, $J = 7.6$ Hz, 2H), 1.56-1.40 (m, 2H), 0.92 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (75 MHz, CDCl_3): δ 165.3, 145.3, 136.2, 131.2, 96.5, 52.1, 31.3, 21.3, 13.9; MS (m/z): 280 (M^+ , 16.64), 93 (100); IR (neat, cm^{-1}): 2959, 1723, 1639, 1605, 1249. HRMS calcd for $\text{C}_9\text{H}_{13}\text{IO}_2$ (M^+): 279.9960, Found: 279.9974.

(5) Methyl 2-(1'-bromovinyl)hex-2(Z)-enoate (4bb)

The reaction of 83.7 mg (0.49 mmol) of **3b** and 105.1 mg (1.0 mmol) of $\text{LiBr}\cdot\text{H}_2\text{O}$ in 1 mL of TFA afforded 87.2 mg (76%) of **4bb**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.88 (t, $J = 7.6$ Hz, 1H), 5.83 (d, $J = 1.2$ Hz, 1H), 5.64 (d, $J = 1.2$ Hz, 1H), 3.77 (s, 3H), 2.26 (q, $J = 7.6$ Hz, 2H), 1.55-1.43 (m, 2H), 0.94 (t, $J = 7.4$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.3, 147.1, 133.4, 122.6, 122.5, 52.1, 31.4, 21.6, 13.8; MS (m/z): 234 (M^+ (^{81}Br), 6.15), 232 (M^+ (^{79}Br), 6.45), 93 (100); IR (neat, cm^{-1}): 2960, 1725, 1614, 1251. HRMS calcd for $\text{C}_9\text{H}_{13}\text{BrNaO}_2$ ($\text{M}^+ + \text{Na}$): 256.9979 (^{81}Br),

254.9991 (^{79}Br), Found: 256.9974 (^{81}Br), 254.9994 (^{79}Br).

(6) Methyl 2-(1'-chlorovinyl)hex-2(Z)-enoate (4bc)

The reaction of 84.5 mg (0.50 mmol) of **3b** and 122.0 mg (2.02 mmol) of $\text{LiCl}\cdot\text{H}_2\text{O}$ in 1 mL of TFA afforded 51.1 mg (55%) of **4bc**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.94 (t, $J = 7.8$ Hz, 1H), 5.60 (d, $J = 1.2$ Hz, 1H), 5.24 (d, $J = 1.2$ Hz, 1H), 3.77 (s, 3H), 2.28 (q, $J = 7.5$ Hz, 2H), 1.55-1.42 (m, 2H), 0.94 (t, $J = 7.4$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.5, 147.7, 133.1, 132.0, 118.3, 52.1, 31.5, 21.7, 13.8; MS (m/z): 190 (M^+ (^{37}Cl), 3.81), 188 (M^+ (^{35}Cl), 11.30), 93 (100); IR (neat, cm^{-1}): 2961, 1727, 1618, 1251. HRMS calcd for $\text{C}_9\text{H}_{13}\text{ClNaO}_2$ ($\text{M}^+ + \text{Na}$): 213.0481 (^{37}Cl), 211.0496 (^{35}Cl), Found: 213.0468 (^{37}Cl), 211.0497 (^{35}Cl).

(7) Methyl 2-(1'-iodovinyl)-4-methylpent-2(Z)-enoate (4ca)

The reaction of 84.3 mg (0.50 mmol) of **3c** and 150.2 mg (1.0 mmol) of NaI in 1 mL of TFA afforded 74 mg (53%) of **4ca**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.55 (d, $J = 10.8$ Hz, 1H), 6.07 (d, $J = 0.8$ Hz, 1H), 6.02 (d, $J = 0.8$ Hz, 1H), 3.76 (s, 3H), 2.82-2.69 (m, 1H), 1.03 (d, $J = 6.8$ Hz, 6H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.5,

151.3, 134.1, 131.0, 96.3, 52.1, 28.8, 21.2; MS (m/z): 280 (M^+ , 19.15), 93 (100); IR (neat, cm^{-1}): 2962, 1724, 1643, 1605, 1434, 1248. HRMS calcd for $\text{C}_9\text{H}_{13}\text{IO}_2$ (M^+): 279.9955, Found: 279.9957.

