Enantioselective Synthesis of α-Quaternary Mannich Adducts by Palladium-Catalyzed Allylic Alkylation: Total Synthesis of (+)-Sibirinine

Yoshitaka Numajiri, Beau P. Pritchett, Koji Chiyoda, and Brian M. Stoltz*

The Warren and Katharine Schlinger Laboratory for Chemistry and Chemical Engineering, Division of Chemistry and Chemical Engineering, California Institute of Technology

1200 East California Boulevard, MC 101-20, Pasadena, CA 91125, USA

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Materials and Methods

Unless otherwise stated, reactions were performed in flame-dried glassware under an argon or nitrogen atmosphere using dry, deoxygenated solvents. Solvents were dried by passage through an activated alumina column under argon. Reaction progress was monitored by thin-layer chromatography (TLC) or Agilent 1290 UHPLC-LCMS. TLC was performed using E. Merck silica gel 60 F254 precoated glass plates (0.25 mm) and visualized by UV fluorescence quenching, p-anisaldehyde, or KMnO₄ staining. Silicycle SiliaFlash® P60 Academic Silica gel (particle size 40–63 nm) was used for flash chromatography. Melting points were measured with BÜCHI Melting Point B-545. ¹H and ¹³C NMR spectra were recorded on a Varian Inova 500 (500 MHz and 126 MHz, respectively) and a Varian Mercury 300 spectrometer (300 MHz and 76 MHz, respectively) and are reported in terms of chemical shift relative to CHCl₃ (δ 7.26 and δ 77.16, respectively). ¹⁹F NMR spectra were recorded on a Varian Mercury 300 MHz (282 MHz). ¹⁹F NMR spectra were reported relative to CFCl₃ (δ 0.0 ppm). Data for ¹H NMR are reported as follows: chemical shift (δ ppm) (multiplicity, coupling constant (Hz), integration). Multiplicities are reported as follows: s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, sept = septuplet, m = multiplet, br s = broad singlet, br d = broad doublet, br t = broad triplet, app = apparent. Data for ¹³C NMR are reported in terms of chemical shifts (δ ppm). IR spectra were obtained by use of a Perkin Elmer Spectrum BXII spectrometer using thin films deposited on NaCl plates and reported in frequency of absorption (cm⁻¹). Optical rotations were measured with a Jasco P-2000 polarimeter operating on the sodium D-line (589 nm), using a 100 mm path-length cell and are reported as: [a]₀D° (concentration in g/100 mL, solvent). Analytical HPLC was performed with an Agilent 1100 Series HPLC utilizing a Chiralpak (AD-H or AS) or Chiralcel (OD-H, OJ-H, or OB-H) columns (4.6 mm x 25 cm) obtained from Daicel Chemical Industries, Ltd. Analytical SFC was performed with a Mettler SFC supercritical CO₂ analytical chromatography system utilizing Chiralpak (AD-H, AS-H or IC) or Chiralcel (OD-H, OJ-H, or OB-H) columns (4.6 mm x 25 cm) obtained from Daicel Chemical Industries, Ltd. High resolution mass spectra (HRMS) were obtained from the Caltech Mass Spectral Facility using a JEOL JMS-600H High Resolution Mass Spectrometer in
fast atom bombardment (FAB+) or electron ionization (EI+) mode, or Agilent 6200 Series TOF with an Agilent G1978A Multimode source in electrospray ionization (ESI+), atmospheric pressure chemical ionization (APCI+), or mixed ionization mode (MM: ESI/APCI).

Reagents were purchased from Sigma-Aldrich, Acros Organics, Strem, or Alfa Aesar and used as received unless otherwise stated. Et$_3$N was distilled from calcium hydride prior to use. MeOH was distilled from magnesium methoxide immediately prior to use. (S)-(CF$_3$)$_3$-t-BuPHOX, $^2$ tris(4,4'-methoxydibenzylideneacetone)dipalladium(0) Pd$_2$(pmdba)$_3$, $^3$ sulfonyl carbamates 2a–g $^4$, and 1,3-dicarbonyl compound 1 $^5$, 5a–h$^6$ were prepared by known methods.

**List of Abbreviations:**
General Procedure A: α-Aminomethyl 1,3-dicarbonyl Substrate Synthesis

Allyl 1-(((tert-butoxycarbonyl)amino)methyl)-2-oxocyclohexane-1-carboxylate (3a).

To a stirred solution of β-keto ester 1 (0.91 g, 5.0 mmol, 1 equiv) in CH₂Cl₂ (25 mL) was added sulfonylmethyl carbamate 2a (1.63 g, 6.0 mmol, 1.2 equiv) in one portion at ambient temperature. After stirring for 5 min, Cs₂CO₃ (4.70 g, 12.5 mmol, 2.5 equiv) was added in one portion. After 12 h, full consumption of starting material was determined by TLC analysis. Saturated aqueous ammonium chloride was added slowly, and the biphasic mixture was stirred at ambient temperature for 20 min and extracted with CH₂Cl₂ (3 x 25 mL). The combined organic layers were dried over Na₂SO₄, filtered, and concentrated in vacuo. Flash column chromatography (SiO₂, 10% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3a (1.55 g, 99% yield) as a faintly yellow oil. Rᵋ = 0.55 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 5.91 (ddt, J = 16.5, 10.4, 5.8 Hz, 1H), 5.33 (m, 1H), 5.25 (m, 1H), 5.17 (m, 1H), 4.63 (m, 2H), 3.54 (dd, J = 13.9, 7.7 Hz, 1H), 3.40 (dd, J = 13.9, 5.7 Hz, 1H), 2.59–2.41 (m, 3H), 1.99 (m, 1H), 1.81 (m, 1H), 1.73–1.51 (m, 3H), 1.40 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 209.0, 171.0, 156.0, 131.6, 119.2, 79.4, 66.4, 62.4, 44.4, 40.9, 33.9, 28.5, 27.3, 22.2; IR (Neat Film, NaCl) 3461, 3404, 2976, 2939, 2867, 1713, 1501, 1452, 1366, 1247, 1229, 1168, 1141 cm⁻¹; HRMS (FAB+) m/z calc’d for C₁₆H₂₆NO₅ [M+H]⁺: 312.1811, found 312.1824.
Spectroscopic Data for 3b–g and 6a–i

**Allyl 1-(benzyloxy carbonylaminomethyl)-2-oxocyclohexane-1-carboxylate (3b).**

The reaction was conducted according to general procedure A. Keto ester 1 (1.66 g, 9.09 mmol); sulfonylmethyl carbamate 2b (3.33 g, 10.9 mmol); Cs2CO3 (7.40 g, 22.7 mmol). The reaction mixture was stirred for 18 h. Flash column chromatography (SiO2, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3b (2.95 g, 8.54 mmol, 94% yield) as a colorless oil. Rf = 0.27 (20% EtOAc in hexanes); 1H NMR (500 MHz, CDCl3) δ 7.38–7.28 (m, 5H), 5.86 (ddt, J = 16.6, 10.5, 5.9 Hz, 1H), 5.41 (m, 1H), 5.32 (m, 1H), 5.23 (m, 1H), 5.11–5.01 (m, 2H), 4.63–4.52 (m, 2H), 3.62 (dd, J = 13.8, 7.7 Hz, 1H), 3.46 (dd, J = 13.8, 5.6 Hz, 1H), 2.59–2.42 (m, 3H), 2.00 (m, 1H), 1.81 (m, 1H), 1.72–1.53 (m, 3H); 13C NMR (126 MHz, CDCl3) δ 208.8, 170.7, 156.5, 136.6, 131.5, 128.6, 128.2, 128.1, 119.3, 66.8, 66.4, 62.2, 44.8, 40.9, 33.9, 27.2, 22.1; IR (Neat Film, NaCl) 3450, 3394, 2943, 1724, 1711, 1509, 1453, 1265, 1219, 1141, 981 cm⁻¹; HRMS (ESI+) m/z calc’d for C19H24NO5 [M+H]+: 346.1649, found 346.1634.

**Allyl 1-((4-methoxyphenoxy) carbonylaminomethyl)-2-oxocyclohexane-1-carboxylate (3c).**

The reaction was conducted according to general procedure A. Keto ester 1 (182 mg, 1.00 mmol); sulfonylmethyl carbamate 2c (386 mg, 1.20 mmol); Cs2CO3 (910 mg, 2.50 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO2, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3c (265 mg, 0.733 mmol, 73% yield) as a colorless oil. Rf = 0.18 (20% EtOAc in hexanes); 1H NMR (500 MHz, CDCl3) δ 7.01–6.97 (m, 2H), 6.88–6.82 (m, 2H), 5.91 (m, 1H), 5.67 (m, 1H), 5.34 (m, 1H), 5.26 (m, 1H), 4.67–4.64 (m, 2H), 3.78 (s, 3H), 3.67 (dd, J = 13.9, 7.7 Hz, 1H), 3.53
(dd, $J = 13.9, 5.6$ Hz, 1H), 2.62–2.46 (m, 3H), 2.03 (m, 1H), 1.84 (m, 1H), 1.76–1.58 (m, 3H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 208.9, 170.7, 157.0, 155.3, 144.7, 131.5, 122.4, 119.4, 114.4, 66.5, 62.2, 55.7, 45.0, 40.9, 34.0, 27.2, 22.1; IR (Neat Film, NaCl) 3377, 2943, 1742, 1732, 1709, 1545, 1514, 1489, 1480, 1210, 1055 cm$^{-1}$; HRMS (ESI+) $m/z$ calc’d for C$_{19}$H$_{24}$NO$_6$ [M+H]$^+$: 362.1598, found 362.1601.

**Allyl 1-((phenoxycarbonylamino)methyl)-2-oxocyclohexane-1-carboxylate (3d).**

![Diagram of Allyl 1-((phenoxycarbonylamino)methyl)-2-oxocyclohexane-1-carboxylate (3d).]

The reaction was conducted according to general procedure A. Keto ester 1 (182 mg, 1.00 mmol); sulfonylmethyl carbamate 2d (350 mg, 1.20 mmol); Cs$_2$CO$_3$ (910 mg, 2.50 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO$_2$, 15% EtOAc in hexanes) afforded $\alpha$-aminomethyl $\beta$-keto ester 3d (310 mg, 0.936 mmol, 94% yield) as a colorless oil. $R_f = 0.25$ (20% EtOAc in hexanes); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.37–7.29 (m, 2H), 7.18 (m, 1H), 7.12–7.05 (m, 2H), 5.92 (ddt, $J = 17.3, 10.5, 5.9$ Hz, 1H), 5.71 (m, 1H), 5.34 (m, 1H), 5.26 (m, 1H), 4.71–4.62 (m, 2H), 3.68 (dd, $J = 13.9, 7.8$ Hz, 1H), 3.53 (dd, $J = 13.9, 5.6$ Hz, 1H), 2.64–2.47 (m, 3H), 2.04 (m, 1H), 1.84 (m, 1H), 1.77–1.58 (m, 3H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 208.9, 170.7, 154.8, 151.1, 131.5, 129.3, 125.4, 121.6, 119.5, 66.5, 62.1, 45.0, 40.9, 34.0, 27.3, 22.1; IR (Neat Film, NaCl) 3377, 2943, 1745, 1728, 1709, 1514, 1489, 1202, 1143 cm$^{-1}$; HRMS (ESI+) $m/z$ calc’d for C$_{19}$H$_{24}$NO$_6$ [M+H]$^+$: 332.1492, found 332.1483.

