Diversity-oriented synthesis of bicyclic and tricyclic alkaloids

Mónica Díaz-Gavilán, Warren R. J. D. Galloway, Kieron O'Connell, James Hodkingson and David R. Spring*

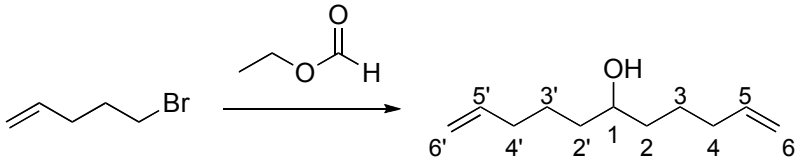
1. General experimental details

Reactions were performed using oven-dried glassware under an atmosphere of nitrogen with anhydrous, freshly distilled solvents when indicated only. Dichloromethane, ethyl acetate, methanol and *n*-hexane were distilled from calcium hydride. Anhydrous dimethylformamide (DMF) was used as obtained from commercial sources. All other reagents were used as obtained from commercial sources. Room temperature refers to ambient temperature. Temperatures of 0°C were maintained using an ice-water bath and temperatures below 0°C were maintained using an acetone-cardice bath Yields refer to chromatographically and spectroscopically pure compounds unless otherwise stated. All flash chromatography was carried out using slurry-packed Merck 9325 Keiselgel 60 silica gel. Where possible, reactions were monitored by thin layer chromatography (TLC) performed on commercially prepared glass plates precoated with Merck silica gel 60 F254 or aluminium oxide 60 F254. Visualisation was by the quenching of UV fluorescence (ν_{max} = 254 nm) or by staining with ceric ammonium molybdate, potassium permanganate, iodine or Dragendorff 's reagent (0.08% w/v bismuth subnitrate and 2% w/v KI in 3M aq. AcOH). Infrared spectra were recorded on a Perkin-Elmer Spectrum One spectrometer with internal referencing. Selected absorption maxima (ν_{max}) are reported in wavenumbers (cm^{-1}). Melting points were obtained using a Büchi® melting point apparatus (model B-545) and are uncorrected. Proton magnetic resonance spectra were recorded using an internal deuterium lock at ambient probe temperatures on the following instruments: Bruker DPX-400 (400 MHz), Bruker Avance 400 QNP (400 MHz), Bruker Avance 500 BB ATM (500 MHz) and Bruker Avance 500 Cryo Ultrashield (500 MHz). Chemical shifts (δ_H) are quoted in ppm, to the nearest 0.01 ppm, and are referenced to the residual non-deuterated solvent peak. Coupling constants (*J*) are reported in Hertz to the nearest 0.5 Hz. Data are reported as follows: chemical shift,

multiplicity [b, broad; s, singlet; d, doublet; t, triplet; q, quartet; quint, quintet; sept, septet; m, multiplet; or as a combination of these (*e.g.* dd, dt, *etc.*)], coupling constant(s), integration and assignment. Proton assignments were determined either on the basis of unambiguous chemical shift or coupling pattern, by patterns observed in 2D experiments (^{1}H-^{1}H COSY, HMBC and HMQC) or by analogy to fully interpreted spectra for related compounds. NOESY experiments were used to determine the stereochemistry when necessary. Numbering of compounds for NMR assignment does not correspond to the numbering for nomenclature. Carbon magnetic resonance spectra were recorded by broadband proton spin decoupling at ambient probe temperatures using an internal deuterium lock on the following instruments: Bruker DPX-400 (100 MHz), Bruker Avance 400 QNP (100 MHz), Bruker Avance 500 BB ATM (125 MHz) and Bruker Avance 500 Cryo Ultrashield (125 MHz). Chemical shifts (δ_C) are quoted in ppm, to the nearest 0.1 ppm, and are referenced to the residual non-deuterated solvent peak.. Assignments were supported by DEPT editing and determined either on the basis of unambiguous chemical shift, by patterns observed in 2D experiments (HMBC and HMQC) or by analogy to fully interpreted spectra for related compounds. High resolution mass spectroscopy measurements were made by the EPSRC mass spectrometry service (Swansea) or recorded in-house using a Waters LCT Premier Mass Spectrometer or a Micromass Quadrapole-Time of Flight (Q-ToF) spectrometer. Mass values are reported within the error limits of ±5 ppm mass units. ESI = electrospray ionisation.

2. Synthesis of *N*-Boc-aminodialkenes

Undeca-1,10-dien-6-ol[1,2]

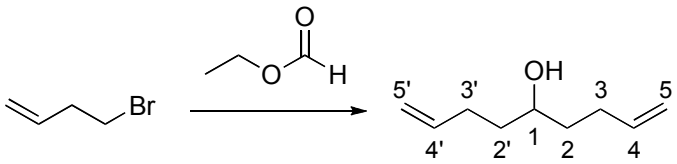


A suspension of magnesium turnings (2.5 equiv) and iodine (cat) in dry THF (2 mL/mmol of bromide) was prepared under nitrogen atmosphere. To this mixture, 5-bromo-1-pentene (2.5 equiv) was slowly added at rt. While the addition, an increase in the temperature of the reaction mixture confirmed the initiation of the Grignard formation. Once the addition of the bromide was completed, the mixture was allowed to stir at rt during 45 min, after which it was cooled down to 0 °C for the slow addition of ethyl formate (1.0 equiv). After the addition, the cold bath was removed and the mixture was stirred at rt overnight. The reaction was cooled down to 0 °C for quenching by addition of aqueous ammonium chloride (saturated solution). The resulting aqueous phase was extracted with diethyl ether (x3) and the final organic phase dried over magnesium sulphate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica (elution with petrol ether (30/40):diethyl ether 15:1) to afford the final alcohol (98%) as a yellow oil [R_f 0.22 (petroleum ether (30-40):diethyl ether 6:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 3329, 3077, 2978, 2931, 2860, 2338, 1827, 1641, 1458, 1440, 1415, 1325, 1068, 993, 908, 826 and 741; δ_H (400 MHz; $CDCl_3$) 5.80 (ddt, J_1 = 17.0 Hz, J_2 = 10.2 Hz, J_3 = 6.7 Hz, 2H, H-5, 5'), 4.99 (dq, J_1 = 17.1 Hz, J_2 = 1.6 Hz, 2H, H_{trans}-6_A, $6'_A$), 4.94 (ddt, J_1 = 10.2 Hz, J_2, = 2.3 Hz, J_3 = 1.2 Hz, 2H, H_{cis}-6_B, $6'_B$), 3.60 (m, 1H, H-1), 2.13-1.99 (m, 4H, H-4, 4'), 1.60-1.35 (m, 8H, H-2, 2', 3, 3'); δ_C (100 MHz; $CDCl_3$) 138.7 (CH-5 and 5'), 114.6 (CH_2-6 and 6'), 71.7 (CH-1), 36.9, 33.7 (CH_2-2, 2', 4 and 4'), 24.9 (CH_2-3 and 3').

[1] F. D. Boyer and I. Hanna, *Eur. J. Org. Chem.* 2006, 471
[2] M. Rejzek, and R.A. Stockman, *Tetrahedron Lett.* 2002, **43**(37), 6505

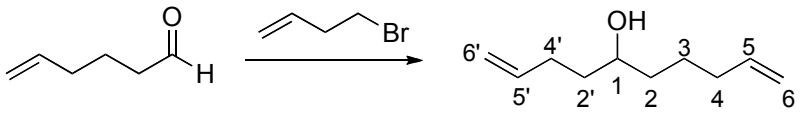
Nona-1,8-dien-5-ol[3,4]



The procedure described for the preparation of undeca-1,10-dien-6-ol was followed, using this time the Grignard of 4-bromo-1-butene. After the addition of ethyl formate at 0 °C, the reaction was stirred at rt, overnight. Quenching as described above and purification by flash chromatography on silica (elution with petroleum ether (30/40):diethyl ether 10:1), afforded the alcohol as a yellow oil in 94% yield [R_f 0.31 (petroleum ether (30-40):diethyl ether 6:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 3345, 3078, 2978, 2933, 2848, 1641, 1449, 1416, 993, 908; δ_H (400 MHz; $CDCl_3$) 5.83 (ddt, J_1 = 17.2 Hz, J_2 = 10.4 Hz, J_3 = 6.7 Hz, 2H, H-4, 4'), 5.04 (dq, J_1 = 17.2 Hz, J_2 = 1.6 Hz, 2H, H_{trans}-5_A, 5'$_A$), 4.96 (m, 2H, H_{cis}-5_B, 5'$_B$), 3.64 (m, 1H, H-1), 2.25-2.06 (m, 4H, H-3, 3'), 1.62-1.47 (m, 4H, H-2, 2'); δ_C (100 MHz; $CDCl_3$) 138.5 (CH-4 and 4'), 114.8 (CH_2-5 and 5'), 71.0 (CH-1), 36.5, 30.0 (CH_2-2, 2', 3 and 3').

Deca-1,9-dien-5-ol[1]



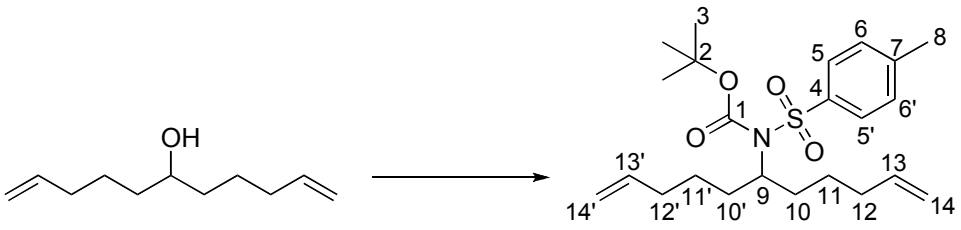
A suspension of magnesium turnings (2.0 equiv) and iodine (cat.) in dry THF (2 mL/mmol of bromide) was prepared at rt, under nitrogen atmosphere. To this mixture, 4-bromo-1-butene (2.0 equiv) was added slowly at rt While the addition, an increase in the temperature of the reaction mixture confirmed the initiation of the Grignard formation. Once the addition of the bromide was completed, the mixture was allowed to stir at rt during 1 h, after which it was cooled down to 0 °C for the slow addition of a solution of 5-hexenal (1.0 equiv) in dry THF (1mL/mmol of aldehyde). After the addition, the cold bath was removed and the mixture was stirred at rt overnight. The

[3] B. D. Schwartz, C. S. P. McErlean, M. T. Fletcher, B. E. Mazomenos, M. A. Konstantopoulou, W. Kitching, and J. J. De Voss, *Org. Lett*. 2005, **7**(6), 1173
[4] S. J. Roe and R. A. Stockman, *Chem. Commun.,* 2008, **29**, 3432

reaction was cooled down to 0 °C for quenching by addition of aqueous ammonium chloride (saturated solution). The resulting aqueous phase was extracted with diethyl ether (x3) and the final organic phase dried over magnesium sulphate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica (elution with petroleum ether (30/40):diethyl ether 8:1), to furnish the alcohol as a yellow oil in 51% yield [R_f 0.24 (petroleum ether (30-40):diethyl ether 4:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3327, 3078, 2977, 2931, 2858, 1641, 1440, 1416, 993, 908; δ_H (400 MHz; $CDCl_3$) 5.77 (ddt, J_1 = 17.0 Hz, J_2 = 10.3 Hz, J_3 = 6.6 Hz, 1H, H-5 or 5'), 5.74 (ddt, J_1 = 16.0 Hz, J_2 = 10.2 Hz, J_3 = 6.6 Hz, 1H, H-5 or 5'), 5.01-4.86 (m, 4H, H-6, 6'), 3.56 (m, 1H, H-1), 2.19-1.96 (m, 4H, H-4, 4'), 1.55-1.30 (m, 6H, H-2, 2', 3); δ_C (100 MHz; $CDCl_3$) 139.1, 139.0 (CH-5 and 5'), 115.2, 115.0 (CH_2-6 and 6'), 71.7 (CH-1), 37.3, 36.9, 34.1, 30.5, 28.3, 25.3 (CH_2-2, 2', 3, 4 and 4').

tert-Butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(4-pentenyl)-5-hexenyl]carbamate

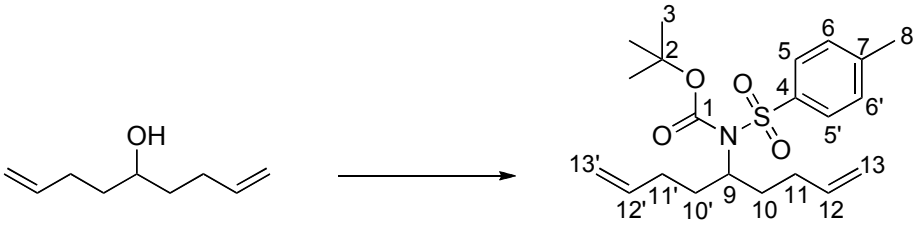


A mixture of triphenylphosphine (1.5 equiv), undeca-1,10-dien-6-ol (1.0 equiv) and *tert*-butyltosylcarbamate (1.5 equiv) in anhydrous THF (10 mL/mmol of alcohol), was prepared under nitrogen at rt The mixture was stirred and cooled at -10 ºC and diisopropyl azodicarboxylate (1.5 equiv) was added dropwise. The mixture was then stirred at that temperature for 30 min before heating up to 40 ºC. After 24 h stirring, the solvent was removed under reduced pressure and the residue was purified by column chromatography (stepped gradient elution with petroleum ether (30/40) and petroleum ether:diethyl ether 50:1) to afford *tert*-butyl *N*-(*p*-toluenesulfonyl)-*N*-[1-(4-pentenyl)-5-hexenyl]carbamate as a yellow oil in 65% yield [R_f 0.23 (petroleum ether (30-40):diethyl ether 10:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3076, 2979, 2931, 2864, 1724, 1640, 1598, 1457, 1395, 1351, 1275, 1252, 1149, 1087, 992, 911, 841, 812, 770, 723, 669; δ_H (400 MHz; $CDCl_3$) 7.82 (d, J =

8.4 Hz, 2H$_{Ar}$), 7.28 (d, J = 8.4 Hz, 2H$_{Ar}$), 5.78 (ddt, J_1 = 17.1 Hz, J_2 = 10.4 Hz, J_3 = 6.7 Hz, 2H, H-13, 13'), 4.99 (dq, J_1 = 17.5 Hz, J_2 = 1.2 Hz, 2H, H$_{trans}$-14$_A$, 14'$_A$), 4.95 (dq, J_1 = 10.9 Hz, J_2 = 1.2 Hz, 2H, H$_{cis}$-14$_B$, 14'$_B$), 4.39 (tt, J_1 = 8.4 Hz, J_2 = 6.4 Hz, 1H, H-9), 2.43 (s, 3H, H-8), 2.13-2.02 (m, 4H, H-12, 12'), 1.96-1.89 (m, 2H), 1.74-1.65 (m, 2H), 1.47-1.39 (m, 4H), 1.37 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 151.0 (C-1), 143.8 (C-4), 138.3 (CH), 137.6 (C-7), 128.9 (CH), 128.3 (CH), 114.6 (CH_2-14 and 14'), 83.8 (C-2), 59.9 (CH-9), 33.3, 33.0 (CH_2-10, 10', 12 and 12'), 27.5 (CH_3-3), 25.6 (CH_2-11 and 11'), 21.5 (CH_3-8); HRMS (ESI$^+$) calcd for $C_{23}H_{35}NO_4NaS$ $(M + Na)^+$ 444.2185, found 444.2195.

tert-Butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-4-pentenyl]carbamate[4,5]



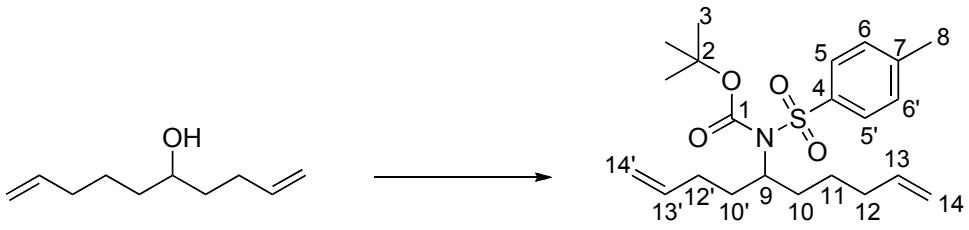
Compound _tert_-butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-4-pentenyl]carbamate was prepared from nona-1,8-dien-5-ol, according to the procedure described for the preparation of _tert_-butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(4-pentenyl)-5-hexenyl]carbamate. The reaction was stirred for 18 h at 40 °C, after which the solvent was removed under reduced pressure and the residue was purified by column chromatography (stepped gradient elution with petroleum ether (30/40) and petroleum ether (30/40):diethyl ether 30:1), to afford _tert_-butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-4-pentenyl]carbamate as a pale yellow oil in 65% yield [R_f 0.26 (petroleum ether (30-40):diethyl ether 15:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 2979, 2929, 1724, 1641, 1598, 1455, 1395, 1352, 1278, 1253, 1149, 1087, 978, 911, 843, 813, 770, 724, 705, 670; δ_H (400 MHz; $CDCl_3$) 7.82 (d, J = 8.4 Hz, 2H$_{Ar}$), 7.29 (d, J = 8.4 Hz, 2H$_{Ar}$), 5.83 (ddt, J_1 = 16.9 Hz, J_2 = 10.3 Hz, J_3 = 6.4 Hz, 2H, H-12, 12'), 5.04 (dd, J_1 = 17.0 Hz, J_2 = 1.2 Hz, 2H, H$_{trans}$-13$_A$, 13'$_A$), 4.99 (dd, J_1 = 10.4 Hz, J_2 = 1.2 Hz, 2H, H$_{cis}$-13$_B$, 13'$_B$), 4.39 (btt, J_1 = 8.1 Hz, J_2 = 6.4 Hz, 1H, H-9), 2.43 (s, 3H, H-8), 2.15-1.97 (m, 4H, H-11, 11', 10$_A$, 10'$_A$), 1.86-1.77 (m, 2H, H-10$_B$, 10'$_B$), 1.37 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 151.4 (C-1), 144.3 (C-4), 138.2 (CH), 138.0

[5] B.M. Trost, and J.D. Oslob, _J. Am. Chem. Soc._ 1999**, 121**, 3057

(C-7), 129.4 (CH), 128.8 (CH), 115.4 (CH_2-13 and 13'), 84.4 (C-2), 59.6 (CH-9), 33.4, 31.5 (CH_2-10, 10', 11 and 11'), 28.4 (CH_3-3), 22.0 (CH_3-8); HRMS (ESI^+) calcd for $C_{21}H_{31}NO_4NaS$ $(M + Na)^+$ 416.1871, found 416.1889.

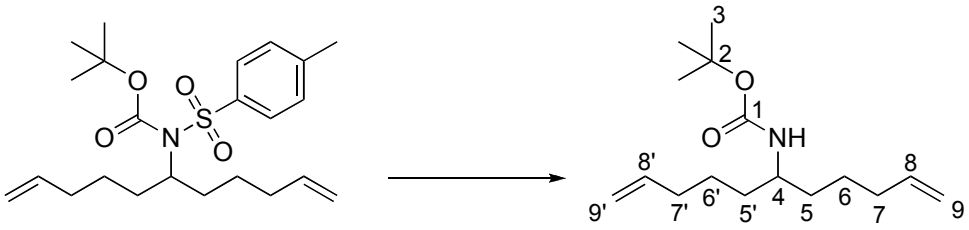
tert-Butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-5-hexenyl]carbamate



tert-Butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-5-hexenyl]carbamate was prepared from deca-1,9-dien-5-ol, according to the procedure described for the preparation of _tert_-butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(4-pentenyl)-5-hexenyl]carbamate. The reaction was stirred for 18 h at 40 °C, after which the solvent was removed under reduced pressure and the residue was purified by column chromatography (stepped gradient elution with petroleum ether (30/40) and petroleum ether (30/40):diethyl ether 50:1, 30:1 and 20:1), to afford _tert_-butyl _N_-(_p_-toluenesulfonyl)-_N_-[1-(3-butenyl)-5-hexenyl]carbamate as a yellow oil in 78% yield [R_f 0.21 (petroleum ether (30-40):diethyl ether 20:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3076, 2979, 2931, 2866, 1776, 1724, 1641, 1598, 1456, 1395, 1350, 1276, 1250, 1149, 1087, 991, 911, 841, 813, 770, 723, 706, 669; δ_H (400 MHz; $CDCl_3$) 7.82 (d, J = 8.0 Hz, $2H_{Ar}$), 7.29 (d, J = 8.0 Hz, $2H_{Ar}$), 5.83 (ddt, J_1 = 17.0 Hz, J_2 = 10.4 Hz, J_3 = 6.4 Hz, 1H, H-13), 5.78 (ddt, J_1 = 17.1 Hz, J_2 = 10.3 Hz, J_3 = 6.7 Hz, 1H, H-13'), 5.07-4.93 (m, 4H, H-14, 14'), 4.41 (m, 1H, H-9), 2.43 (s, 3H, H-8), 2.16-2.00 (m, 4H, H-12, 12'), 2.06-1.64 (m, 4H), 1.46-1.38 (m, 2H), 1.37 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 149.2 (C-1), 142.1 (C-4), 136.6, 136.1 (CH-13 and 13'), 135.9 (C-7), 127.2, 126.6 (CH-5, 5', 6, 6'), 113.2, 112.9 (CH_2-14 and 14'), 82.1 (C-2), 57.8 (CH-9), 31.6, 31.3, 31.1, 29.4 (CH_2-10, 10', 12 and 12'), 26.2 (CH_3-3), 24.4 (CH_2-11), 19.8 (CH_3-8); HRMS (ESI^+) calcd for $C_{22}H_{33}NO_4NaS$ $(M + Na)^+$ 430.2028, found 430.2011.

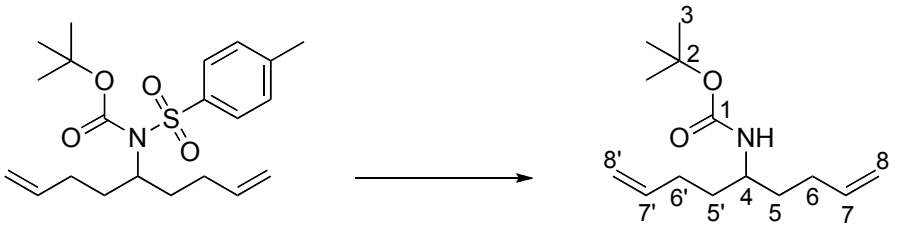
tert-Butyl _N_-[1-(4-pentenyl)-5-hexenyl]carbamate



Magnesium turnings (5.0 equiv) were added to a solution of *tert*-butyl *N*-(*p*-toluenesulfonyl)-*N*-[1-(4-pentenyl)-5-hexenyl]carbamate (1.0 equiv) in anhydrous methanol (18 mL/mmol of *tert*-butyl *N*-(*p*-toluenesulfonyl)-*N*-[1-(4-pentenyl)-5-hexenyl]carbamate) and the mixture was sonicated until the total consumption of the starting material (4 h). The reaction was then stopped by dilution with dichloromethane and quenching with diluted hydrochloric acid (10%). The phases were separated and the aqueous phase was extracted with dichloromethane. The final organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica, eluting with petroleum ether (30/40):diethyl ether 20:1, 15:1 and 10:1, to furnish the desired product as a pale cream oil in 62% yield [R_f 0.4 (petroleum ether (30/40):diethyl ether 10:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3348, 2977, 2931, 2859, 1686, 1641, 1522, 1456, 1442, 1390, 1365, 1248, 1172, 1053, 1026, 994, 909, 868, 778; δ_H (400 MHz; $CDCl_3$) 5.78 (ddt, J_1 = 17.1 Hz, J_2 = 10.3 Hz, J_3 = 6.8 Hz, 2H, H-8, 8'), 4.99 (dq, J_1 = 17.2 Hz, J_2 = 1.5 Hz, 2H, H_{trans}-9_A, $9'_A$), 4.94 (bdq, J_1 = 10.4 Hz, 2H, H_{cis}-9_B, $9'_B$), 4.22 (bb, 1H, N*H*), 3.56 (bb, 1H, H-4), 2.05 (m, 4H, H-7, 7'), 1.50-1.30 (m, 8H, H-5, 5', 6, 6'), 1.44 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 153.9 (C-1), 136.9 (CH-8 and 8'), 112.8 (CH_2-9 and 9'), 77.1 (C-2), 48.6 (CH-4), 33.3, 31.8 (CH_2-5, 5', 7 and 7'), 26.7 (CH_3-3), 25.5 (CH_2-6 and 6'); HRMS (ESI^+) calcd for $C_{16}H_{29}NO_2Na$ $(M + Na)^+$ 290.2096, found 290.2076.

