SUPPORTING INFORMATION

Synthesis of Substituted Naphthalenes and Carbazoles by the Palladium-Catalyzed Annulation of Internal Alkynes

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General. ^1H and ^{13}C NMR spectra were recorded at 300 and 75 MHz or 400 and 100 MHz respectively. Thin-layer chromatography was performed using commercially prepared 60-mesh silica gel plates (Whatman K6F), and visualization was effected with short wavelength UV light (254 nm) and a basic KMnO_4 solution [3 g of KMnO_4 + 20 g of K_2CO_3 + 5 mL of NaOH (5 %) + 300 mL of H_2O]. All melting points are uncorrected. All reagents were used directly as obtained commercially unless otherwise noted. Compounds **1-10**, **24**, **25**, **27**, **30**, **31**, **34**, **35**, **38**, and **39** were reported in our earlier communication.¹ All reagents were used directly as obtained commercially unless otherwise noted. Compounds **20**,² **28**,³ (2-iodophenyl)acetaldehyde,⁴ *N,N*-dimethylaniline,⁵ and 2-iodoindole⁶ were prepared according to previous literature procedures. The following starting materials were prepared as indicated.

Preparation of *o*-(2-Alkenyl)aryl halides.

2-(2-Iodophenyl)propanal. To a suspension of (methoxymethyl)triphenylphosphonium chloride (2.87 g, 8.4 mmol) in dry THF (15 mL) was added KO-*t*-Bu (0.90 g, 8.0 mmol) portionwise under an Ar atmosphere at 25 °C. The resulting red suspension was stirred for 30 min at 25 °C and a solution of 2-iodoacetophenone (0.98 g, 4.0 mmol) in dry THF (5 mL) was added dropwise. After the reaction mixture was stirred at 25 °C for 1 h, the THF was removed under reduced pressure and hexane (30 mL) was added to the residue. The resulting suspension was

stirred for 20 min and the Ph_3PO was removed by filtration. The filtrate was collected, the solvent was removed under reduced pressure, and the residue was purified by flash chromatography (20:1 hexane/EtOAc) on silica gel to afford 1.10 g of 2-(2-iodophenyl)-1-methoxypropene ($E/Z = 90:10$) in a 100 % yield as a yellow oil. To a solution of 2-(2-iodophenyl)-1-methoxypropene ($E/Z = 90:10$) (0.55 g, 2.0 mmol) in CH_2Cl_2 (10 mL) was added 1.2 mL of 47 % hydroiodic acid and the mixture was stirred under an Ar atmosphere at 25 °C for 40 min. The reaction was then diluted with 30 mL of CH_2Cl_2 and the excess acid was carefully neutralized by 30 mL of satd aq NaHCO_3 , during which lots of bubbles were generated. The organic layer was collected, washed with 20 mL of brine, dried over Na_2SO_4 , and filtered, and the solvent was removed under reduced pressure. The residue was purified by flash chromatography (20:1 hexane/EtOAc) on silica gel to afford 0.36 g of 2-(2-iodophenyl)propanal in a 69 % yield as a colorless liquid: ^1H NMR (CDCl_3) δ 1.40 (d, $J = 6.8$ Hz, 3H), 4.08 (q, $J = 6.8$ Hz, 1H), 6.99-7.03 (m, 1H), 7.06 (dd, $J = 1.6, 8.0$ Hz, 1H), 7.35-7.39 (m, 1H), 7.93 (dd, $J = 1.2, 8.0$ Hz, 1H), 9.73 (s, 1H); ^{13}C NMR (CDCl_3) δ 14.7, 56.9, 102.3, 128.6, 129.2, 129.5, 140.3, 141.4, 200.5.

Ethyl (*E*)-4-(2-iodophenyl)-2-pentenoate (13). To a suspension of (carboethoxymethylene)triphenylphosphorane (0.69 g, 1.95 mmol) in 5 mL of CH_2Cl_2 was added dropwise a solution of 2-(2-iodophenyl)propanal (0.34 g, 1.3 mmol) in 5 mL of CH_2Cl_2 at 0 °C under an Ar atmosphere. The resulting mixture was stirred at 25 °C for 3 h and the solvent (CH_2Cl_2) was evaporated under reduced pressure. The solid residue was dissolved in 20 mL of hexane and the mixture was then stirred at 25 °C for 0.5 h. The Ph_3PO was filtered and the solvent was removed under reduced pressure. The oily residue was purified by flash chromatography (20:1 hexane/EtOAc) to afford 0.41 g of the indicated compound as a colorless oil in a 95 % yield: ^1H NMR (CDCl_3) δ 1.28 (t, $J = 7.2$ Hz, 3H), 1.39 (d, $J = 7.2$ Hz, 3H), 3.97-4.04 (m, 1H), 4.19 (q, $J = 7.2$ Hz, 2H), 5.84 (dd, $J = 2.0, 16.0$ Hz, 1H), 6.90-6.95 (m, 1H), 9.08 (dd, $J = 5.6, 16.0$ Hz, 1H), 7.15 (dd, $J = 1.6, 8.0$ Hz, 1H), 7.30-7.34 (m, 1H), 7.85 (dd, $J = 1.2, 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3)

δ 14.5, 19.7, 45.9, 60.6, 101.3, 121.0, 127.9, 128.8, 129.0, 140.0, 145.8, 151.3, 166.9; IR (neat, cm^{-1}) 3058, 2976, 2933, 2902, 1716, 1465; HRMS Calcd for $\text{C}_{13}\text{H}_{15}\text{IO}_2$: 330.0117. Found: 330.0123.