(8) Methyl 2-(1'-bromovinyl)-4-methylpent-2(Z)-enoate (4cb)

The reaction of 86.2 mg (0.51 mmol) of **3c** and 105.1 mg (1.0 mmol) of $\text{LiBr} \cdot \text{H}_2\text{O}$ in 1 mL of TFA afforded 75.0 mg (64%) of **4cb**: Liquid; ^1H NMR (400 MHz, CDCl_3): δ 6.69 (d, $J = 11.2$ Hz, 1H), 5.83 (d, $J = 1.6$ Hz, 1H), 5.66 (d, $J = 1.6$ Hz, 1H), 3.79 (s, 3H), 2.86-2.74 (m, 1H), 1.05 (d, $J = 6.4$ Hz, 6 H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.6, 153.2, 131.1, 122.5, 122.4, 52.2, 28.9, 21.7; MS (m/z): 234 (M^+ (^{81}Br), 0.98), 232 (M^+ (^{79}Br), 1.01), 153 (100); IR (neat, cm^{-1}): 2964, 1725, 1614, 1249. HRMS calcd for $\text{C}_9\text{H}_{13}\text{BrO}_2$ (M^+): 234.0082 (^{81}Br), 232.0093 (^{79}Br), Found: 234.0069 (^{81}Br), 232.0098 (^{79}Br).

(9) Methyl 2-(1'-chlorovinyl)-4-methylpent-2(Z)-enoate (4cc)

The reaction of 85.7 mg (0.50 mmol) of **3c** and 122.1 mg (2.01 mmol) of $\text{LiCl} \cdot \text{H}_2\text{O}$ in 1 mL of TFA afforded 36.9 mg (39%) of **4cc**: Liquid; ^1H NMR (400 MHz, CDCl_3):

δ 6.73 (d, $J = 10.8$ Hz, 1 H), 5.59 (d, $J = 1.0$ Hz, 1H), 5.25 (d, $J = 1.0$ Hz, 1H), 3.77 (s, 3H), 2.85-2.73 (m, 1H), 1.04 (d, $J = 6.8$ Hz, 6H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.7, 153.7, 133.2, 129.6, 118.0, 52.2, 28.9, 21.8; MS (m/z): 190 (M^+ (^{37}Cl), 4.81), 188 (M^+ (^{35}Cl), 14.93), 93 (100); IR (neat, cm^{-1}): 2964, 1726, 1618, 1251. HRMS calcd for $\text{C}_9\text{H}_{13}\text{ClO}_2$ (M^+): 190.0583 (^{37}Cl), 188.0600 (^{35}Cl), Found: 190.0574 (^{37}Cl), 188.0604 (^{35}Cl).

(10) Methyl 2-(1'-iodovinyl)oct-2(Z)-enoate (4da)

The reaction of 96.0 mg (0.48 mmol) of **3d** and 150.1 mg (1.0 mmol) of NaI in 1 mL of TFA afforded 111.7 mg (75%) of **4da**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.77 (t, $J = 7.6$ Hz, 1H), 6.09 (d, $J = 1.2$ Hz, 1H), 6.02 (d, $J = 1.2$ Hz, 1H), 3.77 (s, 3H), 2.21 (q, $J = 7.6$ Hz, 2H), 1.51-1.38 (m, 2H), 1.36-1.26 (m, 4H), 0.88 (t, $J = 7.0$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 165.3, 145.6, 136.1, 131.2, 96.6, 52.1, 31.5, 29.4, 27.7, 22.4, 13.9; MS (m/z): 308 (M^+ , 16.31), 121 (100); IR (neat, cm^{-1}): 2955, 2927, 1724, 1640, 1606, 1434, 1251, 1051. HRMS calcd for $\text{C}_{11}\text{H}_{17}\text{INaO}_2$ ($\text{M}^+ + \text{Na}$): 331.0165, Found: 331.0161.

