Palladium-Catalyzed Cyclization/Carboalkoxylation of Alkenyl Indoles

Cong Liu and Ross A. Widenhoefer*

P. M. Gross Chemical Laboratory

Duke University

Durham, NC 27708-0346

rwidenho@chem.duke.edu

Supporting Information

Experimental procedures, analytical and spectroscopic data for new compounds and copies of NMR spectra (30 pages).

Experimental

General Methods. NMR spectra were obtained on a Varian spectrometer operating at 400 MHz for ^1H NMR and 100 MHz for ^{13}C NMR in CDCl_3 unless noted otherwise. IR spectra were obtained on a Bomen MB-100 FT-IR spectrometer. Gas chromatography was performed on a Hewlett-Parkard 5890 gas chromatography equipped with a 25 m polydimethylsiloxane capillary column. Flash column chromatography was performed employing 200-400 mesh silica gel (EM). Thin layer chromatography (TLC) was performed on silica gel 60 F₂₅₄. Elemental analyses were performed by Complete Analysis Laboratories (Parsippany, NJ) or Robertson Microlit Laboratories (Madison, NJ).

Anhydrous methanol (Aldrich) was used as received. Anhydrous THF (Fischer) was distilled from sodium benzophenone ketyl under nitrogen prior to use. $\text{PdCl}_2(\text{MeCN})_2$ (**2**), $\text{PdCl}_2(\text{PPh}_3)_2$, $[\text{PtCl}_2(\text{CH}_2=\text{CH}_2)]_2$, $\text{Pd}(\text{OAc})_2$, (Aldrich), CuCl_2 (Strem), methyl isobutyrate, *trans*-1-bromo-2-pentene, *cis*-1-bromo-2-pentene, ethyl 6-heptenoate, 4-fluoro-2-methylaniline (Acros), and methyl 5-hexenoate (TCI) were used as received. *N*-Trimethylsilyl-*o*-toluidine (**S1**),¹ *N*-trimethylsilyl-4-fluoro-*o*-toluidine,¹ **1**,² 2-(4-pentenyl)-1*H*-indole (**S2**, Table 1, entry 1),² 5-methoxy-1-methyl-2-(4-pentenyl)-1*H*-indole (Table 1, entry 2),² 2-(1,1-dimethyl-4-pentenyl)-1-methyl-1*H*-indole (Table 1, entry 4),² 2-(2,2-dicarbomethoxy-4-pentenyl)-1-methyl-1*H*-indole (Table 1, entry 5),² *N*-allyl-*N*-methyl-1-methyl-1*H*-indole-2-carboxamide (Table 1, entry 6),³ 1-methyl-2-(4-methyl-4-pentenyl)-1*H*-indole (Table 1, entry 7),² *cis*-2-(2,2-dicarbomethoxy-4-heptenyl)-1-methyl-1*H*-indole (Table 1, entry 8),² dimethyl 2-(2-cyclohexenyl)-2-(1-methyl-1*H*-indol-2-ylmethyl)malonate (Table 1, entry 9),² 1-methyl-2-(3-butenyl)-1*H*-indole (Table 1, entry 10),² 3-(1-methyl-1*H*-indol-3-yl)-propionaldehyde,⁴ 3-(4-pentenyl)-1*H*-indole (Table 1, entry 15) were synthesized employing published procedures.⁵

Alkenyl Indoles

5-Fluoro-2-(4-pentenyl)-1*H*-indole (Table 1, entry 3). 5-Fluoro-2-(4-pentenyl)-1*H*-indole was isolated in 29% yield as a pale yellow oil from the the reaction of *N*-trimethylsilyl-4-fluoro-*o*-toluidine and methyl 5-hexenoate employing a procedure similar to that used to synthesize **S2**.² TLC (hexanes-CH₂Cl₂ = 1:1): *R_f* = 0.50. ¹H NMR: δ 7.84 (s, 1 H), 7.20-7.17 (m, 2 H), 6.87 (dt, *J* = 2.6, 9.2 Hz, 1 H), 6.23-6.22 (m, 1 H), 5.85 (tdd, *J* = 6.6, 10.4, 17.2 Hz, 1 H), 5.11-5.03 (m, 2 H), 2.76 (t, *J* = 7.2 Hz, 2 H), 2.17 (q, *J* = 7.2 Hz, 2 H), 1.83 (quintet, *J* = 7.2 Hz, 2 H). ¹³C{¹H} NMR: δ 158.2 (d, ¹*J*_{CF} = 232 Hz), 141.8, 138.4, 132.6, 129.6 (d, ³*J*_{CF} = 10 Hz), 115.6, 111.0 (d, ³*J*_{CF} = 10 Hz), 109.3 (d, ²*J*_{CF} = 26 Hz), 105.0 (d, ²*J*_{CF} = 24 Hz), 100.2, 33.5, 28.5, 27.9. IR (neat, cm⁻¹): 3415, 2932, 1585, 1485, 1453, 1416, 1313, 1167, 1105, 953. Anal. calcd (found) for C₁₃H₁₄FN: C, 76.82 (76.80); H, 6.94 (6.78).

***trans*-2-(1,1-Dimethyl-3-hexenyl)-1*H*-indole (Table 1, entry 12).** Methyl isobutyrate (3.06 g, 30.0 mmol) was added to a solution of LDA [generated from *n*-BuLi and diisopropylamine] in THF at -78 °C. The resulting solution was stirred for 30 min at -78 °C and treated with *trans*-1-bromo-2-pentene (4.00 g, 30.0 mmol). The resulting mixture was warmed to room temperature, stirred for 4 h, and quenched with saturated aqueous NH₄Cl. The layers were separated and the aqueous layer was extracted with ether (3 × 50 mL). The combined organic extracts were dried (MgSO₄) and concentrated under vacuum. Column chromatography of the residue (SiO₂; hexanes-EtOAc = 10:1) gave methyl *trans*-2,2-dimethyl-4-heptenoate (**S3**) (3.82 g, 75%) as a colorless oil. A solution of *n*-BuLi in hexanes (2.5 M, 15.0 mL, 37.5 mmol) was added dropwise to a solution of **S1** (2.69 g, 15.0 mmol) in hexanes (50 mL) at 0 °C. The resulting orange solution was refluxed for 6 h, cooled to -78 °C, and treated with a solution of **S3** (2.55 g, 15.0 mmol) in THF (10 mL). The resulting mixture was warmed to room temperature, stirred for 1 h, and quenched with brine. The layers were separated and the aqueous layer was extracted with ether (2 × 30 mL). The combined organic extracts were dried (MgSO₄) and

concentrated under vacuum. Column chromatography of the residue (SiO₂; hexanes-CH₂Cl₂ = 10:1) gave *trans*-2-(1,1-dimethyl-3-hexenyl)-1*H*-indole (2.42 g, 71%) as a pale yellow oil.