(2-Iodophenyl)phenylacetaldehyde. To a suspension of (methoxymethyl)triphenylphosphonium chloride (5.76 g, 16.8 mmol) in dry THF (25 mL) was added KO-*t*-Bu (1.80 g, 16.0 mmol) portionwise under an Ar atmosphere at 25 °C. The resulting reddish suspension was stirred for 30 min at 25 °C and a solution of 2-iodobenzophenone (2.46 g, 8.0 mmol) in THF (10 mL) was added dropwise. After the reaction mixture was stirred at 25 °C for 1 h, the solvent was removed under reduced pressure and hexane (50 mL) was added to the residue. The suspension was stirred for 20 min and the Ph_3PO was removed by filtration. The filtrate was collected, the solvent was removed under reduced pressure, and the residue was purified by flash chromatography (10:1 hexane/EtOAc) on silica gel to afford 2.68 g of 1-(2-iodophenyl)-2-methoxy-1-phenylethene (*E/Z* = 61:39) in 100 % yield as a pale yellow oil. To a solution of 1-(2-iodophenyl)-2-methoxy-1-phenylethene (*E/Z* = 61:39) (1.68 g, 5.0 mmol) in CH_2Cl_2 (15 mL) was added 3.0 mL of 47 % hydroiodic acid and the mixture was stirred under an Ar atmosphere at 25 °C for 3 h. Then the excess acid was carefully destroyed by 60 mL of satd aq NaHCO_3 , during which lots of bubbles were generated. The organic layer was collected, washed with 50 mL of brine, dried over Na_2SO_4 , and filtered, and the solvent was removed under reduced pressure. The residue was purified by flash chromatography (15:1 hexane/EtOAc) on silica gel to afford 0.91 g of (2-iodophenyl)phenylacetaldehyde in a 57 % yield as a pale yellow oil: ^1H NMR (CDCl_3) δ 5.39 (s, 1H), 6.98-7.02 (m, 1H), 7.12 (dd, J = 1.6, 7.6 Hz, 1H), 7.22-7.24 (m, 2H), 7.30-7.40 (m, 4H), 7.92 (dd, J = 1.2, 8.0 Hz, 1H), 9.98 (d, J = 1.2 Hz, 1H); ^{13}C NMR (CDCl_3) δ 68.1, 102.7, 128.0, 128.7, 129.2, 129.5, 129.7, 130.3, 135.4, 139.8, 140.4, 198.1.

Ethyl (*E*)-4-(2-iodophenyl)-4-phenyl-2-butenolate (18). Using the procedure used to prepare aryl halide **13**, (2-iodophenyl)phenylacetaldehyde (0.84 g, 2.6 mmol) and (carboethoxymethylene)triphenylphosphorane (1.36 g, 3.9 mmol) were employed to afford 1.01 g of the indicated compound in a 100 % yield as a colorless oil: ^1H NMR (CDCl_3) δ 1.28 (t, $J = 7.2$ Hz, 3H), 4.19 (q, $J = 7.2$ Hz, 2H), 5.27 (dd, $J = 1.6, 6.0$ Hz, 1H), 5.64 (dd, $J = 1.6, 15.6$ Hz, 1H), 6.93-6.97 (m, 1H), 7.11 (dd, $J = 1.6, 7.6$ Hz, 1H), 7.15-7.17 (m, 2H), 7.23-7.38 (m, 5H), 7.87 (dd, $J = 1.2, 7.6$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 14.5, 57.2, 60.7, 102.1, 123.8, 127.2, 128.7, 128.8, 129.0, 129.2, 130.1, 140.2, 140.4, 144.0, 149.2, 166.6; IR (neat, cm^{-1}) 3060, 2980, 1716, 1650, 1494; HRMS Calcd for $\text{C}_{18}\text{H}_{17}\text{IO}_2$: 392.0273. Found: 392.0279.

Ethyl (*E*)-4-(2-iodophenyl)-2-methyl-2-butenolate (22). Using the procedure used to prepare aryl halide **13**, (2-iodophenyl)acetaldehyde⁴ (0.89 g, 3.6 mmol) and (carboethoxyethylene)triphenylphosphorane (1.67 g, 4.3 mmol) were employed to afford 1.19 g of the indicated compound in a 100 % yield as a colorless oil: ^1H NMR (CDCl_3) δ 1.29 (t, $J = 7.2$ Hz, 3H), 1.97-1.98 (m, 3H), 3.62 (d, $J = 7.5$ Hz, 2H), 4.20 (q, $J = 7.2$ Hz, 2H), 6.78-6.84 (m, 1H), 6.90-6.95 (m, 1H), 7.18 (dd, $J = 1.5, 7.5$ Hz, 1H), 7.27-7.32 (m, 1H), 7.84 (dd, $J = 1.2, 7.2$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 13.1, 14.5, 40.4, 60.8, 100.8, 128.5, 128.8, 129.5, 129.7, 138.8, 139.8, 142.2, 168.2; IR (neat, cm^{-1}) 3054, 2979, 2930, 1708, 1648, 1251; HRMS Calcd for $\text{C}_{13}\text{H}_{15}\text{IO}_2$: 330.0117. Found: 330.0123.

(*E*)-1-Phenyl-1-penten-4-yne. To a stirred mixture of cinnamyl bromide (1.97 g, 10.0 mmol) and CuCl (0.099 g, 1.0 mmol) in dry THF (40 mL) was added dropwise a solution of ethynylmagnesium bromide in THF (0.5 M, 20 mL) at 25 °C. The resulting mixture was then stirred at 25 °C for 5 min and at 50 °C for 14 h. It was allowed to cool to room temperature and washed with 50 mL of brine. The organic layer was collected, dried over Na_2SO_4 , and filtered, and the solvent was removed under reduced pressure. The oily residue was purified by flash chromatography (hexane) on silica gel to afford 0.67 g (47 % yield) of the indicated compound as a colorless liquid: ^1H NMR (CDCl_3) δ

2.18 (t, $J = 2.4$ Hz, 1H), 3.13-3.15 (m, 2H), 6.16 (td, $J = 5.6, 16.0$ Hz, 1H), 6.67 (d, $J = 16.0$ Hz, 1H), 7.22-7.24 (m, 1H), 7.29-7.32 (m, 2H), 7.36-7.38 (m, 2H); ^{13}C NMR (CDCl_3) δ 22.2, 70.9, 81.4, 123.8, 126.5, 127.6, 128.7, 131.8, 137.2.