***tert*-Butyl *N*-[1-(3-butenyl)-4-pentenyl]carbamate**[6]

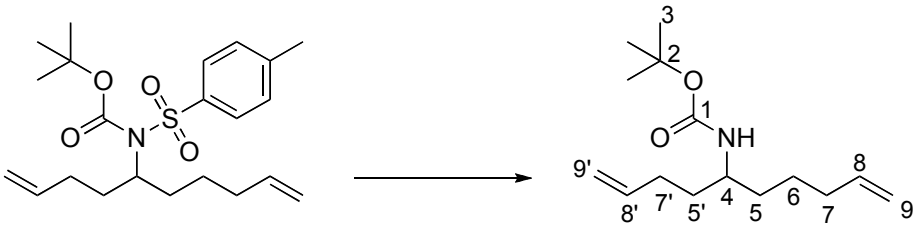


The carbamate following the procedure described above. The reaction mixture was subjected to sonication until complete consumption of the starting material (4 h, tlc analysis). As described, the reaction was stopped by dilution with dichloromethane and quenching with diluted hydrochloric acid (10%). The phases were separated and the aqueous phase was extracted with dichloromethane. The final organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica, eluting with petroleum ether (30/40):diethyl ether 10:1, to furnish the desired product as a low melting point white solid in 89% yield [mp 35.8-36.8 °C (petroleum ether (30/40):diethyl ether), R_f 0.33 (petroleum ether (30/40):diethyl ether 10:1)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3334, 2977, 2928, 2854, 2163, 2010, 1688, 1641, 1522, 1452, 1391, 1366, 1247, 1169, 1119, 1072, 993, 909, 776; δ_H (400 MHz; $CDCl_3$) 5.81 (ddt, J_1 = 16.9 Hz, J_2 = 10.3 Hz, J_3 = 6.6 Hz, 2H, H-7, 7'), 5.02 (dq, J_1 = 17.2 Hz, J_2 = 1.6 Hz, 2H, H_{trans}-8_A, 8'$_A$), 4.96 (bdq, J_1 = 10.2 Hz, 2H, H_{cis}-8_B, 8'$_B$), 4.26 (bd, J = 8.8 Hz, 1H, N*H*), 3.56 (bm, 1H, H-4), 2.10 (m, 4H, H-6, 6'), 1.59-1.52 (m, 2H, H-5_A, 5'$_A$), 1.48-1.38 (m, 2H, H-5_B, 5'$_B$), 1.44 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 156.0 (C-1), 138.6 (CH-7 and 7'), 115.2 (CH_2-8 and 8'), 79.3 (C-2), 50.3 (CH-4), 35.3, 30.6 (CH_2-5, 5', 6 and 6'), 28.8 (CH_3-3); HRMS (ESI^+) calcd for $C_{14}H_{25}NO_2Na$ $(M + Na)^+$ 262.1783, found 262.1782.

[6] J. C. Legeay, W. Lewis, and R. A. Stockman, *Chem. Commun*. 2009, 2207

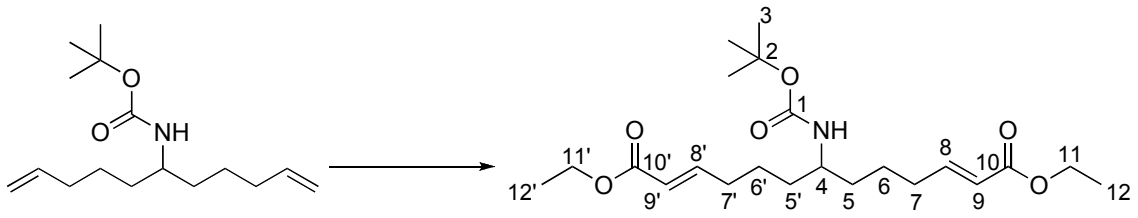
tert-Butyl _N_-[1-(3-butenyl)-5-hexenyl]carbamate



The carbamate following the procedure described above. The reaction mixture was subjected to sonication until complete consumption of the starting material (4 h, tlc analysis). As described, the reaction was stopped by dilution with dichloromethane and quenching with diluted hydrochloric acid (10%). The phases were separated and the aqueous phase was extracted with dichloromethane. The final organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica, eluting with petroleum ether (30/40):diethyl ether 20:1, to furnish the desired product as a pale yellow oil, in 80% yield [R_f 0.28 (petroleum ether (30/40):diethyl ether 15:1)]

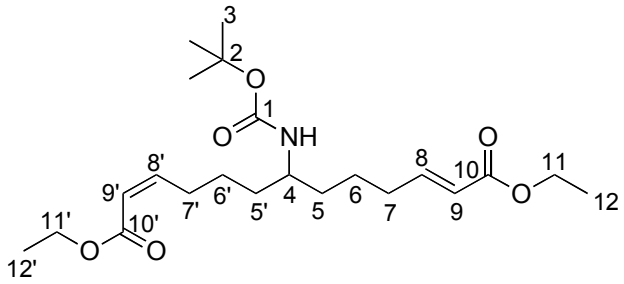
ν_{max} (CH_2Cl_2/cm^{-1}) 3337, 3077, 2978, 2931, 2859, 1685, 1641, 1521 (bb), 1452, 1390, 1365, 1246, 1169, 1050, 994, 908, 864, 778, 748; δ_H (400 MHz; $CDCl_3$) 5.81 (ddt, J_1 = 17.2 Hz, J_2 = 10.7 Hz, J_3 = 6.6 Hz, 1H, H-8 or 8'), 5.78 (ddt, J_1 = 17.2 Hz, J_2 = 10.4 Hz, J_3 = 6.8 Hz, 1H, H-8 or 8'), 5.02 (dq, J_1 = 17.1 Hz, J_2 = 1.6 Hz, 1H, H_{trans}-8_A or $8'_A$), 5.00 (dq, J_1 = 17.2 Hz, J_2 = 1.6 Hz, 1H, H_{trans}-8_A or $8'_A$), 4.97-4.92 (m, 2H, H_{cis}-8_B, $8'_B$), 4.24 (bd, J = 7.6 Hz, 1H, N*H*), 3.58 (bb, 1H, H-4), 2.15-2.00 (m, 4H, H-7, 7'), 1.62-1.25 (m, 6H, H-5, 5', 6), 1.44 (s, 9H, H-3); δ_C (100 MHz; $CDCl_3$) 156.0 (C-1), 138.6, 138.2 (CH-8 and 8'), 114.7, 114.6 (CH_2-9 and 9'), 78.9 (C-2), 50.1 (CH-4), 34.9, 33.6, 30.2 (CH_2-5, 5', 7 and 7'), 28.3 (CH_3-3), 25.1 (CH2-6); HRMS (ESI^+) calcd for $C_{15}H_{27}NO_2Na$ $(M + Na)^+$ 276.1939, found 276.1895.

(2*E*, 11*E*)-Diethyl 7-(*tert*-butoxycarbonylamino)trideca-2,11-dienedioate 1a



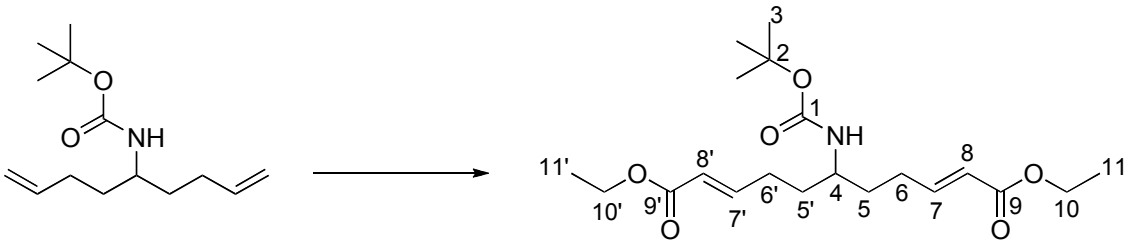
In a dry flask, a 0.08M solution of *tert*-butyl *N*-[1-(4-pentenyl)-5-hexenyl]carbamate (1.0 equiv) in ethyl acrylate was prepared and degassed (nitrogen bubbling during 10-15 min), at rt. To the degassed solution, Hoveyda-Grubbs second generation catalyst (3 mol%) was added solid and nitrogen was again bubbled in the reaction mixture for 10 min more. After this time, the mixture was allowed to stir under nitrogen atmosphere for 24 h. The reaction crude was then loaded directly in a column for removal of the ethyl acrylate and purification of the final product. Gradient elution with petroleum ether (30/40):diethyl ether from 6:1 to 1:1, afforded the desired (*E,E*) isomer **1a** [95%, yellow oil, R_f 0.23 (petroleum ether (30/40):diethyl ether 2:1)], along with the isomer **(*E*,*Z*)-1a** [3%, colorless oil, R_f 0.28 (petroleum ether (30/40):diethyl ether 2:1)].

1a: ν_{max} (CH_2Cl_2/cm^{-1}) 3361, 2980, 2931, 2856, 1805, 1697 (bb), 1653, 1519, 1455, 1391, 1366, 1266, 1170, 1096, 1044, 983, 859, 780; δ_H (400 MHz; $CDCl_3$) 6.92 (dt, J_{trans} = 15.7 Hz, $J_2 = J_3$ = 6.9 Hz, 2H, H-8, 8'), 5.81 (dt, J_{trans} = 15.7 Hz, $J_2 = J_3$ = 1.4 Hz, 2H, H-9, 9'), 4.20 (bb, 1H, N*H*), 4.16 (q, J = 7.3 Hz, 4H, H-11, 11'), 3.56 (bb, 1H, H-4), 2.17 (m, 4H, H-7, 7'), 1.55-1.44 (m, 6H, H-5, 5', 6, 6'), 1.44 (s, 9H, H-3), 1.40-1.30 (m, 2H, H-5, 5', 6, 6'), 1.28 (t, J = 7.3 Hz, 6H, H-12, 12'); δ_C (100 MHz; $CDCl_3$) 167.0 (C-10 and 10'), 156.1 (C-1), 149.0 (CH-8 and 8'), 122.0 (CH-9 and 9'), 79.5 (C-2), 60.6 (CH_2-11 and 11'), 50.5 (CH-4), 35.6, 32.3 (CH_2-5, 5', 7 and 7'), 28.8 (CH_3-3), 24.8 (CH_2-6 and 6'), 14.7 (CH_3-12); HRMS (ESI^+) calcd for $C_{22}H_{37}NO_6Na$ $(M + Na)^+$ 434.2519, found 434.2541.



(2*Z*, 11*E*)-Diethyl 7-(*tert*-butoxycarbonylamino)trideca-2,11-dienedioate (*E,Z*)-1a: δ_H (400 MHz; $CDCl_3$) 6.92 (1H, H-8), 6.17 (dt, J_{cis} = 11.5 Hz, $J_2 = J_3$ = 7.7 Hz, 1H, H-8'), 5.81 (1H, H-9), 5.75 (dt, J_{cis} = 11.5 Hz, $J_2 = J_3$ = 1.5 Hz, 1H, H-9'), 4.20 (bb, 1H, N*H*), 4.16 (4H, H-11, 11'), 3.56 (bb, 1H, H-4), 2.64 (m, 2H, H-7'), 2.17 (m, 2H, H-7), 1.55-1.44 (m, 6H, H-5, 5', 6, 6'), 1.44 (s, 9H, H-3), 1.40-1.30 (m, 2H, H-5, 5', 6, 6'), 1.28 (6H, H-12, 12').

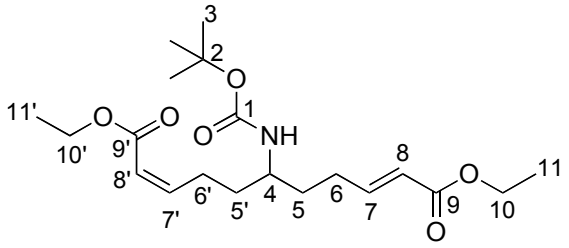
(2*E*, 9*E*)-Diethyl 6-(*tert*-butoxycarbonylamino)undeca-2,9-dienedioate 1b



The carbamate **1b** was prepared following the procedure described above. After 24 h stirring at rt, the reaction crude was loaded directly in a column for removal of the ethyl acrylate and purification of the final product. Stepped gradient elution with petroleum ether (30/40):ethyl acetate 10:1, 8:1, 6:1, 5:1 and 4:1, afforded the desired (*E,E*) isomer **1b** [96%, colorless oil, R_f 0.33 (petroleum ether (30/40):ethyl acetate 4:1)], along with the isomer **(*E,Z*)-1b** [4%, colorless oil, R_f 0.42 (petroleum ether (30/40):ethyl acetate 4:1)].

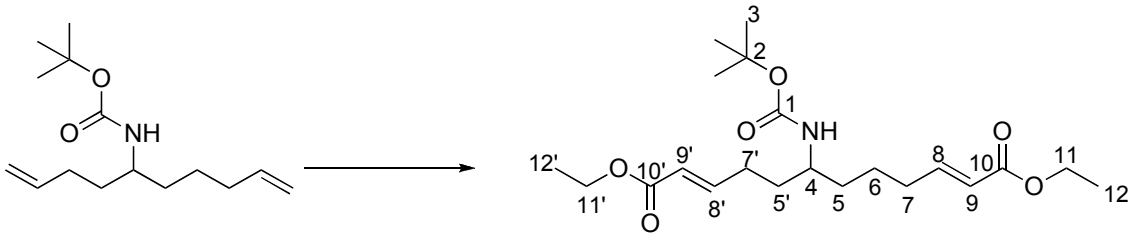
1b: ν_{max} (CH_2Cl_2/cm^{-1}) 3362, 2979, 2928, 2163, 2014, 1713 (bb), 1654, 1520, 1450, 1391, 1366, 1265, 1244, 1169, 1095, 1044, 981, 863; δ_H (400 MHz; $CDCl_3$) 6.92 (dt, J_{trans} = 15.6 Hz, $J_2 = J_3$ = 6.8 Hz, 2H, H-7, 7'), 5.81 (bd, J_{trans} = 15.6 Hz, 2H, H-8, 8'), 4.28 (bd, J = 8.4 Hz, 1H, N*H*), 4.17 (q, J = 7.1 Hz, 4H, H-10, 10'), 3.59 (bb, 1H, H-4),

2.25 (m, 4H, H-6, 6'), 1.67-1.55 (m, 2H, H-5_A, $5'_A$), 1.55-1.45 (m, 2H, H-5_B, $5'_B$), 1.43 (s, 9H, H-3), 1.27 (t, J = 7.2 Hz, 6H, H-11, 11'); δ_C (100 MHz; $CDCl_3$) 166.9 (C-9 and 9'), 156.0 (C-1), 148.4 (CH-7 and 7'), 122.2 (CH-8 and 8'), 79.8 (C-2), 60.6 (CH_2-10 and 10'), 50.5 (CH-4), 34.6, 29.2 (CH_2-5, 5', 6 and 6'), 28.8 (CH_3-3), 14.6 (CH_3-11); HRMS (ESI^+) calcd for $C_{20}H_{33}NO_6Na$ $(M + Na)^+$ 406.2206, found 406.2202.



(*E*,*Z*)-1b: ν_{max} (CH_2Cl_2/cm^{-1}) 3362, 2928, 2846, 2163, 2006, 1718 (bb), 1667, 1523, 1456, 1367, 1264, 1176, 1042; δ_H (400 MHz; $CDCl_3$) 6.87 (dt, J_{trans} = 15.6 Hz, $J_2 = J_3$ = 6.8 Hz, 1H, H-7), 6.16 (dt, J_{cis} = 11.2 Hz, $J_2 = J_3$ = 7.6 Hz, 1H, H-7'), 5.75 (bdt, Jtrans = 15.6 Hz, 1H, H-8), 5.71 (bdt, J_{cis} = 11.6 Hz, $J_2 = J_3$ = 1.4 Hz, 1H, H-8'), 4.32 (bd, J = 8.4 Hz, 1H, N*H*), 4.11 (q, J = 7.2 Hz, 2H, H-10 or 10'), 4.10 (q, J = 7.2 Hz, 2H, H-10 or H-10'), 3.54 (bb, 1H, H-4), 2.72-2.61 (m, 1H, H-$6'_A$), 2.62-2.50 (m, 1H, H-$6'_B$), 2.26-2.13 (m, 2H, H-6), 1.64-1.52 (m, 2H, H-5_A, $5'_A$), 1.52-1.40 (m, 2H, H-5_B, $5'_B$), 1.37 (s, 9H, H-3), 1.22 (t, J = 7.1 Hz, 3H, H-11 or 11'), 1.21 (t, J = 7.1 Hz, 3H, H-11 or 11'); HRMS (ESI^+) calcd for $C_{20}H_{33}NO_6Na$ $(M + Na)^+$ 406.2206, found 406.2212.

(2*E*, 10*E*)-Diethyl 6-(*tert*-butoxycarbonylamino)dodeca-2,10-dienedioate 1c



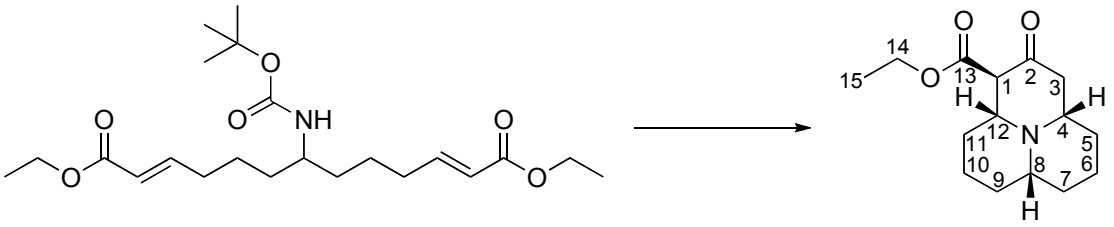
The carbamate **1c** was prepared following the procedure described above. After 24 h stirring at rt, the reaction crude was loaded directly in a column for removal of the ethyl acrylate and purification of the final product. Stepped gradient elution with petroleum ether (30/40):diethyl ether 20:1, 15:1, 6:1, 3:1 and 2:1, afforded the desired (*E,E*) isomer **1c** [81%, colorless oil, R_f 0.16 (petroleum ether (30/40):diethyl ether 2:1)], along

with traces of an (*E,Z*) isomer [5%, yellow oil, R_f 0.21 (petroleum ether (30/40):diethyl ether 2:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 3353, 2997, 2936, 2359, 2191, 1713 (bb), 1653, 1519, 1446, 1366, 1265, 1169, 1041, 979, 853; δ_H (400 MHz; $CDCl_3$) 6.94 (dt, J_{trans} = 15.6 Hz, $J_2 = J_3$ = 6.6 Hz, 1H, H-8 or 8'), 6.92 (dt, J_{trans} = 15.6 Hz, $J_2 = J_3$ = 6.6 Hz, 1H, H-8 or 8'), 5.82 (dt, J_{trans} = 15.6 Hz, J_2 = 1.6 Hz, 1H, H-9 or 9'), 5.81 (dt, J_{trans} = 15.6 Hz, J_2 = 1.6 Hz, 1H, H-9 or 9'), 4.23 (bb, 1H, N*H*), 4.18 (2q, *J* = 7.2 Hz, 4H, H-11, 11'), 3.58 (bb, 1H, H-4), 2.28-2.15 (m, 4H, H-7, 7'), 1.67-1.35 (m, 6H, H-5, 5', 6), 1.44 (s, 9H, H-3), 1.27 (2t, *J* = 7.2 Hz, 6H, H-12, 12'); δ_C (100 MHz; $CDCl_3$) 164.5 (C-10 and 10'), 153.5 (C-1), 146.4, 146.1 (CH-8 and 8'), 119.7 (CH-9 and 9'), 77.5 (C-2), 58.1 (CH_2-11 and 11'), 48.1 (CH-4), 33.1, 32.1, 29.8, 26.8, 22.3 (CH_2-5, 5', 6, 7 and 7'), 26.3 (CH_3-3), 12.2 (CH_3-12); HRMS (ESI^+) calcd for $C_{21}H_{35}NO_6Na$ $(M + Na)^+$ 420.2362, found 420.2356.

3. Folding cascades from aminodialkenes

(1*R*, 3a*S*, 6a*R*, 9a*R*)/(1*S*, 3a*R*, 6a*S*, 9a*S*)-Ethyl 2-oxododecahydropyrido[2,1,6-*de*]quinolizine-1-carboxylate 3a

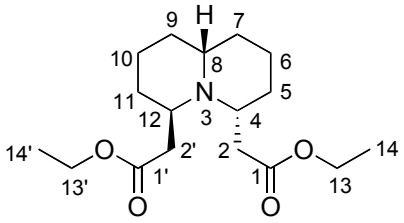


A dry flask was equipped with a Dean-Stark trap containing anhydrous toluene and a few pieces of sodium metal. In the flask, a solution of **1a** (1.0 equiv) was prepared in anhydrous toluene (30mL/mmol of **1a**), at rt, under nitrogen atmosphere. On this solution, stannous (II) triflate (0.5 equiv) was added solid in one portion and the mixture was heated up to reflux. After 24 h, no starting material could be observed on tlc and the reaction was stopped by cooling down to rt. The reaction mixture was then diluted with ethyl acetate and a saturated aqueous solution of sodium bicarbonate. The phases were separated and the aqueous phase was extracted (x3) with ethyl acetate. The final combination of the organic phases was dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (gradient

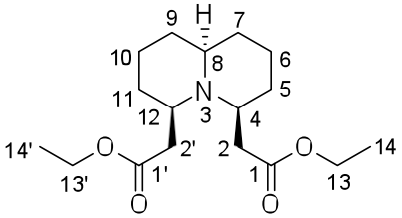
elution using mixtures dichloromethane:acetone 10:0.5 and 10:1), to obtain **3a** as a white solid [mp 60.4-61.4 °C (DCM)] in 72% yield: R_f 0.6 (silica, DCM:acetone 9:1); crystallization by slow evaporation of a solution in dichloromethane, at rt]. Along with **1a**, ***trans*-2a** [colorless oil, 2%, R_f 0.3 (silica, DCM:acetone 9:1)] and ***cis*-2a** [colorless oil, 7%, R_f 0.1 (silica, DCM:acetone 9:1)] were isolated.

1a: ν_{max} (CH_2Cl_2/cm^{-1}) 2930, 2860, 2800, 1743, 1700, 1445, 1370, 1338, 1324, 1303, 1264, 1182, 1152, 1139, 1112, 1046, 982, 856, 756, 678; δ_H (400 MHz; $CDCl_3$) 4.19 (dq, J_{gem} = 10.8 Hz, J_{vec} = 7.2 Hz, 1H, H-14_A), 4.14 (dq, J_{gem} = 10.8 Hz, J_{vec} = 7.2 Hz, 1H, H-14_B), 3.25 (d, J = 11.6 Hz, 1H, H-1), 2.58 (bddd, $J_1 = J_2$ = 10.6 Hz, J_3 = 2.4 Hz, 1H, H-12), 2.33 (dd, J_{gem} = 25.3 Hz, J_{vec} = 13.2 Hz, 1H, H-3_A), 2.29 (m, 1H, H-4), 2.28 (dd, J_{gem} = 25.3 Hz, J_{vec} = 2.0 Hz, 1H, H-3_B), 1.93 (bt, J = 8.2 Hz, 1H, H-8), 1.67-1.54 (m, 6H, H-5_A, 6_A, 7_A, 9_A, 10_A, 11_A), 1.43-1.27 (m, 6H, H-5_B, 6_B, 7_B, 9_B, 10_B, 11_B), 1.22 (t, J = 7.2 Hz, 3H, H-15); δ_C (125 MHz; $CDCl_3$) 203.0 (C-2), 168.7 (C-13), 64.3 (CH-12), 63.7 (CH-1), 62.7 (CH-8), 61.8 (CH-4), 61.0 (CH_2-14), 48.3 (CH_2-3), 34.5 (CH_2-5), 33.8, 33.5 (CH_2-7 and 9), 33.0 (CH_2-11), 23.7, 23.6 (CH_2-6 and 10), 14.17 (CH_3-15); HRMS (ESI^+) calcd for $C_{15}H_{24}NO_3$ $(M + H)^+$ 266.1751, found 266.1716.

Crystallization and X-ray diffraction on 3a: Suitable crystals of **3a** were obtained after dissolving this compound in a small volume of dichloromethane. A vial with a screw top allowed the slow evaporation of the solvents at rt, to the formation of colorless crystals. Relevant crystal data: empirical formula $C_{15}H_{23}NO_3$, M_w=265.34, T = 100(2) K, crystal system triclinic, space group P-1, unit cell dimensions a=8.6717(2) Å, b=8.8865(2) Å, c=9.6551(2) Å and α=86.555(1)°, β=72.478(1)° γ=80.643°, V = 700.02(3) $Å^3$, Z=2, D=1.259 Mg/m^3 (calculated), μ(MoKa)=0.087 mm^{-1}, collected/independent reflections 12,361/4060 [R(int)=0.0271], final R indices [I>2sigma(I)] R_1=0.0412 and wR_2=0.1107, GOF=1.080. CCDC number 746888.