For S3: TLC (hexanes-EtOAc = 10:1): R_f = 0.61. ¹H NMR: δ 5.46 (ttd, J = 1.2, 6.2, 15.2 Hz, 1 H), 5.29 (ttd, J = 1.6, 7.2, 14.8 Hz, 1 H), 3.64 (s, 3 H), 2.17 (dd, J = 0.8, 7.2 Hz, 2 H), 1.98 (quint, J = 7.2 Hz, 2 H), 1.13 (s, 6 H), 0.94 (t, J = 7.6 Hz, 3 H). ¹³C{¹H} NMR: δ 178.5, 136.1, 124.7, 51.9, 43.9, 43.0, 26.0, 25.1, 14.3. IR (neat, cm⁻¹): 2968, 1733, 1433, 1200, 1135, 990, 867, 713. Anal. calcd (found) for C₁₀H₁₈O₂: C, 70.55 (70.61); H, 10.66 (10.83).

For *trans*-2-(1,1-dimethyl-3-hexenyl)-1*H*-indole: TLC (hexanes-CH₂Cl₂ = 1:1): R_f = 0.65. ¹H NMR: δ 8.00 (s, 1 H), 7.58 (dd, J = 0.8, 8.2 Hz, 1 H), 7.34 (dd, J = 0.8, 7.6 Hz, 1 H), 7.19-7.09 (m, 2 H), 6.30 (m, 1 H), 5.53 (ttd, J = 1.4, 7.2, 15.0 Hz, 1 H), 5.32 (ttd, J = 1.2, 7.0, 15.2 Hz, 1 H), 2.35 (dd, J = 1.2, 7.2 Hz, 2 H), 2.02 (quint, J = 7.8 Hz, 2 H), 1.38 (s, 6 H), 0.98 (t, J = 7.6 Hz, 3 H). ¹³C{¹H} NMR: δ 147.9, 136.1, 136.0, 128.8, 125.4, 121.3, 120.3, 119.8, 110.7, 98.3, 46.8, 35.4, 28.0, 26.0, 14.3. IR (neat, cm⁻¹): 3424, 2962, 2929, 1455, 1294, 969, 784, 749, 693. Anal. calcd (found) for C₁₆H₂₁N: C, 84.53 (84.37); H, 9.31 (9.22).

***cis*-2-(1,1-Dimethyl-3-hexenyl)-1*H*-indole (Table 1, entry 11).** *cis*-2,2-Dimethyl-4-heptenoate (**S4**) was isolated in 53% yield as a colorless oil from the reaction of methyl isobutyrate and *cis*-1-bromo-2-pentene employing a procedure similar to that used to synthesize **S3**. *cis*-2-(1,1-Dimethyl-3-hexenyl)-1*H*-indole was isolated in 66% yield as a pale yellow oil from the reaction of **S1** and **S4** employing a procedure similar to that used to synthesize **S2**.

For S4: TLC (hexanes-EtOAc = 10:1): R_f = 0.60. ¹H NMR: δ 5.46 (ttd, J = 1.6, 7.2, 10.8 Hz, 1 H), 5.25 (ttd, J = 1.6, 7.0, 10.8 Hz, 1 H), 3.65 (s, 3 H), 2.26 (d, J = 7.6 Hz, 2 H), 2.03 (quint, J = 7.2 Hz, 2 H), 1.17 (s, 6 H), 0.94 (t, J = 7.6 Hz, 3 H). ¹³C{¹H} NMR: δ 178.5, 134.7, 124.3, 52.0, 42.8, 38.0, 25.1, 20.9, 14.5. IR (neat, cm⁻¹): 2966, 2874, 1734, 1433, 1198, 1142, 867. Anal. calcd (found) for C₁₀H₁₈O₂: C, 70.55 (70.50); H, 10.66 (10.83).

For *cis*-2-(1,1-dimethyl-3-hexenyl)-1*H*-indole: TLC (hexanes-CH₂Cl₂ = 1:1): R_f = 0.67. ¹H NMR: δ 8.00 (s, 1 H), 7.57 (dd, J = 0.8, 8.0 Hz, 1 H), 7.32 (dd, J = 0.8, 7.6 Hz, 1 H), 7.17-7.07 (m, 2 H), 6.30-6.29 (m, 1 H), 5.48 (ttd, J = 1.6, 7.2, 10.8 Hz, 1 H), 5.30 (ttd, J = 1.6, 7.0, 10.8 Hz, 1 H), 2.41 (d, J = 8.2 Hz, 2 H), 2.03 (quint, J = 7.6 Hz, 2 H), 1.40 (s, 6 H), 0.94 (t, J = 7.6 Hz, 3 H). ¹³C{¹H} NMR: δ 147.6, 136.0, 134.5, 128.6, 125.1, 121.3, 120.2, 119.8, 110.6, 98.3, 40.8, 35.5, 28.0, 20.9, 14.3. IR (neat, cm⁻¹): 3424, 2963, 1460, 1296, 784. Anal. calcd (found) for C₁₆H₂₁N: C, 84.53 (84.40); H, 9.31 (9.48).

2-(5-Hexenyl)-1-methylindole (Table 1, entry 13). 2-(5-Hexenyl)-1*H*-indole (**S5**) was isolated in 50% yield as a pale yellow oil from the reaction of **S1** and ethyl 6-heptenoate employing a procedure similar to that used to synthesize **S2**. 2-(5-Hexenyl)-1-methyl-1*H*-indole was isolated in 74% yield as a colorless oil from the reaction of **S5** and methyl iodide employing a procedure similar to that used to synthesize **1**.

For **S5:** TLC (hexanes-CH₂Cl₂ = 1:1): R_f = 0.56. ¹H NMR: δ 7.79 (s, 1 H), 7.59-7.57 (m, 1 H), 7.32-7.29 (m, 1 H), 7.09-7.03 (m, 2 H), 6.29-6.27 (m, 1 H), 5.85 (tdd, J = 6.6, 10.4, 17.2 Hz, H), 5.10-5.00 (m, 2 H), 2.77 (t, J = 7.6 Hz, 2 H), 2.15 (q, J = 7.6 Hz, 2 H), 1.77 (quint, J = 7.6 Hz, 2 H), 1.54 (quint, J = 7.6 Hz, 2 H). ¹³C{¹H} NMR: δ 147.1, 138.9, 136.1, 129.1, 121.2, 120.0, 119.9, 115.0, 110.6, 99.8, 33.8, 28.9, 28.8, 28.4. IR (neat, cm⁻¹): 3404, 2930, 1550, 1457, 1414, 1287, 909, 779, 748. Anal. calcd (found) for C₁₄H₁₇N: C, 84.37 (84.25); H, 8.60 (8.42).

For 2-(5-Hexenyl)-1-methylindole: TLC (hexanes-CH₂Cl₂ = 5:1): R_f = 0.38. ¹H NMR: δ 7.62-7.60 (m, 1 H), 7.34-7.32 (m, 1 H), 7.25-7.21 (m, 2 H), 6.33-6.31 (m, 1 H), 5.90 (tdd, J = 6.6, 10.4, 17.2 Hz, 1 H), 5.14-5.03 (m, 2 H), 3.70 (s, 3 H), 2.80 (t, J = 7.6 Hz, 2 H), 2.20 (q, J = 7.6 Hz, 2 H), 1.81 (quint, J = 7.6 Hz, 2 H), 1.61 (quint, J = 7.6 Hz, 2 H). ¹³C{¹H} NMR: δ 141.5, 138.9, 137.6, 128.2, 120.8, 120.1, 119.5, 115.0, 109.0, 99.0, 33.9, 29.7, 28.9, 28.4, 27.0. IR (neat, cm⁻¹): 2931, 1546, 1468, 909, 770, 746. Anal. calcd (found) for C₁₅H₁₉N: C, 84.46 (84.22); H, 8.98 (8.84).