**Allyl 1-((4-fluorophenoxy)carbonylamino)methyl)-2-oxocyclohexane-1-carboxylate (3e).**

![Diagram of Allyl 1-((4-fluorophenoxy)carbonylamino)methyl)-2-oxocyclohexane-1-carboxylate (3e).]
The reaction was conducted according to general procedure A. Keto ester 1 (182 mg, 1.00 mmol); sulfonylmethyl carbamate 2e (371 mg, 1.20 mmol); Cs₂CO₃ (910 mg, 2.50 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3e (278 mg, 0.796 mmol, 80% yield) as a colorless oil. R_f = 0.28 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.08–6.98 (m, 4H), 5.91 (ddt, J = 17.2, 10.5, 5.9 Hz, 1H), 5.72 (m, 1H), 5.34 (m, 1H), 5.26 (m, 1H), 4.68–4.60 (m, 2H), 3.67 (dd, J = 13.9, 7.8 Hz, 1H), 3.52 (dd, J = 13.9, 5.5 Hz, 1H), 2.64–2.46 (m, 3H), 2.04 (m, 1H), 1.83 (m, 1H), 1.76–1.57 (m, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 208.9, 170.7, 160.0 (J = 243 Hz), 154.8, 147.0 (J = 4 Hz), 131.4, 123.0 (J = 9 Hz), 119.5, 115.9 (J = 23 Hz), 66.6, 62.1, 45.1, 40.9, 34.0, 27.3, 22.1; IR (Neat Film, NaCl) 3377, 2944, 1746, 1732, 1711, 1497, 1219, 1193, 1147 cm⁻¹; HRMS (ESI+) m/z calc’d for C₁₈H₂₁FNO₅ [M+H]^+: 350.1398, found 350.1392.

Allyl 1-(benzamidomethyl)-2-oxocyclohexane-1-carboxylate (3f).

The reaction was conducted according to general procedure A. Keto ester 1 (182 mg, 1.00 mmol); sulfonylmethyl carbamate 2f (413 mg, 1.50 mmol); Cs₂CO₃ (977 mg, 3.0 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3f (250 mg, 0.793 mmol, 79% yield) as a white amorphous solid. R_f = 0.30 (40% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.72 – 7.67 (m, 2H), 7.49 – 7.44 (m, 1H), 7.42 – 7.36 (m, 2H), 6.96 – 6.87 (m, 1H), 5.83 (ddt, J = 17.2, 10.4, 6.0 Hz, 1H), 5.27 (dq, J = 17.1, 1.4 Hz, 1H), 5.18 (dq, J = 10.4, 1.2 Hz, 1H), 4.65 – 4.52 (m, 2H), 3.96 (dd, J = 13.6, 7.7 Hz, 1H), 3.65 (dd, J = 13.6, 5.2 Hz, 1H), 2.61 – 2.49 (m, 3H), 2.05 – 1.97 (m, 1H), 1.87 – 1.81 (m, 1H), 1.75 – 1.58 (m, 3H); ¹³C NMR (126 MHz, CDCl₃) δ 209.5, 170.8, 167.4, 134.4, 131.6, 131.4, 128.6, 127.0, 119.5, 66.6, 62.2, 43.3, 40.9, 34.2, 27.2, 22.1; IR (Neat Film, NaCl) 3447, 3356, 3061, 3028, 2943, 2866, 1712, 1667, 1651, 1602, 1580, 1519, 1488, 1450, 1307, 1280, 1203, 1142 cm⁻¹; HRMS (ESI+) m/z calc’d for C₁₈H₂₂NO₄ [M+H]^+: 316.1543, found 316.1559.
Allyl 1-(((4-methylphenyl)sulfonamido)methyl)-2-oxocyclohexane-1-carboxylate (3g).

The reaction was conducted according to general procedure A. Keto ester 1 (182 mg, 1.00 mmol); sulfonylmethyl carbamate 2g (488 mg, 1.50 mmol); Cs₂CO₃ (977 mg, 3.0 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 25% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 3g (365 mg, 0.999 mmol, >99% yield) as a clear colorless oil. R₎ = 0.25 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.73 – 7.69 (m, 2H), 7.30 (dd, J = 8.4, 1.0 Hz, 2H), 5.88 (ddt, J = 17.2, 10.4, 5.9 Hz, 1H), 5.32 (dq, J = 17.2, 1.5 Hz, 1H), 5.27 (dq, J = 10.4, 1.2 Hz, 1H), 5.20 (dd, J = 8.3, 5.8 Hz, 1H), 4.61 (dt, J = 5.9, 1.3 Hz, 2H), 3.21 (dd, J = 12.5, 8.4 Hz, 1H), 3.06 (dd, J = 12.5, 5.8 Hz, 1H), 2.65 – 2.56 (m, 1H), 2.46 – 2.36 (m, 4H), 2.06 – 1.97 (m, 1H), 1.82 – 1.76 (m, 1H), 1.72 – 1.58 (m, 4H); ¹³C NMR (126 MHz, CDCl₃) δ 209.0, 170.4, 143.6, 137.0, 131.4, 129.9, 127.1, 119.6, 66.6, 61.6, 47.2, 40.9, 34.1, 27.0, 22.1, 21.7; IR (Neat Film, NaCl) 3289, 2942, 2867, 1728, 1709, 1451, 1335, 1206, 1163, 1092 cm⁻¹; HRMS (FAB+) m/z calc’d for C₁₈H₂₄NO₅S [M+H]⁺: 366.1375, found 366.1367.

2-Phenylallyl 1-(((tert-butoxycarbonyl)amino)methyl)-2-oxocyclohexane-1-carboxylate (6a).

The reaction was conducted according to general procedure A. Keto ester 5a (311 mg, 1.2 mmol); sulfonylmethyl carbamate 2a (392 mg, 1.44 mmol); Cs₂CO₃ (977 mg, 3.0 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6a (368 mg, 0.95 mmol, 79% yield) as a pale yellow oil. R₎ = 0.5 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.42 – 7.38 (m, 2H), 7.36 – 7.32 (m, 2H), 7.31 – 7.27 (m, 1H), 5.53 (d, J = 0.9
Hz, 1H), 5.37 (q, $J = 1.1$ Hz, 1H), 5.1 (d, $J = 13.0$ Hz, 1H), 5.07 (t, $J = 7.0$ Hz, 1H), 5.01 (d, $J = 13.0$, 1H), 3.48 (dd, $J = 13.9, 7.6$ Hz, 1H), 3.35 (dd, $J = 13.9, 5.8$ Hz, 1H), 2.38 – 2.27 (m, 2H), 2.26 – 2.18 (m, 1H), 1.81 (m, 1H), 1.69 – 1.63 (m, 1H), 1.60 – 1.50 (m, 1H), 1.49 – 1.41 (m, 2H), 1.39 (s, 9H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 208.7, 170.8, 155.0, 142.4, 137.9, 128.7, 128.3, 126.3, 116.3, 79.4, 66.9, 62.3, 44.3, 40.6, 33.7, 28.4, 27.2, 21.9; IR (Neat Film, NaCl) 3458, 3411, 2975, 2938, 2866, 1715, 1499, 1365, 1167, 1141 cm$^{-1}$; HRMS (ESI+) $m/z$ calc’d for C$_{22}$H$_{29}$NO$_5$Na $[M+Na]^+$: 410.1938, found 410.1923.

**Allyl 1-((t-butoxycarbonylaminomethyl)-2-oxocycloheptane-1-carboxylate (6b).**

![Chemical Structure]

The reaction was conducted according to general procedure A. Keto ester 5b (196 mg, 1.00 mmol); sulfonylmethyl carbamate 2a (326 mg, 1.20 mmol); Cs$_2$CO$_3$ (815 mg, 2.50 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO$_2$, 15% EtOAc in hexanes) afforded $\alpha$-aminomethyl $\beta$-keto ester 6b (234 mg, 0.719 mmol, 72% yield) as a colorless oil. $R_f$ = 0.47 (20% EtOAc in hexanes); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 5.90 (m, 1H), 5.32 (m, 1H), 5.25 (m, 1H), 5.18 (m, 1H), 4.68 – 4.56 (m, 2H), 3.56 (dd, $J = 14.0, 7.7$ Hz, 1H), 3.50 (dd, $J = 14.0, 5.8$ Hz, 1H), 2.68 (m, 1H), 2.56 (ddd, $J = 13.0, 8.3, 3.3$ Hz, 1H), 2.08 (m, 1H), 1.86 – 1.76 (m, 2H), 1.73 – 1.48 (m, 5H), 1.40 (s, 9H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 210.2, 171.7, 156.1, 131.7, 119.0, 79.4, 66.2, 63.9, 45.3, 42.7, 31.7, 30.1, 28.4, 25.7, 25.3; IR (Neat Film, NaCl) 3461, 2976, 2933, 1718, 1501, 1456, 1366, 1248m 1225, 1169 cm$^{-1}$; HRMS (ESI+) $m/z$ calc’d for C$_{17}$H$_{25}$NO$_5$Na $[M+Na]^+$: 348.1781, found 348.1772.

**Allyl 1-((t-butoxycarbonylaminomethyl)-2-oxocyclopentane-1-carboxylate (6c).**

![Chemical Structure]
The reaction was conducted according to general procedure A. Keto ester 5c (168 mg, 1.00 mmol); sulfonylmethyl carbamate 2a (326 mg, 1.20 mmol); Cs₂CO₃ (815 mg, 2.50 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6c (255 mg, 0.858 mmol, 86% yield) as a colorless oil. Rᵣ = 0.50 (33% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 5.87 (ddt, J = 17.2, 10.4, 5.6 Hz, 1H), 5.29 (m, 1H), 5.24 (m, 1H), 5.13 (m, 1H), 4.67 – 4.55 (m, 2H), 3.50 (dd, J = 14.0, 7.0 Hz 1H), 3.46 (dd, J = 14.0, 6.0 Hz, 1H), 2.49 – 2.34 (m, 3H), 2.16 – 1.98 (m, 3H), 1.42 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 213.7, 171.3, 156.3, 131.5, 118.8, 79.7, 66.1, 61.5, 42.1, 38.2, 31.7, 28.4, 19.8; IR (Neat Film, NaCl) 3394, 2976, 1749, 1715, 1504, 1454, 1366, 1229, 1168, 966 cm⁻¹; HRMS (ESI+) m/z calc’d for C₁₅H₂₃NO₅Na [M+Na]⁺: 320.1468, found 320.1467.

Allyl 1-(((tert-butoxycarbonyl)amino)methyl)-4-isobutoxy-2-oxocyclohept-3-ene-1-carboxylate (6d).

The reaction was conducted according to general procedure A. Keto ester 5d⁸ (100 mg, 0.375 mmol); sulfonylmethyl carbamate 2a (122 mg, 0.45 mmol); Cs₂CO₃ (305 mg, 0.936 mmol). The reaction mixture was stirred for 10 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6d (123 mg, 0.311 mmol, 83% yield) as a clear oil. Rᵣ = 0.5 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 5.87 (ddt, J = 17.3, 10.5, 5.7 Hz, 1H), 5.38 (s, 1H), 5.29 (dq, J = 17.2, 1.6 Hz, 1H), 5.21 (dq, J = 10.5, 1.3 Hz, 1H), 4.63 (ddt, J = 13.2, 5.9, 1.4 Hz, 1H), 4.56 (ddt, J = 13.3, 5.8, 1.4 Hz, 1H), 3.64 (dd, J = 13.7, 7.8 Hz, 1H), 3.51 – 3.44 (m, 3H), 2.55 (ddd, J = 17.9, 10.0, 4.2 Hz, 1H), 2.44 (ddd, J = 17.8, 7.1, 3.8 Hz, 1H), 2.36 (m, 1H), 2.03 – 1.94 (m, 2H), 1.89 – 1.76 (m, 2H), 1.40 (s, 9H), 0.94 (dd, J = 6.7, 1.5 Hz, 6H); ¹³C NMR (126 MHz, CDCl₃) δ 198.1, 174.9, 172.1, 156.1, 131.7, 118.8, 105.3, 79.3, 74.9, 66.2, 63.9, 46.4, 34.2, 29.3, 28.5, 27.9, 21.3, 19.2; IR (Neat Film, NaCl) 3459, 3394, 3083, 2961, 2934, 2874, 1734, 1718, 1636, 1610, 1499, 1388, 1366, 1232, 1171 cm⁻¹; HRMS (ESI+) m/z calc’d for C₂₁H₃₃NO₆Na [M+Na]⁺: 418.2200, found 418.2192.
Allyl 2-((tert-butoxycarbonyl)amino)methyl)-1-oxo-1,2,3,4-tetrahydronaphthalene-2-carboxylate (6e).

