Supporting Information

Ruthenium-Catalyzed Carboxylative Cyclization of 1,6-Diynes

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General Information: Unless otherwise noted, all reactions were conducted under an argon atmosphere using anhydrous solvents (passed through activated alumina or molecular sieve columns). Commercially available reagents were used without additional purification. Thin layer chromatography (TLC) was performed using EM Science silica gel 60 F₂₅₄ plates and visualized by using UV light, anisaldehyde, or potassium permanganate stain. Flash chromatography was performed on EM Science silica gel 60 (40-63 μ m) using the indicated solvent system. ¹H NMR and ¹³C NMR were recorded in CDCl₃ on a Varian Mercury 300 MHz, Varian Inova 400 MHz, or Varian Inova 500 MHz spectrometer. Chemical shifts in ¹H NMR spectra were reported in parts per million (ppm) on the δ scale from residual chloroform (7.27 ppm). Data for ¹H NMR are reported as follows: chemical shift, multiplicity (s = single, d = doublet, t = triplet, q = quartet, quin = quintet, m = multiplet), coupling constant in Hertz (Hz) and integration. Data for ¹³C NMR spectra are reported in chemical shift in ppm from chloroform (77.23 ppm). Infrared (IR) spectra were recorded on a Nicolet 730 FT-IR spectrometer and reported in frequency of the absorption (cm⁻¹). High resolution mass spectra (HRMS) were obtained from the Princeton University Mass Spectrometry Facility.

Compound **1**¹, precursor for **7**², **8**³, **11**¹, and **12**⁴ are known compounds. ¹H NMR and ¹³C NMR matched those reported in the literature. Precursor for **9** was prepared according to the same procedure used for the preparation of **1**, except that ethyl acetoacetate was used in place of dimethylmalonate. Precursor for **10** was prepared from the corresponding known diol⁵ using standard silylation conditions⁶.

Table 1. Catalyst Screening for the Carboxylative Cyclization of 1,6-Diyne **1^a**

Entry	Precatalyst	Ligand	Additive	Solvent	Yield ^b	Ratio ^c 2a : 2b : 2c
1	Ru(methallyl) ₂ (COD)	dppe	-	Toluene	<5%	0 : 2 : 1 ^h
2	Ru(methallyl) ₂ (COD)	dppb	-	Toluene	<5%	0 : 2 : 1 ^h
3	RuCl ₂ (PPh ₃) ₃	KBH(pyrazole) ₃	-	Toluene	<5%	N/A ^j
4	RuCl ₂ (PPh ₃) ₃	KBH(pyrazole) ₃	-	Dioxane	<5%	N/A ^j
5	Au(PPh ₃)Cl	-	-	DCM	<5%	N/A ^j
6	Au(PPh ₃)Cl	-	AgSbF ₆	DCM	<5%	N/A ^j
7	Au(PPh ₃)Cl	-	-	Dioxane	<5%	N/A ^j
8	Au(PPh ₃)Cl	-	AgSbF ₆	Dioxane	<5%	N/A ^j
9	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	Toluene	42%	7 : 1 : 3
10	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	DCE	30%	3 : 1 : 2
11	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	Acetone	35%	12 : 2 : 3
12	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	MeCN	10%	N/A ^j
13	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	Dioxane	68%	2a only
14	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	THF	45%	9 : 1 : 2
15	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-Cl-C ₆ H ₄) ₃	DMAP	DME	45%	9 : 3 : 1
16	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(OMe) ₃	DMAP	Dioxane	<5%	N/A ^j
17	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(OPh) ₃	DMAP	Dioxane	<5%	N/A ^j
18	[Ru(<i>p</i> -cymene)Cl ₂] ₂	PCy ₃	DMAP	Dioxane	10%	2 : 4 : 1
19	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(3-Cl-C ₆ H ₄) ₃	DMAP	Dioxane	62%	2a only
20	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	DMAP	Dioxane	74%	2a only
21	[Ru(<i>p</i> -cymene)Cl ₂] ₂	-	DMAP	Dioxane	<5%	N/A ^j
22	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	-	Dioxane	<5%	N/A ^j
23	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	DMAP ^d	Dioxane	47%	5 : 1 : 0
24	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	DMAP ^e	Dioxane	32%	4 : 1 : 0
25	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	Picolinic Acid ^e	Dioxane	<5%	N/A ^j
26	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	Imidazole ^f	Dioxane	22%	4 : 2 : 1
27	[Ru(<i>p</i> -cymene)Cl ₂] ₂	P(4-F-C ₆ H ₄) ₃	TMG ^g	Dioxane	12%	2 : 2 : 1