3-(3-Butenyl)-1-methylindole (Table 1, entry 14). *n*-BuLi (2.5 M solution in hexanes, 4.4 mL, 11.0 mmol) was added dropwise to a mixture of Ph₃PCH₃Br (3.93 g, 11.0 mmol) in THF (50 mL) at 0 °C. The resulting mixture was stirred at 0 °C for 1 h and treated with a solution of 3-(1-methyl-1*H*-indol-3-yl)-propionaldehyde (0.79 g, 4.2 mmol) in THF (10 mL). The resulting mixture was warmed to room temperature, stirred for 2.5 h, and quenched with saturated aqueous NH₄Cl. The aqueous layer was extracted with ether (3 × 30 mL) and the layers were separated. The combined organic extracts were dried (MgSO₄) and concentrated under vacuum. Column chromatography of the residue (SiO₂; hexanes–EtOAc = 5:1) gave 3-(3-butenyl)-1-methylindole (0.70 g, 90%) as a pale yellow oil. TLC (hexanes–EtOAc = 2:1): *R_f* = 0.71. ¹H NMR: δ 7.70-7.68 (m, 1 H), 7.42-7.28 (m, 2 H), 7.19 (dt, *J* = 0.8, 7.6 Hz, 1 H), 6.90 (s, 1 H), 6.03 (tdd, *J* = 6.6, 10.4, 17.2 Hz, 1 H), 5.21-5.07 (m, 2 H), 3.79 (s, 3 H), 2.94 (t, *J* = 7.2 Hz, 2 H), 2.58 (q, *J* = 7.2 Hz, 2 H). ¹³C{¹H} NMR: δ 139.2, 137.3, 128.2, 126.4, 121.8, 119.3, 118.8, 114.9, 109.4, 34.9, 32.8, 25.0. IR (neat, cm⁻¹): 3060, 2913, 1640, 1470, 1376, 1322, 910. Anal. calcd (found) for C₁₃H₁₅N: C, 84.28 (84.01); H, 8.16 (8.06).

Cyclization/Carboalkoxylation of Alkenyl Indoles

I. Methanol as solvent

Table S1. Effect of Pd(II) source and terminal oxidant on the palladium-catalyzed cyclization/carboalkoxylation of **1**.

catalyst	cat load (mol%)	[O]	yield (%) ^a
2	10	CuCl₂	94
PdCl ₂ (PPh ₃) ₂	10	CuCl ₂	15
Pd(OAc) ₂	10	CuCl ₂	18
[PtCl ₂ (CH ₂ =CH ₂)] ₂	5	CuCl ₂	< 1
2	10	BQ	< 1
2	5	CuCl₂	85
2	2	CuCl₂	31

^aAs determined by GC analysis of the crude reaction mixture.

Methyl (9-methyl-2,3,4,9-tetrahydro-1H-carbazol-4-yl)-acetate (3). Methanol (4 mL) and a solution of **1** (99 mg, 0.50 mmol) in methanol (1.0 mL) were added sequentially to a flask containing PdCl₂(MeCN)₂ (**2**) (6.5 mg, 0.025 mmol) and CuCl₂ (200 mg, 1.5 mmol) that had been twice evacuated (12 mmHg) and backfilled with CO (1 atm, balloon). The resulting suspension was stirred for 30 min and concentrated under vacuum. Column chromatography of the residue (SiO₂; hexanes–EtOAc = 5:1) gave **3** (106 mg, 83%) as a pale yellow oil. TLC (hexanes–EtOAc = 5:1): *R_f* = 0.27. ¹H NMR: δ 7.57 (d, *J* = 8.4 Hz, 1 H), 7.29 (d, *J* = 8.2 Hz, 1 H), 7.20 (t, *J* = 7.6 Hz, 1 H), 7.11 (t, *J* = 7.6 Hz, 1 H), 3.76 (s, 3 H),

3.63 (s, 3 H), 3.63-3.58 (m, 1 H), 3.04 (dd, $J = 4.0, 15.2$ Hz, 1 H), 2.79-2.64 (m, 2 H), 2.47 (dd, $J = 10.4, 14.8$ Hz, 1 H), 2.02-1.92 (m, 3 H), 1.87-1.79 (m, 1 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 173.9, 137.2, 136.4, 126.5, 120.9, 119.1, 118.3, 111.5, 109.0, 51.9, 40.2, 29.4, 29.0, 28.6, 22.4, 19.5. IR (neat, cm^{-1}): 2934, 1731, 1470, 1434, 1416, 1379, 1281, 1166, 1080, 1014, 739. Anal. calcd (found) for $\text{C}_{16}\text{H}_{19}\text{NO}_2$: C, 74.68 (74.95); H, 7.44 (7.47).

All polycyclic indoles in Table 1 were synthesized employing a procedure similar to that used to synthesize **3**.

Methyl (2,3,4,9-tetrahydro-1H-carbazol-4-yl)-acetate (S6, Table 1, entry 1).⁶ Pale yellow oil, 83%. TLC (hexanes-EtOAc = 2:1): $R_f = 0.62$. ^1H NMR: δ 7.82 (s, 1 H), 7.56 (d, $J = 7.6$ Hz, 1 H), 7.24 (dd, $J = 0.8, 7.6$ Hz, 1 H), 7.17-7.09 (m, 2 H), 3.76 (s, 3 H), 3.60-3.57 (m, 1 H), 3.04 (dd, $J = 4.0, 15.2$ Hz, 1 H), 2.70-2.64 (m, 2 H), 2.47 (dd, $J = 10.4, 14.8$ Hz, 1 H), 2.00-1.79 (m, 4 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 174.1, 136.0, 134.9, 127.0, 121.2, 119.4, 118.3, 112.1, 110.9, 51.9, 39.9, 29.3, 28.7, 23.4, 19.6. IR (neat, cm^{-1}): 3399, 2932, 1733, 1464, 1434, 1326, 1283, 1168, 1072, 1012, 741

Methyl (6-methoxy-9-methyl-2,3,4,9-tetrahydro-1H-carbazol-4-yl)-acetate (Table 1, entry 2). Pale yellow oil, 86%. TLC (hexanes-EtOAc = 2:1): $R_f = 0.57$. ^1H NMR: δ 7.16 (d, $J = 9.2$ Hz, 1 H), 7.00 (d, $J = 2.4$ Hz, 1 H), 6.84 (dd, $J = 2.4, 8.4$ Hz, 1 H), 3.88 (s, 3 H), 3.75 (s, 3 H), 3.58 (s, 3 H), 3.58-3.54 (m, 1 H), 2.97 (dd, $J = 4.0, 15.2$ Hz, 1 H), 2.76-2.60 (m, 2 H), 2.44 (dd, $J = 10.4, 14.8$ Hz, 1 H), 1.98-1.74 (m, 4 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 173.9, 153.9, 137.0, 132.4, 126.6, 111.1, 110.4, 109.5, 100.9, 56.3, 51.7, 39.8, 29.2, 28.5, 22.4, 19.3. IR (neat, cm^{-1}): 2934, 1732, 1621, 1579, 1484, 1415, 1281, 1254, 1223, 1153, 1080, 793. Anal. calcd (found) for $\text{C}_{17}\text{H}_{21}\text{NO}_3$: C, 71.06 (71.16); H, 7.37 (7.45).