![Chemical Structure of 6e](image)

The reaction was conducted according to general procedure A. Keto ester 5e\(^7\) (230.3 mg, 1.0 mmol); sulfonylmethyl carbamate 2a (326 mg, 1.2 mmol); Cs\(_2\)CO\(_3\) (815 mg, 2.5 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO\(_2\), 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6e (395 mg, 0.999 mmol, >99% yield) as a pale yellow oil. \(R_f = 0.5\) (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 8.03 (dd, \(J = 8.0, 1.4\) Hz, 1H), 7.49 (td, \(J = 7.5, 1.5\) Hz, 1H), 7.34 – 7.29 (m, 1H), 7.23 (dq, \(J = 7.8, 0.7\) Hz, 1H), 5.86 – 5.76 (m, 1H), 5.33 – 5.27 (m, 1H), 5.22 – 5.14 (m, 2H), 4.61 (dt, \(J = 2.4, 1.4\) Hz, 1H), 4.59 (dt, \(J = 2.4, 1.4\) Hz, 1H), 3.79 (dd, \(J = 13.9, 7.9\) Hz, 1H), 3.56 (dd, \(J = 13.9, 5.4\) Hz, 1H), 3.10 (dt, \(J = 17.5, 5.4\) Hz, 1H), 3.02 (ddd, \(J = 17.4, 9.4, 4.8\) Hz, 1H), 2.57 (dt, \(J = 13.8, 5.3\) Hz, 1H), 2.20 (ddd, \(J = 14.1, 9.5, 5.0\) Hz, 1H), 1.41 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 195.6, 171.0, 156.1, 143.4, 134.1, 131.9, 131.5, 129.0, 128.0, 127.0, 118.7, 79.5, 66.1, 59.4, 43.6, 29.3, 28.5, 25.8; IR (Neat Film, NaCl) 3454, 3395, 2977, 2934, 1731, 1717, 1683, 1601, 1505, 1456, 1366, 1235, 1170 cm\(^{-1}\); HRMS (FAB+) \(m/z\) calc’d for C\(_{20}\)H\(_{26}\)NO\(_5\) [M+H]\(^+\) : 360.1811, found 360.1801.

Allyl 1-benzyl-3-((tert-butoxycarbonyl)amino)methyl)-4-oxopiperidine-3-carboxylate (6f).

![Chemical Structure of 6f](image)

The reaction was conducted according to general procedure A. Keto ester 5f\(^7\) (296 mg, 1.08 mmol); sulfonylmethyl carbamate 2a (353 mg, 1.296 mmol); Cs\(_2\)CO\(_3\) (882 mg, 2.7 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO\(_2\), 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6f (349 mg, 0.867 mmol,
80% yield) as a clear colorless oil. $R_f = 0.45 \text{ (25\% EtOAc in hexanes); } ^1H \text{ NMR (500 MHz, C}_6\text{D}_6) \delta 7.20 – 7.12 \text{ (m, 4H), 7.11 – 7.05 (m, 1H), 5.71 (ddt, } J = 16.5, 10.9, 5.7 \text{ Hz, 1H), 5.37 (t, } J = 6.8 \text{ Hz, 1H), 5.09 (dd, } J = 17.2, 1.6 \text{ Hz, 1H), 4.94 (dq, } J = 10.4, 1.3 \text{ Hz, 1H), 4.47 (d, } J = 5.8, 1.4 \text{ Hz, 2H), 3.63 (dd, } J = 13.9, 6.0 \text{ Hz, 1H), 3.57 (dd, } J = 13.9, 7.4 \text{ Hz, 1H), 3.23 – 3.20 \text{ (m, 1H), 3.19 (d, } J = 13.5 \text{ Hz, 1H), 3.10 (d, } J = 13.4 \text{ Hz, 1H), 2.65 (ddd, } J = 14.3, 10.0, 6.7 \text{ Hz, 1H), 2.37 – 2.29 \text{ (m, 2H), 1.99 (d, } J = 11.6, 1H), 1.93 – 1.87 \text{ (m, 1H), 1.37 (s, 9H); } ^13\text{C NMR (126 MHz, C}_6\text{D}_6) \delta 205.9, 170.5, 155.9, 138.3, 132.2, 129.0, 128.7, 127.6, 118.4, 79.0, 66.1, 62.9, 61.9, 58.9, 53.1, 43.0, 40.3, 28.4; \text{ IR (Neat Film, NaCl) 3457, 2976, 2925, 2811, 1718, 1499, 1366, 1250, 1225, 1169 cm}^{-1}; \text{ HRMS (FAB+) } m/z \text{ calc’d for C}_{22}\text{H}_{31}\text{N}_{2}\text{O}_{5} [M+H]^+: 403.2233, \text{ found 403.2238.}

**Allyl 1-benzoyl-3-(tert-butoxycarbonylaminomethyl)-2-oxopiperidine-3-carboxylate (6g).**

![Chemical Structure](image)

The reaction was conducted according to general procedure A. Amido ester 5g (231 mg, 0.800 mmol); sulfonylmethyl carbamate 2a (261 mg, 0.960 mmol); Cs$_2$CO$_3$ (652 mg, 2.00 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO$_2$, 15→20% EtOAc in hexanes) afforded α-aminomethyl amido ester 6g (245 mg, 0.588 mmol, 74% yield) as a colorless oil. $R_f = 0.36 \text{ (33\% EtOAc in hexanes); } ^1H \text{ NMR (500 MHz, CDCl}_3) \delta 7.81 – 7.74 \text{ (m, 2H), 7.50 (m, 1H), 7.44 – 7.36 (m, 2H), 5.97 (ddt, } J = 16.6, 10.4, 6.0 \text{ Hz, 1H), 5.40 (m, 1H), 5.33 (m, 1H), 5.15 (m, 1H), 4.82 – 4.63 \text{ (m, 2H), 3.91 – 3.74 \text{ (m, 2H), 3.71 (dd, } J = 13.9, 7.5 \text{ Hz, 1H), 3.50 (dd, } J = 13.9, 5.9 \text{ Hz, 1H), 2.43 (m, 1H), 2.12 – 1.91 \text{ (m, 3H), 1.41 (s, 9H); } ^13\text{C NMR (126 MHz, CDCl}_3) \delta 174.9, 172.2, 170.7, 156.1, 135.6, 132.1, 131.3, 128.3, 128.3, 119.9, 79.7, 66.8, 58.4, 46.8, 44.7, 29.1, 28.4, 20.0; \text{ IR (Neat Film, NaCl) 3446, 2976, 1714, 1684, 1500, 1449, 1391, 1366, 1271, 1249, 1164, 1141, 939 cm}^{-1}; \text{ HRMS (ESI+) } m/z \text{ calc’d for C}_{22}\text{H}_{28}\text{N}_{2}\text{O}_{6}\text{Na [M+Na]^+: 439.1840, found 439.1854.}
Allyl 4-benzoyl-2-(tert-butoxycarbonylaminomethyl)-3-oxomorpholine-2-carboxylate (6h).

The reaction was conducted according to general procedure A. Morpholinone 5h (100 mg, 0.346 mmol); sulfonylmethyl carbamate 2a (188 mg, 0.691 mmol); Cs₂CO₃ (338 mg, 1.04 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 20→25% EtOAc in hexanes) afforded α-aminomethyl morpholinone 6h (132 mg, 0.315 mmol, 91% yield) as a colorless oil. Rᵣ = 0.34 (10% EtOAc in toluene); ¹H NMR (500 MHz, CDCl₃) δ 7.67 – 7.65 (m, 2H), 7.52 (m, 1H), 7.43 – 7.38 (m, 2H), 5.97 (m, 1H), 5.41 (m, 1H), 5.33 (m, 1H), 5.00 (břs, 1H), 4.76 – 4.73 (m, 2H), 4.30 – 4.17 (m, 2H), 4.05 – 3.90 (m, 2H), 3.87 – 3.72 (m, 2H), 1.42 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 172.7, 167.7, 167.5, 155.8, 134.7, 132.5, 131.0, 128.5, 128.3, 119.9, 83.1, 79.9, 67.2, 62.1, 45.0, 44.8, 28.4; IR (Neat Film, NaCl) 3388, 2977, 2934, 1746, 1714, 1507, 1449, 1367, 1317, 1279, 1233, 1165, 1066, 944, 757, 727, 693 cm⁻¹; HRMS (ESI+) m/z calc’d for C₂₁H₂₆N₂O₇Na [M+Na]⁺: 441.1632, found 441.1636.

Allyl 3-(((tert-butoxycarbonyl)amino)methyl)-4-oxo-9-tosyl-2,3,4,9-tetrahydro-1H-carbazole-3-carboxylate (6i).

The reaction was conducted according to general procedure A. Keto ester 5i⁹ (400 mg, 0.994 mmol); sulfonylmethyl carbamate 2a (307 mg, 1.13 mmol); Cs₂CO₃ (770 mg, 2.36 mmol). The reaction mixture was stirred for 24 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded α-aminomethyl β-keto ester 6i (418 mg, 0.756 mmol, 80% yield) as a clear colorless oil. Rᵣ = 0.33 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 8.21 – 8.17 (m, 1H), 8.15 – 8.12 (m, 1H), 7.78 (d, J = 8.4 Hz, 2H), 7.38 – 7.31 (m, 2H), 7.27 (d, J = 8.4 Hz, 2H), 5.80 (m, 1H), 5.25 – 5.17 (m, 2H), 5.15 (m, 1H),
4.58 (dt, $J = 5.8$, 1.4 Hz, 2H), 3.74 (dd, $J = 14.0$, 7.7 Hz, 1H), 3.59 (m, 2H), 3.41 (ddd, $J = 19.2$, 8.3, 5.2 Hz, 1H), 2.67 (dt, $J = 13.9$, 5.4 Hz, 1H), 2.37 (s, 3H), 2.28 (m, 1H), 1.42 (s, 9H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 191.4, 170.6, 156.1, 150.7, 146.1, 136.2, 135.3, 131.5, 130.4, 126.9, 125.8, 125.7, 125.2, 121.9, 118.9, 117.1, 114.0, 79.6, 66.2, 59.3, 43.3, 29.2, 28.5, 22.1, 21.8; IR (Neat Film, NaCl) 3445, 3054, 2977, 2933, 2254, 1733, 1713, 1596, 1558, 1505, 1481, 1451, 1410, 1380, 1244, 1174, 1090 cm$^{-1}$; HRMS (ESI+) $m/z$ calc’d for C$_{29}$H$_{33}$N$_2$O$_7$S [M+H]$^+$: 553.2003, found 553.1994.
General Procedure B: Palladium-Catalyzed Allylic Alkylation

Please note that the absolute configuration of all products 4 and 7 has been inferred from previous studies, with the exception of 4b, which was assigned by conversion to (–)-isonitramine. For isolated yields, see manuscript Tables 1 and 2. For GC, HPLC, or SFC conditions, as well as optical rotation data, please refer to Table S1.