All reactions were run with 1 equiv. of benzoic acid and 1 eq. of **1** at 0.25 M for 24 h at 65 °C. ^a 5% catalyst and 6% ligand for entries 1-4; 5% precatalyst for entries 5-8, 2.5% catalyst, 7.5% ligand for entries 9-25. ^b Isolated yields. ^c Product ratios determined by ¹H NMR otherwise noted. ^d 7.5% DMAP. ^e 25% DMAP. ^f 10% Picolinic Acid. ^g 10% imidazole. ^h 10% tetramethylguanidine. ⁱ **2a** was obtained in 40% yield. ^j Ratio not obtained due to low yield.

Standard procedure for the cyclization of 1,6-diynes (2a and 3–12):

(5E)-Dimethyl-5-((benzoyloxy)methylene)cyclohex-3-ene-1,1-dicarboxylate

(2a): To a flame dried 1 dram glass vial equipped with a screw-cap and Teflon septum were added [Ru(*p*-cymene)Cl₂]₂ (7.7 mg, 0.013 mmol), P(4-F-C₆H₄)₃

(11.8 mg, 0.0375 mmol), DMAP (6.0 mg, 0.05 mmol) and dioxane (1.0 mL). This mixture was stirred for 15 minutes before diyne **1** (104.0 mg, 0.500 mmol) and benzoic acid (61 mg, 0.50 mmol) were added to the solution followed by an additional dioxane (1.0 mL) to bring the final reaction concentration to 0.25 M. The reaction mixture was then flushed with argon and placed in a pre-heated sand bath (65 °C) at which it was stirred for 24 h. After 24 h, the reaction mixture was loaded directly on to a silica gel column. Purification via flash column chromatography (Hexanes/EtOAc = 8:1) afforded **2a** (122 mg, 0.37 mmol) as a clear colorless oil. The crystal for the X-ray analysis was obtained from resubjection of **2a** in ether and slow evaporation of the ethereal solvent.

Fig SI-1. ORTEP diagram of **2a**

IR (film) 2900, 2850, 1736, 1450, 1261, 1095, 945, 713 cm^{-1} ; ^1H NMR: (400 MHz, CDCl_3) δ 8.10-8.08 (m, 2H), 7.60-7.56 (m, 1H), 7.48-7.44 (m, 2H), 7.41 (s, 1H), 6.09 (dt, $J = 9.9, 1.4$ Hz, 1H), 5.76 (dt, $J = 9.5, 4.2$ Hz, 1H), 3.70 (s, 6H), 3.10 (d, $J = 1.8$ Hz, 2H), 2.73 (dd, $J = 4.2, 1.3$ Hz, 2H); ^{13}C NMR (100 MHz, CDCl_3) δ 171.3, 163.0, 133.4, 133.3, 129.9, 128.9, 128.6, 125.4, 118.3, 67.0, 53.1, 52.9, 52.8, 31.1, 28.5; HRMS (EI) Calc'd for $\text{C}_{18}\text{H}_{18}\text{O}_6$ [M^+] 330.1103, Found 330.1097. For 1D NOE spectrum of **2a**, please refer to the end of this supporting information. For X-Ray structure coordinate data for **2a**, see accompanying CIF file.

(Z)-4,4-Di(methoxycarbonyl)hept-1-en-6-ynyl benzoate (2b): IR (film) 3290, 2954, 1736, 1438, 1266, 1211, 1111, 708 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 8.15-8.12 (m, 2H), 7.63-7.58 (m, 1H), 7.49-7.40 (m, 3H), 4.91-4.83 (dt, $J = 8.1, 1.5$ Hz, 1H), 3.73 (s, 6H), 3.09 (dd, $J = 8.1, 1.5$ Hz, 2H), 2.85 (d, $J = 2.4$ Hz, 2H), 1.96 (t, $J = 2.4$ Hz, 1H); ^{13}C NMR (125 MHz, CDCl_3) δ 170.3, 163.5, 137.7, 133.9, 130.4, 129.1, 128.7, 107.5, 79.0, 71.7, 57.0, 53.2, 27.9, 23.1; HRMS (EI) Calc'd for $\text{C}_{18}\text{H}_{18}\text{O}_6$ [M^+] 330.1103, Found 330.1111.