(11) Methyl 2-(1'-bromovinyl)oct-2(Z)-enoate (4db)

The reaction of 98.1 mg (0.49 mmol) of **3d** and 104.5 mg (1.0 mmol) of LiBr·H₂O in 1 mL of TFA afforded 86.4 mg (67%) of **4db**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.90 (t, *J* = 7.6 Hz, 1H), 5.84 (d, *J* = 1.6 Hz, 1H), 5.65 (d, *J* = 1.6 Hz, 1H), 3.78 (s, 3H), 2.28 (q, *J* = 7.6 Hz, 2H), 1.51-1.39 (m, 2H), 1.35-1.26 (m, 4H), 0.88 (t, *J* = 6.8 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 165.4, 147.5, 133.1, 122.7, 122.4, 52.2, 31.4, 29.4, 27.9, 22.4, 13.9; MS (*m/z*): 262 (*M*⁺ (⁸¹Br), 1.01), 260 (*M*⁺ (⁷⁹Br), 1.03), 181 (100); IR (neat, cm⁻¹): 2955, 2928, 1726, 1647, 1615, 1457, 1435, 1254. HRMS calcd for C₁₁H₁₇O₂ (*M*⁺-Br): 181.1223. Found: 181.1223. HRMS calcd for C₁₀H₁₄BrO (*M*⁺-OCH₃): 231.0211 (⁸¹Br), 229.0223 (⁷⁹Br), Found: 231.0202 (⁸¹Br), 229.0220 (⁷⁹Br).

(12) Methyl 2-(1'-chlorovinyl)oct-2(Z)-enoate (4dc)

The reaction of 98.6 mg (0.50 mmol) of **3d** and 118.2 mg (1.95 mmol) of LiCl·H₂O in 1 mL of TFA afforded 50.8 mg (47%) of **4dc**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.94 (t, *J* = 8.0 Hz, 1H), 5.60 (d, *J* = 1.2 Hz, 1H), 5.24 (d, *J* = 1.2 Hz, 1H), 3.77 (s, 3H), 2.28 (q, *J* = 8.0 Hz, 2H), 1.51-1.38 (m, 2H), 1.35-1.22 (m, 4H), 0.87 (t, *J* = 7.0 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 165.5, 148.1, 133.0, 131.7, 118.3, 52.2, 31.4,

29.5, 28.1, 22.4, 13.9; MS (m/z): 218 (M^+ (^{37}Cl), 0.93), 216 (M^+ (^{35}Cl), 2.82), 181 (100); IR (neat, cm^{-1}): 2956, 2929, 1727, 1650, 1619, 1458, 1435, 1255, 1053. HRMS calcd for $\text{C}_{11}\text{H}_{17}\text{ClO}_2$ (M^+): 218.0899 (^{37}Cl), 216.0912 (^{35}Cl), Found: 218.0886 (^{37}Cl), 216.0917 (^{35}Cl).

(13) Methyl 2-(1'-iodovinyl)-3-phenylprop-2(Z)-enoate (4ea)

The reaction of 100.4 mg (0.49 mmol) of **3e** and 150.2 mg (1.00 mmol) of NaI in 1 mL of HOAc afforded 61.6 mg (40%) of **4ea** (There are some unidentified impurities in the ^1H NMR spectra. The purity by GC is 92%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 7.76-7.65 (m, 2H), 7.52 (s, 1H), 7.45-7.38 (m, 3H), 6.21 (d, $J = 1.4$ Hz, 1H), 6.13 (d, $J = 1.4$ Hz, 1H), 3.86 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 166.0, 139.6, 133.9, 133.5, 131.8, 131.1, 130.0, 128.6, 98.4, 52.6; MS (m/z): 314 (M^+ , 8.26), 128 (100); IR (neat, cm^{-1}): 2949, 1716, 1635, 1597, 1448, 1434, 1255, 1201. HRMS calcd for $\text{C}_{12}\text{H}_{11}\text{IO}_2$ (M^+): 313.9798, Found: 313.9801.

(14) Methyl 2-(1'-bromovinyl)-3-phenylprop-2(Z)-enoate (4eb)

The reaction of 101.5 mg (0.50 mmol) of **3e** and 105.0 mg (1.0 mmol) of LiBr·H₂O

in 1 mL of TFA afforded **4eb** (58.6 mg, 44%).