(S)-Tert-butyl ((1-allyl-2-oxocyclohexyl)methyl)carbamate (4a). In a nitrogen-filled glove box, [Pd$_2$(dba)$_3$] (9.2 mg, 0.010 mmol, 0.05 equiv) and (S)-(CF$_3$)$_3$-t-BuPHOX L1 (14.8 mg, 0.025 mmol, 0.125 equiv) were added to a 20 mL scintillation vial equipped with a magnetic stirring bar. The vial was then charged with toluene (4.1 mL) and stirred at 25 °C for 30 min, generating a yellow solution. To the preformed catalyst solution was added a solution of 3a (62.3 mg, 0.20 mmol, 1 equiv) in toluene (2.0 mL). The vial was sealed and stirred at 25 °C until the full consumption of β-keto ester 3a was observed by TLC analysis. The reaction mixture was concentrated in vacuo. Flash column chromatography (SiO$_2$, 2% EtOAc in CH$_2$Cl$_2$ eluent) afforded α-quaternary ketone 4a (50.2 mg, 94% yield) as a colorless oil. 86% ee, [α]$_D^{25}$ −25.5 (c 0.865, C$_6$H$_6$); R$_f$ = 0.55 (5% EtOAc in DCM); $^1$H NMR (500 MHz, C$_6$D$_6$) δ 5.64 (m, 1H), 5.05 (br t, $J = 6.4$ Hz, 1H), 4.94 (ddt, $J = 10.1$, 2.0, 1.0 Hz, 1H), 4.87 (dq, $J = 17.0$, 1.5 Hz, 1H), 3.30 (dd, $J = 13.9$, 7.2 Hz, 1H), 3.24 (dd, $J = 13.9$, 6.1 Hz, 1H), 2.15 – 2.08 (m, 2H), 2.01 – 1.91 (m, 2H), 1.44 (s, 9H), 1.41 – 1.30 (m, 2H), 1.25 – 1.12 (m, 2H); $^{13}$C NMR (126 MHz, C$_6$D$_6$) δ 213.5, 156.2, 133.3, 118.5, 78.7, 53.1, 45.2, 39.1, 37.9, 33.7, 28.5, 27.1, 20.6; IR (Neat Film, NaCl) 3462, 3395, 2977, 2939, 2867, 1718, 1499, 1167 cm$^{-1}$; HRMS (ESI$^+$) m/z
calc’d for C$_{15}$H$_{25}$NO$_3$Na [M+Na$^+$]: 290.1727, found 290.1718; SFC conditions: 10% IPA, 2.5 mL/min, Chiralpak AD-H column, $\lambda = 210$ nm, $t_R$ (min): major = 7.65, minor = 8.46.

**Spectroscopic Data for 4b–g and 7a–i**

**(S)-Benzyl (1-allyl-2-oxocyclohexyl)methylcarbamate (4b).**

The reaction was conducted according to general procedure B. Keto ester 3b (69.1 mg, 0.200 mmol). The reaction mixture was stirred at 23 °C for 14 h. Flash column chromatography (SiO$_2$, 10→15% EtOAc in hexanes) afforded ketone 4b (57.7 mg, 0.191 mmol, 96% yield) as a colorless oil. 86% ee, $\alpha$D$_{25}$ –38.6 (c 1.20, CHCl$_3$); $R_f = 0.44$ (25% EtOAc in hexanes); $^1$H NMR (300 MHz, CDCl$_3$) $\delta$ 7.42 – 7.25 (m, 5H), 5.67 (m, 1H), 5.21 (m, 1H), 5.16 – 5.00 (m, 4H), 3.34 (dd, $J = 13.9$, 5.9 Hz, 1H), 3.24 (dd, $J = 13.9$, 7.4 Hz, 1H), 2.54 – 2.20 (m, 4H), 1.99 (m, 1H), 1.81 – 1.60 (m, 5H); $^{13}$C NMR (126 MHz, CDCl$_3$) $\delta$ 215.5, 156.9, 136.7, 132.2, 128.6, 128.2, 128.1, 119.2, 66.8, 53.2, 45.4, 39.3, 38.0, 33.7, 27.2, 20.6.; IR (Neat Film, NaCl) 3351, 2937, 1722, 1702, 1510, 1454, 1234, 1134 cm$^{-1}$; HRMS (ESI+) m/z calc’d for C$_{18}$H$_{24}$NO$_3$ [M+H]$^+$: 302.1751, found 302.1756; SFC conditions: 5% IPA, 2.5 mL/min, Chiralpak AD-H column, $\lambda = 210$ nm, $t_R$ (min): major = 8.12, minor = 9.06.

**(S)-4-methoxyphenyl (1-allyl-2-oxocyclohexyl)methylcarbamate (4c).**

The reaction was conducted according to general procedure B. Keto ester 3c (72.3 mg, 0.200 mmol). The reaction mixture was stirred at 23 °C for 24 h. Flash column chromatography (SiO$_2$, 15→20% EtOAc in hexanes) afforded ketone 4c (57.6 mg, 0.181 mmol, 91% yield) as a colorless oil. 83% ee, $\alpha$D$_{25}$ –29.3 (c 0.76, CHCl$_3$); $R_f = 0.25$ (25% EtOAc in hexanes); $^1$H NMR (500 MHz, CDCl$_3$) $\delta$ 7.05 – 6.97 (m, 2H), 6.90 – 6.81
(m, 2H), 5.70 (m, 1H), 5.49 (m, 1H), 5.18 – 5.09 (m, 2H), 3.78 (s, 3H), 3.40 (dd, \(J = 13.9, 6.0\) Hz, 1H), 3.28 (dd, \(J = 13.9, 7.2\) Hz, 1H), 2.55 – 2.44 (m, 2H), 2.41 – 2.28 (m, 2H), 2.03 (m, 1H), 1.90 – 1.64 (m, 5H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 215.6, 157.0, 155.6, 144.8, 132.2, 122.5, 119.3, 114.4, 55.7, 53.2, 45.6, 39.4, 38.0, 33.8, 27.3, 20.6; IR (Neat Film, NaCl) 3345, 2937, 1740, 1700, 1501, 1201 cm\(^{-1}\); HRMS (ESI+) \(m/z\) calc’d for \(C_{18}H_{24}NO_4\) [M+H]: 318.1700, found 318.1705; SFC conditions: 10% IPA, 2.5 mL/min, Chiralcel OB-H column, \(\lambda = 210\) nm, \(t_R\) (min): major = 9.47, minor = 11.13.

\((S)-\)phenyl (1-allyl-2-oxocyclohexyl)methylcarbamate (4d).

![Formula Image]

The reaction was conducted according to general procedure B. Keto ester 3d (66.3 mg, 0.200 mmol). The reaction mixture was stirred at 23 ºC for 24 h. Flash column chromatography (SiO\(_2\), 10→15% EtOAc in hexanes) afforded ketone 4d (51.5 mg, 0.179 mmol, 90% yield) as a colorless oil. 77% ee, \([\alpha]_D^{25}\) −28.9 (c 0.40, CHCl\(_3\)); \(R_f\) = 0.29 (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 7.34 (t, \(J = 7.7\) Hz, 2H), 7.17 (m, 1H), 7.11 (d, \(J = 8.0\) Hz, 2H), 5.70 (m, 1H), 5.53 (m, 1H), 5.20 – 5.11 (m, 2H), 3.41 (dd, \(J = 14.0, 6.0\) Hz, 1H), 3.29 (dd, \(J = 14.0, 7.2\) Hz, 1H), 2.55 – 2.45 (m, 2H), 2.42 – 2.29 (m, 2H), 2.03 (m, 1H), 1.90 – 1.65 (m, 5H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 215.7, 155.1, 151.2, 132.1, 129.3, 125.3, 121.6, 119.4, 53.2, 45.6, 39.4, 38.0, 33.8, 27.3, 20.6; IR (Neat Film, NaCl) 3346, 2937, 1743, 1701, 1501, 1203 cm\(^{-1}\); HRMS (ESI+) \(m/z\) calc’d for \(C_{17}H_{22}NO_3\) [M+H]: 288.1594, found 288.1589; SFC conditions: 10% IPA, 2.5 mL/min, Chiralcel OB-H column, \(\lambda = 210\) nm, \(t_R\) (min): major = 6.53, minor = 8.13.

\((S)-4\)-fluorophenyl (1-allyl-2-oxocyclohexyl)methylcarbamate (4e).

![Formula Image]
The reaction was conducted according to general procedure B. Keto ester 3e (69.9 mg, 0.200 mmol). The reaction mixture was stirred at 23 °C for 24 h. Flash column chromatography (SiO2, 10→15% EtOAc in hexanes) afforded ketone 4e (51.4 mg, 0.168 mmol, 84% yield) as a colorless oil. 77% ee, [α]D 25 = –27.4 (c 0.78, CHCl3); Rf = 0.37 (25% EtOAc in hexanes); 1H NMR (500 MHz, CDCl3) δ 7.10 – 6.97 (m, 4H), 5.69 (m, 1H), 5.54 (m, 1H), 5.17 – 5.10 (m, 2H), 3.40 (dd, J = 13.9, 6.0 Hz, 1H), 3.27 (dd, J = 13.9, 7.2 Hz, 1H), 2.55 – 2.45 (m, 2H), 2.41 – 2.29 (m, 2H), 2.04 (m, 1H), 1.91 – 1.63 (m, 5H); 13C NMR (126 MHz, CDCl3) δ 215.7, 160.0 (J = 243 Hz), 155.1, 147.1 (J = 4 Hz), 132.1, 123.1 (J = 7 Hz), 119.4, 115.9 (J = 24 Hz), 53.2, 45.6, 39.4, 37.9, 33.8, 27.3, 20.6; IR (Neat Film, NaCl) 3347, 2938, 1742, 1699, 1498, 1192 cm⁻¹; HRMS (ESI+) m/z calc’d for C17H21FNO3 [M+H]+: 306.1500, found 306.1493; SFC conditions: 10% IPA, 2.5 mL/min, Chiralpak AS-H column, λ = 210 nm, tR (min): major = 6.94, minor = 8.24.

(S)-N-((1-allyl-2-oxocyclohexyl)methyl)benzamide (4f).

The reaction was conducted according to general procedure B. Keto ester 3f (19.1 mg, 0.60 mmol). The reaction mixture was stirred at 23 °C for 20 h. Flash column chromatography (SiO2, 10→15% EtOAc in hexanes) afforded ketone 4f as a colorless oil. 56% ee, Rf = 0.23 (25% EtOAc in hexanes); 1H NMR (500 MHz, CDCl3) δ 7.76 – 7.72 (m, 2H), 7.49 (m, 1H), 7.45 – 7.40 (m, 2H), 6.78 (m, 1H), 5.66 (m, 1H), 5.15 (d, J = 1.2 Hz, 1H), 5.12 (m, 1H), 3.58 (dd, J = 13.8, 6.1 Hz, 1H), 3.55 (dd, J = 13.8, 6.1 Hz, 1H), 2.56 – 2.47 (m, 2H), 2.40 – 2.32 (m, 2H), 2.03 (m, 1H), 1.92 – 1.79 (m, 2H), 1.77 – 1.61 (m, 3H); 13C NMR (126 MHz, CDCl3) δ 216.6, 167.5, 134.7, 132.3, 131.6, 128.7, 127.0, 119.4, 53.5, 43.9, 39.5, 38.3, 34.1, 27.4, 20.6; IR (Neat Film, NaCl) 3439, 3338, 3070, 2936, 2864, 1693, 1668, 1649, 1535, 1515, 1486, 1454, 1286, 1127 cm⁻¹; HRMS (ESI/APCI) m/z calc’d for C17H22NO2 [M+H]+: 272.1645, found 272.1638; SFC conditions: 20% IPA, 2.5 mL/min, Chiralpak AD-H column, λ = 210 nm, tR (min): major = 4.04, minor = 4.91.
(S)-N-((1-allyl-2-oxocyclohexyl)methyl)-4-methylbenzenesulfonamide (4g).