(Z,Z)-4,4-Di(methoxycarbonyl)hept-1,6-dien benzoate (2c): IR (film) 3400, 1732, 1672, 1452, 1265, 1209, 1108, 707 cm^{-1} ; ^1H NMR (300 MHz, CDCl_3) δ 8.08-8.05 (m, 4H), 7.63-7.57 (m, 2H), 7.48-7.43 (m, 4H), 7.36 (d, $J = 6.0$ Hz, 2H), 4.95 (dt, $J = 6.6, 1.5$ Hz, 2H), 3.70 (s, 6H), 2.96 (d, $J = 7.8, 1.2$ Hz, 4H); ^{13}C -NMR (125 MHz, CDCl_3) δ 171.3, 163.4, 137.2, 133.9, 130.2, 129.0, 128.8, 107.8, 57.5, 52.9, 28.4; HRMS (EI) Calc'd for $\text{C}_{25}\text{H}_{24}\text{O}_8$ [M-OMe^+] 421.1287, Found 421.1295.

(5E)-Dimethyl 5-(acetoxymethylene)cyclohex-3-ene-1,1-dicarboxylate (3): IR (film) 2900, 2850, 2700, 1736, 1436, 1372, 1210, 1107, 829 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.19 (s, 1H), 6.03 (dt, $J = 9.9, 1.9$ Hz, 1H), 5.74 (dt, $J = 9.3, 4.3$ Hz, 1H), 3.73 (s, 6H), 2.96 (d, $J = 1.9$ Hz, 2H), 2.74-2.72 (m, 2H), 2.19 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 177.7, 171.3, 133.2, 125.2, 124.8, 117.7, 53.0, 52.8, 31.0, 28.4, 20.8; HRMS (EI) Calc'd for $\text{C}_{13}\text{H}_{16}\text{O}_6$ [M^+] 268.0947, Found 268.0940.

(5E)-Dimethyl-5-((4-nitrobenzoyloxy)methylene)cyclohex-3-ene-1,1-dicarboxylate (4): IR (film) 2900, 2850, 2700, 1736, 1530, 1267, 1127, 855, 717 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 8.36-8.29 (m, 4H), 7.45 (s, 1H), 6.14 (dt, $J = 9.9, 1.5$ Hz, 1H), 5.86 (dt, $J = 9.6, 4.3$ Hz, 1H), 3.75 (s, 6H), 3.13 (d, $J = 1.8$ Hz, 2H), 2.80 (dd, $J = 4.2, 1.4$ Hz, 2H); ^{13}C NMR (100 MHz, CDCl_3) δ 171.2, 161.3, 150.8, 134.3, 133.0, 131.1, 126.4, 124.4, 123.7, 119.5, 53.1, 53.0, 31.1, 28.6; HRMS (EI) Calc'd for $\text{C}_{18}\text{H}_{17}\text{O}_8$ [M^+] 375.0954, Found 375.0952.

(5E)-Dimethyl 5-((3-phenylpropanoyloxy)methylene)cyclohex-3-ene-1,1-dicarboxylate (5): IR (film) 2900, 2850, 2700, 1736, 1436, 1258, 1141, 750, 700 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 7.29-7.24 (m, 2H), 7.19-7.15 (m, 4H), 6.02 (dt, $J = 9.9, 1.9$ Hz, 1H), 5.72 (dt, $J = 9.5, 4.3$ Hz, 1H), 3.69 (s, 6H), 2.94 (d, $J = 1.8$ Hz, 2H), 2.71 (dd, $J = 4.3, 1.8$ Hz, 2H), 2.67 (t, $J = 7.4$ Hz, 2H), 2.44 (t, $J = 7.4$ Hz, 2H), 1.99 (m, 2H); ^{13}C NMR (100 MHz, CDCl_3) δ 171.2, 170.1, 141.0, 133.2, 128.45, 128.39, 126.0, 125.2,

124.7, 117.7, 53.0, 52.8, 34.9, 33.2, 31.0, 28.4, 26.2; HRMS (EI) Calc'd for C₂₀H₂₂O₆ [M⁺] 358.1416, Found 358.1413.