***N,N*-Dimethyl-2-(*E*-5-phenyl-4-penten-1-ynyl)aniline.** To a solution of $\text{PdCl}_2(\text{PPh}_3)_2$ (42.1 mg, 0.06 mmol), *N,N*-dimethyl-2-iodoaniline⁵ (0.74 g, 3.0 mmol) and (*E*)-1-phenyl-1-penten-4-yne (0.51 g, 3.6 mmol) in Et_3N (15 mL) was added CuI (5.71 mg, 0.03 mmol). The resulting mixture was stirred for 10 min under an Ar atmosphere and was heated to 50 °C. After 6 h, the reaction was allowed to cool to 25 °C. The ammonium salt was removed by filtration and the filtrate was concentrated under reduced pressure. The residue was purified by flash chromatography (20:1 hexane/EtOAc) on silica gel to afford 0.64 g (92 % yield) of the indicated compound as a yellow oil: ^1H NMR (CDCl_3) δ 2.93 (s, 6H), 3.44 (dd, $J = 2.0, 5.6$ Hz, 2H), 6.27 (td, $J = 5.6, 16.0$ Hz, 1H), 6.76 (d, $J = 16.0$ Hz, 1H), 6.86-6.90 (m, 1H), 6.92 (d, $J = 8.4$ Hz, 1H), 7.20-7.25 (m, 2H), 7.29-7.33 (m, 2H), 7.37-7.39 (m, 2H), 7.43 (dd, $J = 1.6, 7.6$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 23.7, 43.9, 82.1, 92.2, 116.4, 117.3, 121.0, 124.6, 126.4, 127.5, 128.7, 128.9, 131.6, 134.6, 137.4, 155.0.

3-Iodo-1-methyl-2-[*E*-3-phenylpro-2-enyl]-1*H*-indole (43). To a solution of *N,N*-dimethyl-2-(*E*-5-phenyl-4-penten-1-ynyl)aniline (0.58 g, 2.2 mmol) in CH_2Cl_2 (10 mL) was added dropwise a solution of I_2 (0.67 g, 1.2 equiv) in CH_2Cl_2 (15 mL) under an Ar atmosphere at 25 °C. The reaction mixture was stirred at 25 °C for 3 h and diluted with 30 mL of CH_2Cl_2 . The excess I_2 was destroyed by adding 50 mL of satd aq $\text{Na}_2\text{S}_2\text{O}_3$. The organic layer was washed with 50 mL of brine, dried over Na_2SO_4 , and filtered, and the solvent was removed under reduced pressure. The residue was purified by flash chromatography (10:1 hexane/EtOAc) to afford 0.73 g of the indicated compound as a yellow solid: mp 85-87 °C; ^1H NMR (CDCl_3) δ 3.72 (s, 3H), 3.79 (dd, $J = 1.2, 5.6$ Hz,

2H), 6.24 (td, $J = 5.6, 16.0$ Hz, 1H), 6.33 (d, $J = 16.0$ Hz, 1H), 7.17-7.31 (m, 8H), 7.43 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 31.0, 59.0, 109.5, 120.5, 121.0, 122.4, 125.4, 126.3, 127.6, 128.7, 130.1, 131.8, 137.1, 137.8, 138.8 (one sp^2 carbon missing due to overlap); IR (CHCl_3 , cm^{-1}) 3055, 3025, 2929, 1674, 1386; HRMS Calcd for $\text{C}_{18}\text{H}_{16}\text{IN}$: 373.0328. Found: 373.0332.

2-Iodo-1-(*E*-3-phenylprop-2-enyl)-1*H*-indole (52). To a suspension of NaH (0.18 g, 4.5 mmol) in dry DMF (15 mL) was added dropwise a solution of 2-iodoindole⁶ (0.73 g, 3.0 mmol) in THF (10 mL) at 0 °C, during which lots of bubbles were generated. The resulting yellow suspension was stirred at 0 °C for 1 h and a solution of cinnamyl bromide (0.59 g, 3.0 mmol) in dry THF (2 mL) was added dropwise at 0 °C. After the reaction mixture was stirred at 0 °C for 20 min, it was warmed up to 25 °C, diluted with 50 mL of Et_2O , and washed with 50 mL of brine. The organic layer was collected, dried over Na_2SO_4 , and filtered, and the solvent was removed under reduced pressure. The residue was purified by flash chromatography (30:1 hexane/ EtOAc) on silica gel to afford 0.61 g of the compound **52** as a white solid: mp 99-101 °C; ^1H NMR (CDCl_3) δ 4.95 (d, $J = 4.8$ Hz, 2H), 6.24 (td, $J = 4.8, 16.0$ Hz, 1H), 6.36 (d, $J = 16.0$ Hz, 1H), 6.84 (s, 1H), 7.07-7.11 (m, 1H), 7.12-7.16 (m, 1H), 7.21-7.29 (m, 5H), 7.35 (d, $J = 8.0$ Hz, 1H), 7.55 (d, $J = 7.6$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 49.2, 83.3, 110.1, 112.6, 119.8, 120.2, 122.1, 124.3, 126.7, 128.0, 128.7, 130.1, 132.4, 136.4, 137.7; IR (CHCl_3 , cm^{-1}) 3077, 3019, 2913, 1455, 1434; HRMS Calcd for $\text{C}_{17}\text{H}_{14}\text{IN}$: 359.0171. Found: 359.0179.

General procedure for preparation of the naphthalenes and carbazoles. To a mixture of the alkyne (0.50 mmol), $\text{Pd}(\text{OAc})_2$ (2.8 mg, 0.025 mmol), PPh_3 (6.6 mg, 0.05 mmol), and Et_3N (55.0 mg, 0.5 mmol) in 2 mL of DMF was added dropwise a solution of the aryl halide (0.25 mmol) in 1 mL of DMF. The resulting mixture was then stirred under an Ar atmosphere at the indicated temperature (see Table 2 in the text). The reaction was monitored by TLC to establish completion. When the reaction was complete, the reaction mixture was allowed to cool to 25 °C, poured into brine (25 mL)

and extracted with EtOAc (3 x 10 mL). The combined organic layers were concentrated and the residue was purified by column chromatography on silica gel to afford the corresponding naphthalene(s) or carbazole(s).