The reaction was conducted according to general procedure B. Keto ester 3g (74.0 mg, 0.202 mmol). The reaction mixture was stirred at 23 °C for 20 h. Flash column chromatography (SiO₂, 15% EtOAc in hexanes) afforded ketone 4g (35.3 mg, 0.109 mmol, 54% yield) as a yellow oil. 24% ee, Rf = 0.3 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.71 (m, 2H), 7.30 (dd, J = 8.3, 0.9 Hz, 2H), 5.61 (ddddd, J = 16.3, 10.8, 7.9, 6.9 Hz, 1H), 5.11 – 5.06 (m, 3H), 2.97 (dd, J = 12.6, 6.7 Hz, 1H), 2.70 (dd, J = 12.6, 7.5 Hz, 1H), 2.50 – 2.43 (m, 2H), 2.41 (s, 3H), 2.31 – 2.21 (m, 2H), 2.01 (m, 1H), 1.84 – 1.55 (m, 5H); ¹³C NMR (126 MHz, CDCl₃) δ 215.7, 143.4, 137.0, 131.5, 129.9, 127.0, 119.7, 52.5, 47.7, 39.2, 37.4, 33.4, 27.1, 21.6, 20.5; IR (Neat Film, NaCl) 3285, 3071, 2865, 1919, 1762, 1703, 1638, 1598, 1495, 1454, 1333, 1164, 1091 cm⁻¹; HRMS (ESI⁺) m/z calc’d for C₁₇H₂₄NO₃S [M+H]⁺: 322.1471, found 322.1456; SFC conditions: 15% IPA, 2.5 mL/min, Chiralcel OJ-H column, λ = 210 nm, t_R (min): major = 3.14, minor = 3.85.

(S)-tert-butyl ((2-oxo-1-(2-phenylallyl)cyclohexyl)methyl)carbamate (7a).

The reaction was conducted according to general procedure B. Keto ester 6a (110 mg, 0.284 mmol); [Pd₂(pmdba)₃] (15.6 mg, 0.014 mmol, 0.05 equiv). The reaction mixture was stirred at 23 °C for 24 h. Flash column chromatography (SiO₂, 20% acetone in hexanes) afforded ketone 7a (88.7 mg, 0.258 mmol, 91% yield) as a yellow oil. 90% ee, [α]D₂⁵ –30.9 (c 4.45, CHCl₃); Rf = 0.55 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.32 – 7.26 (m, 5H), 5.23 (d, J = 1.4 Hz, 1H), 5.08 (d, J = 2.0 Hz, 1H), 4.67 (dd, J = 8.3, 4.4 Hz, 1H), 3.16 (dd, J = 14.0, 8.5 Hz, 1H), 3.09 (dd, J = 13.9, 4.7 Hz, 1H), 2.99 (d, J = 14.1 Hz, 1H), 2.71 (d, J = 14.1 Hz, 1H), 2.38 (ddd, J = 14.4, 10.8, 5.7 Hz, 1H), 2.30 (dt, J = 13.9, 4.8 Hz, 1H), 1.87 (dt, J = 15.3, 5.5 Hz, 1H), 1.77 – 1.60 (m, 5H), 1.38 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 214.9, 156.3, 144.9, 142.7, 128.6, 127.7,
126.7, 118.3, 79.1, 54.0, 44.9, 39.8, 39.7, 34.4, 28.5, 27.2, 20.9; IR (Neat Film, NaCl) 3463, 3374, 2975, 2935, 2865, 1713, 1703, 1699, 1505, 1455, 1365, 1247, 1169 cm⁻¹; HRMS (FAB+) m/z calc’d for C₂₁H₃₀NO₃ [M+H]⁺: 344.2226, found 344.2236; SFC conditions: 15% IPA, 2.5 mL/min, Chiralpak AD-H column, λ = 210 nm, tᵣ (min): major = 2.46, minor = 2.78.

(S)-tert-Butyl (1-allyl-2-oxocycloheptyl)methylcarbamate (7b).

The reaction was conducted according to general procedure B. Keto ester 6b (97.6 mg, 0.300 mmol). The reaction mixture was stirred at 23 °C for 20 h. Flash column chromatography (SiO₂, 10→15% EtOAC in hexanes) afforded ketone 7b (78.7 mg, 0.280 mmol, 93% yield) as a pale yellow oil. 87% ee, [α]D²⁵ = 22.7 (c 0.85, CHCl₃); Rᵣ = 0.53 (20% EtOAC in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 5.72 (ddt, J = 17.3, 10.4, 7.5 Hz, 1H), 5.12 – 5.03 (m, 2H), 4.93 (brs, 1H), 3.31 – 3.19 (m, 2H), 2.65 – 2.56 (m, 1H), 2.46 (ddt, J = 11.3, 8.8, 2.5 Hz, 1H), 2.35 (m, 1H), 2.20 (m, 1H), 1.79 – 1.41 (m, 8H), 1.41 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 217.1, 156.2, 133.2, 118.8, 79.3, 54.8, 45.2, 41.1, 39.4, 33.3, 30.8, 28.5, 26.7, 24.7; IR (Neat Film, NaCl) 3372, 2930, 1716, 1698, 1503, 1365, 1247, 1117 cm⁻¹; HRMS (ESI+) m/z calc’d for C₁₇H₂₈NO₃ [M+H]⁺: 282.2064, found 282.2051; SFC conditions: 5% IPA, 2.5 mL/min, Chiralpak AD-H column, λ = 210 nm, tᵣ (min): major = 4.25, minor = 4.63.

(S)-tert-Butyl (1-allyl-2-oxocyclopentyl)methylcarbamate (7c).

The reaction was conducted according to general procedure B. Keto ester 6c (59.5 mg, 0.200 mmol). The reaction mixture was stirred at 23 °C for 20 h. Flash column chromatography (SiO₂, 10→15% EtOAc in hexanes) afforded ketone 7c (50.0 mg, 0.196 mmol, 98% yield) as a colorless oil. 82% ee, [α]D²⁵ = -12.8 (c 0.96, CHCl₃); Rᵣ = 0.38 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 5.69 (ddt, J = 17.4, 10.2, 7.4
Hz, 1H), 5.14 – 5.05 (m, 2H), 4.86 (brs, 1H), 3.25 (dd, \( J = 13.9, 6.9 \) Hz, 1H), 3.14 (dd, \( J = 13.9, 5.7 \) Hz, 1H), 2.30 – 2.23 (m, 2H), 2.20 – 2.13 (m, 2H), 1.99 – 1.79 (m, 4H), 1.43 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 222.6, 156.3, 133.0, 119.1, 79.5, 52.5, 44.0, 38.4, 37.5, 31.1, 28.5, 18.8; IR (Neat Film, NaCl) 3360, 2975, 1713, 1510, 1365, 1248, 1166 cm\(^{-1}\); HRMS (ESI+) \( m/z \) calc’d for C\(_{14}\)H\(_{23}\)NO\(_3\)Na \([M+Na]^+\): 276.1570, found 276.1565; SFC conditions: 5% IPA, 2.5 mL/min, Chiralpak AD-H column, \( \lambda = 210 \) nm, \( t_R \) (min): major = 2.97, minor = 4.26.

\((\text{S})\text{-}\text{tert-butyl (}(1\text{-allyl-4-isobutoxy-2-oxocyclohept-3-en-1-yl})\text{methyl)carbamate (7d).}\)

The reaction was conducted according to general procedure B. Keto ester 6d (100 mg, 0.253 mmol); [Pd\(_2\)(pmdba)\(_3\)] (13.9 mg, 0.012 mmol, 0.05 equiv). The reaction mixture was stirred at 23 \( ^{\circ} \)C for 24 h. Flash column chromatography (SiO\(_2\), 10% EtOAc in hexanes) afforded ketone 7d (62.2 mg, 0.177 mmol, 70% yield) as a pale yellow oil. 92% ee, \([\alpha]_{D}^{25} = -28.7 \) (c 0.65, CHCl\(_3\)); \( R_f = 0.6 \) (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \( \delta \) 5.70 (ddt, \( J = 17.5, 10.3, 7.4 \) Hz, 1H), 5.28 (s, 1H), 5.10 – 5.03 (m, 3H), 3.53 – 3.44 (m, 2H), 3.33 (dd, \( J = 13.6, 6.4 \) Hz, 1H), 3.18 (dd, \( J = 13.6, 6.4 \) Hz, 1H), 2.55 – 2.42 (m, 2H), 2.37 – 2.28 (m, 2H), 1.98 (dt, \( J = 13.3, 6.7 \) Hz, 1H), 1.94 – 1.87 (m, 1H), 1.81 – 1.72 (m, 3H), 1.41 (s, 9H), 0.95 (d, \( J = 6.7 \) Hz, 6H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \( \delta \) 205.8, 172.7, 156.4, 133.4, 118.8, 104.9, 79.1, 74.7, 55.5, 47.1, 41.3, 36.1, 31.6, 28.6, 28.0, 20.5, 19.3; IR (Neat Film, NaCl) 3373, 3075, 2972, 2931, 2868, 1716, 1694, 1504, 1393, 1366, 1249, 1166 cm\(^{-1}\); HRMS (FAB+) \( m/z \) calc’d for C\(_{20}\)H\(_{34}\)NO\(_4\) \([M+H]^+\): 352.2488, found 352.2474; SFC conditions: 3% IPA, 2.5 mL/min, Chiralpak AS-H column, \( \lambda = 254 \) nm, \( t_R \) (min): major = 4.41, minor = 6.12.

\((\text{S})\text{-}\text{tert-butyl (}(2\text{-allyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl})\text{methyl)carbamate (7e).}\)

O
HN\text{Boc}
O
i\text{Bu}
O
HN\text{Boc}
O
\text{Boc}
The reaction was conducted according to general procedure B. Keto ester \(6e\) (81 mg, 0.225 mmol); \([\text{Pd}_2(\text{pmdba})_3]\) (12.3 mg, 0.011 mmol, 0.05 equiv). The reaction mixture was stirred at 23 °C for 24 h. Flash column chromatography (SiO\(_2\), 10% EtOAc in hexanes) afforded ketone \(7e\) (52.2 mg, 0.167 mmol, 74% yield) as a pale yellow oil. 93% ee, \([\alpha]_D^{25} = -1.3\) (c 1.32, CHCl\(_3\)); \(R_f = 0.6\) (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 8.00 (dd, \(J = 8.0, 1.4\) Hz, 1H), 7.48 (td, \(J = 7.5, 1.5\) Hz, 1H), 7.30 (td, \(J = 7.6, 1.2\) Hz, 1H), 7.23 (d, \(J = 7.6\) Hz, 1H), 5.79 (m, 1H), 5.15 – 5.05 (m, 3H), 3.50 (dd, \(J = 13.9, 6.2\) Hz, 1H), 3.29 (dd, \(J = 13.9, 6.9\) Hz, 1H), 3.11 (ddd, \(J = 16.9, 11.1, 5.3\) Hz, 1H), 2.94 (dt, \(J = 17.5, 4.6\) Hz, 1H), 2.37 (dd, \(J = 14.2, 8.0\) Hz, 1H), 2.28 (dd, \(J = 14.2, 6.8\) Hz, 1H), 2.11 (ddd, \(J = 14.0, 11.1, 5.2\) Hz, 1H), 2.03 (dt, \(J = 14.0, 4.7\) Hz, 1H), 1.41 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 202.2, 156.4, 143.5, 133.7, 132.7, 131.6, 129.0, 127.9, 126.9, 119.2, 79.2, 49.3, 44.8, 36.6, 28.9, 28.5, 25.0; IR (Neat Film, NaCl) 3449, 3378, 3073, 2976, 2930, 1716, 1699, 1678, 1600, 1505, 1455, 1365, 1232, 1170 cm\(^{-1}\); HRMS (FAB+) \(m/z\) calc’d for \(C_{19}H_{26}NO_3\) [M+H]\(^+\): 316.1913, found 316.1920; SFC conditions: 15% IPA, 2.5 mL/min, Chiralpak AD-H column, \(\lambda = 210\) nm, \(t_R\) (min): major = 2.48, minor = 2.80.