(5E)-Dimethyl-5-(((E)-but-2-enoyloxy)methylene)cyclohex-3-ene-1,1-dicarboxylate (6): IR (film) 2850, 2800, 2700, 1732, 1438, 1295, 1101, 970, 837, 685 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 7.22 (s, 1H), 7.13-7.05 (m, 1H), 6.02 (dt, *J* = 9.9, 1.9 Hz, 1H), 5.90 (dq, *J* = 15.5, 1.7 Hz, 1H), 5.70 (dt, *J* = 9.4, 4.2 Hz, 1H), 3.67 (s, 6H), 2.95 (d, *J* = 1.9 Hz, 2H), 2.69-2.68 (m, 2H), 1.89 (d, *J* = 1.7 Hz, 3H); ¹³C NMR (100 MHz, CDCl₃) δ 171.3, 162.8, 147.0, 133.2, 125.0, 124.9, 121.5, 117.7, 53.0, 52.8, 31.0, 28.4, 18.2; HRMS (EI) Calc'd for C₁₅H₁₈O₆ [M⁺] 294.1103, Found 294.1115.

(1E)-((5,5-diacetyl) cyclohex-2-enylidene)methyl benzoate (7): IR (film) 1940, 1731, 1698, 1264, 1124, 1022, 709 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 8.35-8.12 (m, 2H), 7.65-7.61 (m, 1H), 7.53-7.49 (m, 2H), 7.46 (s, 1H), 6.10 (dt, *J* = 9.8, 1.7 Hz, 1H), 5.80 (dt, *J* = 9.5, 4.2 Hz, 1H), 3.12 (d, *J* = 1.8 Hz, 2H), 2.72 (dq, *J* = 4.1, 1.7 Hz, 2H), 2.15 (s, 6H); ¹³C NMR (100 MHz, CDCl₃) δ 205.2, 163.0, 133.7, 129.9, 128.8, 128.6, 125.8, 125.2, 66.5, 30.0, 27.3, 26.0. HRMS (EI) Calc'd for C₁₈H₁₈O₄ [M⁺] 298.1205, Found 298.1215.

(5E)-5-((4-nitrobenzoyloxy)methylene)cyclohex-3-ene-1,1-dimedone (8): IR (film) 2900, 2850, 2300, 1727, 1695, 1528, 1265, 1124, 853, 715 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ 8.36-8.28 (m, 4H), 7.48 (s, 1H), 6.16 (ddd, *J* = 9.8, 1.9, 1.4

Hz, 1H), 5.73 (dt, $J = 9.7, 4.4$ Hz, 1H), 2.92 (d, $J = 1.9$ Hz, 2H), 2.84 (d, $J = 13.8$ Hz, 2H), 2.66 (dd, $J = 4.0, 1.8$ Hz, 2H), 2.52 (d, $J = 13.9$ Hz, 2H), 1.13 (s, 3H), 0.94 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 207.0, 161.2, 150.8, 134.5, 132.8, 131.0, 125.5, 123.7, 123.4, 120.5, 63.9, 50.8, 32.6, 31.0, 29.6, 27.5, 25.5; HRMS (EI) Calc'd for $\text{C}_{21}\text{H}_{21}\text{NO}_6$ [M^+] 383.1369, Found 383.1373.

(1E)-(5-(ethoxycarbonyl)-5-acetylcyclohex-2-enylidene)methyl-4-

nitrobenzoate (9): IR (film) 3100, 2950, 2800, 1735, 1714, 1529, 1348, 1266, 1126, 1013, 853, 717 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 8.36-8.25 (m, 4H), 7.44

(s, 1H), 6.13 (dt, $J = 9.5, 2.0$ Hz, 1H), 5.87 (dt, $J = 9.5, 4.0$ Hz, 1H), 4.24-4.14 (m, 2H), 3.16-2.63 (m, 4H), 2.37 (d, $J = 1.0$ Hz, 3H), 1.22 (dt, $J = 7.5, 1.0$ Hz, 3 H); ^{13}C NMR (125 MHz, CDCl_3) 204.1, 171.5, 161.6, 151.2, 134.6, 133.3, 131.3, 126.8, 125.0, 124.1, 120.1, 62.1, 59.4, 30.9, 28.0, 26.2, 14.2; HRMS (EI) Calc'd for $\text{C}_{19}\text{H}_{19}\text{NO}_7$ [M^+] 373.1162, Found 373.1165.