The reaction of 103.7 mg (0.51 mmol) of **3e** and 105.0 mg (1.0 mmol) of LiBr·H₂O in 1 mL of HOAc afforded **4eb** (59.1 mg, 44%).

4eb: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.74-7.66 (m, 2H), 7.65 (s, 1H), 7.44-7.35 (m, 3H), 5.86 (d, *J* = 1.8 Hz, 1H), 5.79 (d, *J* = 1.8 Hz, 1H), 3.86 (s, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 166.0, 141.5, 133.3, 130.8, 130.1, 128.5, 123.6, 123.2, 52.5; MS (*m/z*): 268 (M⁺ (⁸¹Br), 4.34), 266 (M⁺ (⁷⁹Br), 4.40), 128 (100); IR (neat, cm⁻¹): 2950, 1717, 1644, 1604, 1448, 1434, 1256, 1202. HRMS calcd for C₁₂H₁₁BrO₂ (M⁺): 267.9927 (⁸¹Br), 265.9937 (⁷⁹Br), Found: 267.9919 (⁸¹Br), 265.9939 (⁷⁹Br).

(15) Methyl 2-(1'-chlorovinyl)-3-phenylprop-2(Z)-enoate (4ec)

The reaction of 103.0 mg (0.50 mmol) of **3e** and 120.8 mg (2.00 mmol) of LiCl·H₂O in 1 mL of TFA afforded **4ec** (29.3 mg, 26%).

The reaction of 103.3 mg (0.51 mmol) of **3e** and 123.1 mg (2.03 mmol) of LiCl·H₂O in 1 mL of HOAc afforded **4ec** (33.9 mg, 31%).

4ec: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 7.71 (s, 1H), 7.69-7.61 (m, 2H), 7.40-7.35 (m, 3H), 5.61 (d, $J = 1.8$ Hz, 1H), 5.37 (d, $J = 1.8$ Hz, 1H), 3.86 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 166.1, 142.3, 134.0, 133.4, 130.5, 130.1, 129.4, 128.6, 118.9, 52.6; MS (m/z): 224 (M^+ (^{37}Cl), 3.78), 222 (M^+ (^{35}Cl), 11.39), 128 (100); IR (neat, cm^{-1}): 2951, 1717, 1649, 1608, 1448, 1435, 1258, 1202. HRMS calcd for $\text{C}_{12}\text{H}_{11}\text{ClO}_2$ (M^+): 224.0430 (^{37}Cl), 222.0442 (^{35}Cl), Found: 224.0417 (^{37}Cl), 222.0446 (^{35}Cl).

(16) Methyl 2-(1'-iodovinyl)-3-(*p*-tolyl)prop-2(*Z*)-enoate (4fa)

The reaction of 107.7 mg (0.49 mmol) of **3f** and 150.2 mg (1.00 mmol) of NaI in 1 mL of HOAc afforded 117.5 mg (73%) of **4fa** (There are some unidentified impurities in the ^1H NMR spectra. The purity by GC is 95.5%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 7.62 (d, $J = 7.6$ Hz, 2H), 7.49 (s, 1H), 7.20 (d, $J = 8.0$ Hz, 2H), 6.20 (d, $J = 1.6$ Hz, 1H), 6.13 (d, $J = 1.6$ Hz, 1H), 3.85 (s, 3H), 2.37 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 166.0, 140.5, 139.6, 132.8, 131.6, 131.3, 130.6, 129.3, 98.9, 52.4, 21.5; MS (m/z): 328 (M^+ , 9.21), 142 (100); IR (neat, cm^{-1}): 2949, 1716, 1659, 1605, 1434, 1256. HRMS calcd for $\text{C}_{13}\text{H}_{13}\text{IO}_2$ (M^+): 327.9955, Found: 327.9955.