(S)-\textit{tert}-butyl ((3-allyl-1-benzyl-4-oxopiperidin-3-yl)methyl)carbamate (7f).

\[
\begin{align*}
\text{O} & \quad \text{NHBoc} \\
\text{Bn} & \quad \text{NHBoc}
\end{align*}
\]

The reaction was conducted according to general procedure B. Keto ester \(6f\) (115 mg, 0.286 mmol); \([\text{Pd}_2(\text{pmdba})_3]\) (15.7 mg, 0.014 mmol, 0.05 equiv). The reaction mixture was stirred at 23 °C for 24 h. Flash column chromatography (SiO\(_2\), 10% EtOAc in hexanes) afforded ketone \(7f\) (79.3 mg, 0.223 mmol, 78% yield) as a pale yellow oil. 90% ee, \([\alpha]_D^{25} = -34.0\) (c 1.58, CHCl\(_3\)); \(R_f = 0.55\) (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 7.37 – 7.27 (m, 5H), 5.61 (m, 1H), 5.07 (m, 1H), 5.04 (d, \(J = 1.1\) Hz, 1H), 5.00 (m, 1H), 3.58 (d, \(J = 13.0\) Hz, 1H), 3.53 (d, \(J = 13.0\) Hz, 1H), 3.37 (dd, \(J = 14.0, 7.3\) Hz, 1H), 3.19 (dd, \(J = 14.0, 5.7\) Hz, 1H), 2.84 (m, 1H), 2.69 (d, \(J = 11.6\) Hz, 1H), 2.63 – 2.50 (m, 3H), 2.48 – 2.36 (m, 3H), 1.41 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 212.8, 156.2, 138.3, 132.6, 129.0, 128.5, 127.4, 119.2, 79.3, 62.3, 59.7, 53.6, 53.1, 44.1,
39.5, 38.1, 28.5; IR (Neat Film, NaCl) 3452, 3373, 3063, 2976, 2929, 2807, 1713, 1638, 1504, 1453, 1391, 1365, 1248, 1170 cm⁻¹; HRMS (FAB+) m/z calc’d for C₂₁H₃₁N₂O₃ [M+H]⁺: 359.2335, found 359.2345; SFC conditions: 8% IPA, 2.5 mL/min, Chiralpak AD-H column, λ = 210 nm, tᵣ (min): major = 4.94, minor = 6.46.

(S)-tert-Butyl ((3-allyl-1-benzoyl-2-oxopiperidin-3-yl)methyl)carbamate (7g).

The reaction was conducted according to general procedure B. Amido ester 6g (83.3 mg, 0.200 mmol). The reaction mixture was stirred at 40 ºC for 20 h. Flash column chromatography (SiO₂, 15→20% EtOAc in hexanes) afforded lactam 7g (69.7 mg, 0.187 mmol, 94%) as a colorless oil. 90% ee, [α]D²⁵ +33.6 (c 1.05, CHCl₃); Rᵣ = 0.29 (25% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.56 – 7.46 (m, 3H), 7.44 – 7.37 (m, 2H), 5.78 (m, 1H), 5.24 – 5.15 (m, 2H), 4.96 (m, 1H), 3.84 (m, 1H), 3.73 (dd, J = 12.7, 10.3, 4.3 Hz, 1H), 3.37 (dd, J = 13.8, 6.5 Hz, 1H), 3.22 (dd, J = 13.8, 6.5 Hz, 1H), 2.60 (dd, J = 13.8, 8.0 Hz, 1H), 2.48 (dd, J = 13.8, 6.7 Hz, 1H), 2.12 – 1.93 (m, 3H), 1.82 (m, 1H), 1.42 (s, 9H); ¹³C NMR (126 MHz, CDCl₃) δ 178.6, 175.4, 156.4, 136.3, 131.9, 131.8, 128.4, 127.6, 120.1, 79.5, 48.8, 47.2, 46.0, 39.7, 28.8, 28.5, 19.3; IR (Neat Film, NaCl) 3373, 2975, 1693, 1678, 1502, 1391, 1365, 1248, 1170 cm⁻¹; HRMS (ESI+) m/z calc’d for C₂₁H₂₈N₂O₄Na [M+Na]⁺: 395.1941, found 395.1954; SFC conditions: 10% MeOH, 3.0 mL/min, Chiralpak AD-H column, λ = 254 nm, tᵣ (min): major = 2.64, minor = 3.12.

(R)-tert-Butyl ((2-allyl-4-benzoyl-3-oxomorpholin-2-yl)methyl)carbamate (7h).

The reaction was conducted according to general procedure B. Morpholinone 6h (33.0 mg, 0.079 mmol). The reaction mixture was stirred at 40 ºC for 12 h. Flash column chromatography (SiO₂, 15→20% EtOAc in hexanes) afforded morpholinone 7h (27.3 mg, 0.073 mmol, 92%) as a colorless oil. 99% ee, [α]D²⁵ +10.8 (c 0.93, CHCl₃); Rᵣ = 0.43
(33% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 7.57 – 7.48 (m, 3H), 7.43 – 7.38 (m, 2H), 5.89 (m, 1H), 5.23 – 5.17 (m, 2H), 4.88 (br s, 1H), 4.14 – 3.88 (m, 4H), 3.63 (m, 1H), 3.40 (dd, \(J = 14.1\), 5.6 Hz, 1H), 2.69 (dd, \(J = 14.3\), 7.4 Hz, 1H), 2.52 (dd, \(J = 14.3\), 7.0 Hz, 1H), 1.44 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 173.0, 172.6, 155.9, 135.6, 132.1, 131.7, 128.3, 128.1, 119.9, 82.2, 79.9, 60.6, 46.0, 45.5, 40.0, 28.5; IR (Neat Film, NaCl) 3382, 2978, 1707, 1689, 1509, 1367, 1281, 1250, 1225, 1166, 1091 cm\(^{-1}\); HRMS (ESI+) \(m/z\) calc’d for C\(_{20}\)H\(_{26}\)N\(_2\)O\(_5\)Na \([M+Na]^+\): 397.1734, found 397.1728; SFC conditions: 3% MeOH, 2.5 mL/min, Chiralpak AS-H column, \(\lambda\) = 254 nm, \(t_R\) (min): major = 4.06, minor = 4.62.

(S)-\emph{tert}-butyl ((3-allyl-4-oxo-9-tosyl-2,3,4,9-tetrahydro-1H-carbazol-3-yl)methyl)carbamate (7i).

![Chemical Structure](image)

The reaction was conducted according to general procedure B. Keto ester 6i (100 mg, 0.181 mmol); [Pd\(_2\)(pmdba)\(_3\)] (10.0 mg, 0.009 mmol, 0.05 equiv). The reaction mixture was stirred at 40 \(^\circ\)C for 48 h. Flash column chromatography (SiO\(_2\), 10% EtOAc in hexanes) afforded ketone 7i (46.9 mg, 0.091 mmol, 51% yield) as a white foam.\(^1\) 92% ee, \([\alpha]_D^{25}\) = –13.3 (c 0.28, C\(_6\)H\(_6\)); \(R_f\) = 0.45 (25% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\)) \(\delta\) 8.20 (m, 1H), 8.16 (dd, \(J = 7.3\), 1.8 Hz, 1H), 7.77 (d, \(J = 8.4\) Hz, 2H), 7.41 – 7.31 (m, 2H), 7.28 (m, 2H), 5.77 (m, 1H), 5.11 (m, 1H), 5.08 (dd, \(J = 17.1\), 1.8 Hz, 1H), 5.05 (br t, \(J = 6.7\) Hz, 1H), 3.49 (dd, \(J = 13.9\), 6.2 Hz, 1H), 3.44 (dt, \(J = 19.2\), 4.8 Hz, 1H), 3.33 – 3.28 (m, 1H), 3.27 (dd, \(J = 13.9\), 7.0 Hz, 1H), 2.38 (s, 3H), 2.32 – 2.28 (m, 2H), 2.16 – 2.11 (m, 2H), 1.40 (s, 9H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta\) 199.1, 156.4, 150.1, 146.1, 136.4, 135.6, 132.9, 130.5, 126.8, 126.0, 125.6, 125.1, 121.9, 119.3, 116.6, 114.1, 79.4, 49.4, 44.6, 37.5, 29.5, 28.5, 21.8, 21.6; IR (Neat Film, NaCl) 3432, 3372, 3058, 2976, 2928, 1712, 1657, 1505, 1451, 1407, 1366, 1247, 1173 cm\(^{-1}\); HRMS (ESI+) \(m/z\) calc’d for C\(_{28}\)H\(_{33}\)N\(_2\)O\(_5\)S \([M+H]^+\): 509.2105, found 509.2094; SFC conditions: 15% IPA, 2.5 mL/min, Chiralcel OB-H column, \(\lambda\) = 210 nm, \(t_R\) (min): major = 7.21, minor = 5.19.
<table>
<thead>
<tr>
<th>entry</th>
<th>compound</th>
<th>analytic conditions</th>
<th>ee (%)</th>
<th>polarimetry</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td><img src="image" alt="4a" /></td>
<td>SFC: 5% IPA, 2.5 mL/min Chiralpak AD-H, ( \lambda = 210 ) nm ( t_R ) (min): major 3.73, minor 4.30</td>
<td>86</td>
<td>([\alpha]_D^{25} = -25.5) (c 0.865, C(_6)H(_6))</td>
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<tr>
<td>2</td>
<td><img src="image" alt="4b" /></td>
<td>SFC: 5% IPA, 2.5 mL/min Chiralpak AD-H, ( \lambda = 210 ) nm ( t_R ) (min): major 8.12, minor 9.06</td>
<td>86</td>
<td>([\alpha]_D^{25} = -38.6) (c 1.20, CHCl(_3))</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="4c" /></td>
<td>SFC: 10% IPA, 2.5 mL/min Chiralcel OB-H, ( \lambda = 210 ) nm ( t_R ) (min): major 9.47, minor 11.13</td>
<td>83</td>
<td>([\alpha]_D^{25} = -29.3) (c 0.76, CHCl(_3))</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="4d" /></td>
<td>SFC: 10% IPA, 2.5 mL/min Chiralcel OB-H, ( \lambda = 210 ) nm ( t_R ) (min): major 6.53, minor 8.13</td>
<td>77</td>
<td>([\alpha]_D^{25} = -28.9) (c 0.40, CHCl(_3))</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="4e" /></td>
<td>SFC: 10% IPA, 2.5 mL/min Chiralpak AS-H, ( \lambda = 210 ) nm ( t_R ) (min): major 6.94, minor 8.24</td>
<td>77</td>
<td>([\alpha]_D^{25} = -27.4) (c 0.78, CHCl(_3))</td>
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<tr>
<td>6</td>
<td><img src="image" alt="4f" /></td>
<td>SFC: 20% IPA, 2.5 mL/min Chiralpak AD-H, ( \lambda = 210 ) nm ( t_R ) (min): major 4.04, minor 4.91</td>
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<td>Specific Rotation Not Determined</td>
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<td>7</td>
<td><img src="image" alt="4g" /></td>
<td>SFC: 15% IPA, 2.5 mL/min Chiralcel OJ-H, ( \lambda = 210 ) nm ( t_R ) (min): major 3.14, minor 3.85</td>
<td>24</td>
<td>Specific Rotation Not Determined</td>
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## Determination of Enantiomeric Excess and Optical Rotation (Table S2)