Ethyl 3-(2-ethoxy-2-oxoethyl)-1-ethyl-2-naphthoate (11) and ethyl 3-(2-ethoxy-2-oxoethyl)-2-ethyl-1-naphthoate (12). The reaction mixture was chromatographed using 7:1 hexane/EtOAc to afford 41 mg (52 % yield) of a 60:40 mixture of regioisomers **11/12** as determined by ^1H NMR spectroscopic analysis of the yellow oil. ^1H NMR (CDCl_3) for the major regioisomer **11**: δ 1.22-1.27 (m, 3H), 1.34-1.48 (m, 6H), 3.09 (q, $J = 7.5$ Hz, 2H), 3.81 (s, 2H), 4.16 (q, $J = 7.2$ Hz, 2H), 4.44 (q, $J = 7.2$ Hz, 2H), 7.41-7.56 (m, 2H), 7.64 (s, 1H), 7.76-7.82 (m, 1H), 8.05-8.09 (m, 1H). ^1H NMR (CDCl_3) for the minor regioisomer **12**: δ 1.22-1.27 (m, 6H), 1.34-1.48 (m, 3H), 2.82 (q, $J = 7.5$ Hz, 2H), 3.83 (s, 2H), 4.17 (q, $J = 7.2$ Hz, 2H), 4.54 (q, $J = 7.2$ Hz, 2H), 7.41-7.56 (m, 2H), 7.68-7.71 (m, 1H), 7.76-7.82 (m, 2H). ^{13}C NMR (CDCl_3) for the mixture δ 14.4, 14.4, 14.4, 14.6, 15.5, 15.9, 24.2, 24.7, 39.0, 40.0, 61.2, 61.3, 61.5, 61.6, 124.5, 124.6, 126.0, 126.7, 126.9, 127.0, 128.0, 128.2, 128.6, 128.8, 129.6, 130.7, 131.0, 131.5, 131.6, 131.8, 132.0, 134.1, 137.9, 138.7, 170.0, 170.2, 171.3, 171.6; IR (neat, cm^{-1}) for the mixture 3060, 2979, 2937, 1728, 1449; HRMS Calcd for $\text{C}_{19}\text{H}_{22}\text{O}_4$: 314.1518. Found: 314.1522.

Ethyl (1-methyl-3,4-diphenyl-2-naphthyl)acetate (14). The reaction mixture was chromatographed using 30:1 hexane/EtOAc to afford 68 mg (72 % yield) of the indicated compound as a white solid: mp 80-82 $^{\circ}\text{C}$; ^1H NMR (CDCl_3) δ 1.18 (t, $J = 7.1$ Hz, 3H), 2.72 (s, 1H), 3.69 (s, 2H), 4.08 (q, $J = 7.1$ Hz, 2H), 7.01-7.21 (m, 10H), 7.32-7.38 (m, 1H), 7.48-7.54 (m, 2H), 8.16 (d, $J = 8.4$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 14.4, 15.8, 38.0, 60.8, 124.3, 125.8, 126.0, 126.4, 126.6, 127.6, 127.7, 127.7, 129.3, 130.5, 131.3, 132.1,

132.3, 133.0, 137.5, 139.9, 140.1, 141.0, 171.9; IR (CHCl₃, cm⁻¹) 3018, 1729, 1216; HRMS Calcd for C₂₇H₂₄O₂: 380.1776. Found: 380.1781. Anal. Calcd: C, 85.22; H, 6.35. Found: C, 84.83; H, 6.49.

Ethyl 3-(2-ethoxy-2-oxoethyl)-4-methyl-1-phenyl-2-naphthoate (15) and ethyl 3-(2-ethoxy-2-oxoethyl)-4-methyl-2-phenyl-1-naphthoate (16). The reaction mixture was chromatographed using 7:1 hexane/EtOAc to afford 64 mg (86 % yield) of a 67:33 mixture of regioisomers **15/16** as determined by ¹H NMR spectroscopic analysis of the yellow oil. ¹H NMR (CDCl₃) for the major regioisomer **15**: δ 0.89 (t, *J* = 7.2 Hz, 3H), 1.24 (t, *J* = 7.2 Hz, 3H), 3.95 (s, 2H), 3.96 (q, *J* = 7.2 Hz, 2H), 4.14 (q, *J* = 7.2 Hz, 2H), 7.26-7.59 (m, 8H), 8.12-8.14 (m, 1H). ¹H NMR (CDCl₃) for the minor regioisomer **16**: δ 0.91 (t, *J* = 7.2 Hz, 3H), 1.18 (t, *J* = 7.2 Hz, 3H), 3.67 (s, 2H), 4.02 (q, *J* = 7.2 Hz, 2H), 4.08 (q, *J* = 7.2 Hz, 2H), 7.26-7.59 (m, 7H), 7.85-7.87 (m, 1H), 8.12-8.14 (m, 1H). ¹³C NMR (CDCl₃) for the mixture δ 13.7, 13.9, 14.4, 14.4, 15.5, 15.9, 37.1, 37.5, 60.9, 61.1, 61.1, 61.2, 124.5, 124.6, 125.7, 125.9, 126.2, 126.6, 126.9, 127.0, 127.7, 127.7, 127.8, 128.1, 128.1, 128.8, 129.1, 129.9, 130.7, 130.8, 131.5, 132.1, 133.1, 133.2, 133.9, 135.5, 136.4, 138.5, 138.6, 139.6, 169.5, 169.9, 171.0, 171.5; IR (neat, cm⁻¹) for the mixture 3059, 2980, 2937, 1717, 1228; HRMS Calcd for C₂₄H₂₄O₄: 376.1675. Found: 376.1680.

Ethyl {3,4-bis[(benzyloxy)methyl]-1-methyl-2-naphthyl}acetate (17). The reaction mixture was chromatographed using 10:1 hexane/EtOAc to afford 65 mg of the indicated compound as a yellow solid in a 56 % yield: mp 82-83 °C; ¹H NMR (CDCl₃) δ 1.18 (t, *J* = 7.2 Hz, 3H), 2.64 (s, 3H), 4.01 (s, 2H), 4.05 (q, *J* = 7.2 Hz, 2H), 4.49 (s, 2H),

4.55 (s, 2H), 4.70 (s, 2H), 4.91 (s, 2H), 7.23-7.36 (m, 10H), 7.47-7.50 (m, 2H), 8.04-8.07 (m, 1H), 8.11-8.14 (m, 1H); ^{13}C NMR (CDCl_3) δ 14.4, 15.8, 36.2, 60.9, 65.4, 66.6, 72.8, 72.9, 124.7, 125.3, 126.1, 126.2, 128.0, 128.3, 128.4, 128.6, 128.6, 130.4, 131.6, 132.2, 133.2, 134.4, 134.9, 138.2, 138.4, 171.7 (one sp^2 carbon missing due to overlap); IR (CHCl_3 , cm^{-1}) 3065, 3026, 2975, 2867, 1728, 1326; HRMS Calcd for $\text{C}_{31}\text{H}_{32}\text{O}_4$: 468.2301. Found: 468.2312.