(17) Methyl 2-(1'-bromovinyl)-3-(*p*-tolyl)prop-2(*Z*)-enoate (4fb)

The reaction of 111.8 mg (0.51 mmol) of **3f** and 105.1 mg (1.0 mmol) of LiBr·H₂O in 1 mL of HOAc afforded 88.8 mg (62%) of **4fb**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.62 (s, 1H), 7.61 (d, *J* = 8.4 Hz, 2H), 7.20 (d, *J* = 8.4 Hz, 2H), 5.86 (d, *J* = 1.6 Hz, 1H), 5.80 (d, *J* = 1.6 Hz, 1H), 3.85 (s, 3H), 2.37 (s, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 166.1, 141.5, 140.7, 130.9, 130.5, 129.7, 129.3, 124.0, 123.0, 52.4, 21.4; MS (*m/z*): 282 (M⁺ (⁸¹Br), 4.46), 280 (M⁺ (⁷⁹Br), 4.51), 142 (100); IR (neat, cm⁻¹): 2950, 1716, 1640, 1604, 1511, 1434, 1258, 1050. HRMS calcd for C₁₃H₁₃BrO₂ (M⁺): 282.0084 (⁸¹Br), 280.0093 (⁷⁹Br), Found: 282.0071 (⁸¹Br), 280.0096 (⁷⁹Br).

(18) Methyl 2-(1'-chlorovinyl)-3-(*p*-tolyl)prop-2(*Z*)-enoate (4fc**)**

The reaction of 110.5 mg (0.51 mmol) of **3f** and 120.5 mg (1.99 mmol) of LiCl·H₂O in 1 mL of HOAc afforded 70.4 mg (59%) of **4fc**: Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.69 (s, 1H), 7.57 (d, *J* = 8.4 Hz, 2H), 7.19 (d, *J* = 8.4 Hz, 2H), 5.62 (d, *J* = 1.4 Hz, 1H), 5.38 (d, *J* = 1.4 Hz, 1H), 3.85 (s, 3H), 2.37 (s, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 166.2, 142.3, 140.7, 134.2, 130.6, 130.5, 129.3, 128.2, 118.8, 52.4, 21.4; MS (*m/z*): 238 (M⁺ (³⁷Cl), 3.48), 236 (M⁺ (³⁵Cl), 10.33), 142 (100); IR (neat, cm⁻¹): 2951, 1716, 1641, 1607, 1512, 1435, 1258, 1052. HRMS calcd for

$C_{13}H_{13}ClO_2$ (M^+): 238.0588 (^{37}Cl), 236.0599 (^{35}Cl), Found: 238.0574 (^{37}Cl), 236.0600 (^{35}Cl).

3. Reduction of methyl 2-(1'-iodovinyl)hex-2(Z)-enoate (**4ba**)

DIBAL-H (1.4 mL, 1 M in toluene, 1.4 mmol) was added dropwise to a solution of **4ba** (180.0 mg, 0.64 mmol) in toluene (3 mL) at $-78\text{ }^\circ\text{C}$. After complete conversion of the starting materials as monitored by TLC, the reaction mixture was quenched with 2 mL of CH_3OH and 5 mL of water. The organic layer was separated, and the aqueous layer was extracted with diethyl ether (3 x 25 mL). The combined organic layer was dried over Na_2SO_4 . Evaporation and column chromatography on silica gel (petroleum ether/ethyl acetate = 10:1) afforded 118.7 mg (73%) of **5ba**: Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.03 (d, $J = 1.2$ Hz, 1H), 5.99 (d, $J = 1.2$ Hz, 1H), 5.53 (t, $J = 7.4$ Hz, 1H), 4.15 (s, 2H), 2.13-2.00 (m, 3H), 1.45-1.34 (m, 2H), 0.90 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 142.4, 129.9, 129.8, 102.5, 64.9, 30.7, 22.0, 13.8; MS (m/z): 252 (M^+ , 4.26), 79 (100); IR (neat, cm^{-1}): 3333, 2958, 2929, 2870, 1608, 1456, 1107, 900. HRMS calcd for $\text{C}_8\text{H}_{13}\text{IO}$ (M^+): 274.9903, Found: 274.9914.