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<th>analytic conditions</th>
<th>ee (%)</th>
<th>polarimetry</th>
</tr>
</thead>
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<tr>
<td>1</td>
<td><img src="image" alt="7a" /></td>
<td>SFC: 15% IPA, 2.5 mL/min Chiralpak AD-H, $\lambda = 210$ nm $t_R$ (min): major 2.46, minor 2.78</td>
<td>90</td>
<td>$[\alpha]_{D}^{25} \approx -30.87$ (c 4.45, CHCl$_3$)</td>
</tr>
<tr>
<td>2</td>
<td><img src="image" alt="7b" /></td>
<td>SFC: 5% IPA, 2.5 mL/min Chiralpak AD-H, $\lambda = 210$ nm $t_R$ (min): major 4.25, minor 4.63</td>
<td>87</td>
<td>$[\alpha]_{D}^{25} \approx -22.7$ (c 0.85, CHCl$_3$)</td>
</tr>
<tr>
<td>3</td>
<td><img src="image" alt="7c" /></td>
<td>SFC: 5% IPA, 2.5 mL/min Chiralpak AD-H, $\lambda = 210$ nm $t_R$ (min): major 2.97, minor 4.26</td>
<td>82</td>
<td>$[\alpha]_{D}^{25} \approx -12.8$ (c 0.96, CHCl$_3$)</td>
</tr>
<tr>
<td>4</td>
<td><img src="image" alt="7d" /></td>
<td>SFC: 3% IPA, 2.5 mL/min Chiralpak AS-H, $\lambda = 254$ nm $t_R$ (min): major 4.41, minor 6.12</td>
<td>92</td>
<td>$[\alpha]_{D}^{25} \approx -28.7$ (c 0.65, CHCl$_3$)</td>
</tr>
<tr>
<td>5</td>
<td><img src="image" alt="7e" /></td>
<td>SFC: 15% IPA, 2.5 mL/min Chiralpak AD-H, $\lambda = 210$ nm $t_R$ (min): major 2.48, minor 2.80</td>
<td>93</td>
<td>$[\alpha]_{D}^{25} \approx -1.3$ (c 1.32, CHCl$_3$)</td>
</tr>
<tr>
<td>6</td>
<td><img src="image" alt="7f" /></td>
<td>SFC: 8% IPA, 2.5 mL/min Chiralpak AD-H, $\lambda = 210$ nm $t_R$ (min): major 4.94, minor 6.46</td>
<td>90</td>
<td>$[\alpha]_{D}^{25} \approx -34.0$ (c 1.58, CHCl$_3$)</td>
</tr>
<tr>
<td>7</td>
<td><img src="image" alt="7g" /></td>
<td>SFC: 10% MeOH, 3.0 mL/min Chiralpak AD-H, $\lambda = 254$ nm $t_R$ (min): major 2.64, minor 3.12</td>
<td>90</td>
<td>$[\alpha]_{D}^{25} \approx +33.6$ (c 1.05, CHCl$_3$)</td>
</tr>
<tr>
<td>8</td>
<td><img src="image" alt="7h" /></td>
<td>SFC: 3% MeOH, 2.5 mL/min Chiralpak AS-H, $\lambda = 254$ nm $t_R$ (min): major 4.06, minor 4.62</td>
<td>99</td>
<td>$[\alpha]_{D}^{25} \approx +10.8$ (c 0.93, CHCl$_3$)</td>
</tr>
<tr>
<td>9</td>
<td><img src="image" alt="7i" /></td>
<td>SFC: 15% IPA, 2.5 mL/min Chiralcel OB-H, $\lambda = 210$ nm $t_R$ (min): major 7.21, minor 5.19</td>
<td>92</td>
<td>$[\alpha]_{D}^{25} \approx -13.3$ (c 0.28, C$_6$H$_6$)</td>
</tr>
</tbody>
</table>
Total Synthesis of (–)-Isonitramine and (+)-Sibirinine

Synthesis of alcohol 9:

To a solution of enantioenriched ketone 4b (851 mg, 2.82 mmol) in CH₂Cl₂ (14.2 mL) was added DIBAL (6.21 mL, 1.0 M solution in CH₂Cl₂, 6.21 mmol, 2.20 equiv) dropwise at –78 ºC. After stirring at –78 ºC for 15 min, the reaction mixture was quenched with saturated aqueous Rochelle’s salt (20 mL) and stirred at 23 ºC for 2 h. The phases were separated and the aqueous phase was extracted with CH₂Cl₂ (2 x 25 mL). The combined organic phases were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. The crude product was used for the next reaction without further purification.

To a solution of the crude alcohol in Ac₂O (7.1 mL) was added pyridine (7.1 mL) at room temperature. After full consumption of the starting material was observed by TLC analysis, the reaction mixture was concentrated and azeotropically dried with toluene twice. The resulting residue was used in the next reaction without further purification.

To a flame-dried flask was added cyclohexene (1.43 mL, 14.1 mmol, 5.00 equiv), diethyl ether (10 mL), and BH₃•Me₂S (7.05 mL, 2.0 M solution in THF, 3.5 mmol, 1.24 equiv) at 0 ºC. The reaction mixture was stirred at 0 ºC for 3 h, then the solid was allowed to settle without stirring, and the supernatant was removed using a syringe. To the resulting solid was added THF (8.0 mL) and a solution of acetate 8 in THF (6.2 mL) at 0 ºC. After full consumption of acetate 8 by TLC analysis, the reaction mixture was quenched with NaBO₃ (3.25 g, 21.2 mmol, 7.52 equiv) and H₂O (14 mL) and stirred at room temperature for 1 h. The reaction mixture was diluted with EtOAc, the phases were separated, and the aqueous phase was extracted with EtOAc (2 x 25 mL). The combined organic phases were dried over Na₂SO₄, filtered, and concentrated under reduced pressure. Flash column chromatography (SiO₂, 30 → 50% EtOAc in hexanes) afforded alcohol 9 (886 mg, 86% yield, over 3 steps) as a colorless oil. [α]D⁰²⁵ +7.5 (c 0.95, CHCl₃); Rf = 0.33 (50% EtOAc in hexanes); ¹H NMR (500 MHz, CDCl₃) δ 7.39–7.28 (m, 5H), 5.35 (m, 1H),
5.14–5.02 (m, 2H), 4.77 (dd, \(J = 9.7, 4.5\) Hz, 1H), 3.68–3.58 (m, 2H), 3.30 (dd, \(J = 14.3, 8.0\) Hz, 1H), 2.88 (dd, \(J = 14.2, 5.5\) Hz, 1H), 2.05 (s, 3H), 1.71–1.16 (m, 12H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\)) \(\delta 171.4, 157.1, 136.7, 128.6, 128.3, 128.2, 75.3, 66.9, 63.5, 45.5, 40.9, 30.0, 26.9, 26.0, 25.3, 23.9, 21.4, 20.4\); IR (Neat Film, NaCl) 3385, 2937, 2866, 1718, 1528, 1455, 1374, 1247, 1026 cm\(^{-1}\); HRMS (ESI+) \(m/z\) calc’d for C\(_{20}\)H\(_{30}\)NO\(_5\) [M+H\(^{+}\)]: 364.2118, found 364.2109.

**Synthesis of spiroamine 10:**

![Synthesis of spiroamine 10](image)

To a solution of primary alcohol 9 (865 mg, 2.38 mmol) in CH\(_2\)Cl\(_2\) (12 mL) was added Et\(_3\)N (0.497 mL, 3.57 mmol, 1.50 equiv) and MsCl (0.203 mL, 2.63 mmol, 1.10 equiv) at 0 °C. After full consumption of alcohol 9 was observed by TLC analysis, the reaction mixture was quenched with saturated aqueous NaHCO\(_3\) (25 mL) and the phases were separated. The aqueous phase was extracted with CH\(_2\)Cl\(_2\) (2 x 25 mL). The combined organic phases were dried over Na\(_2\)SO\(_4\), filtered, and concentrated under reduced pressure. The crude product was used in the next reaction without further purification.

To a suspension of sodium hydride (114 mg, 60 wt% dispersion in mineral oil, 2.86 mmol) in THF (6 mL) was added a solution of the above methanesulfonylate in THF (6 mL) at 0 °C. The reaction mixture was stirred at reflux for 2 h. Upon cooling to 23 °C, the reaction mixture was quenched with saturated aqueous NH\(_4\)Cl (20 mL) and diluted with CH\(_2\)Cl\(_2\) (20 mL). The phases were separated, and the aqueous phase was extracted with CH\(_2\)Cl\(_2\) (3 x 25 mL). The combined organic phases were dried over Na\(_2\)SO\(_4\), filtered, and concentrated under reduced pressure. Flash column chromatography (SiO\(_2\), 15% EtOAc in hexanes) afforded spirocyclic carbamate 10 (732 mg, 89% yield, over 2 steps) as a colorless oil. \([\alpha]_D^{25} +46.8\) (c 0.97, CHCl\(_3\)); \(R_f = 0.57\) (33% EtOAc in hexanes); \(^1\)H NMR (500 MHz, CDCl\(_3\), mixture of rotamers) \(\delta 7.39–7.26\) (m, 5H), 5.20–5.01 (m, 2H), 4.86–4.61 (m, 1H), 3.96–2.91 (m, 4H), 2.05 (s, 3H), 1.87–1.00 (m, 12H); \(^{13}\)C NMR (126 MHz, CDCl\(_3\), mixture of rotamers) \(\delta 170.6, 155.7, 137.0, 128.6, 128.1, 128.0, 75.2\)
(74.3), 67.2, 51.4 (50.7), 44.8, 37.0 (36.9), 30.6 (29.1), 30.2, 26.5, 22.4 (21.8), 21.3, 20.8 (20.7), 20.6 (20.5); IR (Neat Film, NaCl) 2938, 2861, 1732, 1699, 1434, 1242 cm⁻¹; HRMS (ESI+) m/z calc’d for C₂₀H₂₉NO₄ [M+H]⁺: 346.2013, found 346.2016.

Synthesis of (−)-isonitrarnine (11):

To a solution of spirocyclice carbamate 10 (712 mg, 2.06 mmol) in ethylene glycol (13 mL) was added KOH (3.00 g, 53.4 mmol, 25.92 equiv) and hydrazine hydrate (0.51 mL) at 23 °C. After stirring at 120 °C for 1.5 h, the reaction mixture cooled to 23 °C and diluted with H₂O (100 mL). The aqueous phase was extracted with CH₂Cl₂ (200 mL) using a continuous liquid/liquid extractor and the organic phase was concentrated under reduced pressure. Flash column chromatography (SiO₂, CHCl₃:MeOH:NH₃(aq) = 46:50:4 eluent) afforded (−)-isonitrarnine (11) (270 mg, 77% yield) as a white solid. [α]D²⁵ −4.1 (c 0.96, CHCl₃); Lit: [α]D²⁰ −5.0 (c 2.1, CHCl₃)¹²c; Rf = 0.30 (CHCl₃:MeOH:NH₃(aq) = 46:50:4); m.p. 86.9–88.8 °C; ¹H NMR (500 MHz, CDCl₃) δ 3.66 (dd, J = 11.3, 3.7 Hz, 1H), 3.04 (m, 1H), 2.94 (m, 1H), 2.60 (ddd, J = 11.3, 11.3, 3.4 Hz, 1H), 2.52 (d, J = 11.3 Hz, 1H), 2.24 (m, 1H), 2.06 (m, 1H), 1.78–1.14 (m, 8H), 1.06 (ddd, J = 13.3, 13.3, 5.5 Hz, 1H), 0.96 (m, 1H); ¹³C NMR (126 MHz, CDCl₃) δ 80.7, 61.0, 47.4, 36.9, 36.3, 29.9, 29.0, 24.4, 23.3, 20.4; IR (Neat Film, NaCl) 3292, 2929, 2858, 1539, 1457, 1419, 1282, 1064 cm⁻¹; HRMS (ESI+) m/z calc’d for C₁₀H₂₀NO [M+H]⁺: 170.1539, found 170.1541.