Ethyl *E*-4-(2-iodophenyl)-4-phenyl-3-butenolate (19). The reaction mixture was chromatographed using 15:1 hexane/EtOAc to afford 47 mg (48 % yield) of the indicated compound as a yellow oil: ^1H NMR (CDCl_3) δ 1.25 (t, $J = 7.2$ Hz, 3H), 2.92 (dd, $J = 8.0$, 16.4 Hz, 1H), 3.05 (dd, $J = 6.4$, 16.4 Hz, 1H), 4.15 (q, $J = 7.2$ Hz, 2H), 6.44-6.47 (m, 1H), 7.02-7.06 (m, 1H), 7.19 (dd, $J = 1.6$, 7.6 Hz, 1H), 7.24-7.30 (m, 5H), 7.39-7.43 (m, 1H), 7.92 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 14.5, 35.6, 60.9, 100.0, 121.7, 126.8, 127.7, 128.5, 128.6, 129.2, 130.8, 139.4, 139.7, 144.1, 146.0, 171.6; IR (neat, cm^{-1}) 3059, 2981, 1717; HRMS Calcd for $\text{C}_{18}\text{H}_{17}\text{IO}_2$: 392.0273. Found: 392.0279.

Ethyl 2-(3,4-diphenyl-1,2-dihydronaphthalen-2-yl)acrylate (23). The reaction mixture was chromatographed using 15:1 hexane/EtOAc to afford 69 mg (73 % yield) of the indicated compound as a yellow solid: mp 135-137 $^{\circ}\text{C}$; ^1H NMR (CDCl_3) δ 1.31 (t, $J = 7.2$ Hz, 3H), 2.99 (dd, $J = 2.4$, 16.0 Hz, 1H), 3.47 (dd, $J = 7.2$, 16.0 Hz, 1H), 4.01 (dd, $J = 1.6$, 7.2 Hz, 1H), 4.20-4.25 (m, 2H), 5.80-5.81 (m, 1H), 6.28 (d, $J = 1.2$ Hz, 1H), 6.80 (d, $J = 7.6$ Hz, 1H), 7.00-7.13 (m, 10H), 7.20-7.22 (m, 3H); ^{13}C NMR (CDCl_3) δ 14.4, 34.5, 41.3, 61.1, 126.5, 126.5, 126.6, 126.8, 127.0, 127.6, 127.7, 128.3, 128.4, 128.8, 131.2, 133.6, 136.9, 137.2, 138.6, 138.9, 139.7, 142.0, 167.1; IR (CH_2Cl_2 , cm^{-1}) 3054, 3020, 2981, 2899, 1709, 1264; HRMS Calcd for $\text{C}_{27}\text{H}_{24}\text{O}_2$: 380.1776. Found: 380.1784.

(3,4-Diphenyl-2-naphthyl)acetonitrile (26). The reaction mixture was chromatographed using 10:1 hexane/EtOAc to afford 36 mg or 34 mg of the indicated compound as a yellow solid in 45 % (entry 18) or 43 % (entry 19) yield: mp 193-195 °C; ^1H NMR (CDCl_3) δ 3.61 (d, J = 0.9 Hz, 2H), 7.02-7.10 (m, 4H), 7.17-7.25 (m, 6H), 7.38-7.44 (m, 1H), 7.49-7.57 (m, 2H), 7.95 (d, J = 8.1 Hz, 1H), 8.11 (s, 1H); ^{13}C NMR (CDCl_3) δ 23.5, 118.4, 126.6, 126.8, 126.9, 127.1, 127.2, 127.3, 127.8, 127.9, 128.4, 130.2, 131.0, 132.4, 132.9, 138.2, 138.7, 138.7, 140.1 (one sp^2 carbon missing due to overlap); IR (neat, cm^{-1}) 3020, 2254, 1487, 1442; HRMS Calcd for $\text{C}_{24}\text{H}_{17}\text{N}$: 319.1361. Found: 319.1366.

3-Methyl-1,2-diphenylnaphthalene (29). The reaction mixture was chromatographed using hexane to afford 24 mg (32 % yield) of the indicated compound as a white solid: mp 147-148 °C; ^1H NMR (CDCl_3) δ 2.26 (d, J = 0.6 Hz, 3H), 7.01-7.05 (m, 2H), 7.08-7.24 (m, 8H), 7.28-7.34 (m, 1H), 7.42-7.48 (m, 2H), 7.77 (s, 1H), 7.82-7.85 (m, 1H); ^{13}C NMR (CDCl_3) δ 22.1, 125.5, 125.9, 126.3, 126.5, 127.0, 127.3, 127.6, 127.6, 127.7, 130.3, 131.2, 131.5, 133.1, 134.6, 138.8, 139.6, 140.1, 140.8; IR (CHCl_3 , cm^{-1}) 3019, 1489, 1442, 1215; HRMS Calcd for $\text{C}_{23}\text{H}_{18}$: 294.1408. Found: 294.1413.

Ethyl (6,7-dimethoxy-1,2-dipropyl-3-naphthyl)acetate (32). The reaction mixture was chromatographed using 3:1 hexane/EtOAc to afford 66 mg (73 % yield) of the indicated compound as a pale yellow solid: mp 94-96 °C; ^1H NMR (CDCl_3) δ 1.07 (t, J = 7.2 Hz, 3H), 1.11 (t, J = 7.2 Hz, 3H), 1.25 (t, J = 7.2 Hz, 3H), 1.47-1.60 (m, 2H), 1.63-1.77 (m, 2H), 2.71-2.76 (m, 2H), 2.95-3.01 (m, 2H), 3.76 (s, 2H), 3.96 (s, 3H), 4.00 (s, 3H), 4.17 (q, J = 7.2 Hz, 2H), 7.04 (s, 1H), 7.22 (s, 1H), 7.44 (s, 1H); ^{13}C NMR

(CDCl₃) δ 14.4, 15.0, 15.1, 24.2, 24.6, 31.5, 32.3, 40.0, 55.9, 55.9, 61.0, 103.4, 106.9, 126.8, 127.4, 128.3, 129.8, 135.3, 135.3, 148.8, 149.4, 172.5; IR (CHCl₃, cm⁻¹) 3020, 2958, 2871, 1729, 1510, 1473; HRMS Calcd for C₂₂H₃₀O₄: 358.2144. Found: 358.2148.