4. Synthetic application of methyl 2-(1'-iodovinyl)hex-2(Z)-enoate (**4ba**)

(1) Methyl 2-(4'-phenylbut-1'-en-3'-yn-2'-yl)hex-2(E)-enoate (**6ba**)

A mixture of $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (6.8 mg, 5 mol%, 0.01 mmol), CuI (4.1 mg, 10 mol%, 0.02 mmol), Et_2NH (22.2 mg, 0.30 mmol), phenylacetylene (41.6 mg, 0.41 mmol), and **4ba** (55.9 mg, 0.20 mmol) in CH_3CN (2 mL) was stirred at room temperature over a period of 24 h under nitrogen. After complete conversion of the starting materials as monitored by TLC, the reaction mixture was diluted with 10 mL of Et_2O and quenched with 5 mL of water. The organic layer was separated, and the aqueous layer was extracted with diethyl ether (3 x 25 mL). The combined organic layer was dried over Na_2SO_4 . Evaporation and column chromatography on silica gel (petroleum ether/diethyl ether = 30:1) afforded **6ba** (44.1 mg, 87%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 7.46-7.38 (m, 2H), 7.34-7.26 (m, 3H), 6.94 (t, $J = 7.6$ Hz, 1H), 5.85 (s, 1H), 5.39 (s, 1H), 3.79 (s, 3H), 2.32 (q, $J = 7.3$ Hz, 2H), 1.59-1.45 (m, 2H), 0.96 (t, $J = 7.2$ Hz, 3H); ^{13}C NMR (100 MHz, CDCl_3): δ 166.6, 145.8, 131.8, 131.6, 128.23, 128.18, 126.7, 125.1, 123.0, 89.1, 88.7, 52.0, 31.4, 21.9, 13.8; MS (m/z): 254 (M^+ , 62.02), 165 (100); IR (neat, cm^{-1}): 2959, 1720, 1639, 1600, 1489, 1435, 1250, 1058. HRMS calcd for $\text{C}_{17}\text{H}_{18}\text{NaO}_2$ ($\text{M}^+ + \text{Na}$): 277.1199, Found: 277.1196.

(2) Methyl 2-(oct-1'-en-3'-yn-2'-yl)hex-2(E)-enoate (6bb)

A mixture of $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (7.1 mg, 5 mol%, 0.01 mmol), CuI (3.9 mg, 10 mol%, 0.02 mmol), Et_2NH (21.8 mg, 0.30 mmol), 1-hexyne (33.0 mg, 0.40 mmol), and **4ba** (57.3 mg, 0.20 mmol) in CH_3CN (2 mL) afforded **6bb** (30.6 mg, 64%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.82 (t, $J = 7.8$ Hz, 1H), 5.62 (s, 1H), 5.19 (s, 1H), 3.73 (s, 3H), 2.31-2.18 (m, 4H), 1.51-1.41 (m, 4H), 1.40-1.33 (m, 2H), 0.96-0.84 (m, 6H); ^{13}C NMR (100 MHz, CDCl_3): δ 166.7, 145.0, 132.4, 125.5, 125.1, 90.5, 79.9, 51.9, 31.3, 30.6, 21.9, 21.8, 19.0, 13.8, 13.5; MS (m/z): 234 (M^+ , 100); IR (neat, cm^{-1}): 2959, 2933, 2222, 1723, 1640, 1598, 1461, 1434, 1249, 1058. HRMS calcd for $\text{C}_{15}\text{H}_{22}\text{O}_2$ (M^+): 234.1614, Found: 234.1617.

(3) Methyl 2-(hex-5'-hydroxy-5'-methyl-1'-en-3'-yn-2'-yl)hex-2(*E*)-enoate (**6bc**)

A mixture of $\text{Pd}(\text{PPh}_3)_2\text{Cl}_2$ (7.1 mg, 5 mol%, 0.01 mmol), CuI (3.8 mg, 10 mol%, 0.02 mmol), 2-methyl-3-butyn-2-ol (33.5 mg, 0.40 mmol), **4ba** (55.8 mg, 0.20 mmol), and Et_3N (1 mL) in DMSO (1 mL) was stirred at room temperature over a period of 2 h under nitrogen. After complete conversion of the starting materials as monitored by TLC, the reaction mixture was diluted with 10 mL of Et_2O and quenched with 5 mL