(1E)-(5,5-bis(tert-butyldiphenylsiloxymethyl)cyclohex-2-

enylidene)methyl acetate (10): IR (film) 3050, 2950, 2700, 1757, 1427, 1214, 1112, 822, 700 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 7.68-7.64 (m,

8H), 7.44-7.40 (m, 4H), 7.36-7.33 (t, $J = 7.0$ Hz, 8 H), 7.18 (s, 1H), 5.94 (dt, $J = 10.0, 2.0$ Hz, 1H), 5.60 (dt, $J = 10.0, 4.5$ Hz, 1H), 3.62 (dd, $J = 3.0, 1.0$ Hz, 4H), 2.45 (d, $J = 1.5$ Hz, 2H), 2.11 (m, 5H), 1.05 (s, 18H); ^{13}C NMR (125 MHz, CDCl_3) 168.0, 135.9, 133.81, 133.4, 129.8, 127.8, 127.8, 127.1, 124.6, 120.1, 66.4, 40.2, 29.9, 27.1, 26.3, 21.0, 19.7; HRMS (EI) Calc'd for $\text{C}_{39}\text{H}_{43}\text{O}_4\text{Si}_2$ [$\text{M}-t\text{Bu}$] $^+$ 631.2700, Found 631.2702.

(1E)-3,3-Dimethyl-10-(4-nitrobenzoyloxy)methylene-2,4-dioxaspiro[5.5]undec-8-ene (11):

IR (film) 3000, 2950, 2800, 1733, 1529, 1347, 1266, 1125, 1069, 1013, 827, 717 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 8.39-8.31

(m, 4H), 7.50 (s, 1H), 6.14 (dt, $J = 9.5, 2.0$ Hz, 1H) 5.80 (dt, $J = 9.5, 4.5$ Hz, 1H), 3.66 (d, $J = 8.0$ Hz, 4H), 2.65 (d, $J = 2.0$ Hz, 2H), 2.15 (q, $J = 2.0$ Hz, 2H), 1.47 (d, $J = 4.5$ Hz, 6H); ^{13}C NMR (125 MHz, CDCl_3) 161.6, 134.9, 133.7, 131.3, 127.0, 124.8, 124.0, 120.8, 98.6, 68.5, 32.1, 31.8, 28.5, 25.2, 22.9; HRMS (EI) Calc'd for $\text{C}_{19}\text{H}_{21}\text{O}_6$ [M^+] 359.1369, Found 359.1367.

(1Z)-(1,2-Dihydro-1-tosylpyridin-3(6H)-ylidene)methyl 4-nitro benzoate (12):

IR (film) 2800, 2700, 1737, 1528, 1347, 1263, 1163, 1125, 853, 716 cm^{-1} ; ^1H NMR (400 MHz, CDCl_3) δ 8.40-8.37 (m, 2H), 8.31-8.29 (m, 2H), 7.71-7.69 (m, 2H), 7.33

(s, 1H), 7.31-7.29 (m, 2H), 6.09 (dt, $J = 9.9, 1.5$ Hz, 1H), 5.77 (dt, $J = 9.9, 3.8$ Hz, 1H), 4.12 (d, $J = 1.6$ Hz, 2H), 3.86 (m, 2H), 2.43 (s, 3H); ^{13}C NMR (100 MHz, CDCl_3) δ 178.8, 161.1, 151.0, 143.9, 133.85, 133.8, 132.2, 131.1, 129.6, 127.7, 127.6, 124.7, 123.9, 122.9, 117.2, 44.8, 41.6, 21.5; HRMS (EI) Calc'd for $\text{C}_{20}\text{H}_{18}\text{N}_2\text{O}_6\text{S}$ [M^+] 414.0886, Found 414.0879.

9:1 mixture of Dimethyl (5E) and (5Z)-(acetoxymethylene)cyclohex-3-ene-1,1-dicarboxylate (eq 6):