Ethyl [1,2-di(benzyloxy)methyl-6,7-dimethoxy-3-naphthyl]acetate (33). The reaction mixture was chromatographed using 2:1 hexane/EtOAc to afford 72 mg (60 % yield) of the indicated compound as a white solid: mp 83-85 °C; ¹H NMR (CDCl₃) δ 1.20 (t, J = 7.2 Hz, 3H), 3.84 (s, 2H), 3.86 (s, 3H), 3.97 (s, 3H), 4.07 (q, J = 7.2 Hz, 2H), 4.52 (s, 2H), 4.53 (s, 2H), 4.70 (s, 2H), 4.88 (s, 2H), 7.04 (s, 1H), 7.30-7.37 (m, 11H), 7.58 (s, 1H); ¹³C NMR (CDCl₃) δ 14.4, 39.5, 55.9, 56.0, 61.0, 65.6, 66.1, 72.7, 72.8, 103.8, 106.5, 128.0, 128.0, 128.2, 128.4, 128.4, 128.6, 128.6, 129.5, 129.7, 130.4, 132.4, 132.5, 138.4, 138.4, 149.8, 149.9, 172.1; IR (CHCl₃, cm⁻¹) 3019, 2939, 1727, 1509, 1259; HRMS Calcd for C₃₂H₃₄O₆: 514.2355. Found: 514.2362.

Ethyl [6,7-dimethoxy-2-phenyl-1-(phenylethynyl)-3-naphthyl]acetate (36) and ethyl [6,7-dimethoxy-1-phenyl-2-(phenylethynyl)-3-naphthyl]acetate (37). The reaction mixture was chromatographed using 3:1 hexane/EtOAc to afford 74 mg (66 % yield) of a 83:17 mixture of regioisomers **36/37** as determined by ¹H NMR spectroscopic analysis of the yellow oil. ¹H NMR (CDCl₃) for the major regioisomer **36**: δ 1.23 (t, J = 7.2 Hz, 3H), 3.74 (s, 2H), 4.00 (s, 3H), 4.04 (s, 3H), 4.18 (q, J = 7.2 Hz, 2H), 6.89 (s, 1H), 7.12 (s, 1H), 7.14-7.55 (m, 10H), 7.63 (s, 1H). ¹H NMR (CDCl₃) for the minor regioisomer **37**: δ 1.16 (t, J = 7.2 Hz, 3H), 3.59 (s, 2H), 4.00-4.05 (m, 5H), 4.08 (s, 3H), 7.14-7.55 (m, 11H), 7.67 (s, 1H), 7.77 (s, 1H). Additional ¹³C NMR (CDCl₃) for the mixture δ 14.3, 14.4, 39.9, 41.1, 55.8, 56.0, 56.1, 60.9, 61.1, 87.9, 88.3, 97.1, 98.2, 105.4,

105.5, 106.5, 106.5, 119.4, 119.5, 123.8, 127.0, 127.2, 127.5, 127.6, 128.1, 128.2, 128.3, 128.4, 128.6, 129.1, 129.3, 130.3, 130.8, 131.3, 131.3, 131.4, 139.6, 140.3, 142.3, 142.5, 149.8, 150.2, 150.2, 150.7, 171.9, 172.0 (five sp^2 carbons and one sp^3 carbon missing due to overlap); IR ($CHCl_3$, cm^{-1}) 3057, 3020, 2980, 1731, 1506, 1255; HRMS Calcd for $C_{30}H_{26}O_4$: 450.1831. Found: 450.1839.

(3-Benzyl-6,7-dimethoxy-2-phenyl-1-naphthyl)methanol (40). The reaction mixture was chromatographed using 1:1 hexane/EtOAc to afford 30 mg (31 % yield) of the indicated compound as a yellow solid: mp 144-146 °C; 1H NMR ($CDCl_3$) δ 1.45 (br s, 1H), 3.80 (s, 2H), 4.00 (s, 3H), 4.04 (s, 3H), 4.75 (s, 2H), 6.88-6.91 (m, 2H), 7.05-7.20 (m, 6H), 7.34-7.38 (m, 3H), 7.48 (s, 1H), 7.54 (s, 1H); ^{13}C NMR ($CDCl_3$) δ 40.5, 56.1, 56.2, 60.5, 103.7, 106.8, 125.9, 126.7, 127.3, 127.8, 128.3, 128.3, 129.2, 129.4, 129.9, 132.7, 135.7, 139.4, 139.9, 141.1, 149.7, 150.0; IR ($CHCl_3$, cm^{-1}) 3354 (br), 3016, 2940, 1509; HRMS Calcd for $C_{26}H_{24}O_3$: 384.1725. Found: 384.1731.

Ethyl 3-benzyl-6,7-dimethoxy-1-phenyl-2-naphthoate (41) and ethyl 3-benzyl-6,7-dimethoxy-2-phenyl-1-naphthoate (42). The reaction mixture was chromatographed using 2:1 hexane/EtOAc to afford 81 mg of compound **41** (76 % yield) as a pale yellow solid and 9 mg of compound **42** (8 % yield) as a yellow oil. Naphthalene **41**: mp 129-131 °C; 1H NMR ($CDCl_3$) δ 0.77 (t, J = 7.2 Hz, 3H), 3.71 (s, 3H), 3.80 (q, J = 7.2 Hz, 2H), 3.97 (s, 3H), 4.19 (s, 2H), 6.83 (s, 1H), 7.05 (s, 1H), 7.18-7.33 (m, 5H), 7.36-7.47 (m, 6H); NOE: H^a - H^b ; ^{13}C NMR ($CDCl_3$) δ 13.7, 39.6, 55.8, 56.1, 60.8, 105.5, 106.3, 126.3, 126.4, 126.9, 127.7, 128.2, 128.5, 129.6, 130.0, 130.3, 131.2, 133.5, 136.9, 138.7, 140.4, 149.7, 150.3, 169.9; IR ($CHCl_3$, cm^{-1}) 3057, 3024, 2962, 1713, 1507; HRMS Calcd for $C_{28}H_{26}O_4$: 426.1831. Found: 426.1831. Anal. Calcd: C, 78.85; H,