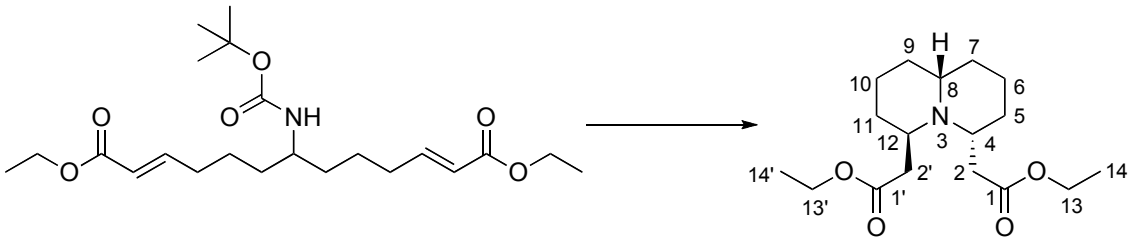


(±)-Diethyl octahydro-1*H*-quinolizine-4,6-diyl)diacetate, *trans*-2a[2]: ν_{max} (CH_2Cl_2/cm^{-1}) 2923, 2852, 1736; δ_H (500 MHz; $CDCl_3$) 4.13 (qd, J_1 = 7.2 Hz, J_2 = 1.5 Hz, 3H, H-13), 4.12 (q, J = 7.2 Hz, 3H, H-13'), 3.59 (m, 1H, H-12), 2.81 (dd, J_{gem} = 14.6 Hz, J_{vec} = 4.3 Hz, 1H, H-2_A), 2.70 (m, 1H, H-4), 2.61 (dd, J_{gem} = 14.3 Hz, J_{vec} = 3.0 Hz, 1H, H-$2'_A$), 2.49 (dd, J_{gem} = 14.3 Hz, J_{vec} = 10.7 Hz, 1H, H-$2'_B$), 2.23 (dddd, $J_1 = J_2$ = 10.8 Hz, $J_3 = J_4$ = 2.5 Hz, 1H, H-8), 2.19 (dd, J_{gem} = 14.6 Hz, J_{vec} = 8.5 Hz, 1H, H-2_B), 1.70-1.67 (m, 1H, H-5_A), 1.67-1.45 (m, 8H), 1.35-1.31 (m, 1H, H-5_B), 1.30-1.12 (m, 2H), 1.25 (t, J = 7.1 Hz, 3H, 14 or 14'), 1.24 (t, J = 7.1 Hz, 3H, H-14 or 14'); δ_C (125 MHz; $CDCl_3$) 173.3 (C-1'), 172.5 (C-1), 60.4 (CH_2-13 and 13'), 55.1 (CH-4), 54.3 (CH-8), 50.9 (CH-12), 39.0 (CH_2-2), 34.7 (CH_2), 34.4 (CH_2), 32.7 (CH_2-5), 29.4 (CH_2), 27.5 (CH_2-2'), 23.8 (CH_2), 18.5 (CH_2), 14.2 (CH_3-14 and 14'); HRMS (ESI$^+$) calcd for $C_{17}H_{30}NO_4$ $(M + H)^+$ 312.2175, found 312.2171.



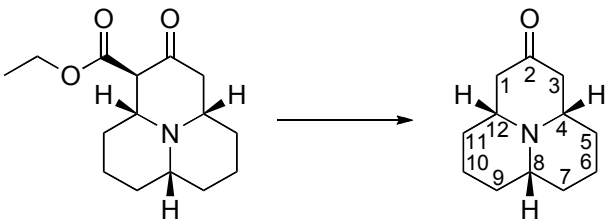
(±)-Diethyl octahydro-1*H*-quinolizine-4,6-diyl)diacetate, *cis*-2a: δ_H (500 MHz; $CDCl_3$) 4.14 (dq, J_{gem} = 10.8 Hz, J_{vec} = 7.1 Hz, 2H, H-13_A, $13'_A$), 4.10 (dq, J_{gem} = 10.8 Hz, J_{vec} = 7.1 Hz, 2H, H-13_B, $13'_B$), 3.42 (m, 1H, H-4, 12), 3.16 (m, 1H, H-8), 2.71 (dd, J_{gem} = 14.9 Hz, J_{vec} = 7.0 Hz, 2H, H-2_A, $2'_A$), 2.26 (dd, J_{gem} = 14.9 Hz, J_{vec} = 6.3 Hz, 2H, H-2_B, $2'_B$), 1.74 (m, 2H, H-5_A, 11_A), 1.65 (m, 2H, H-5_B, 11_B), 1.60-1.50 (m, 4H, H-6_A, 6_B, 10_A, 10_B), 1.28 (m, 2H, H-7_A, 9_A), 1.15 (m, 2H, 7_B, 9_B); δ_C (125 MHz; $CDCl_3$) 172.8 (C-1 and 1'), 60.2 (CH_2-13 and 13'), 50.2 (CH-4 and 12), 49.9 (CH-8), 39.4 (CH_2-2 and 2'), 27.7 (CH_2-7 and 9), 27.3 (CH_2-5 and 11), 20.0 (CH_2-6 and 10), 14.3 (CH_3-14 and 14').

(4*R*,6*R*)/(4*S*,6*S*)-Diethyl 2,2'-(octahydro-1*H*-quinolizine-4,6-diyl)diacetate, *trans*-2a[2]



In a dry flask, a solution of **1a** (1.0 equiv) was prepared in anhydrous toluene (30 mL/mmol of **1a**), at rt, under nitrogen atmosphere. The solution was cooled to 0 °C before the addition of 3.0 equiv of the Lewis acid (aluminium chloride (1M in nitrobenzene) or scandium triflate), after which the cold bath was removed and the mixture was heated up to reflux. After 20 h, no starting material could be observed on tlc and the reaction was stopped by cooling down to rt and dilution with ethyl acetate and a saturated aqueous solution of sodium bicarbonate. The phases were separated and the aqueous phase was extracted (x3) with ethyl acetate. The final combination of the organic phases was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica gel. Elution with mixtures petroleum ether (30/40):diethyl ether 2:1→ 1.5:1, afforded ***trans*-2a** as a colorless oil in 43% ($AlCl_3$) or 50% yield ($Sc(OTf)_3$), and elution with mixtures ethyl acetate:acetone 1:1 and 0:1 afforded the monocycle in 13% ($AlCl_3$) or 21% yield ($Sc(OTf)_3$).

Decahydro-1*H*-pyrido[2,1,6-*de*]quinolizin-2-one

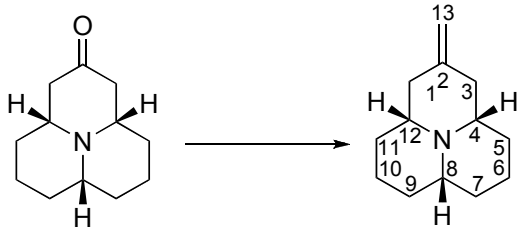


A solution of **3a** (1.0 equiv) in ethanol (26 mL/mmol of **3a**) was prepared at rt. On this solution, sodium carbonate (5.0 equiv, 10% solution in water) was added at rt and the mixture was taken to a 100 °C preheated oil bath. After stirring 24 h at this temperature,

no starting material could be detected on tlc analysis. After cooling down to rt, the reaction was diluted with distilled water and dichloromethane and the phases were separated. The basic aqueous phase was extracted (x 3) with dichloromethane and the resulting organic phases were combined, dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography using Alumina (pH 7, activity I) and eluting with dichloromethane:acetone 9:1 mixture. This way, decahydro-1*H*-pyrido[2,1,6-*de*]quinolizin-2-one was obtained as a colorless oil in 76% yield [R_f 0.2 (alumina plate, dichloromethane); R_f 0.4 (silica plate, dichloromethane:acetone 2:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 2928, 2860, 2789, 1740, 1444, 1385, 1327, 1278, 1178, 1117, 1107, 1090, 1061, 1033, 995, 869, 746; δ_H (500 MHz; $CDCl_3$) 2.37 (dd, J_{gem} = 13.3 Hz, J_{vec} = 13.3 Hz, 2H, H-1_A, 3_A), 2.24 (dd, J_{gem} = 13.3 Hz, J_{vec} = 1.1 Hz, 1H, H-1_B, 3_B), 2.22 (m, 2H, H-4, 12), 1.90 (bdddd, $J_1 = J_2$ = 10.5 Hz, $J_3 = J_4$ = 2.1 Hz, 1H, H-8), 1.71-1.68 (m, *2*H, H-6_A, 10_A), 1.64-1.60 (m, 2H, H-5_A, 11_A), 1.62-1.60 (m, *2*H, H-7_A, 9_A), 1.48-1.29 (m, 6H, H-5_B, 6_B, 7_B, 9_B, 10_B, 11_B); δ_C (125 MHz; $CDCl_3$) 208.2 (C-2), 62.8 (CH-8), 62.4 (CH-4 and 12), 48.8 (CH_2-1 and 3), 34.4 (CH_2-5 and 11), 33.6 (CH_2-7 and 9), 23.8 (CH_2-6 and 10); HRMS (ESI^+) calcd for $C_{12}H_{20}NO$ $(M + H)^+$ 194.1545, found 194.1541.

2-Methylenedodecahydropyrido[2,1,6-*de*]quinolizine 4

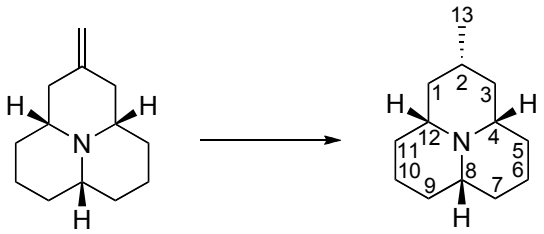


Methyltriphenylphosphonium bromide (1.8 equiv) was dried in the reaction flask, by heating at 120 °C, under high vacuum, for 2 h. After this time, the flask was allowed to cool down to rt, after which it was purged with nitrogen. Anhydrous tetrahydrofuran (12 mL/mmol of phosphonium salt) was then added to the flask to make a white suspension that was then cooled to -78 °C for the addition of *n*-butyllithium (1.5M in hexanes, 1.5 equiv). The cold bath was then removed and the bright yellow mixture was stirred at rt for 2 h. After this time, a solution of the ketone (1.0 equiv) in anhydrous THF (12

mL/mmol of ketone) was slowly added at rt and the final mixture was heated up to 69 °C. After 3 h stirring at this temperature, no starting material could be observed on tlc and the reaction was stopped by cooling down to rt and dilution with ethyl acetate and distilled water. The phases were separated and the organic phase was washed with distilled water (x 3), dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography (Alumina pH 7, activity I). Elution with petroleum ether (30/40): ethyl acetate 25:1 mixture, afforded the product **4** in 61% yield [colorless oil, R_f 0.3 (alumina plate, petroleum ether (30/40):diethyl ether 15:1); R_f 0.2 (silica plate, dichloromethane:acetone 4:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 2926, 2858, 2789, 2753, 2728, 2619, 1657, 1444, 1383, 1320, 1115, 1036, 997, 967, 880, 868, 745; δ_H (500 MHz; $CDCl_3$) 4.57 (s, 2H, H-13), 2.15-2.05 (m, $J_{1A\text{-}12} = J_{3A\text{-}4} = 2.3$ Hz, $J_{1B\text{-}12} = J_{3B\text{-}4} = 12.8$ Hz, 4H, H-1_A, 1_B, 3_A, 3_B), 1.86-1.81 (m, 3H, H-4, 8, 12), 1.67-1.65 (m, 2H, H-6_A, 10_A), 1.60-1.54 (m, 4H, H-5_A, 7_A, 9_A, 11_A), 1.41-1.27 (m, 6H, H-5_B, 6_B, 7_B, 9_B, 10_B, 11_B); δ_C (125 MHz; $CDCl_3$) 146.2 (C-2), 106.1 (CH_2-13), 63.5 (CH-4 and 12), 62.6 (CH-8), 42.4 (CH_2-1 and 3), 34.0, 33.9 (CH_2-5, 7, 9 and 11), 24.0 (CH_2-6 and 10); HRMS (ESI^+) calcd for $C_{13}H_{22}N$ $(M + H)^+$ 192.1752, found 192.1750.

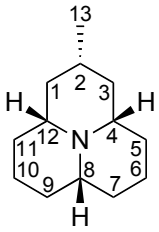
(2*r*, 3a*R*, 7a*r*, 10a*S*)-2-Methyldodecahydropyrido-1*H*-[2,1,6-*de*]quinolizine, myrrhine[7]



A solution of **4** (1.0 equiv) in methanol was prepared at rt. On this solution, *p*-toluenesulfonic acid (1.5 equiv) was added and the mixture was stirred at rt for 15 min, to allow the formation of the *p*-toluenesulfonic salt of **4**. After this time, Raney Nickel® (slurry in water) was added and the flask was purged with hydrogen (slightly higher

[7] W.A. Ayer, R. Dawe, R.A. Eisner, and K. Furuichi, *Can. J. Chem.,* 1976, **54**, 473;R.H. Mueller, M.E. Thompson, and R.M. DiPardo, *J. Org. Chem.,* 1984, **49**, 2217; A. I. Gerasyuto, and R.P. Hsung, *J. Org. Chem.,* 2007, **72**, 2476

pressure of hydrogen than the atmospheric was required for the reaction to proceed). The progress of the reaction was controlled by tlc and until consumption of the starting material could be verified by tlc (after 3-9 h stirring at rt). The catalyst was then removed by filtration through a thin lay of Celite® while washing with methanol. Evaporation of the filtrate under vacuum yielded a white solid that was identified as the *p*-toluenesulfonic salt of myrrhine [mp 192.0-194 °C (MeOH)]. The solid was dissolved in distilled water and this aqueous phase was washed with ethyl acetate (x3). The final aqueous phase was then taken to pH 8-10 by addition of sodium bicarbonate (saturated solution in water) and the basic aqueous phase was extracted with dichloromethane (x3). The final organic phase was dried over magnesium sulfate and evaporated under vacuum. ^{1}H- and ^{13}C-NMR of the residue showed the peaks corresponding to myrrhine as the only visible diastereoisomer. Further purification was performed by flash chromatography (Alumina pH 7, activity I; elution with mixture petroleum ether (30/40):ethyl acetate 25:1), to yield two colorless oils that were identified as myrrhine (52%) and its epimer ***epi*-myrrhine** (5%).[8]

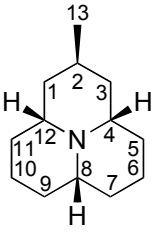


myrrhine[9]*:* ν_{max} (CH_2Cl_2/cm^{-1}) 2926, 2857, 2787, 2726, 2616, 1446, 1386, 1324, 1256, 1222, 1131, 1122, 1067, 1044, 1022, 997, 747; δ_H (500 MHz; $CDCl_3$) 1.88-1.76 (m, 3H, H-4, 8, 12), 1.68-1.60 (bb, 2H, H-6_A, 10_A), 1.58-1.48 (bm, 6H, H-1_A, 3_A, 5_A, 7_A, 9_A, 11_A), 1.49-1.42 (bb, 1H, H-2), 1.39-1.28 (bm, 6H, H-5_B, 6_B, 7_B, 9_B, 10_B, 11_B), 1.09-0.97 (bm, 2H, H-1_B, 3_B), 0.85 (d, J = 6.2 Hz, 3H, H-13); δ_C (125 MHz; $CDCl_3$) 62.5 (CH-8), 62.1 (CH-4 and 12), 42.6 (CH_2-1 and 3), 34.0, 33.9 (CH_2-5, 7, 9 and 11), 30.3 (CH-2),

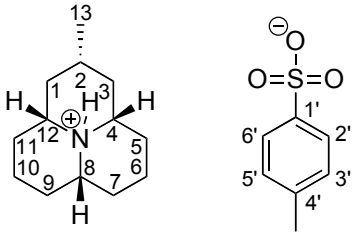
[8] Both isomers present similar R_f on alumina plates [R_f 0.3 (petroleum ether (30/40):ethyl acetate 20:1] and silica plates [R_f 0.24 (acetone)]. Myrrhine elutes in the first fractions while its epimer elutes afterwards.

[9] NMR data agree with the previously reported: Lebrun, B.; Braekman, J.C.; Daloze, D. *Magn. Reson. Chem.* **1999**, *37*, 60-64.

24.2 (CH_2-6 and 10), 22.0 (CH_3-13); HRMS (ESI^+) calcd for $C_{13}H_{24}N$ $(M + H)^+$ 194.1909, found 194.1918.



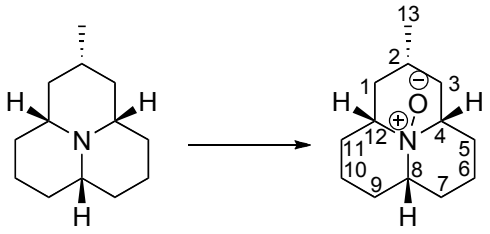
***epi*-myrrhine**: ν_{max} (CH_2Cl_2/cm^{-1}) 2926, 2850, 2497, 2100, 1744, 1463; δ_H (500 MHz; $CDCl_3$) 2.65-2.61 (m, 3H, H-4, 8, 12), 2.28 (ddt, J_1 = 26.4 Hz, J_2 = 13.7 Hz, J_3 = J_4 = 4.0 Hz, 4H, H-5_A, 7_A, 9_A, 11_A), 1.98 (ddd, J_1 = 25.3 Hz, J_2 = 13.1 Hz, J_3 = 1.5 Hz, 2H, H-1_A, 3_A,), 1.87 (dquint, J_{gem} = 13.5 Hz, J_2 = J_3 = J_4 = J_5 = 3.3 Hz, 2H, H-6_A, 10_A), 1.71 (m, 7H, H-1_B, 2, 3_B, 5_B, 7_B, 9_B, 11_B), 1.48 (qt, J_1 = J_2 = J_3 = 13.5 Hz, J_4 = J_5 = 3.7 Hz, 2H, H-6_B, 10_B), 0.98 (d, J = 6.5 Hz, 3H, H-13); δ_C (125 MHz; $CDCl_3$) 65.4 (CH-8), 65.2 (CH-4 and 12), 38.5 (CH_2-1 and 3), 30.4, 30.3 (CH_2-5, 7, 9 and 11), 29.6 (CH-2), 22.7 (CH_2-6 and 10), 21.0 (CH_3-13); HRMS (ESI^+) calcd for $C_{13}H_{24}N$ $(M + H)^+$ 194.1909, found 194.1958.



myrrhine·*p*TsOH: ν_{max} (CH_2Cl_2/cm^{-1}) 3399, 2952, 2873, 2711, 2652, 2167, 1599, 1496, 1453, 1428, 1226, 1200, 1168, 1118, 1036, 1012, 998, 970, 949, 827, 799, 680; δ_H (500 MHz; CD_3OD) 7.70 (bd, J = 7.7 Hz, 2H, H-2', 6'), 7.23 (bd, J = 7.1 Hz, 2H, H-3', 5'), 3.07-2.98 (m, 3H, H-4, 8, 12), 2.36 (s, 3H, CH_3-Ar), 1.89-1.84 (m, 6H, H-1_A, 3_A, 5_A, 7_A, 9_A, 11_A), 1.82-1.76 (m, 3H, H-2, 6_A, 10_A), 1.66-1.50 (m, 6H, H-5_B, 6_B, 7_B, 9_B, 10_B, 11_B), 1.15 (m, 2H, H-1_B, 3_B), 0.94 (d, J = 6.5 Hz, 3H, H-13); δ_C (125 MHz; $CDCl_3$) 143.6 (C-1'), 141.8 (C-4'), 130.0 (CH-3' and 5'), 127.0 (CH-2' and 6'), 65.5 (CH-8), 65.2 (CH-4 and 12), 40.5 (CH_2-1 and 3), 32.4, 33.3 (CH_2-5, 7, 9 and 11), 29.7 (CH-2),

22.9 (CH_2-6 and 10), 21.4 (CH_3-13), 21.3 (CH_3-Ar); HRMS (ESI^+) calcd for $C_{13}H_{25}N$ $(M + H)^+$ 195.1982, found 195.1924.

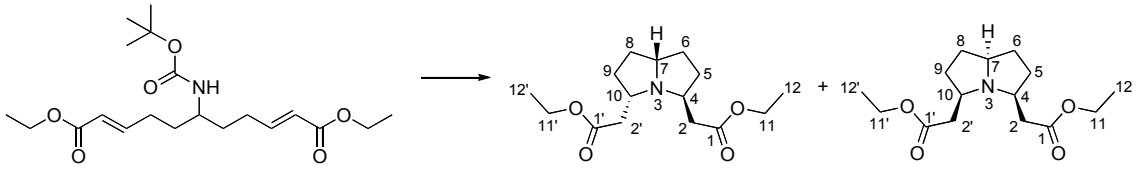
(2*r*, 3a*R*, 7a*r*, 10a*S*)-2-Methyl dodecahydro-1*H*-pyrido[2,1,6-*de*]quinolizine-4-oxide; myrrhine-*N*-oxide[7,9]



A solution of **1** (1.0 equiv) in dichloromethane (100 mL/mmol of **1**) was prepared at rt and cooled to 0 °C for the addition of solid *m*-chloroperbenzoic acid (57-86%, 1.6-2.4 equiv). The mixture was stirred at 0 °C for 4 h, after which the consumption of the starting material and the formation of the new product were checked by tlc and LCMS. The reaction was then stopped by removal of the solvent under vacuum. **Myrrhine-*N*-oxide** was purified by flash chromatography on alumina (pH 7, activity I), eluting with a mixture dichloromethane:methanol 10:0.3 [white solid, 96%, R_f 0.2 (silica plate, acetone:methanol 3:1)].

ν_{max} (CH_2Cl_2/cm^{-1}) 2923, 2870, 1646, 1445, 975, 922, 761; δ_H (500 MHz; $CDCl_3$) 3.20-2.90 (m, 3H, H-4, 8, 12), 2.13 (dddd, $J_1 = J_2 = J_3$ = 13.1 Hz, J_4 = 3.6 Hz, 4H, H-5_A, 7_A, 9_A, 11_A), 1.87 (ddd, $J_1 = J_2 = J_3$ = 12.7 Hz, 2H, H-1_A, 3_A), 1.68 (dquint, J_{gem} = 13.3 Hz, $J_2 = J_3 = J_4 = J_5$ = 2.6 Hz, 2H, H-6_A, 10_A), 1.64 (bb, 1H, H-2), 1.49-1.38 (m, 2H, H-6_B, 10_B), 1.34-1.28 (m, 6H, H-1_B, 3_B, 5_B, 7_B, 9_B, 11_B), 0.90 (d, J = 6.5 Hz, 3H, H-13); δ_C (125 MHz; $CDCl_3$) 73.6 (CH-8), 73.3 (CH-4 and 12), 35.5 (CH_2-1 and 3), 27.3, 27.2 (CH_2-5, 7, 9 and 11), 29.7 (CH-2), 23.0 (CH_2-6 and 10), 21.3 (CH_3-13); HRMS (ESI^+) calcd for $C_{13}H_{24}NO$ $(M + H)^+$ 210.1858, found 210.1864.

(3*R*,5*R*)/(3*S*,5*S*)-Diethyl 2,2'-(hexahydro-1*H*-pyrrolizin-3,5-diyl)diacetate[10] ***trans*-2b** and **(3*R*,5*S*,7a*r*)-diethyl 2,2'-(hexahydro-1*H*-pyrrolizin-3,5-diyl)diacetate *cis*-2b**



Method A (Lewis acid mediated): In a dry flask, a solution of **1b** (1.0 equiv) was prepared in anhydrous dichloromethane (30 mL/mmol of **1b**), at rt, under nitrogen atmosphere. The solution was cooled to 0 °C before the addition of 1.1 equiv of aluminium chloride (1M in nitrobenzene), after which the cold bath was removed and the mixture was allowed to stir at rt. After 24 h, no starting material could be observed on tlc and the reaction was stopped by cooling down to rt and dilution with dichloromethane. The organic phase was washed with sodium bicarbonate (saturated solution in water). The phases were separated and the organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica gel. First, elution with mixtures petroleum ether (30/40):ethyl acetate 2:1, 1:2 and 0:1, afforded ***cis*-2b** as a colorless oil in 28% yield, and elution with ethyl acetate:acetone 1:1 afforded ***trans*-2b** as a colorless oil in 42% yield.

Method B (Trifluoroacetic acid mediated): The acyclic compound **1b** was dissolved in a mixture of anhydrous dichloromethane/trifluoroacetic acid 4/1 (60 mL/mmol of **1b**), at rt, under nitrogen. The mixture was allowed to stir during 24 h, after which no starting material was visible on tlc. The reaction was stopped by dilution with dichloromethane and washes of the organic phase with sodium bicarbonate (saturated solution in water). The final organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography, as described above, to furnish ***cis*-2b** in 34% and ***trans*-2b** in 53% yield.