of water. The organic layer was separated and the aqueous layer was extracted with diethyl ether (3 x 20 mL). The combined organic layer was washed with brine and dried over Na₂SO₄. Evaporation and column chromatography on silica gel (petroleum ether/ethyl acetate = 8:1, then 4:1) afforded **6bc** (32.5 mg, 69%): Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.82 (t, *J* = 7.6 Hz, 1H), 5.67 (d, *J* = 1.6 Hz, 1H), 5.25 (d, *J* = 1.6 Hz, 1H), 3.71 (s, 3H), 2.78-2.69 (bs, 1H), 2.20 (q, *J* = 7.6 Hz, 2H), 1.51-1.37 (m, 2H), 1.46 (s, 6H), 0.89 (t, *J* = 7.6 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 166.5, 145.6, 131.7, 126.7, 124.6, 93.6, 81.3, 65.3, 51.9, 31.4, 31.2, 21.9, 13.8; MS (*m/z*): 236 (*M*⁺, 77.92), 189 (100); IR (neat, cm⁻¹): 3460, 2961, 1722, 1640, 1597, 1436, 1366, 1253, 1059. HRMS calcd for C₁₄H₂₀O₃ (*M*⁺): 236.1415, Found: 236.1415.

(4) Methyl 2-(1'-phenylvinyl)hex-2(*E*)-enoate (6bd)

To a solution of ZnBr₂ (270.5 mg, 1.20 mmol) in 2 mL of THF was added 1.2 mL of phenylmagnesium bromide (1M, 1.2 mmol) prepared from magnesium (384.7 mg, 16 mmol) and bromobenzene (2.5120 g, 16 mmol) in 16 mL of THF by a syringe at 0 °C under nitrogen. After the addition, the reaction was stirred and warmed up to room temperature naturally. To a solution of Pd(PPh₃)₄ (17.8 mg, 0.015mmol) and **4ba** (86.1 mg, 0.31mmol) in 2 mL of THF was added the above prepared solution of phenylzinc bromide (cooled to 0 °C and then transferred quickly via a syringe) at 0 °C

under nitrogen. The reaction mixture was warmed up to room temperature naturally. After 2 h, the reaction was complete as monitored by TLC, quenched with 5 mL of water, extracted with diethyl ether (3 x 25 mL). The combined organic layer was washed with brine and dried over *anhydrous* Na₂SO₄. Evaporation and column chromatography on silica gel (petroleum ether/ diethyl ether = 30:1) afforded **6bd** (66.3 mg, 94%): Liquid; ¹H NMR (400 MHz, CDCl₃) δ 7.41-7.37 (m, 2H), 7.36-7.25 (m, 3H), 7.13 (t, *J* = 7.6 Hz, 1H), 5.81 (s, 1H), 5.14 (s, 1H), 3.65 (s, 3H), 2.22 (q, *J* = 7.5 Hz, 2H), 1.54-1.43 (m, 2H), 0.94 (t, *J* = 7.4 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃): δ 167.4, 146.1, 142.5, 139.2, 133.4, 128.3, 127.7, 125.7, 116.2, 51.8, 31.5, 22.1, 13.9; MS (*m/z*): 230 (*M*⁺, 85.47), 171 (100); IR (neat, cm⁻¹): 2959, 2931, 1720, 1638, 1614, 1247. HRMS calcd for C₁₅H₁₈NaO₂ (*M*⁺+Na): 253.1199, Found: 253.1192.

(5) Methyl 2-(1',3'(E)-octadien-2'-yl)hex-2(E)-enoate (6be)

To a solution of 1(*E*)-hexenyl iodide (255.7 mg, 1.22 mmol) in THF (2 mL) was added a solution of *n*-BuLi (0.48 mL, 2.5 M in hexanes, 1.20 mmol) at -78 °C. After 1 h at -40 °C, a solution of ZnBr₂ (338 mg, 1.5 mmol) in 2.5 mL of THF was added by a syringe. After the addition, the reaction mixture was stirred for another 10 min at -40 °C, warmed up to room temperature naturally and kept at rt for 30 min. Then Pd(PPh₃)₄ (18.1 mg, 0.015 mmol), **4ba** (84.6 mg, 0.30 mmol), and 2 mL of THF