Methyl (6-fluoro-2,3,4,9-tetrahydro-1H-carbazol-4-yl)-acetate (Table 1, entry 3). Colorless oil, 74%. TLC (hexanes-EtOAc = 2:1): $R_f = 0.45$. ^1H NMR (Figure S1): δ 7.78 (s, 1 H), 7.19-7.14 (m, 2 H), 6.85 (dt, $J = 2.6, 9.0$ Hz, 1 H), 3.73 (s, 3 H), 3.52-3.46 (m, 1 H), 2.92 (dd, $J = 4.0, 15.2$ Hz, 1 H), 2.720-2.66 (m, 2 H), 2.42 (dd, $J = 10.4, 14.8$ Hz, 1 H), 1.97-1.75 (m, 4 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (Figure S2): δ 173.8, 158.0 (d, $^1J_{\text{CF}} = 233$ Hz), 136.9, 132.5, 127.5 (d, $^3J_{\text{CF}} = 10$ Hz), 112.8, 111.3 (d, $^3J_{\text{CF}} = 10$ Hz), 109.3

(d, $^2J_{\text{CF}} = 26$ Hz), 103.6 (d, $^2J_{\text{CF}} = 24$ Hz), 51.9, 39.8, 29.2, 28.8, 23.6, 19.6. IR (neat, cm^{-1}): 3409, 2936, 1713, 1583, 1484, 1453, 1317, 1290, 1169, 1128, 797. HRMS calcd (found) for $\text{C}_{15}\text{H}_{16}\text{FNO}_2$ (M^+): 261.1165 (261.1159).

Methyl (1,1,9-trimethyl-2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Table 1, entry 4).

Pale yellow oil, 84%. TLC (hexanes-EtOAc = 2:1): $R_f = 0.74$. ^1H NMR: δ 7.60 (d, $J = 7.6$ Hz, 1 H), 7.32 (d, $J = 8.0$ Hz, 1 H), 7.25 (t, $J = 7.6$ Hz, 1 H), 7.15 (t, $J = 7.4$ Hz, 1 H), 3.86 (s, 3 H), 3.80 (s, 3 H), 3.65-3.60 (m, 1 H), 3.02 (dd, $J = 3.6, 15.2$ Hz, 1 H), 2.53 (dd, $J = 11.2, 15.2$ Hz, 1 H), 2.10 (ddt, $J = 2.4, 5.2, 12.8$ Hz, 1 H), 1.95 (dt, $J = 2.0, 13.6$ Hz, 1 H), 1.83-1.78 (m, 1 H), 1.67 (ddd, $J = 2.4, 5.6, 13.2$ Hz, 1 H), 1.54 (s, 3 H), 1.43 (s, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 173.9, 142.7, 137.9, 126.1, 121.4, 119.2, 118.5, 111.5, 109.0, 51.8, 39.7, 38.4, 32.5, 32.2, 29.7, 29.2, 27.7, 25.1. IR (neat, cm^{-1}): 2932, 1747, 1727, 1470, 1285, 1165, 1015, 742. Anal. calcd (found) for $\text{C}_{18}\text{H}_{23}\text{NO}_2$: C, 75.76 (75.60); H, 8.12 (8.12).

Methyl (2,2 dicarbomethoxy-9-methyl-2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Table 1, entry 5). Pale yellow oil, 87%. TLC (hexanes-EtOAc = 2:1): $R_f = 0.43$. ^1H NMR: δ 7.51 (d, $J = 8.0$ Hz, 1 H), 7.29 (d, $J = 8.4$ Hz, 1 H), 7.19 (t, $J = 7.8$ Hz, 1 H), 7.08 (t, $J = 7.8$ Hz, 1 H), 3.80 (s, 3 H), 3.75 (s, 3 H), 3.69 (s, 3 H), 3.67 (s, 3 H), 3.70-3.63 (m, 1 H), 3.45 (d, $J = 16.4$ Hz, 1 H), 3.31 (dd, $J = 3.6, 15.8$ Hz, 1 H), 3.20 (d, $J = 16.0$ Hz, 1 H), 2.86 (dd, $J = 6.0, 13.6$ Hz, 1 H), 2.32 (dd, $J = 10.4, 15.8$ Hz, 1 H), 2.05 (dd, $J = 8.8, 13.6$ Hz, 1 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 173.1, 172.2, 170.9, 137.8, 133.4, 125.9, 121.3, 119.3, 119.0, 109.6, 109.3, 54.4, 53.2, 51.9, 51.7, 40.3, 35.4, 29.5, 28.6, 28.4. IR (neat, cm^{-1}): 2953, 1747, 1722, 1085, 1018, 738. Anal. calcd (found) for $\text{C}_{20}\text{H}_{23}\text{NO}_6$: C, 64.33 (64.48); H, 6.21 (6.29).

Methyl (2,9-dimethyl-1-oxo-2,3,4,9-tetrahydro-1*H*- β -carbolin-4-yl)-acetate (Table 1, entry 6). Colorless oil, 91%. TLC (hexanes-EtOAc = 10:1): $R_f = 0.21$. ^1H NMR: δ 7.61 (td, $J = 0.8, 8.0$ Hz, 1 H), 7.37-7.30 (m, 2 H), 7.14 (dt, $J = 1.0, 8.0$ Hz, 1 H), 4.11 (s, 3 H), 3.94 (dd, $J = 4.8, 12.8$ Hz, 1 H), 3.68 (s, 3 H), 3.67-3.63 (X portion of ABX, partially obscured, 1 H), 3.46 (dd, $J = 6.4, 12.8$ Hz, 1 H), 3.12 (s, 3 H), 2.68, 2.66 (AB portion of ABX, $J_{\text{AB}} = 15.2$ Hz, 2 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 172.8, 161.8, 139.4, 126.3, 124.9, 123.2, 120.8, 120.5, 120.3, 110.6, 54.3, 52.1, 37.3, 34.7, 31.5, 29.1. IR (neat, cm^{-1}): 2948,

1727, 1649, 1493, 1440, 1248, 1165, 1082, 742. Anal. calcd (found) for $C_{16}H_{18}N_2O_3$: C, 67.12 (66.98); H, 6.34 (6.38).