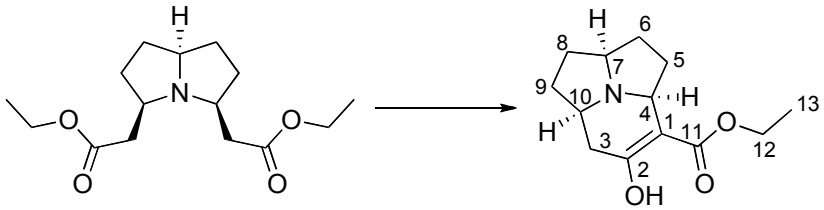
***cis*-2b**: R_f 0.28 (ethyl acetate:acetone 1:1); ν_{max} (CH_2Cl_2/cm^{-1}) 2966, 2925, 2854, 1728, 1464, 1369, 1269, 1173, 1107, 1031, 952, 720; δ_H (400 MHz; $CDCl_3$) 4.13 (bq, J = 7.2

[10] Numbering pyrrolizidine: P. E. Sonnet, D. A. Netzel, and R. Mendoza, *J. Heterocyclic Chem.* **1979**, *16*, 1041; T.A. Crabb, R.F. Newton and D. Jackson, *Chem. Rev.,* 1971, **71**(1), 109

Hz, 4H, H-11 and 11'), 3.59 (m, 1H, H-7), 3.20 (bquint, J = 6.5 Hz, 2H, H-4, 10), 2.55 (dd, J_{gem} = 15.0 Hz, J_{vec} = 5.8 Hz, 2H, H-2_A, 2'$_A$), 2.25 (dd, J_{gem} = 14.8 Hz, J_{vec} = 8.0 Hz, 1H, H-2_B, 2'$_B$), 2.05-1.91 (m, 4H, H-5_A, 6_A, 8_A, 9_A), 1.54-1.39 (m, 4H, 5_B, 6_B, 8_B, 9_B), 1.26 (t, J = 7.2 Hz, 6H, H-12, 12'); δ_C (100 MHz; $CDCl_3$) 172.0 (C-1 and 1'), 64.8 (CH-7), 63.3 (CH-4 and 10), 60.6 (CH_2-11 and 11'), 42.0 (CH_2-2 and 2'), 31.8, 31.6 (CH_2-5, 6, 8 and 9), 14.6 (CH_3-12 and 12'); HRMS (ESI^+) calcd for $C_{15}H_{26}NO_4$ $(M + H)^+$ 284.1862, found 284.1877.

***trans*-2b**: R_f 0.12 (ethyl acetate:acetone 1:1); ν_{max} (CH_2Cl_2/cm^{-1}) 2962, 2921, 2839, 1733, 1472, 1369, 1175, 1030; δ_H (400 MHz; $CDCl_3$) 4.21-4.10 (m, 4H, H-11 and 11'), 3.65 (m, 1H, H-7), 3.55 (m, 1H, H-10), 3.37 (bquint, J = 6.8 Hz, 1H, H-4), 2.85 (dd, J_{gem} = 14.5 Hz, J_{vec} = 5.3 Hz, 1H, H-2'$_A$), 2.53 (dd, J_{gem} = 15.2 Hz, J_{vec} = 5.1 Hz, 1H, H-2_A), 2.33 (dd, J_{gem} = 15.2 Hz, J_{vec} = 8.5 Hz, 1H, H-2_B), 2.27 (dd, J_{gem} = 14.5 Hz, J_{vec} = 9.6 Hz, 1H, H-2'$_B$), 2.12 (tdd, J_1 = 13.56 Hz, J_2 = 5.4 Hz, J_3 = 1.3 Hz, 1H, H-6_A), 2.06-1.98 (m, 2H, H-5_A, 8_A), 1.88 (m, 1H, H-9_A), 1.68-1.56 (m, 2H, H-5_B, 6_B), 1.46-1.30 (m, 2H, H-8_B, 9_B), 1.26 (t, J = 7.2 Hz, 6H, H-12, 12'); δ_C (100 MHz; $CDCl_3$) 172.5, 172.4 (C-1 and 1'), 66.5 (CH-7), 60.9, 60.7 (CH_2-11 and 11'), 58.6 (CH-10), 55.1 (CH-4), 42.7 (CH_2-2), 37.0 (CH_2-2'), 34.4 (CH_2-6), 32.6 (CH_2-8), 32.4 (CH_2-5), 30.5 (CH_2-9), 14.6 (CH_3-12 and 12'); HRMS (ESI^+) calcd for $C_{15}H_{26}NO_4$ $(M + H)^+$ 284.1862, found 284.1880.

(2a*S*,4a*S*,7a*R*)/(2a*R*,4a*R*,7a*S*)-Ethyl 6-hydroxy-1,2,2a,3,4,4a,7,7a-octahydropyrrolo [2,1,5-*cd*]indolizine-5-carboxylate, *cis*-3b



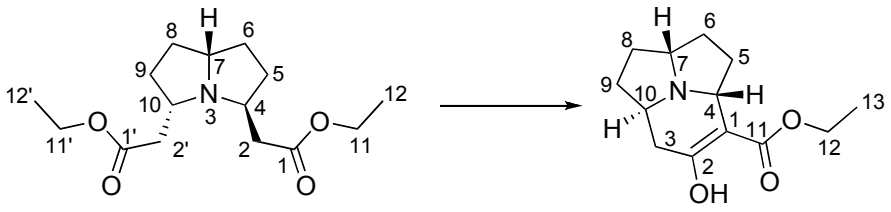
In a dry flask, a solution of diisopropylamine (2.5 equiv) in dry THF (3 mL/mmol of diisopropylamine) was prepared under nitrogen, at rt. The solution was cooled to -18 °C and *n*-butyllithium (1.5 equiv) was added dropwise. The mixture was stirred at -18 °C for 30 min,[11] after which a solution of ***cis*-2b** (1.0 equiv) in dry THF (5 mL/mmol) was

[11] A. Barbieri, P.C. Montevecchi, D. Nanni, M.L. Navacchia, *Tetrahedron*, 1996, **52**(41), 13255

slowly added. The reaction was stirred at -18 °C for 24 h, after which analysis by tlc revealed the permanence of only traces of the starting material. The reaction was then cooled down to -78 °C, quenched by addition of distilled water, and transferred to a separating funnel. There, it was diluted with ethyl acetate and a saturated aqueous solution of sodium bicarbonate and the phases were separated. The aqueous phase was still extracted with ethyl acetate (x 3), and the final combination of the organic phases was dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (stepped gradient elution using mixtures chloroform:2.0M methanolic ammonia:methanol 10:0.1:0.1, 10:0.1:0.2 and 10:0.1:0.5) to furnish the final tricycle as a yellow oil in 38% yield [R_f 0.24 (silica, chloroform:2.0M methanolic ammonia:methanol 10:0.1:0.7)]

ν_{max} (CH_2Cl_2/cm^{-1}) 3415 (bb), 3323 (bb), 2947, 2926, 1731, 1665, 1615, 1543, 1463, 1262, 1217, 1172, 1097; δ_H (500 MHz; $CDCl_3$) 4.20 (dq, J_1 = 10.8 Hz, J_2 = 7.1 Hz, 1H, H-12$_A$), 4.08 (dq, J_1 = 10.8 Hz, J_2 = 7.1 Hz, 1H, H-12$_B$), 4.02 (bb, 1H, H-7), 3.24 (bb, 1H, H-10), 3.01 (bb, 1H, H-4), 2.76 (dt, J_1 = 13.5 Hz, J_3 = 8.3 Hz, 1H, H-6$_A$), 2.51 (bm, 1H, H-9$_A$), 2.27 (dd, J_{gem} = 16.7 Hz, J_{vec} = 10.6 Hz, 1H, H-3$_A$), 1.90-1.66 (m, 7H, H-3$_B$, 5$_A$, 5$_B$, 6$_B$, 8$_A$, 8$_B$, 9$_B$), 1.26 (t, J = 7.1 Hz, 3H, H-13); δ_C (125 MHz; $CDCl_3$) 63.0 (CH-4), 58.9 (CH_2-12), 48.8 (CH-7), 46.8 (CH-10), 40.6 (CH_2-6), 35.8 (CH_2-9), 30.7 (CH_2-3), 27.7, 25.6 (CH_2-5 and 8), 14.5 (CH_3-13); HRMS (ESI$^+$) calcd for $C_{13}H_{19}NO_3$ (M) 237.1365, found 237.1627.

(2a*R*,4a*R*,7a*R*)/(2a*S*,4a*S*,7a*S*)-Ethyl 6-hydroxy-1,2,2a,3,4,4a,7,7a-octahydropyrrolo [2,1,5-*cd*]indolizine-5-carboxylate *trans*-3b

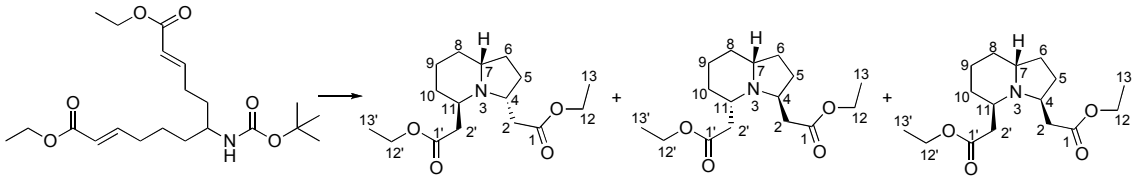


The tricycle ***trans*-3b** was prepared from the bicycle ***trans*-2b**, following the procedure above. After 24 h stirring at -18°C, analysis by tlc showed the permanence of only traces of the starting material and the formation of a new product. The reaction was then cooled down to -78 °C, quenched by addition of distilled water, and transferred to a

separating funnel. There, it was diluted with ethyl acetate and a saturated aqueous solution of sodium bicarbonate and the phases were separated. The aqueous phase was still extracted with ethyl acetate (x 3), and the final combination of the organic phases was dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (stepped gradient elution using mixtures chloroform:2.0M methanolic ammonia:methanol 10:0.1:0.1 and 10:0.1:2) to furnish the final tricycle as a yellow solid in 91% yield [mp 71.0-72.0 °C ($CHCl_3$:MeOH); R_f 0.29 (silica, chloroform:2.0M methanolic ammonia:methanol 10:0.1:0.4)]

ν_{max} (CH_2Cl_2/cm^{-1}) 2961, 2899, 2869, 1732, 1646, 1610, 1466, 1407, 1377, 1352, 1280, 1262, 1226, 1179, 1064, 840; δ_H (400 MHz; $CDCl_3$) 4.26 (dq, J_1 = 10.8 Hz, J_2 = 7.0 Hz, 1H, H-12_A), 4.20 (dq, J_1 = 10.8 Hz, J_2 = 7.0 Hz, 1H, H-12_B), 3.80 (dd, J_1 = 9.6 Hz, J_2 = 6.4 Hz, 1H, H-4), 3.58 (m, 1H, H-7), 2.62 (tt, J_1 = 10.4 Hz, J_2 = 4.0 Hz, 1H, H-10), 2.40 (dd, J_{gem} = 16.8 Hz, J_{vec} = 4.0 Hz, 1H, H-3_A), 2.33 (ddd, J_{gem} = 16.8 Hz, J_{vec} = 10.4 Hz, J_3 = 0.8 Hz, 1H, H-3_B), 2.32-2.24 (m, 1H, H-8_A), 2.17-2.04 (m, 2H, H-5_A, 6_A), 2.00-1.91 (m, 1H, H-9_A), 1.76-1.66 (m, 1H, H-5_B), 1.65-1.46 (m, 3H, H-6_B, 8_B, 9_B), 1.30 (t, J = 7.2 Hz, 3H, H-13); δ_C (100 MHz; $CDCl_3$) 172.6 (C-2), 172.4 (C-11), 100.9 (C-1), 62.2 (CH-7), 60.1 (CH_2-12), 57.9 (CH-4), 54.4 (CH-10), 36.0 (CH_2-3), 34.1 (CH_2-6), 31.8 (CH_2-9), 31.6 (CH_2-8), 30.7 (CH_2-5), 14.6 (CH_3-13); HRMS (ESI^+) calcd for $C_{13}H_{20}NO_3$ $(M + H)^+$ 238.1443, found 238.1464.

(3*R*,5*R*,8a*R*)/(3*S*,5*S*,8a*S*)-Diethyl 2,2'-(octahydroindolizine-3,5-diyl)diacetate, *trans*-2c and **(3*S*,5*S*,8a*R*)/(3*R*,5*R*,8a*S*)-Diethyl 2,2'-(octahydroindolizine-3,5-diyl)diacetate, *trans*-2c'**



Method A (Aluminium chloride): The reaction was set up following the procedure described above for the preparation of ***trans*-2b** and ***cis*-2b** (Method A) (**1c** (1.0 equiv), aluminium chloride (1.1 equiv, 1M in nitrobenzene), anhydrous dichloromethane (30 mL/mmol of **3c**), rt, 24 h). The reaction was stopped by cooling down to rt and dilution with dichloromethane. The organic phase was washed with sodium bicarbonate (saturated solution in water). The phases were separated and the organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica gel. Gradient elution with mixtures petroleum ether (30/40):ethyl acetate 6:1→0:1, afforded pure ***trans*-2c** as a colorless oil in 55% yield [R_f 0.64 (petroleum ether:ethyl acetate 1:2), R_f 0.39 (dichloromethane:acetone 9:1)], along with 30% ***trans*-2c'** [R_f 0.51 (petroleum ether:ethyl acetate 1:2)] and 8% ***cis*-2c** [R_f 0.28 (petroleum ether:ethyl acetate 1:2)].

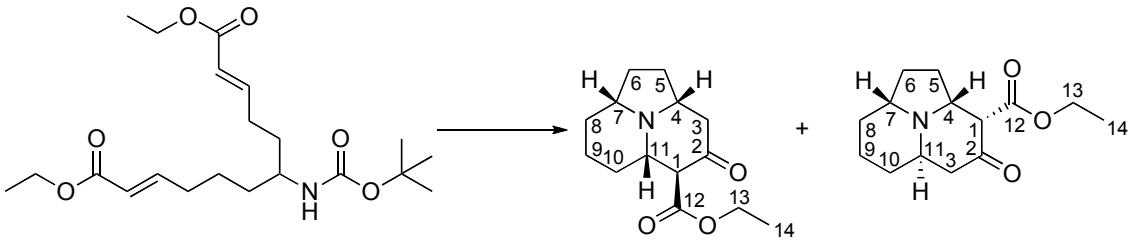
Method B (Stannous(II) triflate): A solution of **3c** (1.0 equiv) in dry acetonitrile (30 mL/mmol of **3c**) was prepared at rt, under nitrogen. To this solution, stannous triflate (0.5 equiv) was added and the mixture was refluxed for 24 h, after which the reaction was stopped by dilution with dichloromethane and washes of the organic phase with sodium bicarbonate (saturated solution in water). The final organic phase was dried over magnesium sulfate, filtered and evaporated under vacuum. The residue was purified by flash chromatography on silica, using mixtures dichloromethane:acetone 10:1, 10:1.5 and 0:1[12], to furnish **8c-*trans*-1** in 10% yield, **8c-*trans*-2** in 69% yield [colorless oil, R_f 0.25 (dichloromethane:acetone 9:1), R_f 0.55 (chloroform:acetone 9:1)] and ***cis*-2c** in 15% yield [R_f 0.24 (chloroform:acetone 9:1)].

[12] Elution with dichloromethane:acetone 10:1 affords pure ***trans*-2c**. The best results for the separation of ***trans*-2c'**and ***cis*-2c** are obtained using chloroform:acetone 10:1.

***trans*-2c**: ν_{max} (CH_2Cl_2/cm^{-1}) 2930, 2851, 1738, 1719, 1463, 1372, 1334, 1257, 1174, 1152, 1115, 1032; δ_H (500 MHz; $CDCl_3$) 4.06 (q, J = 7.1 Hz, 4H, H-12 and 12'), 3.55 (m, 1H, H-11), 2.91 (m, 1H, H-4), 2.67 (dd, J_{gem} = 15.0 Hz, J_{vec} = 4.2 Hz, 1H, H-2_A), 2.54 (dd, J_{gem} = 14.5 Hz, J_{vec} = 4.2 Hz, 1H, H-$2'_A$), 2.40 (tdd, J_1 = 9.8 Hz, J_2 = 6.5 Hz, J_3 = 2.8 Hz, 1H, H-7), 2.35 (dd, J_{gem} = 14.5 Hz, J_{vec} = 9.3 Hz, 1H, H-$2'_B$), 2.19 (dd, J_{gem} = 14.9 Hz, J_{vec} = 8.9 Hz, 1H, H-2_B), 1.87 (dq, J_1 = 12.8 Hz, J_2 = 8.5 Hz, 1H, H-5_A), 1.76 (m, 1H, 8_A), 1.72 (tdd, J_1 = 12.5 Hz, J_2 = 6.1 Hz, J_3 = 3.35 Hz, 1H, H-6_A), 1.65-1.55 (m, 3H, H-9_A, 10_A, 10_B), 1.48-1.36 (m, 2H, H-5_B, 9_B), 1.23 (bt, J = 7.2 Hz, 6H, H-13, 13'), 1.30-1.20 (m, 1H, H6_B), 1.09 (qd, J_1 = 11.9 Hz, J_2 = 3.8 Hz, 1H, H-8_B); δ_C (125 MHz; $CDCl_3$) 173.4 (C-1'), 172.4 (C-1), 60.4, 60.2 (CH_2-12 and 12'), 56.0 (CH-7), 55.2 (CH-4), 50.2 (CH-11), 38.9 (CH_2-2), 32.2 (CH_2-8), 29.6 (CH_2-6), 29.3 (CH_2-10), 28.5 (CH_2-5), 28.1 (CH_2-2'), 19.2 (CH_2-9), 14.2 (CH_3-13 and 13'); HRMS (ESI^+) calcd for $C_{16}H_{28}NO_4$ $(M + H)^+$ 298.2018, found 298.2018.

***trans*-2c'**: ν_{max} (CH_2Cl_2/cm^{-1}) 2928, 2852, 1733, 1444, 1370, 1295, 1242, 1158, 1133, 1097, 1033; δ_H (500 MHz; $CDCl_3$) 4.13 (m, 4H, H-12, 12'), 3.76 (bqd, J_1 = 7.3 Hz, J_2 = 3.1 Hz, 1H, H-4), 2.78 (dd, J_{gem} = 14.6 Hz, J_{vec} = 3.6 Hz, 1H, CH_2-$2'_A$), 2.79-2.72 (m, 1H, H-11), 2.54 (dd, J_{gem} = 13.8 Hz, J_{vec} = 3.0 Hz, 1H, H-2_A), 2.37 (m, 1H, H-7), 2.23 (dd, J_{gem} = 14.4 Hz, J_{vec} = 9.5 Hz, 1H, H-$2'_B$), 2.14 (dd, J_{gem} = 14.0 Hz, J_{vec} = 11.0 Hz, 1H, H-2_B), 1.98-1.90 (m, 1H, H-5_A), 1.83-1.63 (m, 3H, H-9_A, 10_A, 9_B), 1.55-1.46 (m, 2H, H-6_A, 8_A), 1.46-1.37 (m, 1H, H-5_B), 1.30-1.10 (m, 9H, H-6_B, 8_B, 10_B, 13, 13'); δ_C (125 MHz; $CDCl_3$) 172.9 (C-1), 172.0 (C-1'), 60.4, 60.3 (CH_2-12 and 12'), 58.9 (CH-7), 55.9 (CH-4), 53.8 (CH-11), 39.6 (CH_2-2'), 31.7 (CH_2-2 and 10), 29.6, 29.5 (CH_2-6 and 8), 26.9 (CH_2-5), 24.1 (CH_2-9), 14.2, 14.0 (CH_3-13 and 13'); HRMS (ESI^+) calcd for $C_{16}H_{28}NO_4$ $(M + H)^+$ 298.2018, found 298.2017.

(2a*R*, 5*S*, 5a*S*, 9a*R*)/(2a*S*, 5*R*, 5a*R*, 9a*S*)-Ethyl 4-oxododecahydro-1*H*-pyrrolo[2,1,5-*de*]quinolizine-5-carboxylate (3c) and (2a*R*, 3*S*, 5a*R*, 5a*R*)/ (2a*S*, 3*R*, 5a*S*, 5a*S*)-ethyl 4-oxodecahydro-1*H*-pyrrolo[2,1,5-*de*]quinolizine-3-carboxylate (3c')



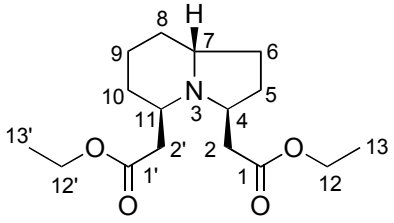
A dry flask was equipped with a Dean-Stark trap containing anhydrous toluene and a few pieces of sodium metal. In the flask, a solution of **1c** (1.0 equiv) was prepared in anhydrous toluene (30 mL/mmol of **1c**), at rt, under nitrogen atmosphere. On this solution, stannous (II) triflate (1.1 equiv) was added solid in one portion and the mixture was heated up to reflux. After 24 h, the reaction was stopped by cooling down to rt and dilution with ethyl acetate and a saturated aqueous solution of sodium bicarbonate. The phases were separated and the aqueous phase was extracted (x3) with ethyl acetate. The final combination of the organic phases was dried over magnesium sulfate and evaporated under vacuum. The residue was purified by flash chromatography on silica gel (stepped gradient elution using mixtures dichloromethane:acetone 10:0.5, 10:1, 10:1.25 and 8:1), to obtain an inseparable 4:1 mixture of **3c**:**3c'** in 50% yield [white solid, mp 60.4-61.4 °C (DCM), R_f 0.62 (silica, DCM:acetone 9:1)], along with the bicycle ***cis*-2c** in 13% yield [yellow oil, R_f 0.07 (silica, DCM:acetone 9:1), R_f 0.14 (silica, petroleum ether (30/40):diethyl ether 1:1), R_f 0.28 (petroleum ether:ethyl acetate 1:2]

3c + 3c': ν_{max} (CH_2Cl_2/cm^{-1}) 2934 (bb), 1745, 1717, 1372, 1336, 1261, 1152; HRMS (ESI^+) calcd for $C_{14}H_{22}NO_3$ $(M + H)^+$ 252.1600, found 252.1604.

3c: δ_H (500 MHz; $CDCl_3$) 4.23 (m, 2H, H-13), 3.20 (d, J = 10.6 Hz, 1H, H-1), 2.63 (ddd, $J_1 = J_2$ = 10.5 Hz, J_3 = 2.8 Hz, 1H, H-11), 2.60 (dd, J_1 = 12.5 Hz, J_2 = 1.7 Hz, 1H, H-3_A), 2.42 (m, 1H, H-4), 2.42-2.30 (m, 1H, H-3_B), 2.05 (bm, 1H, H-7), 1.95-1.78 (m, 4H, H-5_A, 6_A, 8_A, 9_A), 1.75-1.65 (m, 1H, H-10_A), 1.55-1.40 (m, 2H, H-5_B, 6_B), 1.32-1.20 (m, 3H, H-8_B, 9_B, 10_B), 1.28 (t, J = 7.1 Hz, 3H, H-14); δ_C (125 MHz; $CDCl_3$) 203.9 (C-

2), 168.7 (C-12), 62.9 (CH-1), 62.3 (CH-7), 62.5 (CH-4), 61.0 (CH_2-13), 61.0 (CH-11), 47.2 (CH_2-3), 31.5 (CH_2-10), 30.4 (CH_2-8), 28.9 (CH_2-6), 28.4 (CH_2-5), 24.0 (CH_2-9), 14.19 (CH_3-14).

3c': δ_H (500 MHz; $CDCl_3$) 4.21 (m, 2H, H-13), 3.33 (d, J = 11.3 Hz, 1H, H-1), 2.70 (m, 1H, H-4), 2.42 (m, 1H, H-11), 2.42-2.30 (m, 2H, H-3), 2.05 (bm, 1H, H-7), 1.95-1.78 (m, 4H, H-5_A, 6_A, 8_A, 9_A), 1.75-1.65 (m, 1H, H-10_A), 1.55-1.40 (m, 2H, H-5_B, 6_B), 1.42-1.32 (m, 1H, H-9_B), 1.32-1.20 (m, 2H, H-8_B, 10_B), 1.28 (t, J = 7.1 Hz, 3H, H-14); δ_C (125 MHz; $CDCl_3$) 203.7 (C-2), 168.3 (C-12), 64.5, 58.8 (CH-4 and CH-7), 63.4 (CH-1), 62.4 (CH-11), 61.0 (CH_2-13), 47.1 (CH_2-3), 32.7 (CH_2-10), 30.5 (CH_2-8), 29.0 (CH_2-6), 27.5 (CH_2-5), 24.1 (CH_2-9), 14.19 (CH_3-14).