were added subsequently under nitrogen. After 10.5 h, the reaction was complete as monitored by TLC, quenched with 5 mL of dilute aqueous HCl (5%), extracted with diethyl ether (3 x 25 mL), and dried over Na₂SO₄. Evaporation and column chromatography on silica gel (petroleum ether/diethyl ether = 50:1) afforded **6be** (55.5 mg, 78%): Liquid; ¹H NMR (400 MHz, CDCl₃) δ 6.95 (t, *J* = 7.4 Hz, 1H), 6.14 (d, *J* = 16.0 Hz, 1H), 5.42 (dt, *J*₁ = 16.0 Hz, *J*₂ = 6.8 Hz, 1H), 5.24-5.20 (bs, 1H), 4.83 (d, *J* = 1.2 Hz, 1H), 3.69 (s, 3H), 2.11-2.03 (m, 4H), 1.45-1.37 (m, 2H), 1.37-1.20 (m, 4H), 0.92-0.81 (m, 6H); ¹³C NMR (100 MHz, CDCl₃): δ 167.4, 145.5, 141.9, 133.3, 132.0, 130.8, 116.6, 51.8, 32.1, 31.3, 31.2, 22.1, 22.0, 13.8; MS (*m/z*): 236 (*M*⁺, 75.20), 107 (100); IR (neat, cm⁻¹): 2958, 2930, 1721, 1641, 1597, 1247. HRMS calcd for C₁₅H₂₅O₂ (*M*⁺+H): 237.1849, Found: 237.1848.

(6) Methyl 2-(1'-hexen-2'-yl)hex-2(*E*)-enoate (6bf**)**

To a solution of *n*-BuLi (0.48 mL, 2.5 M in hexanes, 1.20 mmol) at -78 °C was added a solution of ZnBr₂ (338 mg, 1.5 mmol) in 2 mL of THF by a syringe. After the addition, the reaction mixture was stirred and warmed up to room temperature slowly. After the addition of anhydrous DMF (1 mL), the reaction mixture was stirred and transferred quickly into a solution of Pd(PPh₃)₄ (17.8 mg, 0.015 mmol) and **4ba** (84.2 mg, 0.30 mmol) in 2 mL of THF under nitrogen. After 7 h, the reaction was complete as monitored by TLC. Then it was quenched with 5 mL of H₂O and 5 mL of saturated

aqueous NH_4Cl , extracted with diethyl ether (3 x 25 mL), and dried over Na_2SO_4 . Evaporation and column chromatography on silica gel (petroleum ether/diethyl ether = 20:1) afforded **6bf** (32.0 mg, 51%): Liquid; ^1H NMR (400 MHz, CDCl_3) δ 6.83 (t, J = 7.4 Hz, 1H), 5.17-5.11 (m, 1H), 4.80-4.76 (m, 1H), 3.73 (s, 3H), 2.23-2.12 (m, 4H), 1.49-1.41 (m, 2H), 1.38-1.25 (m, 4H), 0.97-0.84 (m, 6H); ^{13}C NMR (100 MHz, CDCl_3): δ 167.5, 144.5, 144.3, 134.7, 115.1, 51.7, 36.0, 31.5, 29.8, 22.5, 22.3, 13.9; MS (m/z): 210 (M^+ , 26.34), 181 (100); IR (neat, cm^{-1}): 2958, 2930, 1720, 1628, 1461, 1434, 1245. HRMS calcd for $\text{C}_{13}\text{H}_{23}\text{O}_2$ ($\text{M}^+ + \text{H}$): 211.1693, Found: 211.1687.

References:

1. Winkler, J. D.; Quinn, K. J.; Mackinnon, C. H.; Hiscock, S. D.; McLaughlin, E. C. *Org. Lett.* **2003**, 5, 1805.
2. (a) Larock, R. C.; Liu, C. *J. Org. Chem.* **1983**, 48, 2151; (b) MacInnes, I.; Walton, J. C. *J. Chem. Soc., Perkin Trans. II*, **1987**, 1077.
3. Mukaiyama, T.; Harada, T. *Chem. Lett.* **1981**, 621.

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dyb-2-11

NOE spectra for 5ba