6.15. Found: C, 78.69; H, 6.18. Naphthalene **42**: ^1H NMR (CDCl_3): δ 0.89 (t, $J = 7.2$ Hz, 3H), 3.90 (s, 2H), 3.97 (s, 3H), 3.99 (s, 3H), 4.01 (q, $J = 7.2$ Hz, 2H), 6.91-6.93 (m, 2H), 7.07 (s, 1H), 7.14-7.21 (m, 6H), 7.30-7.34 (m, 3H), 7.55 (s, 1H); ^{13}C NMR (CDCl_3) δ 13.9, 39.8, 56.1, 56.1, 61.2, 103.7, 106.4, 124.4, 126.0, 127.4, 128.0, 128.4, 129.0, 129.2, 130.0, 130.5, 135.4, 137.2, 139.4, 141.0, 150.0, 150.4, 169.7 (one sp^2 carbon missing due to overlap); IR (CHCl_3 , cm^{-1}) 3021, 2937, 1714, 1506; HRMS Calcd for $\text{C}_{28}\text{H}_{26}\text{O}_4$: 426.1831. Found: 426.1831.

2-Benzyl-9-methyl-3,4-dipropyl-9H-carbazole (44). The reaction mixture was chromatographed using 20:1 hexane/EtOAc to afford 29 mg (33 % yield) of the indicated compound as a pale yellow solid: mp 113-115 $^{\circ}\text{C}$; ^1H NMR (CDCl_3) δ 1.02 (t, $J = 7.2$ Hz, 3H), 1.19 (t, $J = 7.2$ Hz, 3H), 1.46-1.55 (m, 2H), 1.77-1.84 (m, 2H), 2.70-2.74 (m, 2H), 3.19-3.23 (m, 2H), 3.73 (s, 3H), 4.24 (s, 2H), 7.02 (s, 1H), 7.16-7.24 (m, 4H), 7.25-7.30 (m, 2H), 7.36 (d, $J = 8.0$ Hz, 1H), 7.41-7.45 (m, 1H), 8.07 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 15.1, 15.1, 23.5, 25.3, 29.1, 31.3, 32.7, 40.7, 108.3, 108.5, 118.9, 120.0, 122.4, 123.0, 124.8, 126.1, 128.5, 128.9, 130.3, 136.8, 137.1, 140.0, 141.4, 141.8; IR (CHCl_3 , cm^{-1}) 3018, 2957, 2930, 1597, 1216; HRMS Calcd for $\text{C}_{26}\text{H}_{29}\text{N}$: 355.2300. Found: 355.2310.

2-Benzyl-3,4-bis[(benzyloxy)methyl]-9-methyl-9H-carbazole (45). The reaction mixture was chromatographed using 10:1 hexane/EtOAc to afford 72 mg (56 % yield) of the indicated compound as a pale yellow solid: mp 112-114 $^{\circ}\text{C}$; ^1H NMR (CDCl_3) δ 3.73 (s, 3H), 4.27 (s, 2H), 4.43 (s, 2H), 4.57 (s, 2H), 4.62 (s, 2H), 5.11 (s, 2H), 7.06 (d, $J = 7.2$ Hz, 2H), 7.16-7.25 (m, 5H), 7.28-7.35 (m, 10H), 7.42-7.46 (m, 1H), 8.06 (d, $J = 8.0$ Hz, 1H); ^{13}C NMR (CDCl_3) δ 29.2, 40.1, 65.7, 66.4, 72.8, 72.8, 108.4, 110.9, 115.5, 119.3,

121.5, 122.6, 123.3, 125.4, 126.1, 127.0, 127.9, 127.9, 128.5, 128.5, 128.5, 128.9, 132.7, 138.4, 138.5, 138.6, 141.5, 141.5, 141.7 (one sp^2 carbon missing due to overlap); IR (CHCl_3 , cm^{-1}) 3015, 1597, 1216; HRMS Calcd for $\text{C}_{36}\text{H}_{33}\text{NO}_2$: 511.2511. Found: 511.2520.

2-Benzyl-3,4-bis(hydroxymethyl)-9-methyl-9H-carbazole (46). The reaction mixture was chromatographed using 1:1 hexane/EtOAc to afford 34 mg (41 % yield) of the indicated compound as a yellow solid: mp 191-193 °C; ^1H NMR (CD_3OD) δ 3.31 (s, 1H), 3.31 (s, 1H), 3.75 (s, 3H), 4.35 (s, 2H), 4.84 (s, 2H), 5.30 (s, 2H), 7.12-7.23 (m, 6H), 7.27 (s, 1H), 7.38-7.44 (m, 2H), 8.26 (d, J = 8.0 Hz, 1H); ^{13}C NMR (CD_3OD) δ 29.2, 40.9, 58.5, 59.6, 109.6, 111.7, 120.2, 122.1, 123.7, 124.1, 126.5, 127.1, 129.5, 129.8, 130.1, 136.0, 139.7, 142.6, 142.9, 143.1; IR (CHCl_3 , cm^{-1}) 3397 (br), 3060, 3019, 2924, 1598, 1215; HRMS Calcd for $\text{C}_{22}\text{H}_{21}\text{NO}_2$: 331.1572. Found: 331.1579.

Ethyl 2-benzyl-9-methyl-4-phenyl-9H-carbazole-3-carboxylate (48) and ethyl 2-benzyl-9-methyl-3-phenyl-9H-carbazole-4-carboxylate (49). The reaction mixture was chromatographed using 20:1 hexane/EtOAc to afford 106 mg (91 % yield) of a 60:40 mixture of regioisomers **48/49** as determined by ^1H NMR spectroscopic analysis of the yellow oil. Carbazole **48**: ^1H NMR (CDCl_3) δ 0.80 (t, J = 7.2 Hz, 3H), 3.79 (s, 3H), 3.84 (q, J = 7.2 Hz, 2H), 4.30 (s, 2H), 6.91-6.95 (m, 2H), 7.15 (s, 1H), 7.18-7.23 (m, 1H), 7.27-7.40 (m, 6H), 7.46-7.50 (m, 5H); ^{13}C NMR (CDCl_3) δ 13.7, 29.4, 40.3, 60.8, 108.5, 109.0, 119.3, 119.5, 122.3, 122.8, 125.8, 126.1, 126.3, 127.9, 128.4, 128.6, 129.5, 129.6, 135.9, 136.6, 139.4, 140.9, 141.5, 141.9, 170.2; IR (CHCl_3 , cm^{-1}) 3062, 2981, 1709, 1593; HRMS Calcd for $\text{C}_{29}\text{H}_{25}\text{O}_2\text{N}$: 419.1885. Found: 419.1892. Carbazole **49**: ^1H NMR