***cis*-2c: (3*S*,5*R*,8a*R*)/ (3*R*,5*S*,8a*S*)-Diethyl 2,2'-(octahydroindolizine-3,5-diyl)diacetate**: ν_{max} (CH_2Cl_2/cm^{-1}) 2925, 2853, 1728, 1445, 1369, 1160, 1038; δ_H (500 MHz; $CDCl_3$) 4.18-4.02 (m, 4H, H-12, 12'), 3.34 (m, 2H, H-4, 11), 3.22 (m, 1H, H-7), 2.73 (dd, J_{gem} = 14.4 Hz, J_{vec} = 9.2 Hz, 1H, H-2'$_A$), 2.59 (dd, J_{gem} = 15.2 Hz, J_{vec} = 3.9 Hz, 1H, H-2_A), 2.35 (dd, J_{gem} = 14.4 Hz, J_{vec} = 6.4 Hz, 1H, H-2'$_B$), 2.09 (dd, J_{gem} = 15.3 Hz, J_{vec} = 9.2 Hz, 1H, H-2_B), 2.12-2.08 (m, 1H, H-5_A), 2.02-1.98 (m, 1H, 9_A), 1.83-1.77 (m, 1H, H-6_A), 1.77-1.69 (m, 1H, H-10_A), 1.50-1.43 (m, 1H, H-5_B), 1.41-1.33 (m, 1H, 6_B), 1.33-1.17 (m, 4H, H-10_B, 9_B, 8_A, 8_B), 1.24 (bt, J = 7.1 Hz, 6H, H-13, 13'); δ_C (125 MHz; $CDCl_3$) 172.8 (C-1), 172.5 (C-1'), 60.1 (CH_2-12 and 12'), 55.5 (CH-4), 54.3 (CH-7), 50.0 (CH-11), 41.4 (CH_2-2), 38.8 (CH_2-2'), 29.7 (CH_2-8), 29.1 (CH_2-6), 28.6 (CH_2-5), 27.1 (CH_2-9), 22.9 (CH_2-10), 14.3, 14.2 (CH_3-13 and 13'); HRMS (ESI^+) calcd for $C_{16}H_{28}NO_4$ $(M + H)^+$ 298.2018, found 298.2029.

4. Scaffold Hunter analysis

We have visually assessed the skeletal diversity of the DOS through the use of "*Scaffold Hunter*", a computer-based tool developed by Waldmann *et al.*,[i] which extracts the molecular scaffolds present in a compound collection and correlates the relationship between them in a hierarchical tree-like arrangement (Fig. 1).[ii]

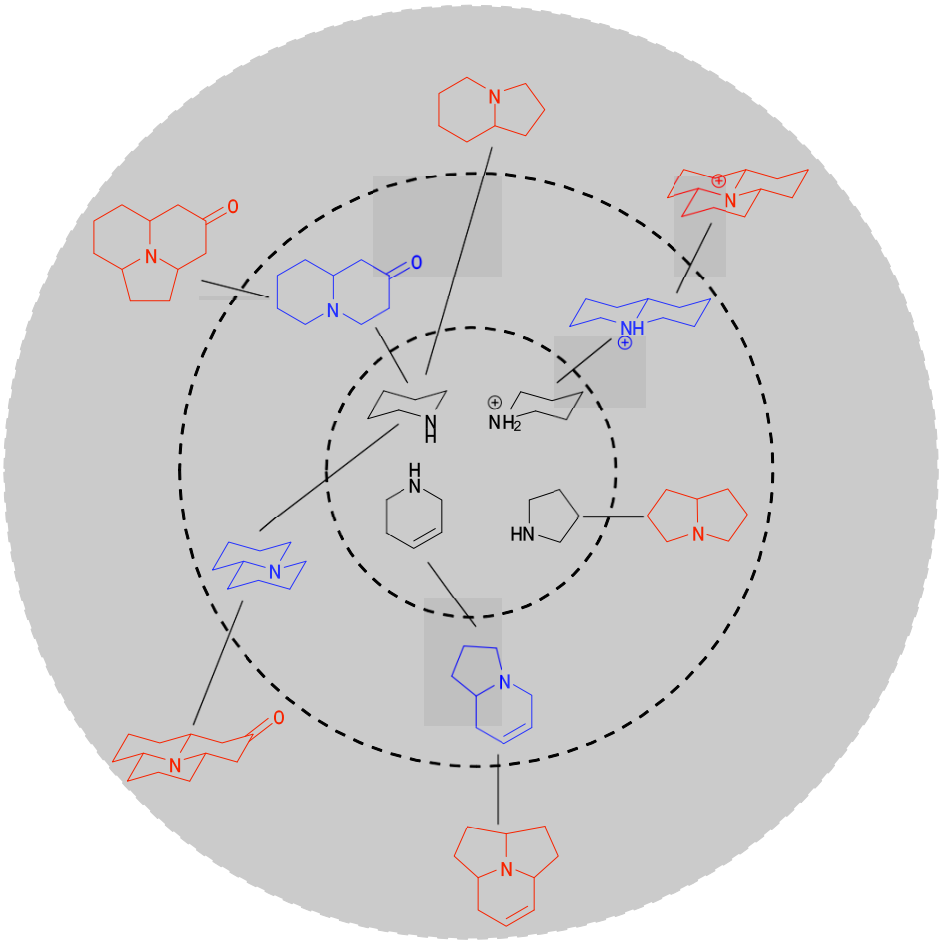


Figure 1: Hierarchical classification determined by *"Scaffold Hunter"* illustrating the molecular scaffolds present in the DOS and the relationship between scaffolds at different levels of hierarchy. Key: parental scaffolds (black), daughter scaffolds (blue), and molecular scaffolds (red).

Terminal side chains are first removed from each molecule to give a series of distinct frameworks which are defined by the rings and unsaturated groups that rigidify the molecule. According to a set of prioritisation rules rings are then iteratively removed

from each of these molecular scaffolds to reveal the last remaining ring which defines the 'parental' scaffold. Out of the 14 final compounds synthesised, 7 distinct molecular scaffolds were prepared.

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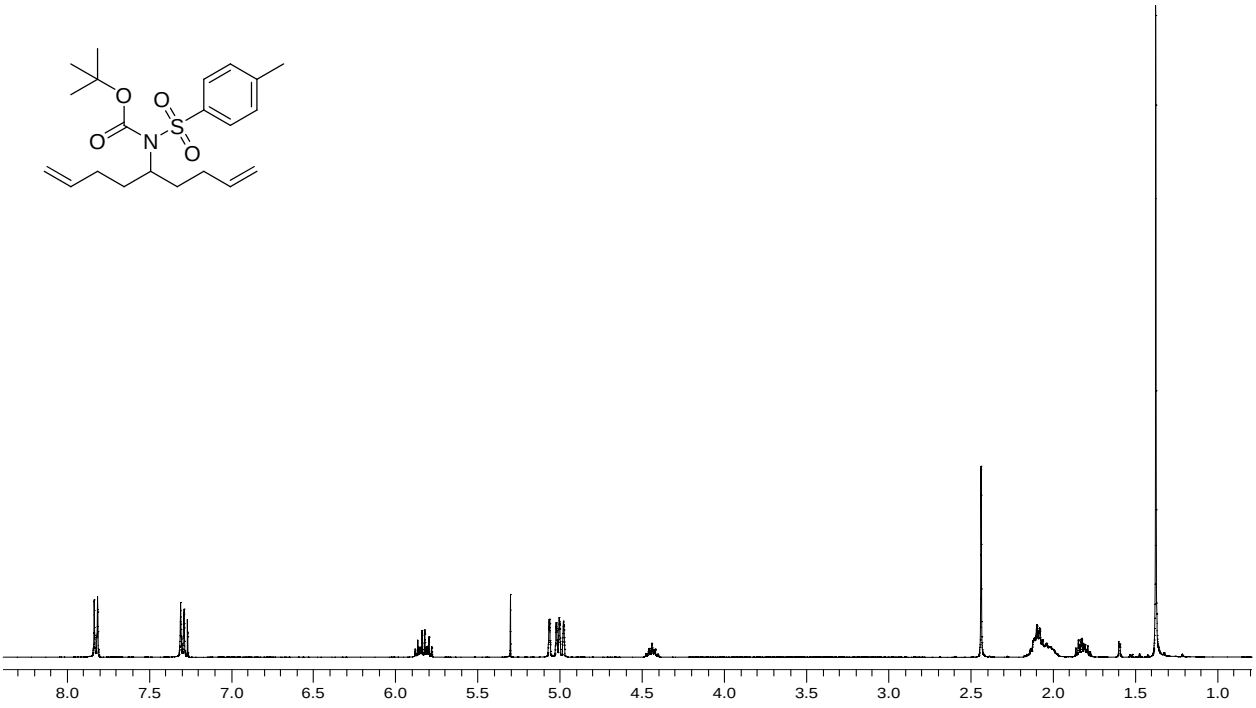
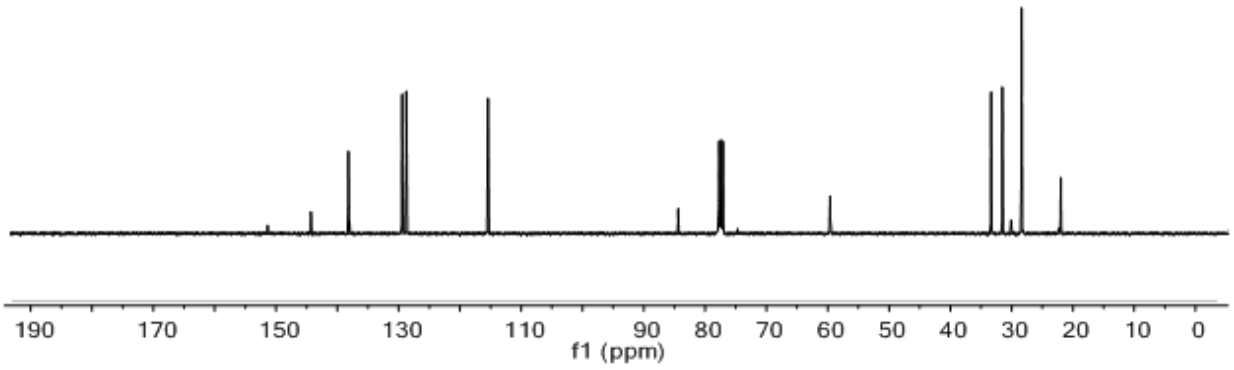
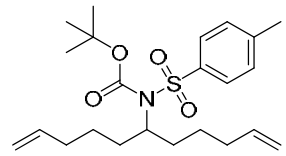
[i] S. Wetzel, K. Klein, S. Renner, D. Rauh, T. I. Oprea, P. Mutzel and H. Waldmann, *Nat. Chem. Biol.*, 2009, **5**, 581-583.

[ii] For a recent example see: D. Morton, S. Leach, C. Cordier, S. Warriner and A. Nelson, *Angew. Chem. Int. Edit.*, 2009, **48**, 104-109.

^{1}H and ^{13}C NMR spectra



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S
O
O

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3.0
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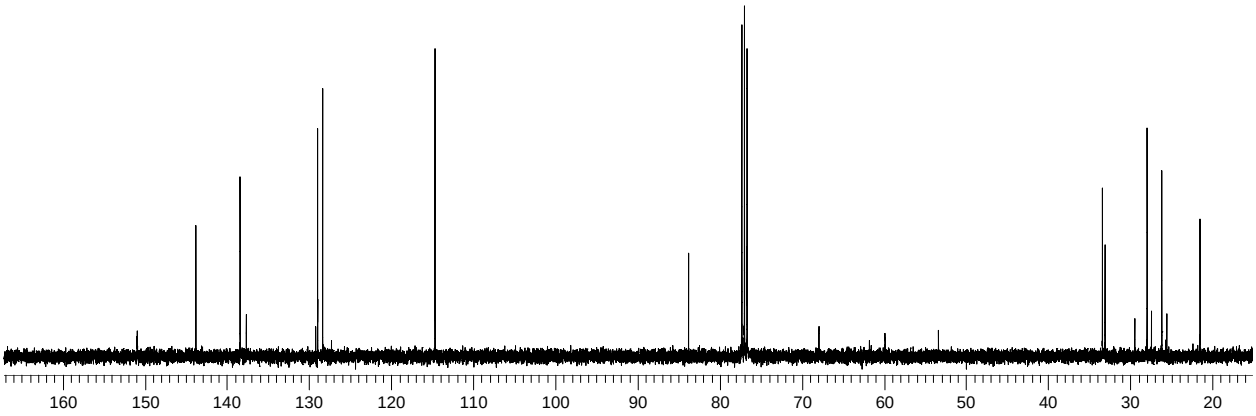
1.0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150
140
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120
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100
90
80
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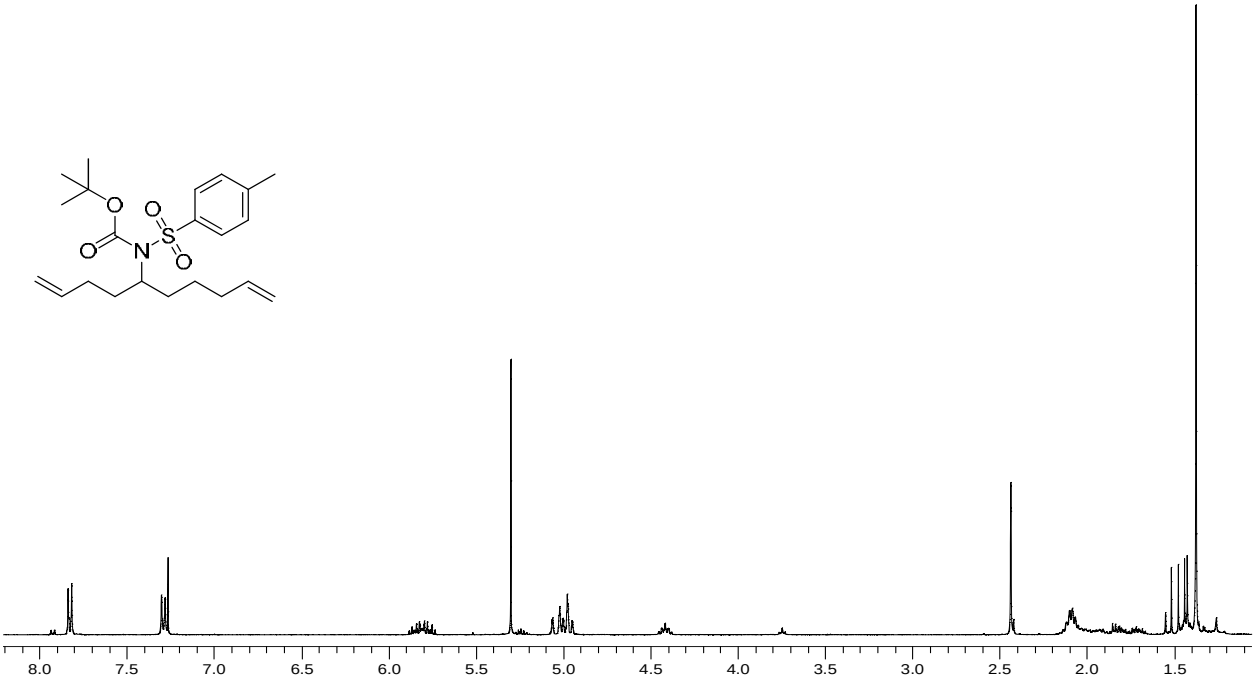
50
40
30
20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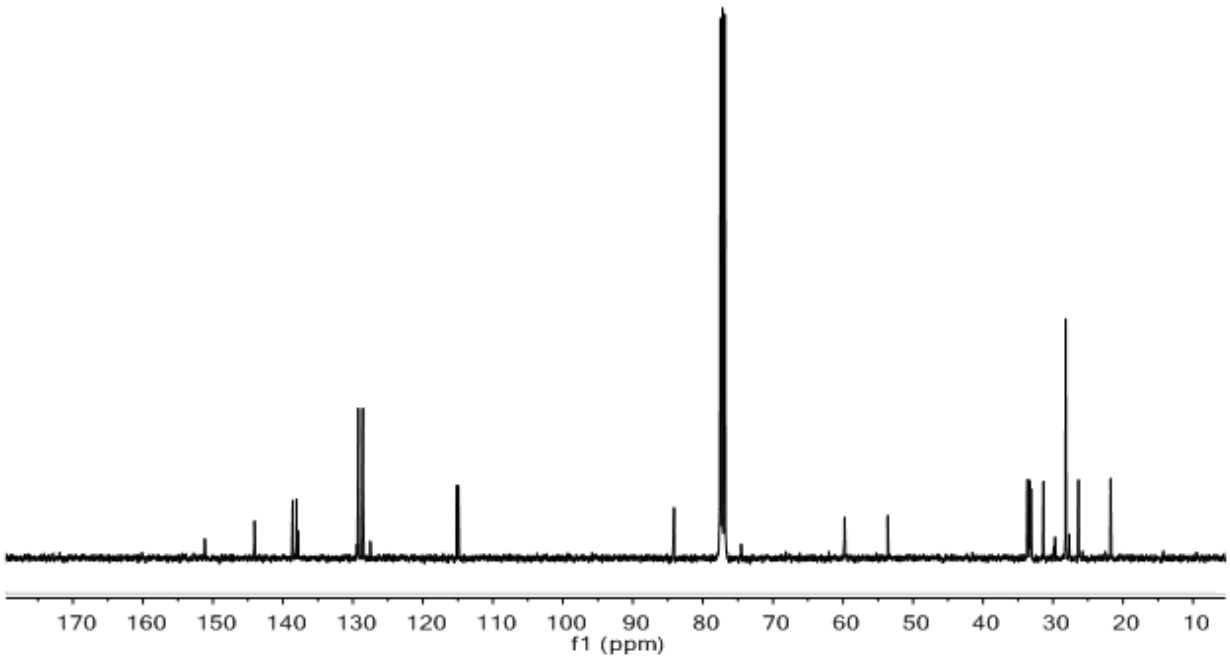
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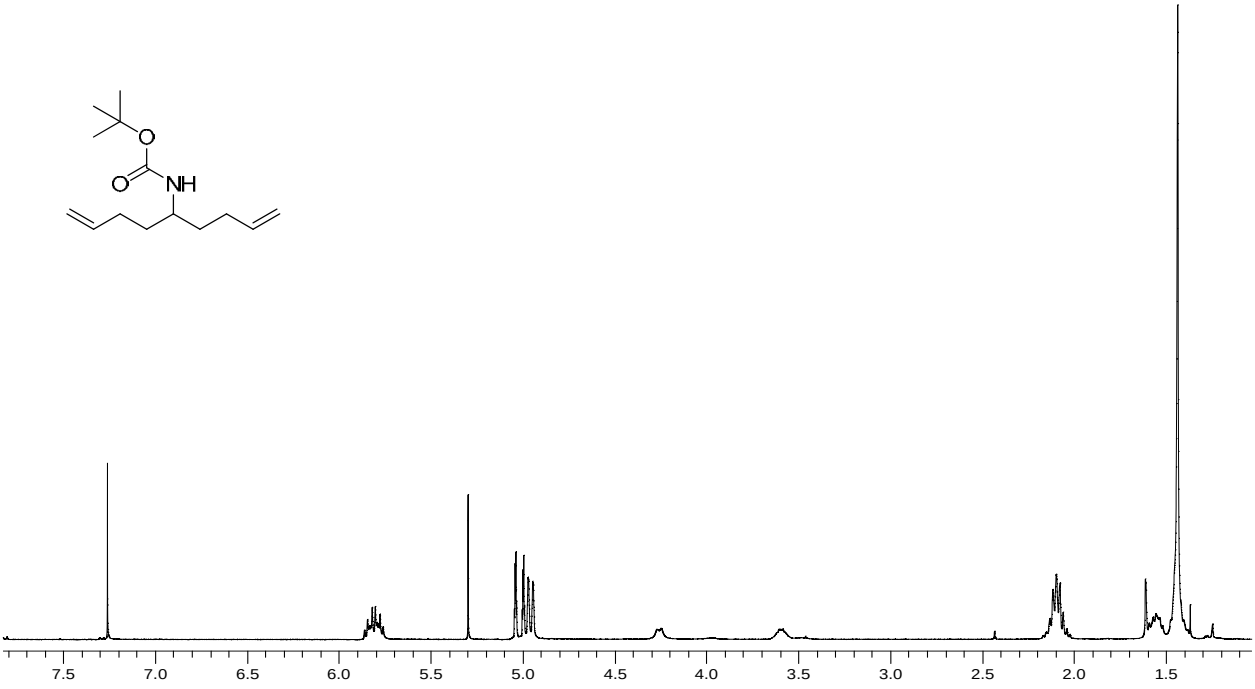
f1 (ppm)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O
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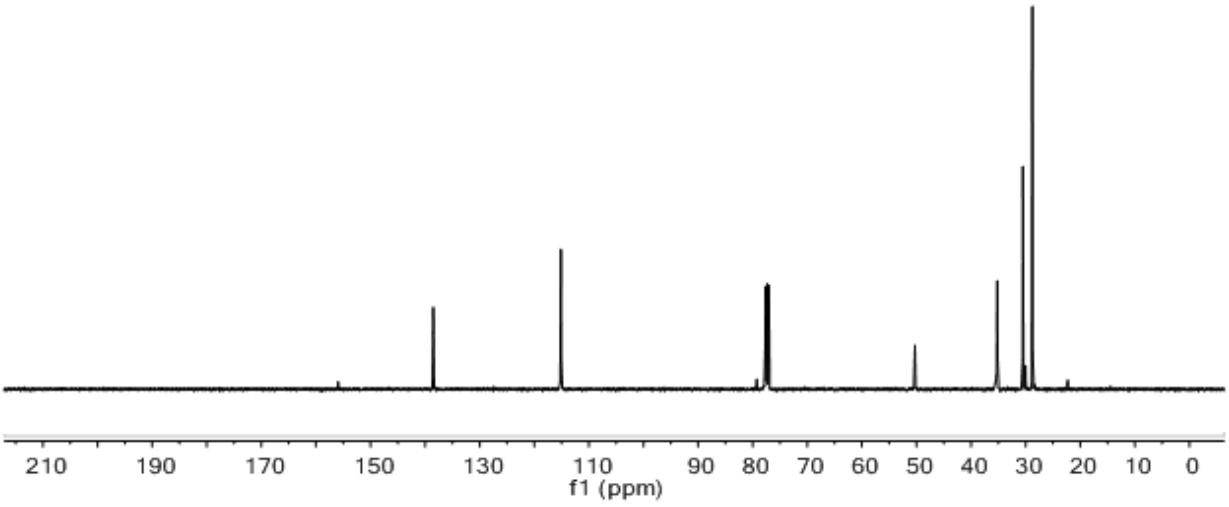
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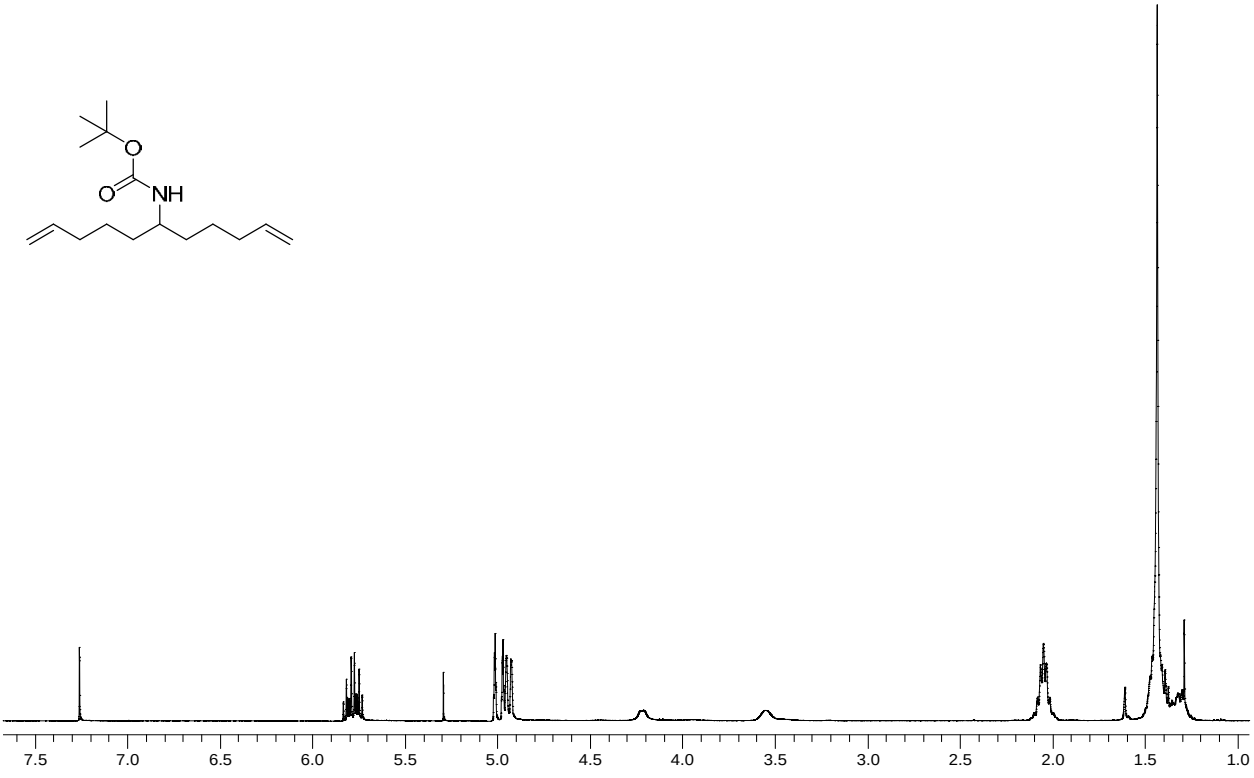
f1 (ppm)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O
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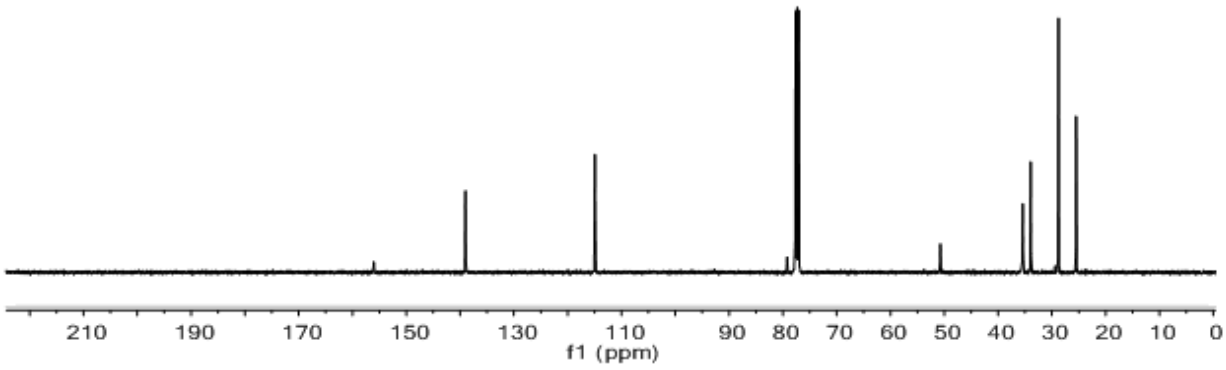
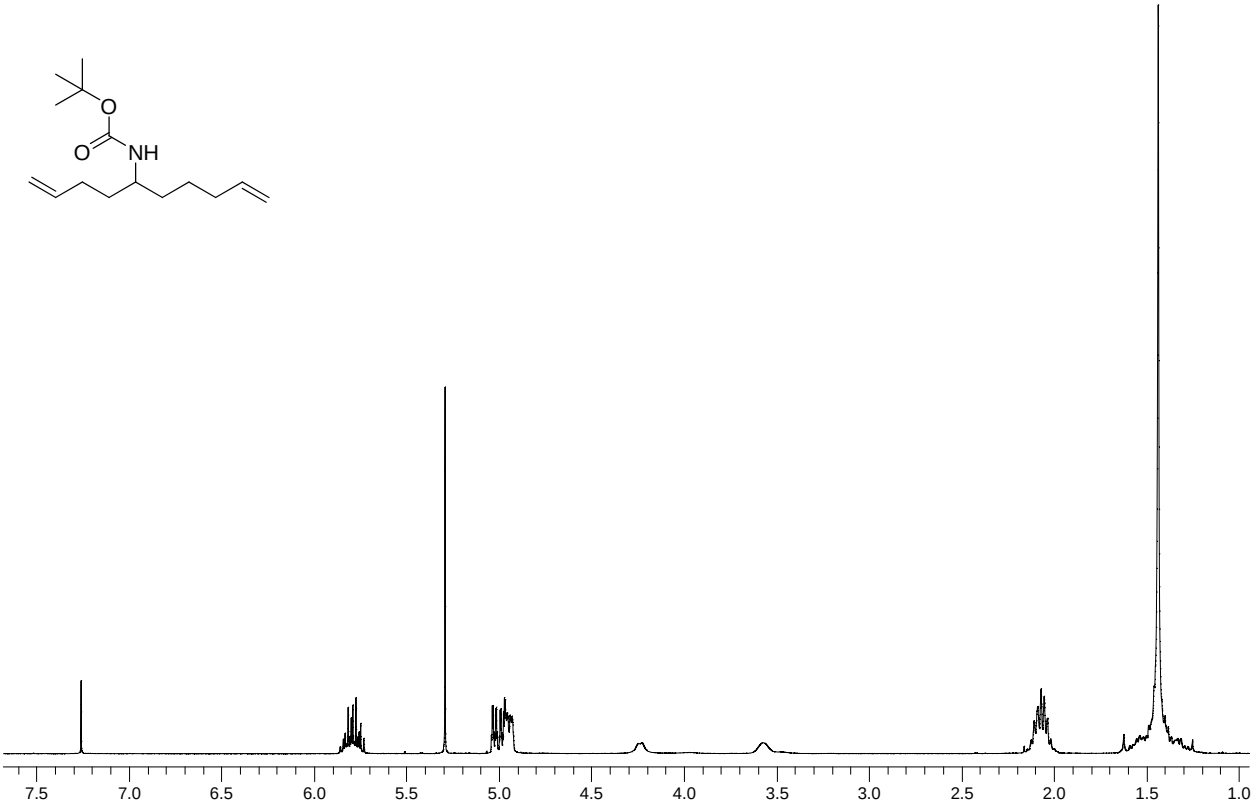
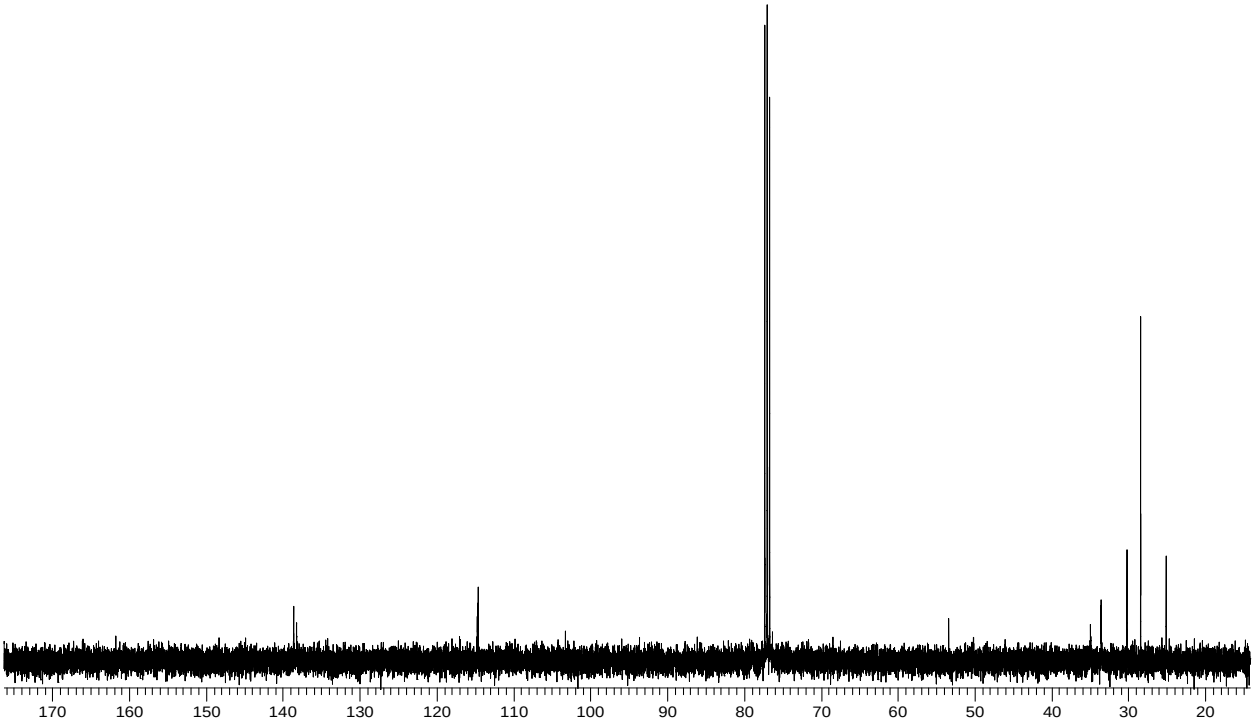
2.0
1.5
1.0