E:Z = 9:1

To a solution of **3** (54 mg, 0.20 mmol) in methanol (5.0 mL) was added NaOMe (11 mg, 0.20 mmol) and stirred for 4 h before the TLC indicated full

consumption of starting material. The mixture was filtered through a pad of silica, concentrated

in vacuo, and carried onto next step without further purification. To a two-neck 10 mL round bottom flask equipped with a reflux condenser and a septum was added NaOAc (33 mg, 0.40 mmol) in acetic anhydride (5.0 mL) which was then heated to reflux. To this refluxing solution was slowly added the mixture from the previous reaction, dissolved in acetic anhydride (total volume: 1.0 mL), over 3 h via syringe pump. Upon completion of the addition the mixture was stirred for additional 3 h before the reflux condenser was removed and was evaporated until the reaction volume of circa 1.0 mL. The concentrated reaction mixture was then loaded directly unto the silica gel column. Purification via flash column chromatography (hexanes/ EtOAc = 8:1) provided product (27 mg, 0.10 mmol) as a faint yellow oil which the ^1H NMR show 1:9 ratio of the *cis* isomer versus **3**. ^1H NMR (500 MHz, CDCl_3) δ 7.19 (s, 0.9H), δ 7.01 (s, 0.1H), 6.53-6.51 (m, 0.1H), 6.03 (dt, $J = 9.9, 1.9$ Hz, 0.9H), 5.85-5.82 (m, 0.1H), 5.74 (dt, $J = 9.3, 4.3$ Hz, 0.9H), 3.73 (s, 5.4H), 3.72 (s, 0.6H), 2.96 (d, $J = 1.9$ Hz, 2H), 2.79 (d, $J = 1.4$ Hz, 0.2H), 2.74-2.72 (m, 1.8H), 2.19 (s, 2.7H) 2.15 (s, 0.3H); ^{13}C NMR (100 MHz, CDCl_3) δ 171.3, 171.1, 167.7, 166.2, 133.2, 130.6, 126.8, 125.2, 124.8, 121.2, 120.5, 117.7, 53.0, 52.8, 31.8, 31.6, 31.0, 30.1, 29.7, 28.4. 20.8.

Fig SI-2. Functionalization of the cyclized product

(1E)-(5,5-bis(*tert*-butyldiphenylsiloxy)methyl)cyclohexylidene)methyl acetate (14**):** Enol acetate **10** (90 mg, 0.13 mmol) was dissolved in ethyl acetate (2.0 mL). Palladium hydroxide (10% wt on activated carbon; 9 mg) was added and the resulting reaction mixture was stirred under a balloon of hydrogen. After 18 h, the mixture was filtered through a plug of celite and the product was purified by flash chromatography (2-5% EtOAc in hexanes) to give **14** (62 mg, 0.090 mmol, 70%); IR (film) 3050, 2931, 2857, 1754, 1427, 1225, 1113, 823, 739, 701, 613 cm⁻¹; ¹H NMR (500 MHz, CDCl₃) δ 7.66-7.61 (m, 8H), 7.48-7.38 (m, 4H), 7.35-7.30 (t, *J* = 7.0 Hz, 8 H), 6.94 (s, 1H), 3.59 (d, *J* = 9.9 Hz, 2H), 3.53 (d, *J* = 9.6 Hz, 2H), 2.27 (s, 2H), 1.97 (m, 5H), 1.56-1.35 (m, 4H), 1.05 (s, 18H); ¹³C NMR (125 MHz, CDCl₃) δ 168.6, 135.9, 133.9, 133.8, 129.7, 129.7, 129.0, 127.8, 127.8, 122.8, 66.7, 42.5, 30.27, 29.5, 29.2, 27.13, 22.6, 20.9, 19.6; HRMS (EI) Calc'd for C₃₉H₄₅O₄Si₂ [M-*t*Bu]⁺ 633.2856, Found 633.2872.

1-formyl-5,5-bis(*tert*-butyldiphenylsiloxy)methyl)cyclohex-2-enyl

acetate (15): Enol acetate **10** (10 mg, 0.015 mmol) was dissolved in methylene chloride (0.5 mL). The resulting solution was cooled to -40

°C and DMDO (0.07 M solution in acetone; 0.25 mL, 0.018 mmol) was added dropwise. The reaction mixture was stirred at -40 °C for 30 min before being warmed to room temperature overnight. The product was purified directly by Prep TLC (500 micron, Silca gel, 10% EtOAc in hexanes) to give **15** (9.0 mg, 0.013 mmol, 85%). IR (film) 2929, 2856, 1734, 1427, 1245, 1112, 823, 739, 701 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 9.37 (s, 1H) 7.64-7.51 (m, 8H), 7.42-7.25 (m, 12H), 6.02-5.96 (m, 1H), 5.73 (d, J = 10.2 Hz, 1H), 3.73-3.43 (m, 4H), 2.05-1.98 (m, 5H), 1.78 (s, 2H), 1.05 (s, 9H), 1.00 (s, 9H); HRMS (EI) Calculated for $\text{C}_{39}\text{H}_{43}\text{O}_5\text{Si}_2 [\text{M}-t\text{Bu}]^+$ 647.2649, Found 647.2643.