Methyl (4,9-dimethyl-2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Table 1, entry 7). Pale yellow solid, 87%. mp 85-87 °C. TLC (hexanes-EtOAc = 2:1): R_f = 0.72. 1H NMR: δ 7.68 (d, J = 8.0 Hz, 1 H), 7.28 (d, J = 8.0 Hz, 1 H), 7.18 (t, J = 7.6 Hz, 1 H), 7.09 (t, J = 7.6 Hz, 1 H), 3.66 (s, 3 H), 3.61 (s, 3 H), 3.04 (d, J = 13.6 Hz, 1 H), 2.70 (dd, J = 5.6, 12.0 Hz, 2 H), 2.65 (d, J = 13.6 Hz, 1 H), 2.16-2.08 (m, 1 H), 1.97 (quint, J = 6.0 Hz, 2 H), 1.75-1.69 (m, 1 H), 1.60 (s, 3 H). $^{13}C\{^1H\}$ NMR: δ 173.0, 137.2, 135.6, 125.7, 120.6, 119.8, 118.8, 116.0, 109.1, 51.5, 45.6, 36.8, 35.0, 29.3, 27.2, 22.6, 19.7. IR (neat, cm^{-1}): 2933, 1727, 1469, 1433, 1412, 1373, 1314, 1092, 1018. Anal. calcd (found) for $C_{17}H_{21}NO_2$: C, 75.25 (75.03); H, 7.80 (7.55).

2,2-Dicarbomethoxy-4-(1-carbomethoxypropyl)-9-methyl-1,3,4,9-tetrahydrocarbazole (Table 1, entry 8). White solid, 62%. mp 174-176 °C. TLC (hexanes-EtOAc = 2:1): R_f = 0.41. 1H NMR: δ 7.57 (d, J = 8.0 Hz, 1 H), 7.28 (d, J = 8.0 Hz, 1 H), 7.18 (t, J = 7.8 Hz, 1 H), 7.07 (t, J = 7.6 Hz, 1 H), 3.93-3.91 (m, 1 H), 3.80 (s, 3 H), 3.79 (s, 3 H), 3.66 (s, 3 H), 3.620 (s, 3 H), 3.52 (d, J = 16.0 Hz, 1 H), 3.35 (br d, J = 11.2 Hz, 1 H), 3.07 (d, J = 15.8 Hz, 1 H), 2.45 (dd, J = 5.0, 13.0 Hz, 1 H), 2.02 (dd, J = 11.2, 14.8 Hz, 1 H), 1.69-1.60 (m, 1 H), 1.06-0.97 (m, 1 H). $^{13}C\{^1H\}$ NMR: δ 175.6, 172.3, 170.7, 137.9, 134.4, 126.1, 121.2, 119.3, 109.3, 108.8, 55.0, 53.4, 53.1, 52.0, 49.6, 34.6, 30.9, 29.6, 28.3, 18.4, 13.5. IR (neat, cm^{-1}): 2952, 1730, 1469, 1437, 1048, 737. Anal. calcd (found) for $C_{22}H_{27}NO_6$: C, 65.82 (65.81); H, 6.78 (6.70).

1,5,5-Tricarbomethoxy-7-methyl-2,3,4a,6,7,11c-hexahydro-1*H*,4*H*-benzo[*c*]carbazole (Table 1, entry 9). White solid, 45%. mp 174-176 °C. TLC (hexanes-EtOAc = 2:1): R_f = 0.41. 1H NMR: δ 7.55 (d, J = 8.0 Hz, 1 H), 7.30 (d, J = 8.4 Hz, 1 H), 7.17 (t, J = 7.6 Hz, 1 H), 7.04 (t, J = 7.8 Hz, 1 H), 3.93-3.91 (m, 1 H), 3.90-3.88 (m, 1 H), 3.84 (s, 3 H), 3.80 (s, 3 H), 3.71 (s, 3 H), 3.70 (s, 3 H), 3.55 (d, J = 17.6 Hz, 1 H), 3.11 (dd, J = 2.6, 17.4 Hz, 1 H), 3.08 (td, J = 3.8, 12.8 Hz, 1 H), 2.01 (br d, J = 13.6 Hz, 1 H), 1.59-1.22 (m, 5 H). $^{13}C\{^1H\}$ NMR: δ 175.6, 171.0, 170.4, 137.9, 133.7, 126.1, 120.9, 119.4,

119.1, 109.3, 107.3, 59.2, 53.3, 52.1, 42.3, 42.2, 37.4, 33.8, 29.6, 24.6, 23.7, 23.1, 22.2. IR (neat, cm^{-1}): 2950, 1732, 1469, 1433, 1260, 1048, 911, 737. Anal. calcd (found) for $\text{C}_{23}\text{H}_{27}\text{NO}_6$: C, 66.81 (67.06); H, 6.58 (6.68).

3-Carbomethoxy-9-methyl-2,3,4,9-tetrahydro-1H-carbazol (Table 1, entry 10).⁷ Pale yellow oil, 76%. TLC (hexanes-EtOAc = 2:1): R_f = 0.61. ^1H NMR: δ 7.48 (d, J = 8.0 Hz, 1 H), 7.25 (d, J = 8.4 Hz, 1 H), 7.20 (dt, J = 0.8, 7.6 Hz, 1 H), 7.11 (dt, J = 0.8, 7.8 Hz, 1 H), 3.75 (s, 3 H), 3.63 (s, 3 H), 3.10 (dd, J = 5.4, 15.0 Hz, 1 H), 2.96-2.70 (m, 4 H), 2.38-2.33 (m, 1 H), 2.47 (dtd, J = 6.0, 10.4, 13.2 Hz, 1 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 176.3, 137.3, 134.9, 127.1, 121.1, 119.1, 118.0, 108.9, 107.7, 82.1, 40.4, 29.4, 26.0, 24.4, 21.5. IR (neat, cm^{-1}): 2934, 1731, 1470, 1434, 1416, 1379, 1281, 1166, 1080, 1014, 739.

cis-3-Carbomethoxy-4-ethyl-1,1-dimethyl-2,3,4,9-tetrahydro-1H-carbazole (cis-S7, Table 1, entry 11). White solid, 92%. mp 64-67 °C. TLC (hexanes-EtOAc = 2:1): R_f = 0.68. ^1H NMR (Figure S3): δ 7.96 (s, 1 H), 7.57 (dd, J = 0.8, 8.0 Hz, 1 H), 7.32 (dd, J = 0.8, 8.4 Hz, 1 H), 7.19-7.10 (m, 2 H), 3.82 (s, 3 H), 3.43 (td, J = 4.8, 8.8 Hz, 1 H), 3.08 (ddd, J = 2.6, 5.0, 13.2 Hz, 1 H), 2.23 (t, J = 13.6 Hz, 1 H), 1.94 (dd, J = 2.2, 13.8 Hz, 1 H), 1.70-1.55 (m, 2 H), 1.45 (s, 3 H), 1.30 (s, 3 H), 1.06 (t, J = 7.6 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (Figure S4): δ 175.9, 141.2, 136.3, 127.8, 121.5, 119.5, 119.4, 112.6, 110.9, 51.9, 42.9, 36.4, 36.3, 32.0, 30.3, 29.7, 26.7, 13.8. IR (neat, cm^{-1}): 3406, 2958, 1727, 1713, 1455, 1430, 1140, 1013, 908, 734. HRMS calcd (found) for $\text{C}_{18}\text{H}_{23}\text{NO}_2$ (M^+): 285.1729 (285.1722).