210
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


O
O
NH
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0


170
160
150
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130
120
110
100
90
80
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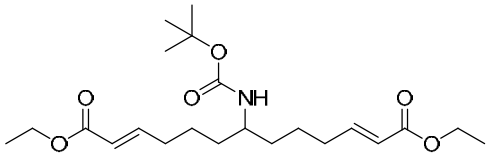
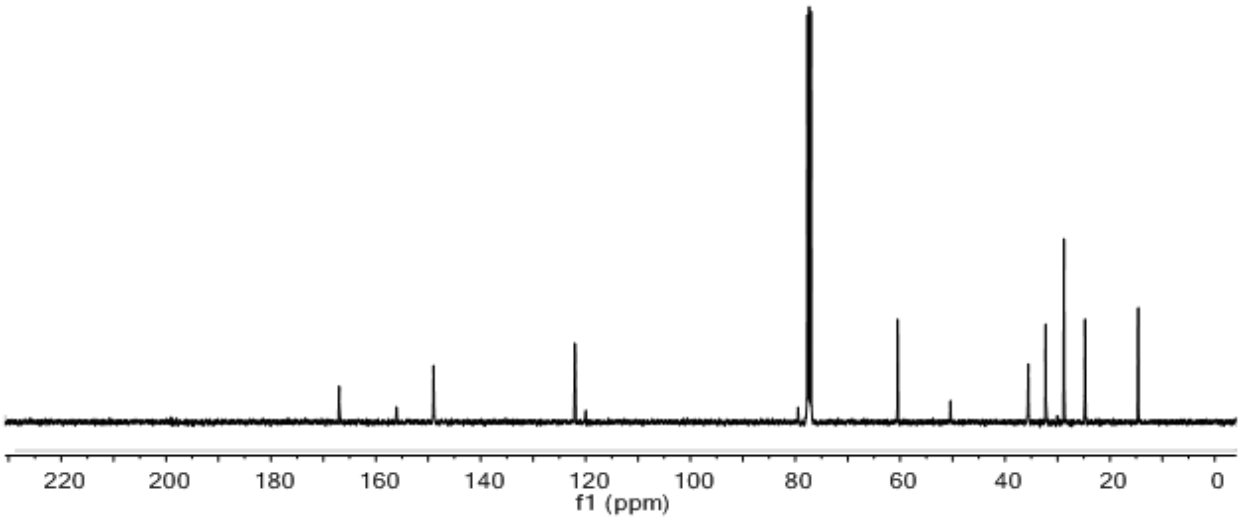
60
50
40
30
20


O
O
O
NH
O
O
O

1a

8.5
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5


220
200
180
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140
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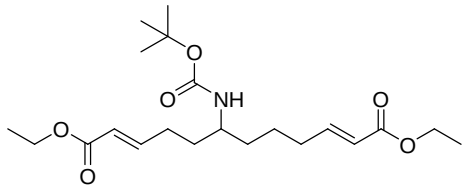
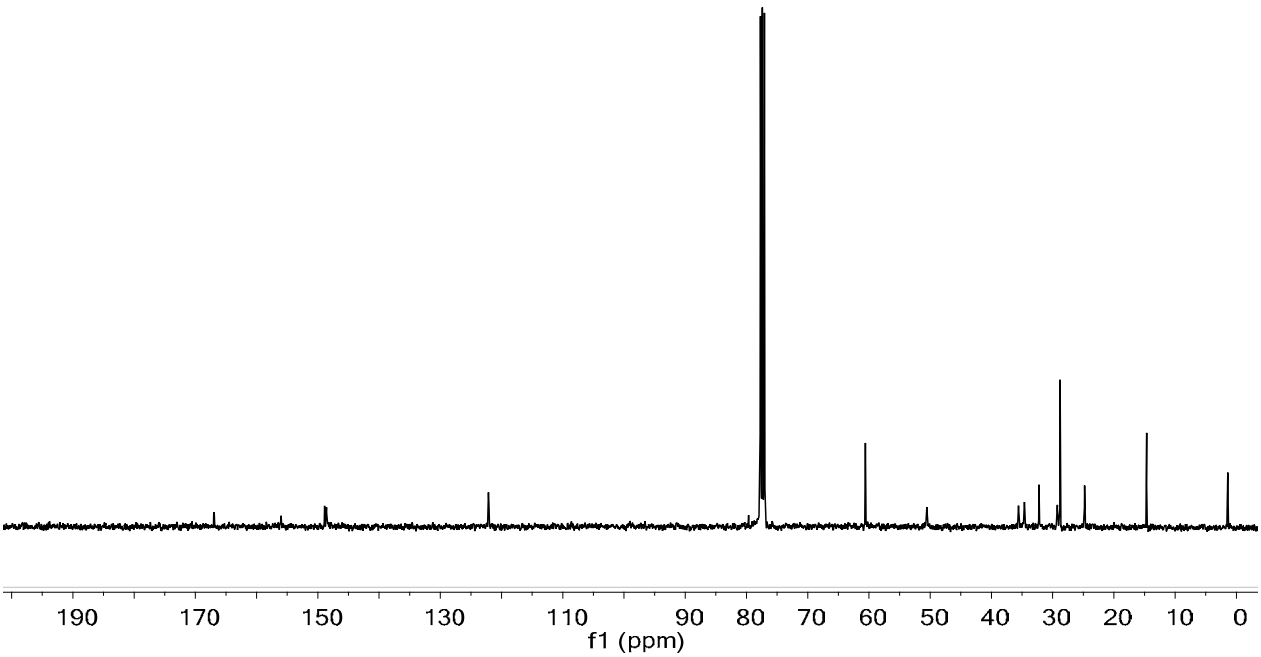
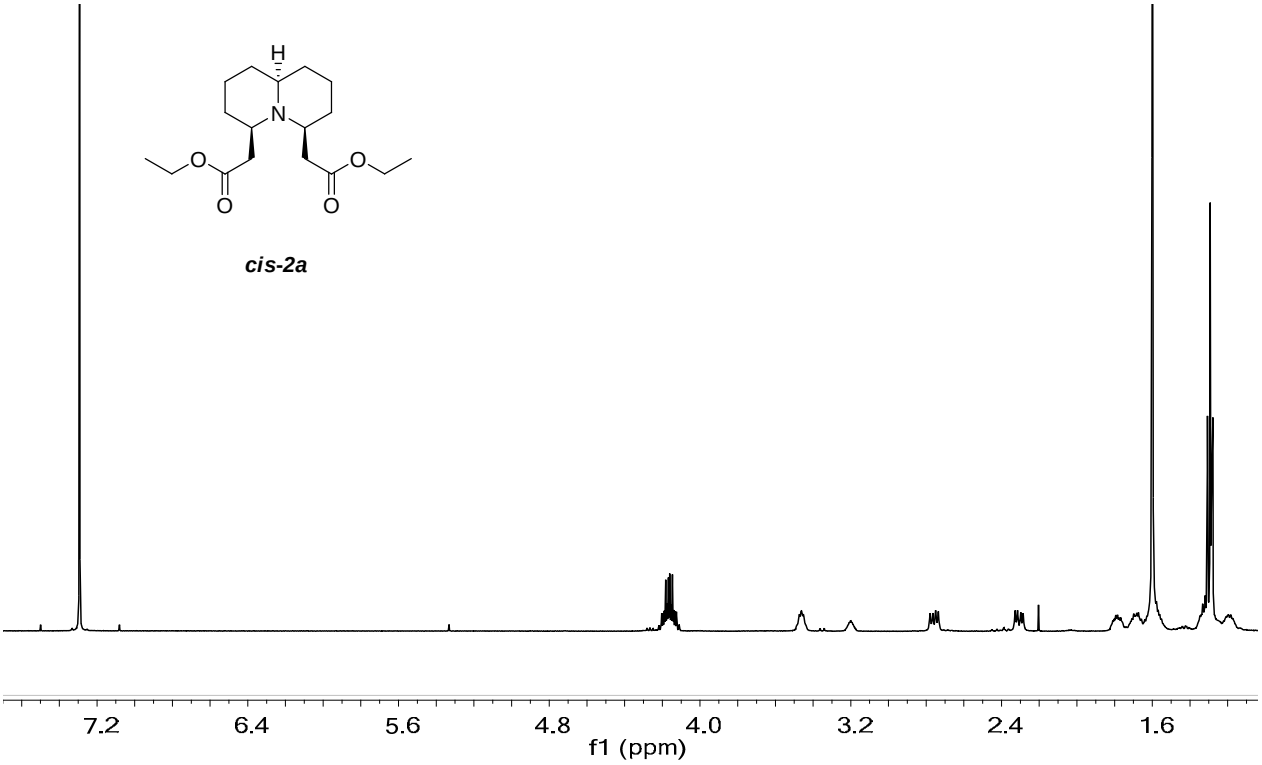
100
80
60
40
20
0
f1 (ppm)


O
O
NH
O
O
O
O

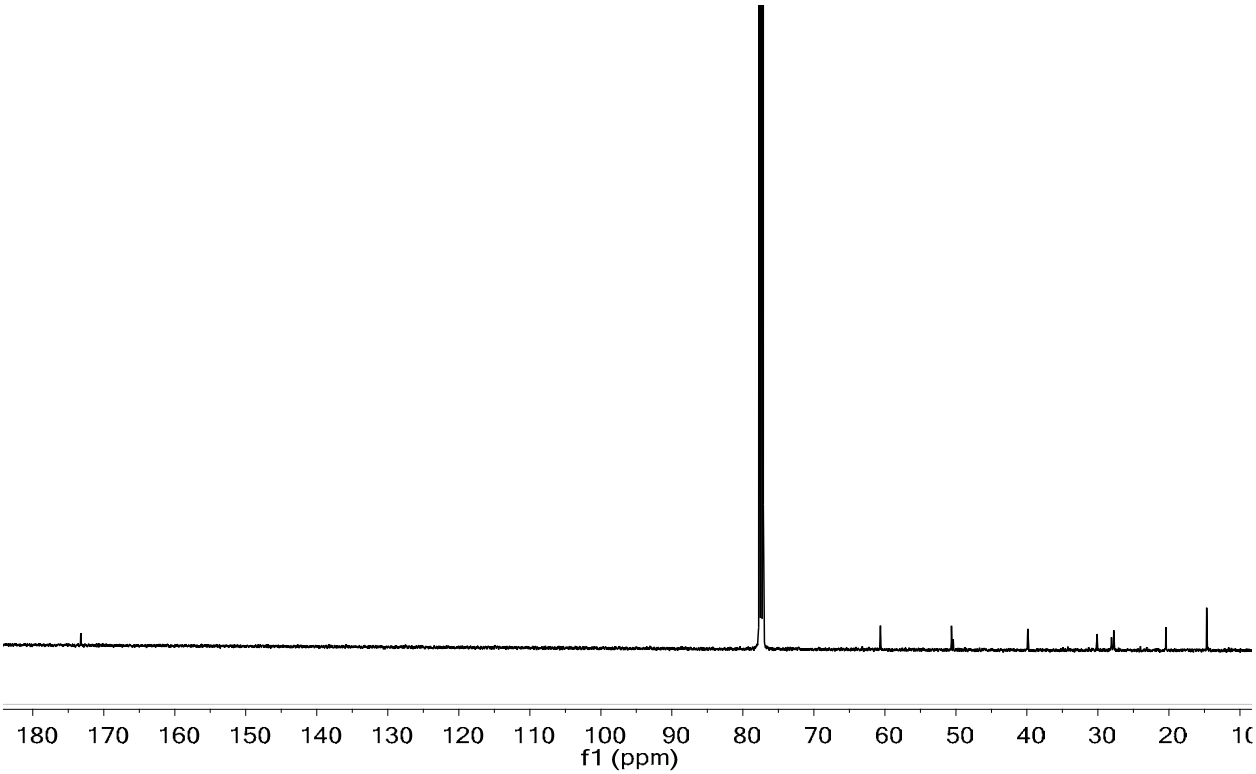
1c

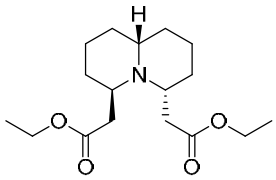
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0


190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
f1 (ppm)


H
N
O
O
O
O
7.2
6.4
5.6
4.8
4.0
3.2
2.4
1.6
f1 (ppm)

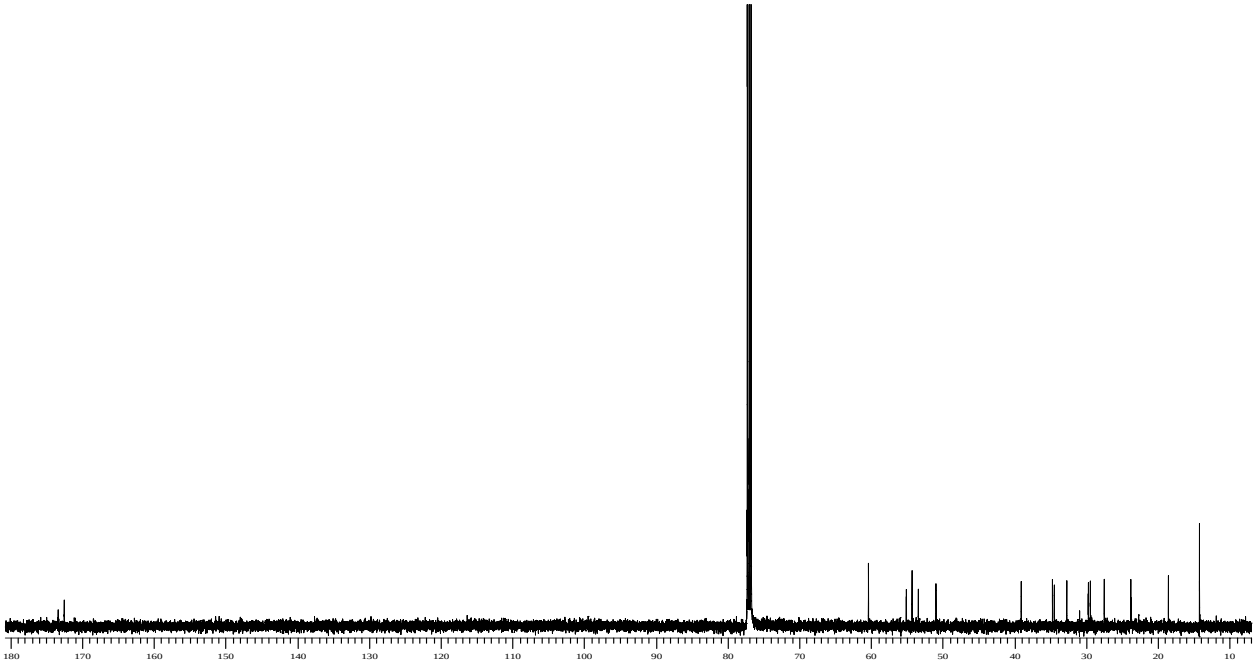
cis-2a

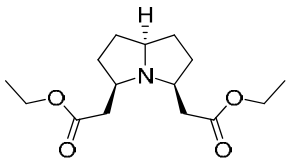

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
f1 (ppm)


H
N
O
O
O
O

***trans*-2a**

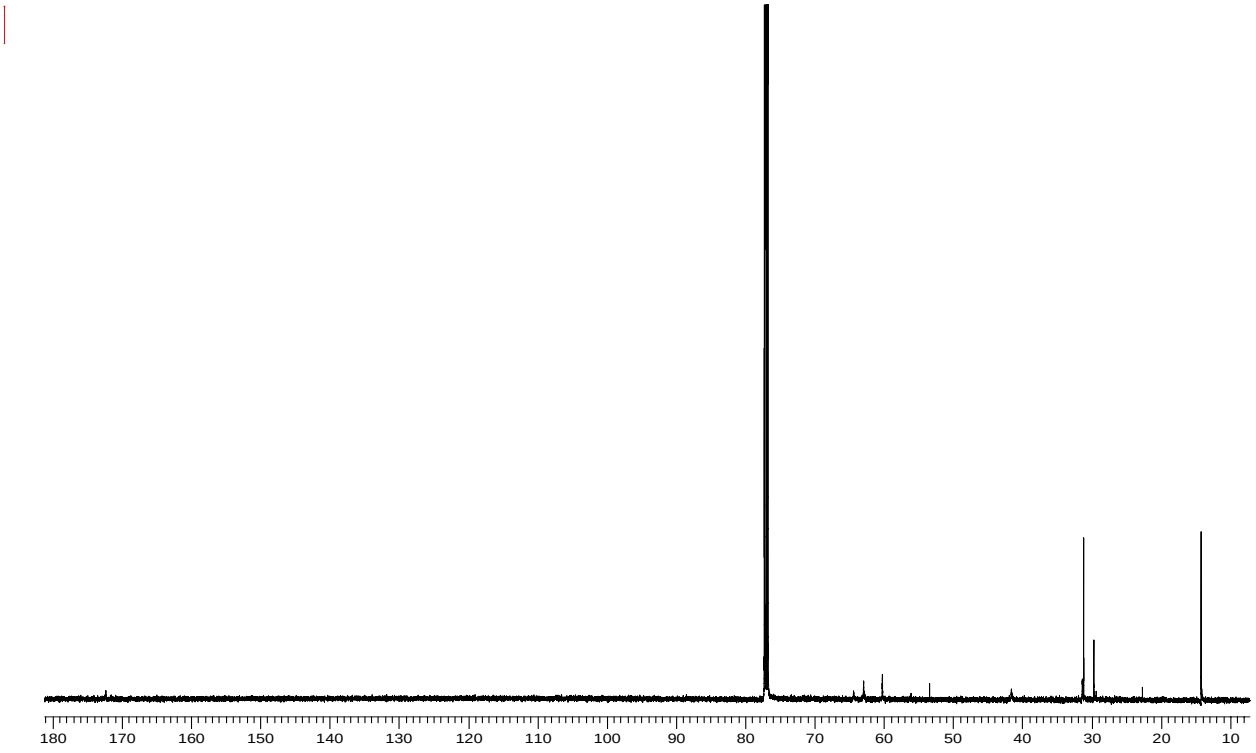
8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10