(CDCl₃) δ 0.94 (t, J = 7.2 Hz, 3H), 3.81 (s, 3H), 4.01 (s, 2H), 4.11 (dq J = 2.0, 7.2 Hz, 2H), 6.94-6.96 (m, 2H), 7.12-7.25 (m, 6H), 7.29-7.34 (m, 4H), 7.39 (d, J = 8.4 Hz, 1H), 7.46-7.50 (m, 1H), 7.97 (d, J = 8.0 Hz, 1H). Additional ¹³C NMR (CDCl₃) for the mixture: δ 13.8, 13.9, 29.4, 29.4, 40.2, 40.3, 60.8, 61.3, 108.5, 108.7, 109.0, 111.1, 117.6, 119.2, 119.5, 121.1, 121.9, 122.3, 122.8, 125.8, 126.0, 126.1, 126.3, 127.2, 127.8, 127.9, 127.9, 128.4, 128.4, 128.5, 129.1, 129.5, 130.6, 131.4, 135.8, 136.6, 137.3, 139.3, 139.4, 140.7, 140.9, 141.4, 141.5, 141.8, 141.9, 169.8, 170.2 (three sp² carbons missing due to overlap).

Ethyl 2-benzyl-4,9-dimethyl-9H-carbazole-3-carboxylate (50) and ethyl 2-benzyl-3,9-dimethyl-9H-carbazole-4-carboxylate (51). The reaction mixture was chromatographed using 10:1 hexane/EtOAc to afford 69 mg (78 % yield) of a 82:18 mixture of regioisomers **50/51** as determined by ¹H NMR spectroscopic analysis of the yellow oil. Carbazole **50**: ¹H NMR (CDCl₃) δ 1.26 (t, J = 7.2 Hz, 3H), 2.85 (s, 3H), 3.77 (s, 3H), 4.23 (s, 2H), 4.28 (q, J = 7.2 Hz, 2H), 7.03 (s, 1H), 7.20-7.30 (m, 6H), 7.39 (d, J = 8.4 Hz, 1H), 7.46-7.49 (m, 1H), 8.18 (d, J = 7.6 Hz, 1H); NOE: H^a-H^b; ¹³C NMR (CDCl₃) δ 14.3, 18.3, 29.3, 40.5, 61.2, 107.9, 108.6, 119.5, 120.0, 122.8, 123.6, 125.5, 126.3, 126.4, 128.5, 129.3, 131.3, 136.1, 141.0, 141.4, 141.7, 171.0; IR (CHCl₃, cm⁻¹) 3057, 3027, 2983, 2901, 1710, 1596; HRMS Calcd for C₂₄H₂₃O₂N: 357.1729. Found: 357.1734. Carbazole **51**: ¹H NMR (CDCl₃) δ 1.45 (t, J = 7.2 Hz, 3H), 2.33 (s, 3H), 3.76 (s, 3H), 4.19 (s, 2H), 4.59 (q, J = 7.2 Hz, 2H), 7.13-7.30 (m, 7H), 7.34-7.39 (m, 1H), 7.42-7.49 (m, 1H), 7.89 (dd, J = 1.2, 10.4 Hz, 1H); ¹³C NMR (CDCl₃) δ 14.6, 16.4, 29.3, 40.8, 61.7, 108.7, 111.6, 117.8, 119.2, 121.1, 121.4, 124.3, 126.0, 126.3, 127.8, 128.7, 128.9, 137.5, 139.8, 140.4, 141.6.

Ethyl 7-benzyl-9-phenylpyrido[1,2-*a*]indole-8-carboxylate (53). The reaction mixture was chromatographed using 1:1 hexane/EtOAc to afford 34 mg (41 % yield) of the indicated compound as a yellow oil: ^1H NMR (CD_3OD) δ 0.92 (t, $J = 7.2$ Hz, 3H), 4.01 (q, $J = 7.2$ Hz, 2H), 5.28 (d, $J = 2.0$ Hz, 2H), 6.90 (s, 1H), 7.04-7.08 (m, 1H), 7.20-7.28 (m, 3H), 7.33-7.52 (m, 11 H); ^{13}C NMR (CD_3OD) δ 13.8, 43.5, 61.4, 104.2, 109.1, 120.6, 121.7, 123.6, 128.0, 128.2, 128.4, 128.5, 128.6, 128.8, 129.2, 129.3, 129.6, 132.5, 134.4, 136.3, 136.9, 138.5, 168.3 (one sp^2 carbon missing due to overlap); IR (neat, cm^{-1}) 3056, 3026, 2979, 2933, 1717, 1134; HRMS Calcd for $\text{C}_{28}\text{H}_{23}\text{NO}_2$: 405.1729. Found: 405.1735.

References

1. Huang, Q.; Larock, R. C. *Org. Lett.* **2002**, *4*, 2505.
2. Sakamoto, T.; Nagano, T.; Kondo, Y.; Yamanka, H. *Synthesis* **1990**, 215.
3. Negishi, E.; Coperet, C.; Ma, S.; Mita, T.; Sugihara, T.; Tour, J. M. *J. Am. Chem. Soc.* **1996**, *118*, 5904.
4. Gibson, S. E.; Guillo, N.; Middleton, R. J.; Thuilliez, A.; Tozer, M. J. *J. Chem. Soc., Perkin Trans I* **1997**, 447.
5. Bunett, J. F.; Mitchel, E.; Galli, C. *Tetrahedron* **1985**, *41*, 4119.
6. Bergman, J.; Venemalm, L. *J. Org. Chem.* **1992**, *57*, 2495.

compounds 11 and 12, Table 2

data/dat2/nmr300/gh216-5.fid

compound 26, Table 2

data/dat2/nmr300/qh220-3.fid

data/drxl/nmr400/qh281-5.fid