trans-3-Carbomethoxy-4-ethyl-1,1-dimethyl-2,3,4,9-tetrahydro-1H-carbazole (trans-S7, Table 1, entry 12). Pale yellow viscous oil, 84%. TLC (hexanes-EtOAc = 2:1): R_f = 0.66. ^1H NMR (Figure S5): δ 7.96 (s, 1 H), 7.62 (d, J = 8.0 Hz, 1 H), 7.32 (dd, J = 0.8, 8.2 Hz, 1 H), 7.18-7.08 (m, 2 H), 3.80 (s, 3 H), 3.55 (ddd, J = 3.0, 6.6, 9.2 Hz, 1 H), 2.96 (ddd, J = 2.4, 9.2, 12.4 Hz, 1 H), 2.24-2.13 (m, 1 H), 2.02 (t, J = 13.2 Hz, 1 H), 1.97-1.89 (m, 2 H), 1.39 (s, 3 H), 1.37 (s, 3 H), 0.83 (t, J = 7.6 Hz, 3 H). $^{13}\text{C}\{^1\text{H}\}$ NMR (Figure S6): δ 177.1, 141.8, 136.4, 127.3, 121.3, 119.8, 119.5, 111.0, 109.7, 52.1, 42.7, 42.1, 36.9, 31.7, 29.4, 29.3, 25.2, 9.3. IR (neat, cm^{-1}): 3391, 2961, 1717, 1455, 1455, 1167, 908, 740. HRMS calcd (found) for $\text{C}_{18}\text{H}_{23}\text{NO}_2$ (M^+): 285.1729 (285.1732).

The stereochemistry of *cis*-**S7** and *trans*-**S7** were established by ^1H NOE analysis. In particular, Irradiation of H_4 led to the enhancement of H_3 in *cis*-**S7** but not in *trans*-**S7**. The stereochemistry of *cis*-**S7** was confirmed via X-ray crystallographic analysis (Tables S2-S5, Figure S7).

Methyl (5-methyl-5,6,7,8,9,10-hexahydro-cyclohepta[b]indol-10-yl)-acetate (Table 1, entry 13). Pale yellow oil, 74%. TLC (hexanes-EtOAc = 2:1): R_f = 0.70. ^1H NMR: δ 7.60 (d, J = 7.6 Hz, 1 H), 7.25 (d, J = 8.0 Hz, 1 H), 7.19 (dt, J = 1.0, 7.6 Hz, 1 H), 7.12 (dt, J = 0.8, 7.6 Hz, 1 H), 3.93-3.88 (m, 1 H), 3.67 (s, 3 H), 3.65 (s, 3 H), 3.03 (ddd, J = 2.4, 6.2, 16.0 Hz, 1 H), 2.81 (ddd, J = 2.4, 12.0, 15.6 Hz, 1 H), 2.68 (d, J = 8.0 Hz, 2 H), 2.13-1.59 (m, 6 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 173.7, 138.7, 136.1, 127.4, 120.8, 119.1, 118.0, 115.4, 109.1, 51.8, 38.8, 31.9, 31.8, 29.7, 27.7, 25.9, 25.6. IR (neat, cm^{-1}): 2922, 2852, 1730, 1470, 1434, 1382, 1360, 1285, 1165, 1015, 739. Anal. calcd (found) for $\text{C}_{17}\text{H}_{21}\text{NO}_2$: C, 75.25 (75.24); H, 7.80 (7.75).

2-Carbomethoxy-9-methyl-2,3,4,9-tetrahydro-1H-carbazole (Table 1, entry 14).⁷ Pale yellow solid, 58%. TLC (hexanes-EtOAc = 2:1): R_f = 0.61. ^1H NMR: δ 7.50 (d, J = 7.6 Hz, 1 H), 7.29 (d, J = 8.4 Hz, 1 H), 7.15 (dt, J = 0.8, 7.8 Hz, 1 H), 7.13 (dt, J = 1.0, 7.8 Hz, 1 H), 3.81 (s, 3 H), 3.66 (s, 3 H), 3.04-2.75 (m, 5 H), 2.40-2.34 (m, 1 H), 2.47 (dtd, J = 5.6, 10.8, 13.2 Hz, 1 H). $^{13}\text{C}\{^1\text{H}\}$ NMR: δ 175.9, 137.3, 134.0, 127.0, 121.1, 119.1, 118.1, 108.9, 108.8, 52.2, 40.6, 29.4, 26.6, 24.9, 20.7. IR (neat,

cm⁻¹): 2948, 2846, 1742, 1732, 1470, 1380, 1168, 1380, 1168, 1011, 739. Anal. calcd (found) for C₁₅H₁₇NO₂: C, 74.05 (73.96); H, 7.04 (7.17).

Methyl (2,3,4,9-tetrahydro-1*H*-carbazol-1-yl)-acetate (Table 1, entry 15). Pale yellow oil, 85%. TLC (hexanes-EtOAc = 5:1): *R_f* = 0.64. ¹H NMR: δ 8.74 (s, 1 H), 7.51 (dd, *J* = 0.8, 8.4 Hz, 1 H), 7.33 (td, *J* = 0.8, 8.2 Hz, 1 H), 7.17 (dt, *J* = 1.0, 7.6 Hz, 1 H), 7.11 (dt, *J* = 1.0, 7.6 Hz, 1 H), 3.80 (s, 3 H), 3.43-3.36 (m, 1 H), 2.76-2.63 (m, 4 H), 2.13-2.06 (m, 1 H), 2.00-1.82 (m, 2 H), 1.72-1.65 (m, 1 H). ¹³C{¹H} NMR: δ 175.3, 136.5, 135.9, 127.5, 121.6, 119.3, 118.3, 111.1, 110.5, 52.3, 40.6, 30.9, 30.2, 21.7, 21.3. IR (neat, cm⁻¹): 3406, 2930, 2846, 1727, 1466, 1363, 1329, 1009, 741. Anal. calcd (found) for C₁₅H₁₇NO₂: C, 74.05 (73.90); H, 7.04 (7.07).

II. THF as solvent

S6. THF (4 mL), methanol (180 μL, 5.0 mmol), and a solution of **S2** (99 mg, 0.50 mmol) in THF (1.0 mL) were added sequentially to a flask containing **2** (6.5 mg, 0.025 mmol) and CuCl₂ (200 mg, 1.5 mmol) under CO (1 atm). The resulting suspension was stirred for 30 min and concentrated under vacuum. Column chromatography of the residue (SiO₂; hexanes–EtOAc = 5:1) gave **S6** (106 mg, 83%) as a pale yellow oil. Employment of fewer than ten equivalents of methanol led to diminished yields of **S6**.

The remaining tricyclic indole derivatives depicted in Scheme 2 were synthesized from **S2** employing a procedure similar to that used to synthesize **S6**.

Ethyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate. Pale yellow oil, 73%. TLC (hexanes-EtOAc = 2:1): *R_f* = 0.58. ¹H NMR: δ 7.78 (s, 1 H), 7.52 (d, *J* = 8.4 Hz, 1 H), 7.26-7.23 (m, 1 H), 7.14-7.06 (m, 1 H), 4.20 (q, *J* = 7.2 Hz, 2 H), 3.58-3.52 (m, 1 H), 2.99 (dd, *J* = 4.0, 15.2 Hz, 1 H), 2.69-2.66 (m, 2 H), 2.41 (dd, *J* = 10.4, 14.8 Hz, 1 H), 2.00-1.74 (m, 4 H), 1.29 (t, *J* = 6.8 Hz, 3 H). ¹³C{¹H} NMR: δ 173.6, 136.0, 134.9, 127.1, 121.3, 119.5, 118.4, 112.4, 110.9, 60.6, 40.2, 29.3, 28.7, 23.5, 19.7, 14.6. IR (neat, cm⁻¹): 3399, 2932, 1729, 1713, 1463, 1370, 1326, 1301, 1281, 1177, 1071, 1030, 741. Anal. calcd

(found) for $C_{16}H_{19}NO_2$: C, 74.68 (74.40); H, 7.44 (7.65).

***n*-Octyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate.** Pale yellow oil, 82%. TLC (hexanes-EtOAc = 2:1): R_f = 0.75. 1H NMR: δ 7.78 (s, 1 H), 7.53 (d, J = 8.4 Hz, 1 H), 7.26-7.24 (m, 1 H), 7.14-7.06 (m, 1 H), 4.14 (t, J = 6.2 Hz, 2 H), 3.58-3.53 (m, 1 H), 2.99 (dd, J = 4.0, 15.2 Hz, 1 H), 2.69-2.67 (m, 2 H), 2.42 (dd, J = 10.4, 14.8 Hz, 1 H), 1.98-1.73 (m, 4 H), 1.68-1.62 (m, 2 H), 1.39-1.26 (m, 10 H), 0.91 (t, J = 6.8 Hz, 3 H). $^{13}C\{^1H\}$ NMR: δ 173.7, 136.1, 134.9, 127.1, 121.3, 119.5, 118.4, 112.4, 110.9, 64.9, 40.3, 32.1, 29.5, 29.4, 28.9, 28.8, 26.2, 23.5, 23.0, 19.7, 14.4. IR (neat, cm^{-1}): 3402, 2925, 2855, 1713, 1454, 739. Anal. calcd (found) for $C_{22}H_{31}NO_2$: C, 77.38 (77.13); H, 9.15 (9.23).

Isopropyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate. Pale yellow oil, 75%. TLC (hexanes-EtOAc = 2:1): R_f = 0.61. 1H NMR (Figure S8): δ 7.79 (s, 1 H), 7.54 (d, J = 7.6 Hz, 1 H), 7.26-7.23 (m, 1 H), 7.15-7.06 (m, 1 H), 5.10 (septet, J = 7.6 Hz, 1 H), 3.58-3.53 (m, 1 H), 2.99 (dd, J = 4.0, 15.2 Hz, 1 H), 2.70-2.62 (m, 2 H), 2.39 (dd, J = 10.4, 14.8 Hz, 1 H), 2.00-1.76 (m, 4 H), 1.29 (d, J = 6.4 Hz, 3 H), 1.26 (d, J = 6.4 Hz, 3 H). $^{13}C\{^1H\}$ NMR (Figure S9): δ 173.2, 136.0, 134.9, 127.1, 121.3, 119.4, 118.5, 112.4, 110.8, 67.9, 40.6, 29.4, 28.7, 23.5, 22.3, 22.1, 19.8. IR (neat, cm^{-1}): 3402, 2978, 2934, 1729, 1453, 1372, 1107, 741. HRMS calcd (found) for $C_{17}H_{21}NO_2$ (M^+): 271.1572 (271.1568).

Cyclohexyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate. Pale yellow oil, 73%. TLC (hexanes-EtOAc = 2:1): R_f = 0.71. 1H NMR (Figure S10): δ 7.78 (s, 1 H), 7.56 (d, J = 7.6 Hz, 1 H), 7.29-7.27 (m, 1 H), 7.15-7.07 (m, 2 H), 4.86 (tt, J = 3.6, 8.8 Hz, 1 H), 3.59-3.52 (m, 1 H), 2.99 (dd, J = 4.0, 15.2 Hz, 1 H), 2.72-2.69 (m, 2 H), 2.41 (dd, J = 10.4, 14.8 Hz, 1 H), 1.99-1.69 (m, 8 H), 1.58-1.27 (m, 6 H). $^{13}C\{^1H\}$ NMR (Figure S11): δ 173.1, 136.1, 134.9, 127.1, 121.3, 119.5, 118.5, 112.5, 110.9, 72.8, 40.6, 32.0, 31.9, 29.5, 28.7, 25.7, 24.0, 23.5, 19.8. IR (neat, cm^{-1}): 3403, 2935, 1725, 1453, 1281, 1182, 1014, 908, 741. HRMS calcd (found) for $C_{20}H_{25}NO_2$ (M^+): 311.1885 (311.1887).

[illegible]

Figure S4. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of *cis*-**S7** (Table 1, entry 11).

Figure S5. ¹H NMR spectrum of *trans*-**S7** (Table 1, entry 12).

[illegible]

Figure S7. X-ray crystal structure of *cis*-S7.

Figure S8. ^1H NMR spectrum of isopropyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Scheme 2).

Figure S9. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of isopropyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Scheme 2).

Figure S10. ^1H NMR spectrum of cyclohexyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Scheme 2).

Figure S11. $^{13}\text{C}\{^1\text{H}\}$ NMR spectrum of cyclohexyl (2,3,4,9-tetrahydro-1*H*-carbazol-4-yl)-acetate (Scheme 2).

Table S2. X-ray crystal data and collection and refinement of parameters for *cis*-S7.

empirical formula	C ₁₈ H ₂₃ NO ₂
fw	285.38
crystal size (mm)	0.30 × 0.30 × 0.20
crystal system	Orthorhombic
space group	P bca
<i>a</i> (Å)	9.4635(4)
<i>b</i> (Å)	16.8018(7)
<i>c</i> (Å)	20.2194(9)
<i>V</i> (Å ³)	3214.96(24)
<i>Z</i>	8
scan mode	w
2 θ limits (deg)	5.00 < 2 θ < 50.00
<i>D_c</i> (mg*cm ⁻³)	1.179
unique reflections	2842
data with <i>I</i> _{net} > 2.5 σ (<i>I</i>)	2151
<i>F</i> (000)	1232.69
<i>R_f</i>	0.044
<i>R_w</i>	0.049
GoF	1.9942
No. of parameters	191
max Δ/σ	0.000
largest resid density (e/Å ³)	0.230

Table S3. Atomic coordinates for *cis*-**S7**.