H
N
O
O
O
O

***cis*-2b**

8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0


180
170
160
150
140
130
120
110
100
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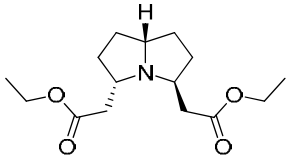
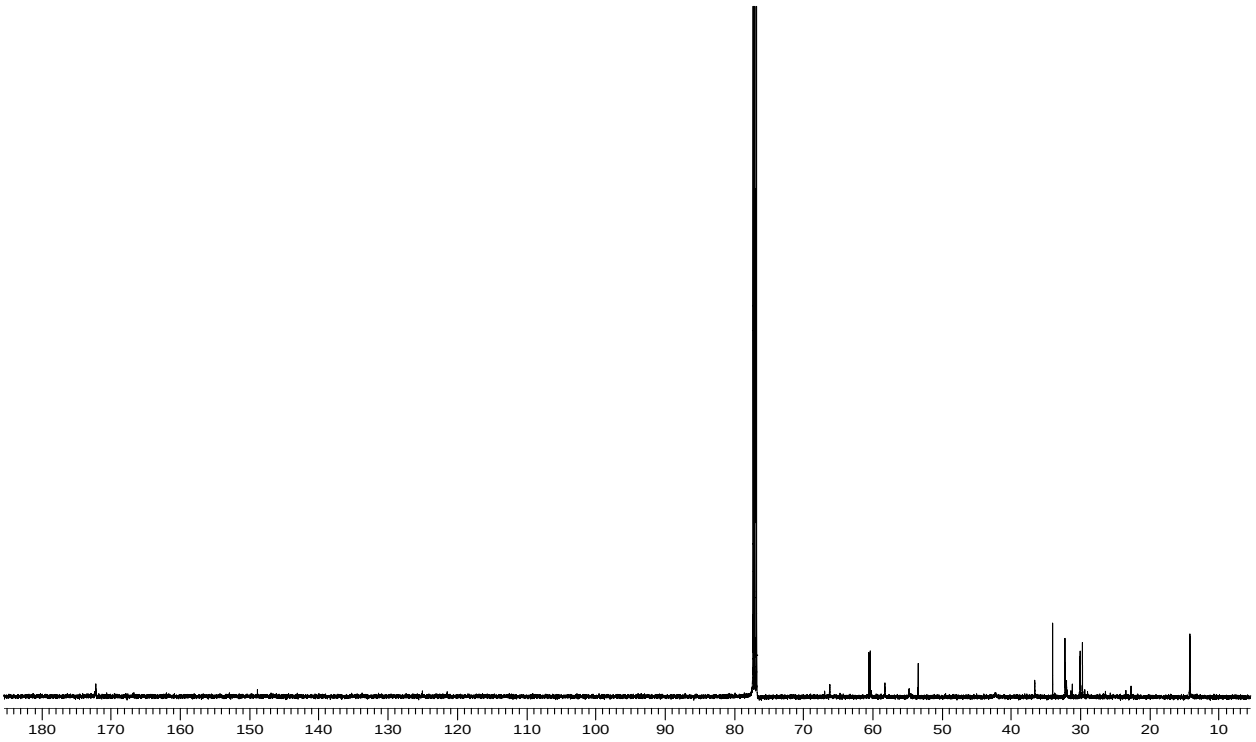
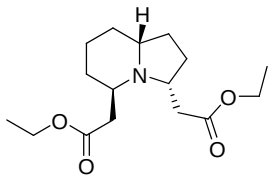
80
70
60
50
40
30
20
10


H
N
O
O
O
O

***trans*-2b**

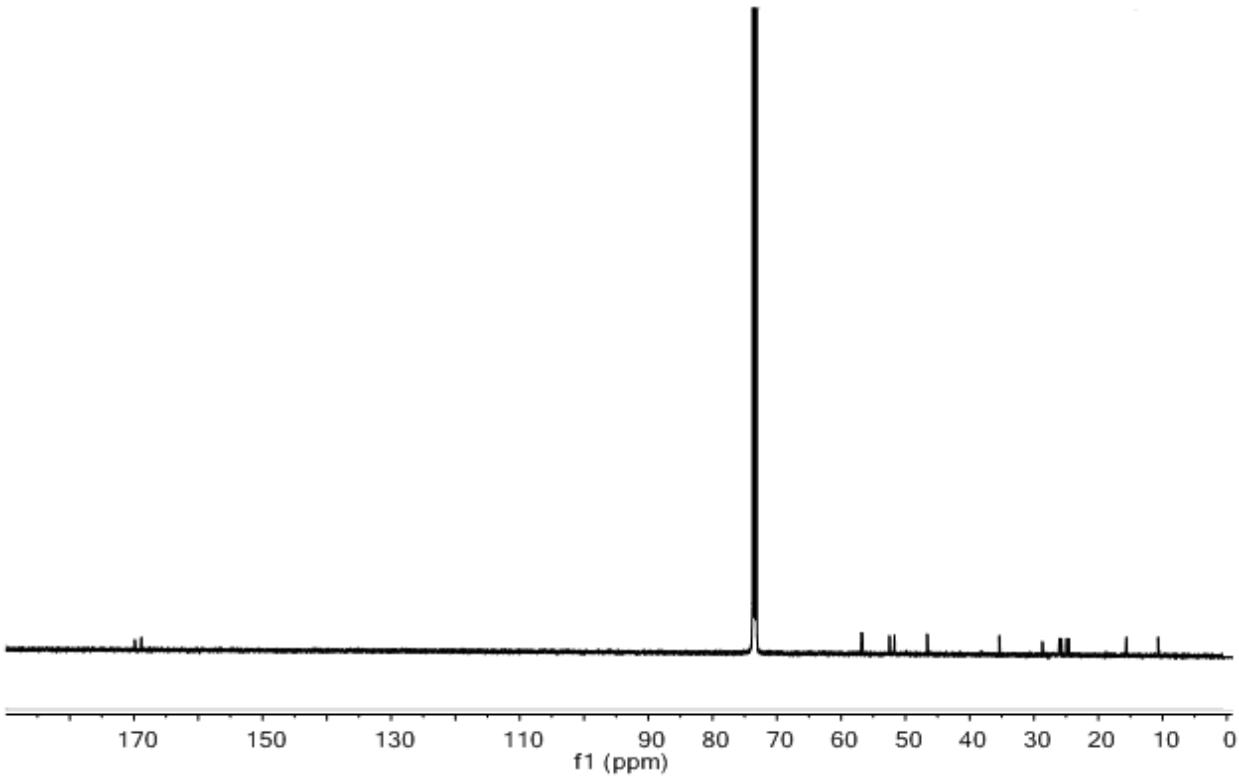
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0

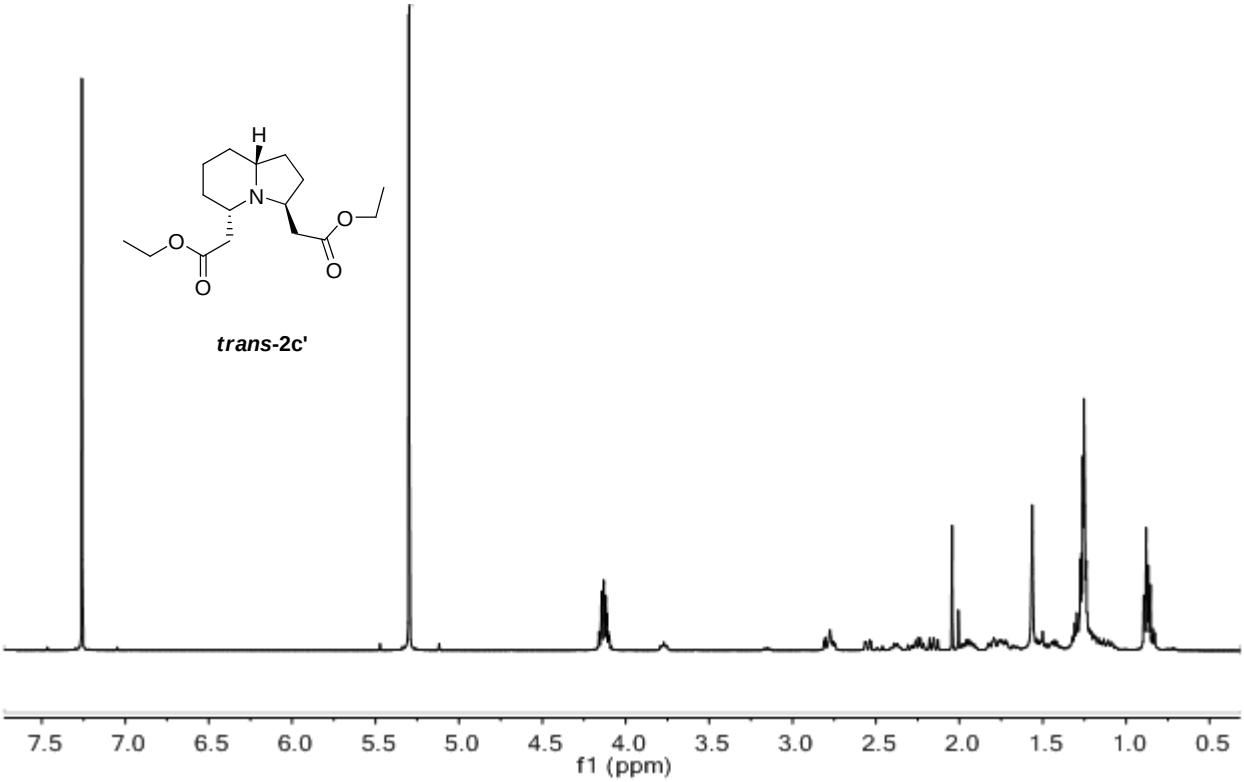

180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10


H
N
O
O
O
O

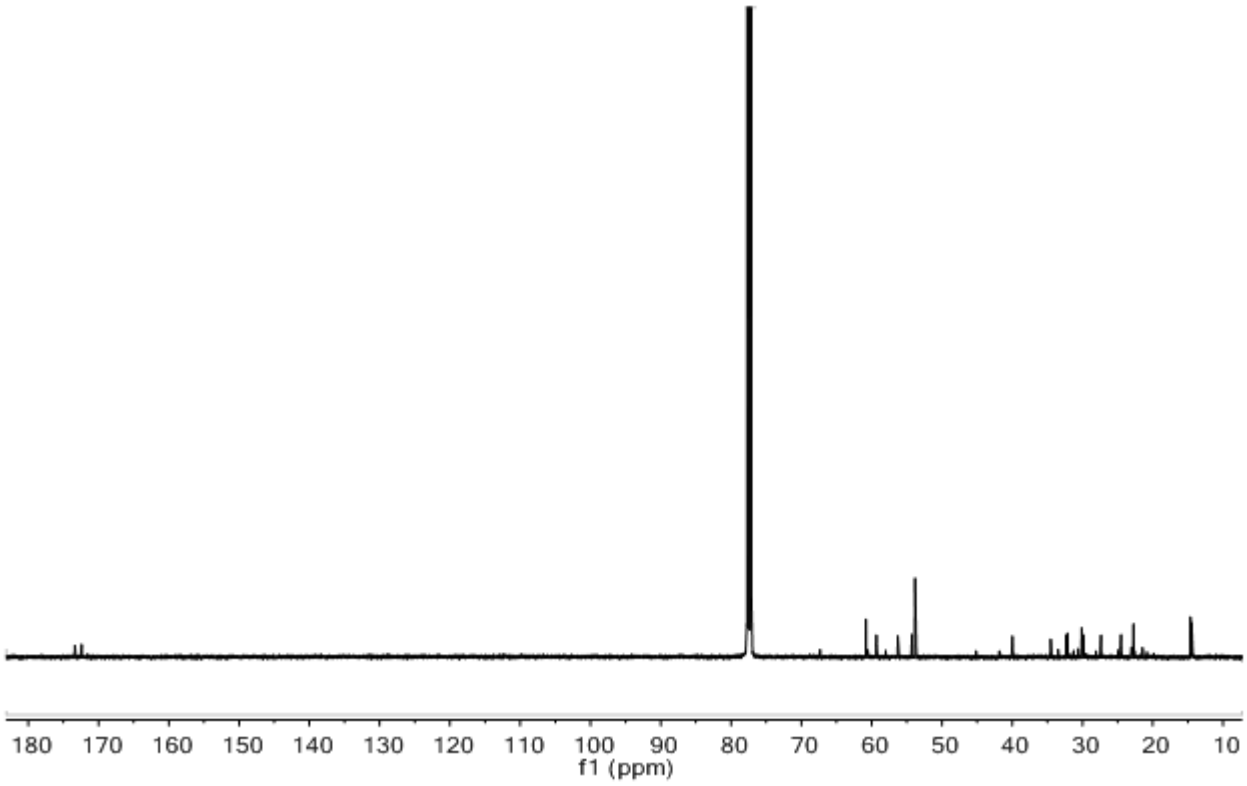
***trans*-2c**

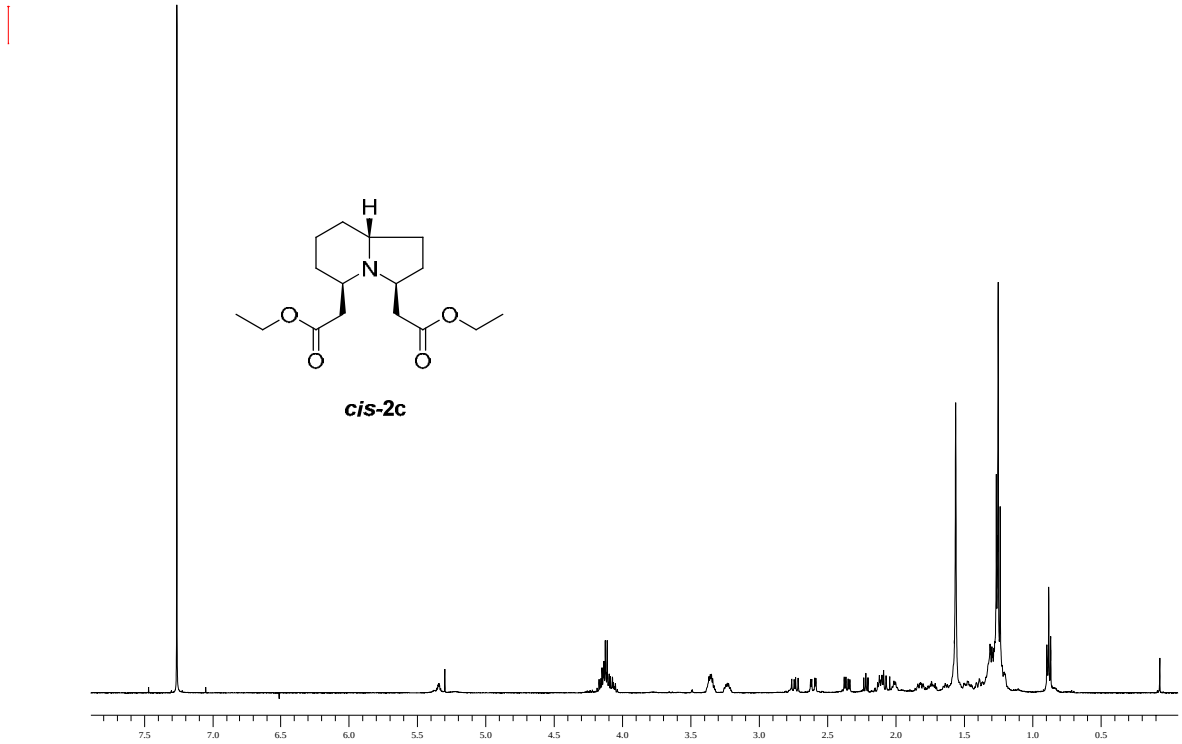
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0


170
150
130
110
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

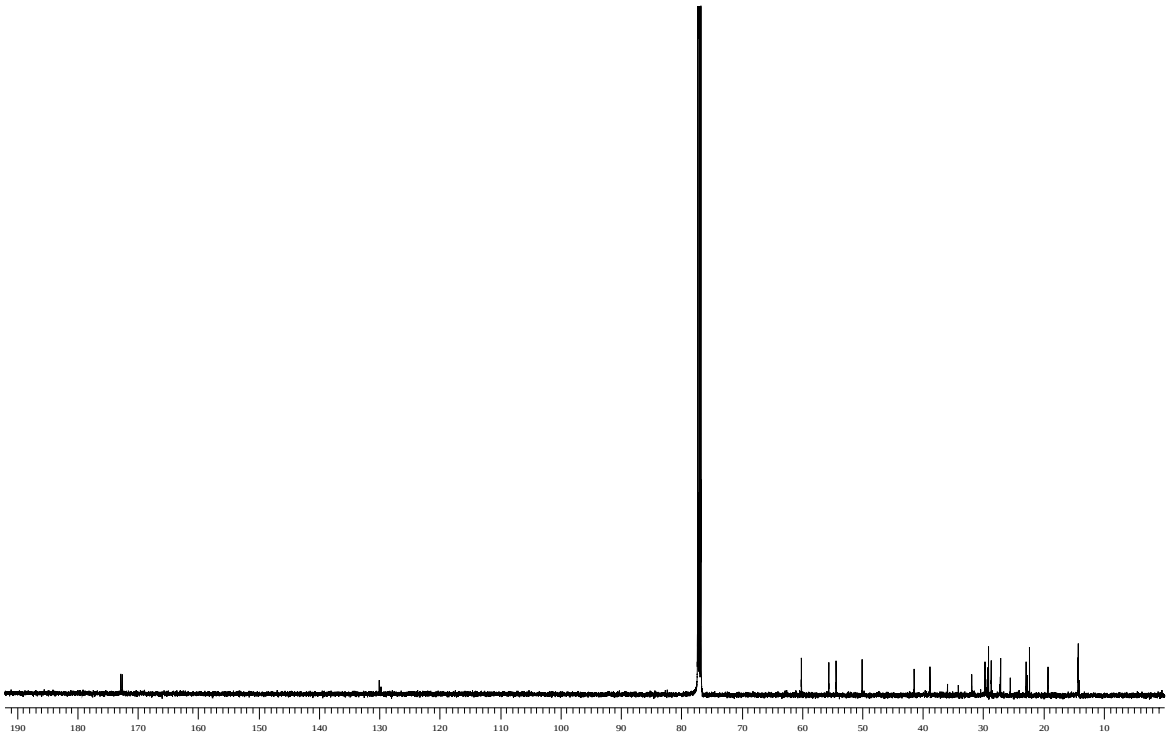

H
N
O
O
O
O
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
f1 (ppm)

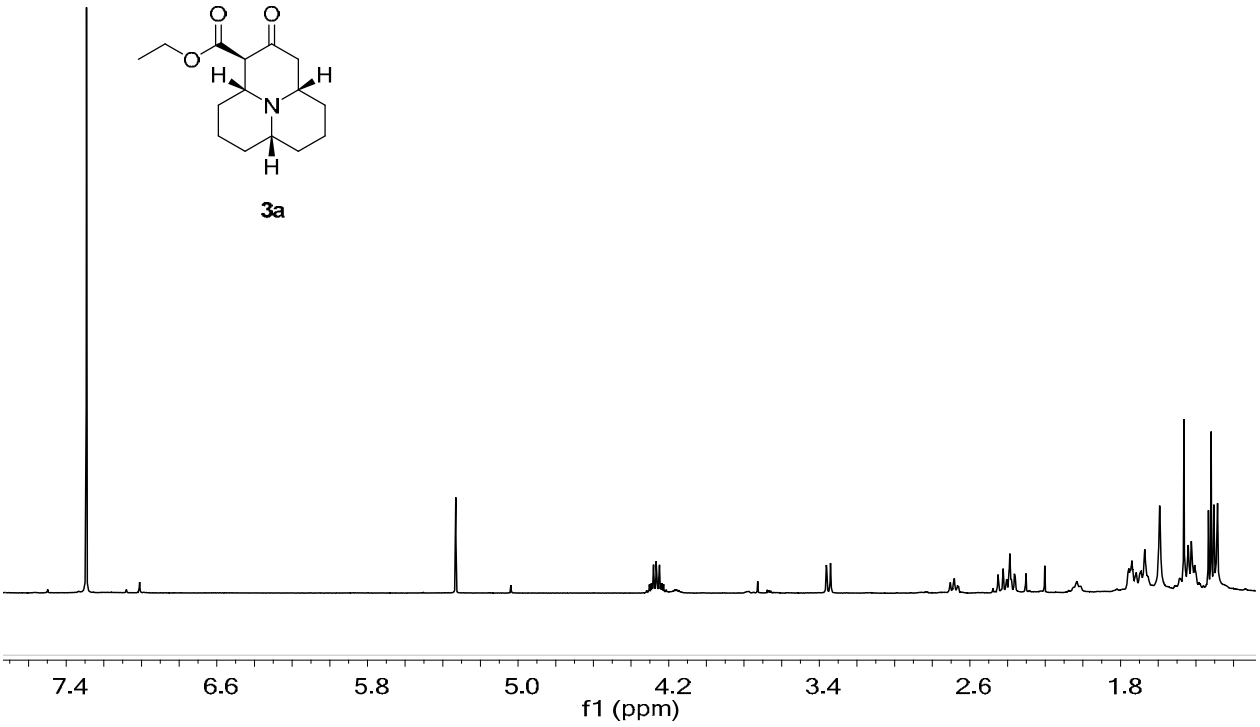
***trans*-2c'**


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
f1 (ppm)