5,5-bis(*tert*-butyldiphenylsiloxy)methyl)cyclohex-1-enecarbaldehyde

(16): Enol acetate **10** (25 mg, 0.036 mmol) was dissolved in 1 mL of methanol and THF solution (1:1). The resulting mixture was cooled to 0 °C and was treated dropwise with a solution of lithium hydroxide (monohydrate; 3.0 mg, 0.072 mmol) in water (500 μL). After 10 min, the reaction mixture was quenched with 1 N HCl (2.0 mL) and then concentrated under reduced pressure to remove the organic solvents. The resulting aqueous mixture was extracted with methylene chloride. The organic layer was dried over sodium sulfate and concentrated under reduced pressure. The product was purified by Prep TLC (500 micro, Silica gel; 20% EtOAc in hexanes) to give **16** (19 mg, 0.029 mmol, 82%). IR (film) 3100, 2950, 2800, 2360, 1686, 1427, 1113, 1081, 823, 701, 614 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 9.36 (s, 1H) 7.65-7.59 (m, 8H), 7.44-7.25 (m, 12H), 6.60 (s, 1H), 3.58 (d, J = 15.0 Hz, 2H), 3.52 (d, J =

16.0 Hz, 2H), 2.12 (bs, 4H), 1.64 (t, $J = 10.0$ Hz, 2H), 1.03 (s, 18H); ^{13}C NMR (125 MHz, CDCl_3) δ 194.3, 150.5, 135.9, 135.9, 133.8, 133.6, 129.8, 127.9, 127.8, 66.2, 39.3, 27.2, 25.4, 23.5, 19.6; HRMS (EI) Calc'd for $\text{C}_{37}\text{H}_{41}\text{O}_3\text{Si}_2 [\text{M}-t\text{Bu}]^+$ 589.2594, Found 589.2610.

3-bromo-5,5-bis(*tert*-butyldiphenylsiloxymethyl)cyclohex-1-

enecarbaldehyde (17): Enol acetate **10** (10 mg, 0.015 mmol) was dissolved in dioxane (800 μL) and water (200 μL) and cooled to 0 $^\circ\text{C}$.

N-bromosuccinimide (3.0 mg, 0.017 mmol) was added in one portion. The mixture was allowed to warm to room temperature where it was stirred for 2 h. The reaction mixture was concentrated to dryness and the resulting crude product was portioned between water and methylene chloride. The methylene chloride layer was dried over sodium sulfate and concentrated under reduced pressure. The product was purified by Prep TLC (500 micron, Silica gel; 10% EtOAc in hexanes) to give **17** (9.1 mg, 0.013 mmol, 88%). IR (film) 3070, 2930, 2857, 2360, 1692, 1427, 1113, 998, 739, 701 cm^{-1} ; ^1H NMR (500 MHz, CDCl_3) δ 9.38 (s, 1H) 7.64-7.50 (m, 8H), 7.43-7.24 (m, 12H), 6.56 (s, 1H), 4.46 (dt, $J = 6.0, 3.6$ Hz, 1H), 3.61 (d, $J = 1.2$ Hz, 2 H), 3.50 (d, $J = 10.2$ Hz, 1H), 3.37 (d, $J = 9.6$ Hz, 1H), 2.41-2.38 (m, 1H), 2.22-1.94 (m, 3H), 1.06 (s, 9H), 1.01 (s, 9H); ^{13}C NMR (125 MHz, CDCl_3) δ 193.4, 147.8, 140.5, 135.9, 135.8, 133.5, 133.3, 133.1, 130.1, 130.0, 130.0, 129.9, 128.1, 127.9, 67.9, 63.8, 43.3, 42.5, 37.6, 27.2, 24.9, 19.6, 19.5; HRMS (EI) Calc'd for $\text{C}_{37}\text{H}_{40}\text{BrO}_3\text{Si}_2 [\text{M}-t\text{Bu}]^+$ 667.1699, Found 667.1697.

NOE Data for 2a:

Deuterium Labeling Studies

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