	x	y	z	Biso
C1	0.02874(17)	0.79392(10)	0.11622(9)	1.68(7)
C2	-0.05462(18)	0.72554(10)	0.09752(9)	1.81(7)
C3	-0.19807(19)	0.71188(11)	0.08345(10)	2.31(8)
C4	-0.24171(20)	0.63628(12)	0.06763(11)	2.90(9)
C5	-0.14632(22)	0.57284(12)	0.06497(11)	3.22(10)
C6	-0.00548(22)	0.58352(11)	0.07885(10)	2.79(9)
C7	0.03926(19)	0.66002(10)	0.09542(9)	2.01(7)
N8	0.17156(15)	0.68707(9)	0.11287(8)	2.02(6)
C9	0.16402(18)	0.76754(10)	0.12567(9)	1.77(8)
C10	0.28773(18)	0.81435(11)	0.15173(10)	2.09(7)
C11	0.24555(19)	0.90297(10)	0.15059(10)	2.19(8)
C12	0.09426(18)	0.91798(10)	0.17392(9)	1.89(7)
C13	-0.01612(17)	0.87909(10)	0.12696(9)	1.73(7)
C14	0.42010(20)	0.80247(12)	0.10921(11)	3.05(10)
C15	0.31926(22)	0.78672(12)	0.22280(11)	3.09(9)
C16	0.06414(19)	1.00519(11)	0.18294(9)	2.00(7)
O17	0.13272(13)	1.05963(7)	0.16040(7)	2.70(6)
O18	-0.05199(14)	1.01646(8)	0.21922(7)	3.09(6)
C19	-0.09264(24)	1.09858(12)	0.23161(12)	3.71(10)
C20	-0.03301(19)	0.92675(11)	0.06259(9)	2.04(8)
C21	-0.13613(21)	0.89125(11)	0.01339(10)	2.60(8)
H3	-0.264	0.755	0.085	3.1
H4	-0.340	0.627	0.058	3.7
H5	-0.180	0.521	0.053	4.0
H6	0.060	0.540	0.077	3.6
H8	0.255	0.655	0.116	2.8

H11a	0.253	0.922	0.106	3.0
H11b	0.309	0.932	0.178	3.0
H12	0.085	0.893	0.216	2.7
H13	-0.106	0.879	0.149	2.5
H14a	0.401	0.819	0.065	3.8
H14b	0.496	0.833	0.127	3.8
H14c	0.446	0.747	0.109	3.8
H15a	0.236	0.794	0.249	3.9
H15b	0.345	0.731	0.223	3.9
H15c	0.396	0.818	0.241	3.9
H19a	-0.177	1.100	0.258	4.5
H19b	-0.018	1.125	0.255	4.5
H19c	-0.110	1.125	0.190	4.5
H20a	0.058	0.930	0.042	2.8
H20b	-0.065	0.979	0.073	2.8
H21a	-0.141	0.924	-0.026	3.4
H21b	-0.105	0.839	0.002	3.4
H21c	-0.228	0.888	0.034	3.4

^a Biso is the Mean of the Principal Axes of the Thermal Ellipsoid.

Table S4. Bond lengths for *cis*-S7.

C(1)-C(2)	1.4440(23)	C(10)-C(11)	1.542(3)
C(1)-C(9)	1.3682(24)	C(10)-C(14)	1.532(3)
C(1)-C(13)	1.5084(24)	C(10)-C(15)	1.539(3)
C(2)-C(3)	1.4059(25)	C(11)-C(12)	1.528(3)
C(2)-C(7)	1.4152(25)	C(12)-C(13)	1.5555(24)
C(3)-C(4)	1.373(3)	C(12)-C(16)	1.5039(25)
C(4)-C(5)	1.398(3)	C(13)-C(20)	1.537(3)

C(5)-C(6)	1.374(3)	C(16)-O(17)	1.2106(22)
C(6)-C(7)	1.394(3)	C(16)-O(18)	1.3348(22)
C(7)-N(8)	1.3780(22)	O(18)-C(19)	1.4540(24)
N(8)-C(9)	1.3784(22)	C(20)-C(21)	1.516(3)
C(9)-C(10)	1.5055(24)		

Table S5. Bond angles for *cis-S7*.

C(2)-C(1)-C(9)	106.86(15)	C(9)-C(10)-C(14)	111.80(15)
C(2)-C(1)-C(13)	129.69(15)	C(9)-C(10)-C(15)	108.65(15)
C(9)-C(1)-C(13)	123.41(15)	C(11)-C(10)-C(14)	109.22(15)
C(1)-C(2)-C(3)	135.27(16)	C(11)-C(10)-C(15)	110.81(15)
C(1)-C(2)-C(7)	106.48(15)	C(14)-C(10)-C(15)	109.02(15)
C(3)-C(2)-C(7)	118.23(16)	C(10)-C(11)-C(12)	113.41(14)
C(2)-C(3)-C(4)	119.24(17)	C(11)-C(12)-C(13)	111.80(14)
C(3)-C(4)-C(5)	121.33(17)	C(11)-C(12)-C(16)	112.07(14)
C(4)-C(5)-C(6)	121.27(17)	C(13)-C(12)-C(16)	110.86(14)
C(5)-C(6)-C(7)	117.65(18)	C(1)-C(13)-C(12)	107.30(14)
C(2)-C(7)-C(6)	122.26(16)	C(1)-C(13)-C(20)	113.68(14)
C(2)-C(7)-N(8)	107.83(15)	C(12)-C(13)-C(20)	111.59(14)
C(6)-C(7)-N(8)	129.91(17)	C(12)-C(16)-O(17)	126.08(16)
C(7)-N(8)-C(9)	108.94(14)	C(12)-C(16)-O(18)	111.16(15)
C(1)-C(9)-N(8)	109.87(15)	O(17)-C(16)-O(18)	122.75(17)
C(1)-C(9)-C(10)	127.40(16)	C(16)-O(18)-C(19)	116.56(15)
N(8)-C(9)-C(10)	122.54(15)	C(13)-C(20)-C(21)	114.69(15)
C(9)-C(10)-C(11)	107.33(15)		

References

- 1) Smith, A. B. III; Visnick, M.; Haseltine, J. N.; Sprengeler, P. A. *Tetrahedron* **1986**, 42, 2957.
- 2) Liu, C.; Han, X.; Wang, X.; Widenhoefer, R. *J. Am. Chem. Soc.* **2004**, 126, 3700.
- 3) Abbiati, G.; Beccalli, E. M.; Broggini, G.; Zoni, C. *J. Org. Chem.* **2003**, 68, 7625.
- 4) Ferreira, E. M.; Stoltz, B. M. *J. Am. Chem. Soc.* **2003**, 125, 9578.
- 5) Youn, S. W.; Pastine, S. J.; Sames, D. *Org. Lett.* **2004**, 6, 581.
- 6) Rodriguez, J. G.; Temprano, F.; Esteban-Calderon, C.; Martinez-Ripoll, M. *J. Chem. Soc., Perkin Trans 1* **1989**, 11, 2117.
- 7) Marinelli, E. R. *Tetrahedron Lett.* **1982**, 23, 2745.