Synthesis of (+)-sibirinine (12):

An oven-dried 1-dram vial was charged with a magnetic stirring bar, 11 (20 mg, 0.118 mmol), powdered 3 Å molecular sieves (40 mg), and CH₂Cl₂ (1.5 mL). To this stirring
suspension was added acetaldehyde (0.133 mL, 2.36 mmol, 20.0 equiv). The vial was sealed with a teflon cap, and the reaction was stirred at 23 °C for 30 h. The reaction mixture was then filtered through celite, washing with CH₂Cl₂. The filtrate was concentrated under reduced pressure to yield a pale yellow oil, which was used in the subsequent reaction without further purification.

The above crude hemiaminal was dissolved in CH₂Cl₂ (1.2 mL) and cooled to 0 °C (water/ice bath). To this stirring solution was added m-CPBA (29 mg, 0.13 mmol) in one portion. After 15 min, full consumption of starting material was observed by TLC analysis. The reaction mixture was filtered through celite, washing with CH₂Cl₂, and concentrated under reduced pressure. Flash column chromatography (SiO₂, CH₂Cl₂: NH₃ (7N solution in MeOH) = 92:8 eluent) afforded (+)-sibirinine (12) (22.9 mg, 92% yield, over 2 steps) as a colorless oil. [α]D₂⁵ +10.3 (c 0.56, CHCl₃); Rf = 0.40 (CH₂Cl₂: NH₃ (7N solution in MeOH) = 9:1); ¹H NMR (500 MHz, CDCl₃) δ 4.50 (qd, J = 5.8, 1.5 Hz, 1H), 3.73 (dd, J = 13.4, 7.1 Hz, 1H), 3.53 (ddd, J = 12.0, 4.1, 1.5 Hz, 1H), 3.21 (d, J = 12.2 Hz, 1H), 3.11 (dt, J = 12.2, 2.5 Hz, 1H), 3.03 (ddd, J = 14.7, 13.4, 5.5, 1.6 Hz, 1H), 2.45 (ttd, J = 14.4, 13.5, 5.9 Hz, 1H), 2.32 (dd, J = 14.1, 5.8 Hz, 1H), 1.87 (dt, J = 13.1, 3.8, 1.7 Hz, 1H), 1.79 (dq, J = 12.3, 3.6 Hz, 1H), 1.65 (d, J = 5.8 Hz, 3H), 1.64 – 1.60 (m, 1H), 1.57 – 1.46 (m, 2H), 1.46 (dt, J = 13.0, 4.0 Hz, 1H), 1.41 – 1.31 (m, 2H), 1.23 (m, 1H), 1.17 (m, 1H); ¹³C NMR (126 MHz, CDCl₃) δ 102.2, 84.4, 77.8, 62.5, 38.2, 34.7, 27.0, 26.3, 24.7, 21.2, 19.6, 14.6; IR (Neat Film, NaCl) 2934, 2854, 1466, 1446, 1367, 1138, 1120, 1103, 961, 940 cm⁻¹; HRMS (ESI/APCI) m/z calc’d for C₁₂H₂₂NO₂ [M+H]+: 212.1645, found 212.1640.

Comparison of Synthetic Material to Published Data

As detailed above, we found that hemiaminal formation and subsequent N-oxidation of (−)-isonitramine furnished (+)-sibirinine. This finding is in contrast to a previous report, where (−)-sibirinine was obtained in a similar sequence from (−)-isonitramine.¹¹ Given that the optical rotation of our synthesized (−)-isonitramine matches those found in previously reported syntheses,¹² and that the optical rotation reported in the isolation
paper of (–)-isonitramine\textsuperscript{13} has been refuted,\textsuperscript{12e} the optical rotation values reported in the isolation of sibirinine\textsuperscript{11} should be regarded as incorrect.

Limited spectral data were available for sibirinine (12) in the isolation paper.\textsuperscript{11} Full \textsuperscript{13}C NMR, partial \textsuperscript{1}H NMR, optical rotation, and HRMS data were reported. Comparisons between data obtained from the synthetic material and data available in the literature are detailed in the following table.

\textbf{Comparison of Synthetic and Natural Sibirinine (Table S3)}

<table>
<thead>
<tr>
<th>Synthetic (±)-sibirinine</th>
<th>Natural\textsuperscript{11}</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textsuperscript{1}H NMR (500 MHz, CDCl\textsubscript{3})</td>
<td>\textsuperscript{1}H NMR (CDCl\textsubscript{3})</td>
</tr>
<tr>
<td>4.50 (qd, J = 5.8, 1.5 Hz, 1H)</td>
<td>4.58 (qd, J = 5.7, 1.2 Hz, 1H)</td>
</tr>
<tr>
<td>3.21 (d, J = 12.2 Hz, 1H)</td>
<td>3.31 (d, J = 12 Hz, 1H)</td>
</tr>
<tr>
<td>3.11 (dt, J = 12.2, 2.5 Hz, 1H)</td>
<td>3.17 (dd, J = 12, 2.3 Hz, 1H)</td>
</tr>
<tr>
<td>1.65 (d, J = 5.8 Hz, 3H)</td>
<td>1.65 (d, J = 5.7 Hz, 3H)</td>
</tr>
<tr>
<td>\textsuperscript{13}C NMR (126 MHz, CDCl\textsubscript{3})</td>
<td>\textsuperscript{13}C NMR (CDCl\textsubscript{3})</td>
</tr>
<tr>
<td>102.2</td>
<td>101.9</td>
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<tr>
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<td>14.4</td>
</tr>
</tbody>
</table>


The carbazole allylic alkylation product decomposes in chloroform after approximately 30 minutes. The resulting impurity was not isolated or identified.


$^1$H NMR (500 MHz, CDCl$_3$) of compound $3a$. 

O

O

NHBoc

Supporting Information for Numajiri, Pritchett, Chiyoda, and Stoltz
Infrared spectrum (Thin Film, NaCl) of compound 3a.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 3a.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 3b.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 3b.

Infrared spectrum (Thin Film, NaCl) of compound 3b.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 3c.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 3c.

Infrared spectrum (Thin Film, NaCl) of compound 3c.
\(^1\)H NMR (500 MHz, CDCl\(_3\)) of compound 3d.
**Infrared spectrum (Thin Film, NaCl) of compound 3d.**

**$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 3d.**
$^1$H NMR (500 MHz, CDCl$_3$) of compound 3e.
13C NMR (126 MHz, CDCl3) of compound 3e.

Infrared spectrum (Thin Film, NaCl) of compound 3e.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 3f.
Infrared spectrum (Thin Film, NaCl) of compound 3f.

\(^{13}\text{C} \text{NMR (126 MHz, CDCl}_3\text{)}\) of compound 3f.
1H NMR (500 MHz, CDCl3) of compound 3g.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 3g.

Infrared spectrum (Thin Film, NaCl) of compound 3g.
$^1$H NMR (500 MHz, C$_6$D$_6$) of compound 4a.
\textsuperscript{13}C NMR (126 MHz, C\textsubscript{6}D\textsubscript{6}) of compound \textbf{4a}.

Infrared spectrum (Thin Film, NaCl) of compound \textbf{4a}. 

\textsuperscript{13}C NMR (126 MHz, C\textsubscript{6}D\textsubscript{6}) of compound \textbf{4a}. 

Supporting Information for Numajiri, Pritchett, Chiyoda, and Stoltz

SI 48
$^{1}$H NMR (500 MHz, CDCl$_3$) of compound 4b.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4b.

Infrared spectrum (Thin Film, NaCl) of compound 4b.
\(^1\text{H NMR (500 MHz, CDCl}_3\text{)}\) of compound 4c.
Infrared spectrum (Thin Film, NaCl) of compound 4c.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4c.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 4d.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4d.

Infrared spectrum (Thin Film, NaCl) of compound 4d.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 4e.
Infrared spectrum (Thin Film, NaCl) of compound 4e.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4e.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 4f.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4f.

Infrared spectrum (Thin Film, NaCl) of compound 4f.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 4g.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 4g.

Infrared spectrum (Thin Film, NaCl) of compound 4g.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6a.
13C NMR (126 MHz, CDCl3) of compound 6a.

Infrared spectrum (Thin Film, NaCl) of compound 6a.
1H NMR (500 MHz, CDCl3) of compound 6b.
Infrared spectrum (Thin Film, NaCl) of compound 6b.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 6b.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6c.
Infrared spectrum (Thin Film, NaCl) of compound **6c**.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound **6c**.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6d.
Infrared spectrum (Thin Film, NaCl) of compound 6d.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 6d.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6e.
Infrared spectrum (Thin Film, NaCl) of compound 6e.

$^13$C NMR (126 MHz, CDCl$_3$) of compound 6e.
$^1$H NMR (500 MHz, C$_6$D$_6$) of compound 6f.

Supporting Information for Numajiri, Pritchett, Chiyoda, and Stoltz
$^{13}$C NMR (126 MHz, C$_6$D$_6$) of compound 6f.

Infrared spectrum (Thin Film, NaCl) of compound 6f.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6g.
Infrared spectrum (Thin Film, NaCl) of compound 6g.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 6g.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6h.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 6h.

Infrared spectrum (Thin Film, NaCl) of compound 6h.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 6i.
Infrared spectrum (Thin Film, NaCl) of compound 6i.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 6i.
$^{1}$H NMR (500 MHz, CDCl$_3$) of compound 7a.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7a.

Infrared spectrum (Thin Film, NaCl) of compound 7a.
\[^{1}\text{H}\text{ NMR (500 MHz, CDCl}_3\)](500 MHz, CDCl\textsubscript{3})\text{ of compound 7b.}
Infrared spectrum (Thin Film, NaCl) of compound 7b.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7b.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 7c.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7c.

Infrared spectrum (Thin Film, NaCl) of compound 7c.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 7d.
Infrared spectrum (Thin Film, NaCl) of compound 7d.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7d.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 7e.
Infrared spectrum (Thin Film, NaCl) of compound 7e.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7e.
$^{1}$H NMR (500 MHz, CDCl$_3$) of compound 7f.
Infrared spectrum (Thin Film, NaCl) of compound 7f.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7f.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 7g.
Infrared spectrum (Thin Film, NaCl) of compound 7g.

$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7g.
$\text{H NMR (500 MHz, CDCl}_3\text{)}$ of compound 7h.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7h.

Infrared spectrum (Thin Film, NaCl) of compound 7h.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 7i.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 7i.

Infrared spectrum (Thin Film, NaCl) of compound 7i.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 9.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 9.

Infrared spectrum (Thin Film, NaCl) of compound 9.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 10.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 10.

Infrared spectrum (Thin Film, NaCl) of compound 10.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 11.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 11.

Infrared spectrum (Thin Film, NaCl) of compound 11.
$^1$H NMR (500 MHz, CDCl$_3$) of compound 12.
$^{13}$C NMR (126 MHz, CDCl$_3$) of compound 12.

Infrared spectrum (Thin Film, NaCl) of compound 12.