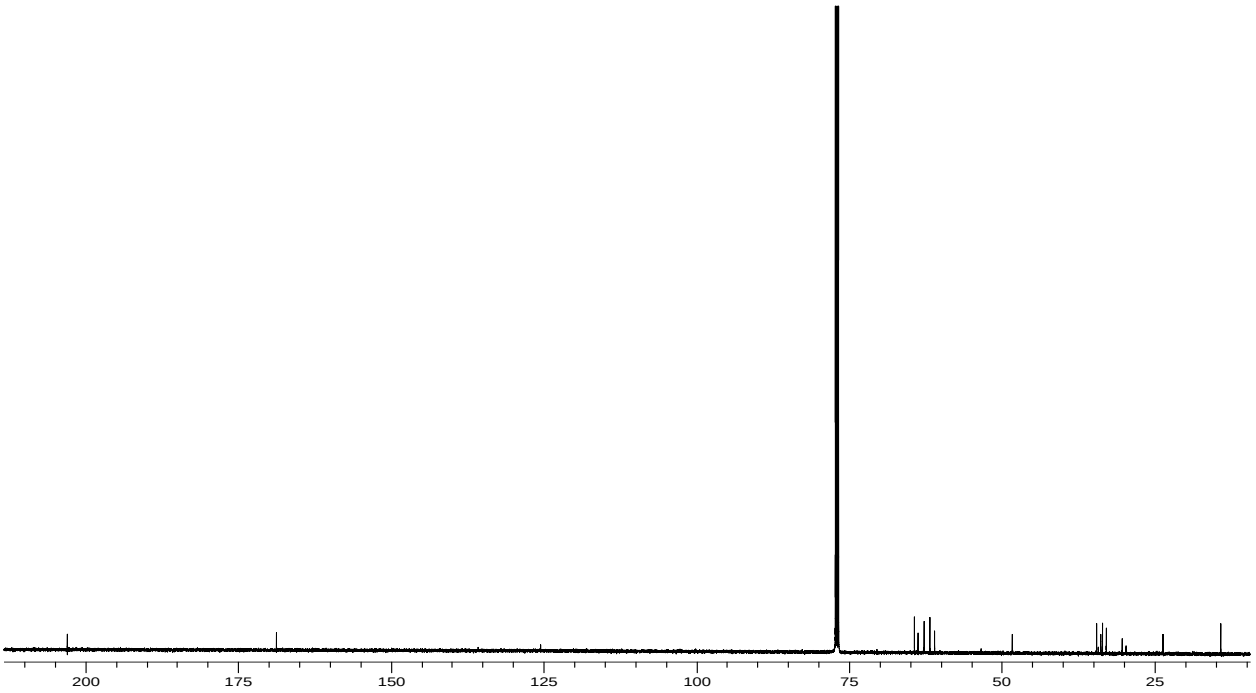

H
N
O
O
O
O
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5

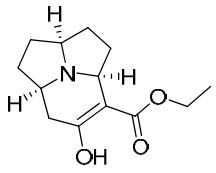
***cis*-2c**


190
180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10



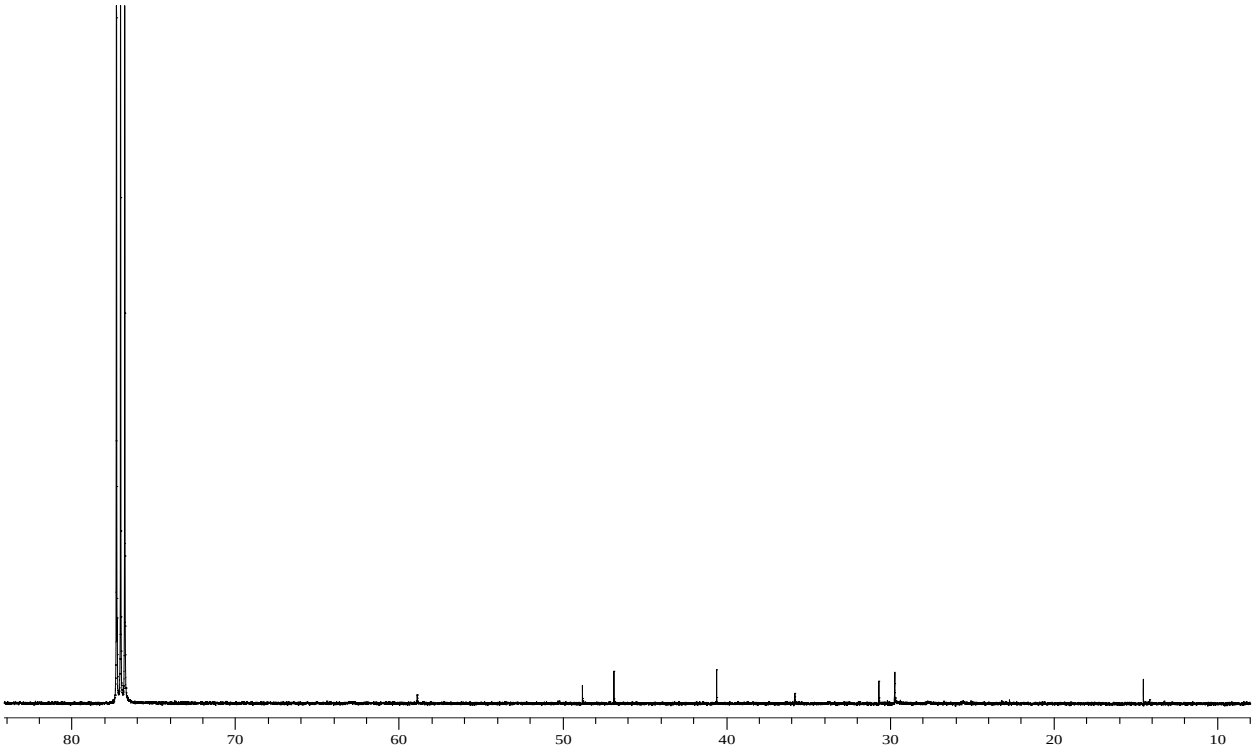
3a

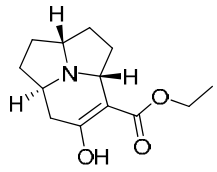



H
N
H
H
O
O
OH

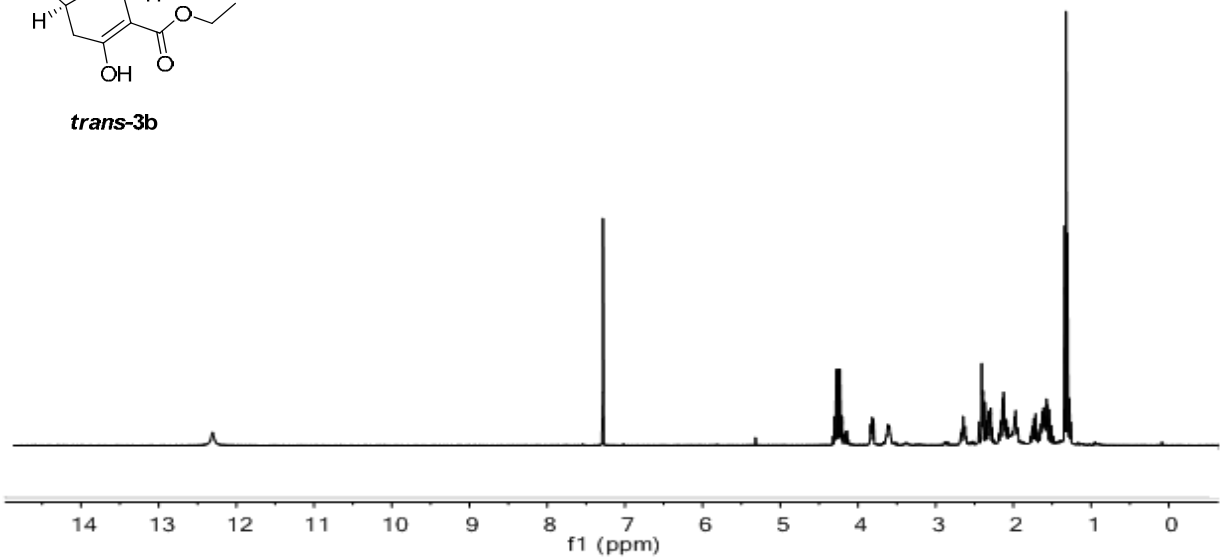
***cis*-3b**

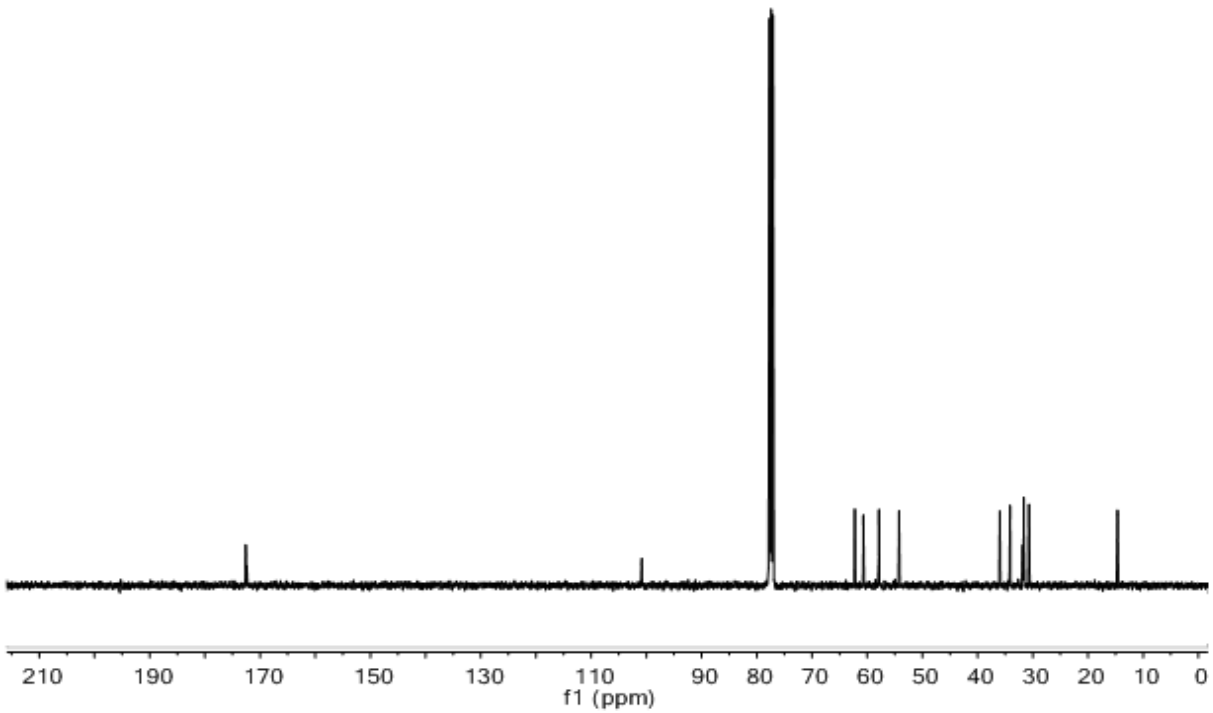
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5

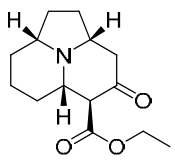

80
70
60
50
40
30
20
10


H
N
H
H
O
O
OH

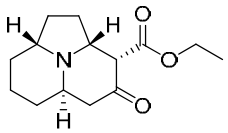
***trans*-3b**


14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
f1 (ppm)

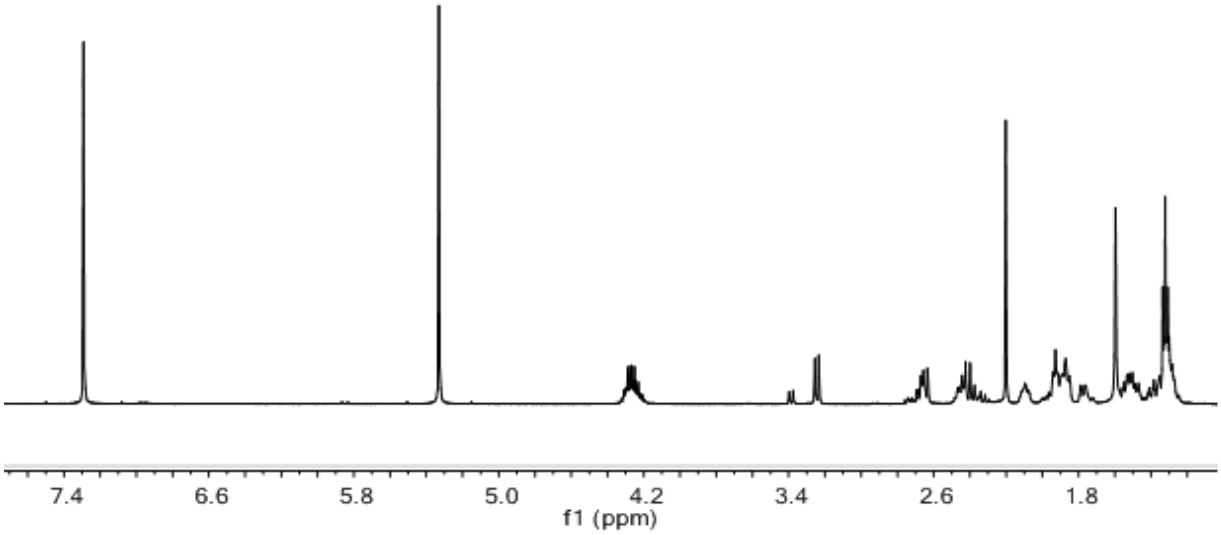

210
190
170
150
130
110
90
80
70
60
50
40
30
20
10
0
f1 (ppm)

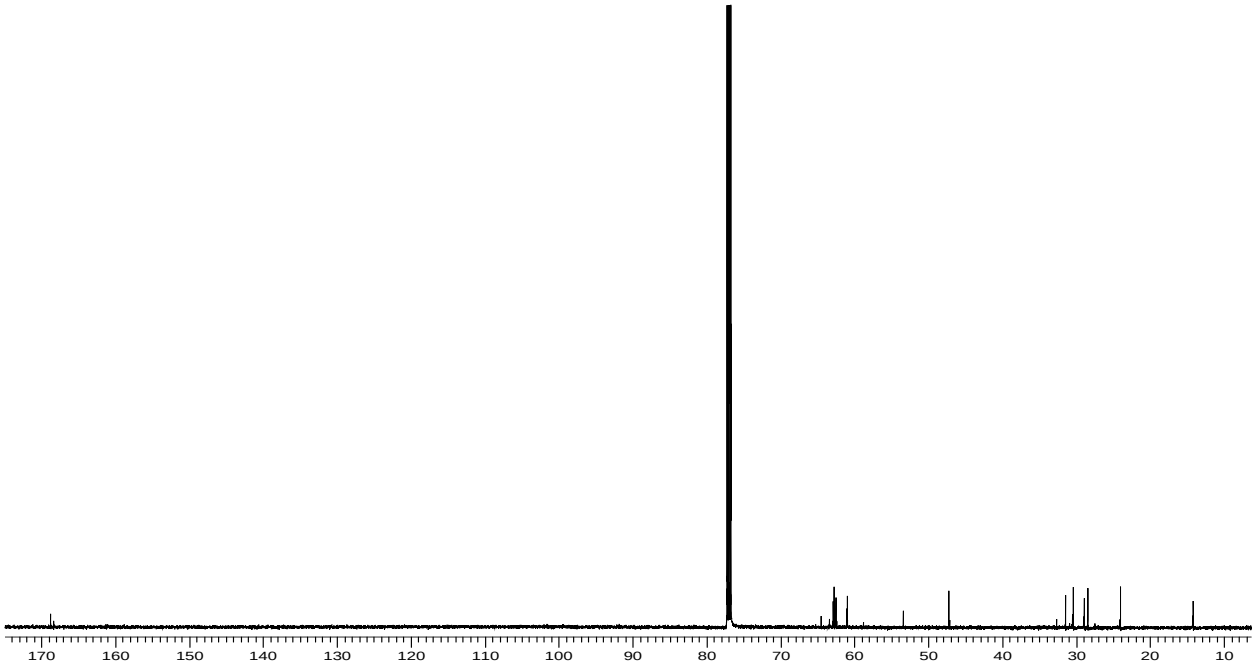


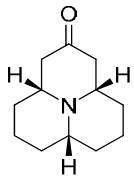
3c

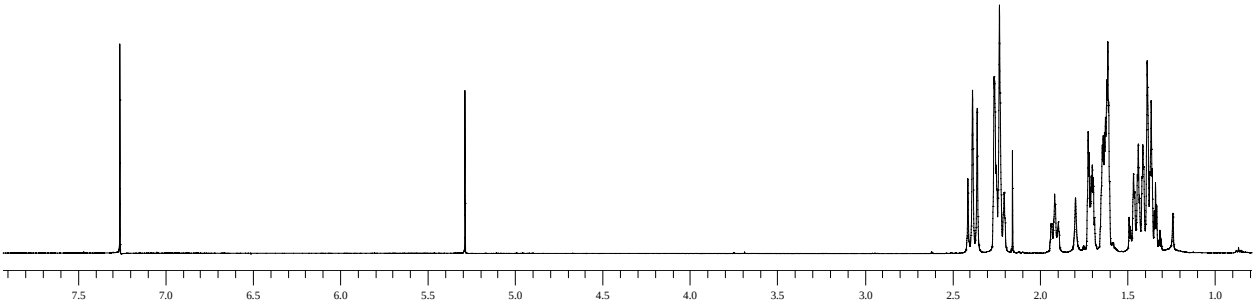


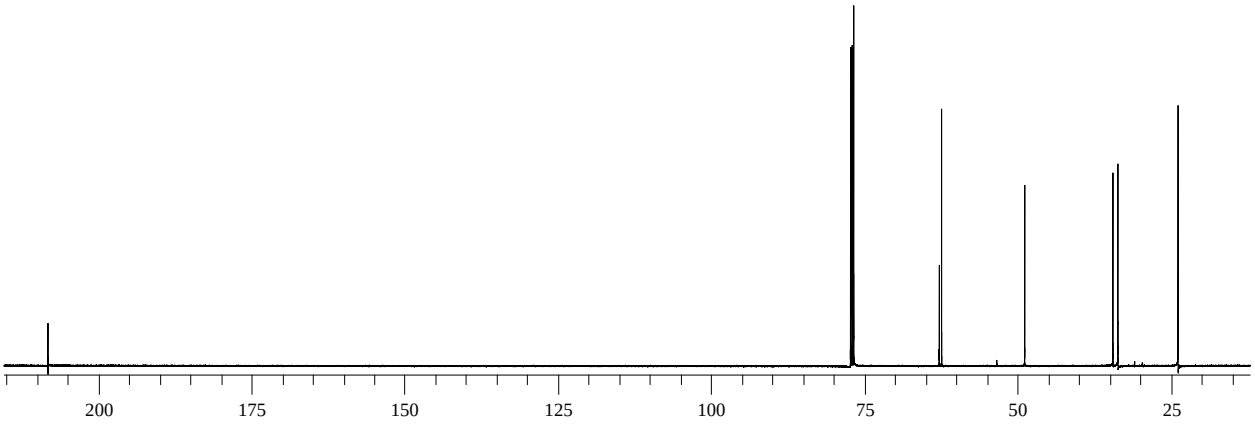
3c'

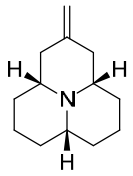

7.4
6.6
5.8
5.0
4.2
3.4
2.6
1.8
f1 (ppm)


170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

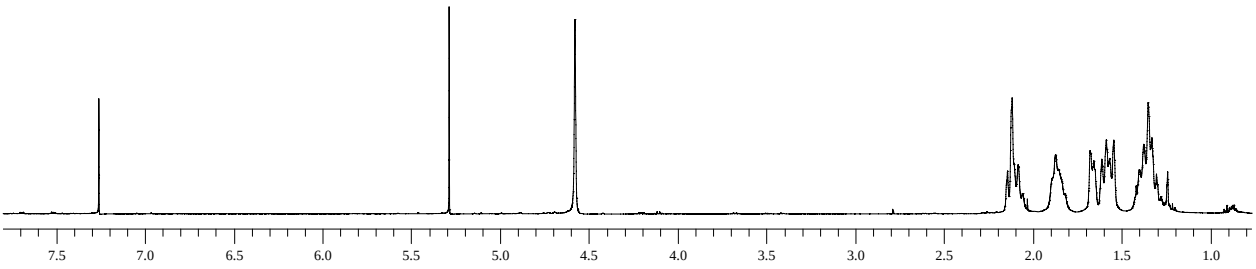

O
H
H
N
H

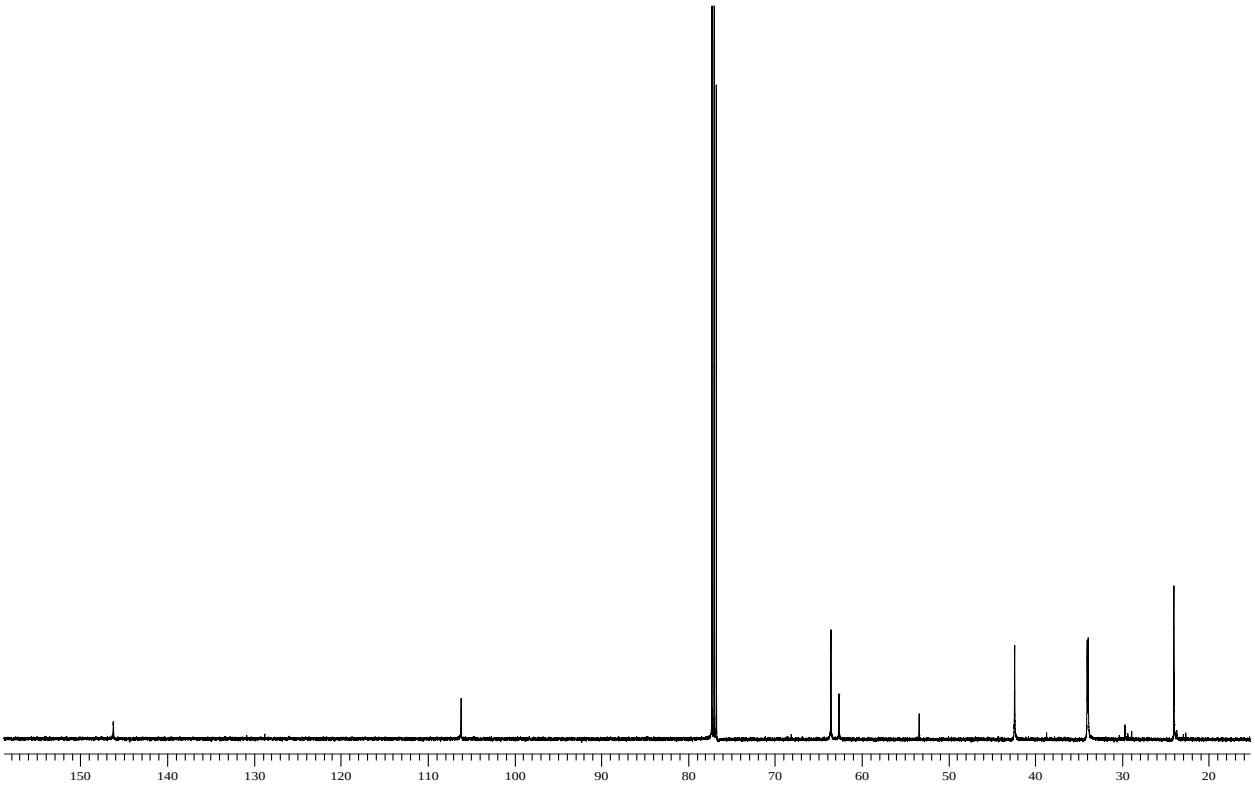

7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0

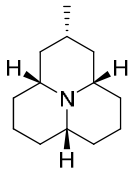

200
175
150
125
100
75
50
25


H
H
N
H

4

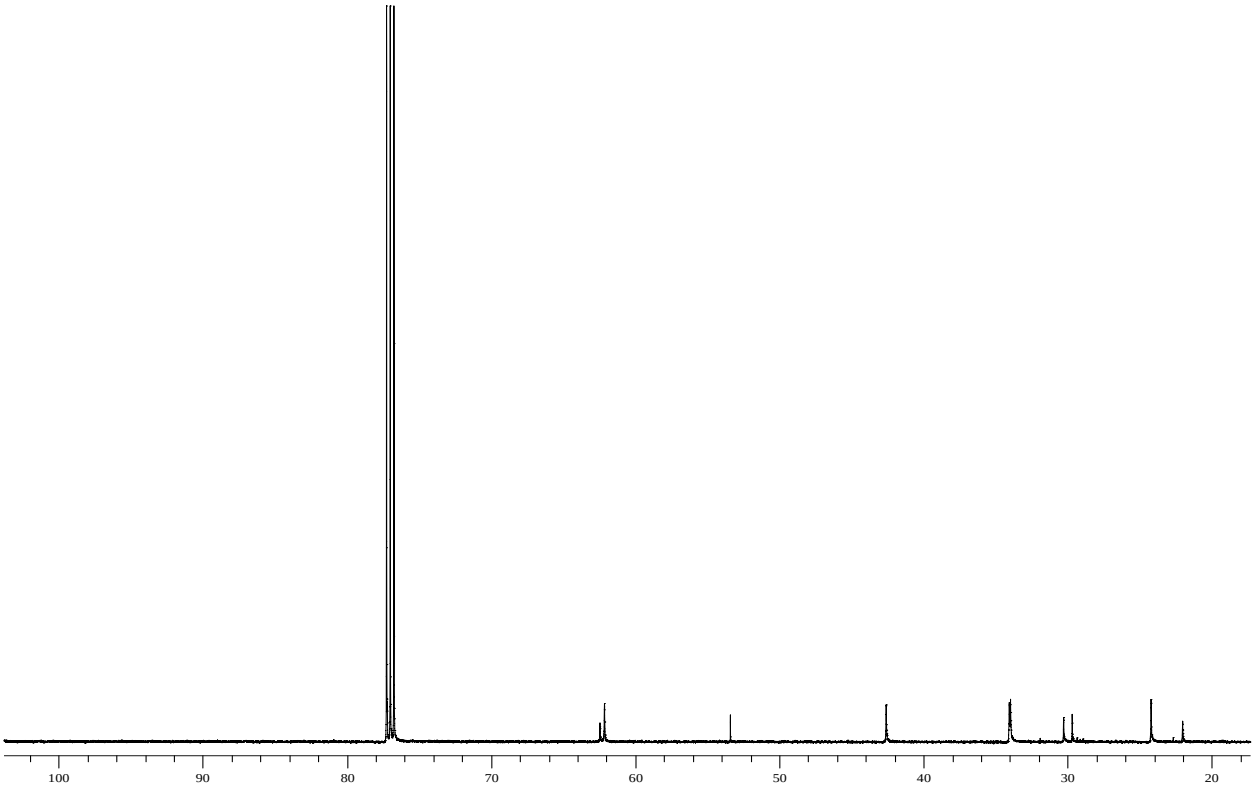

7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0

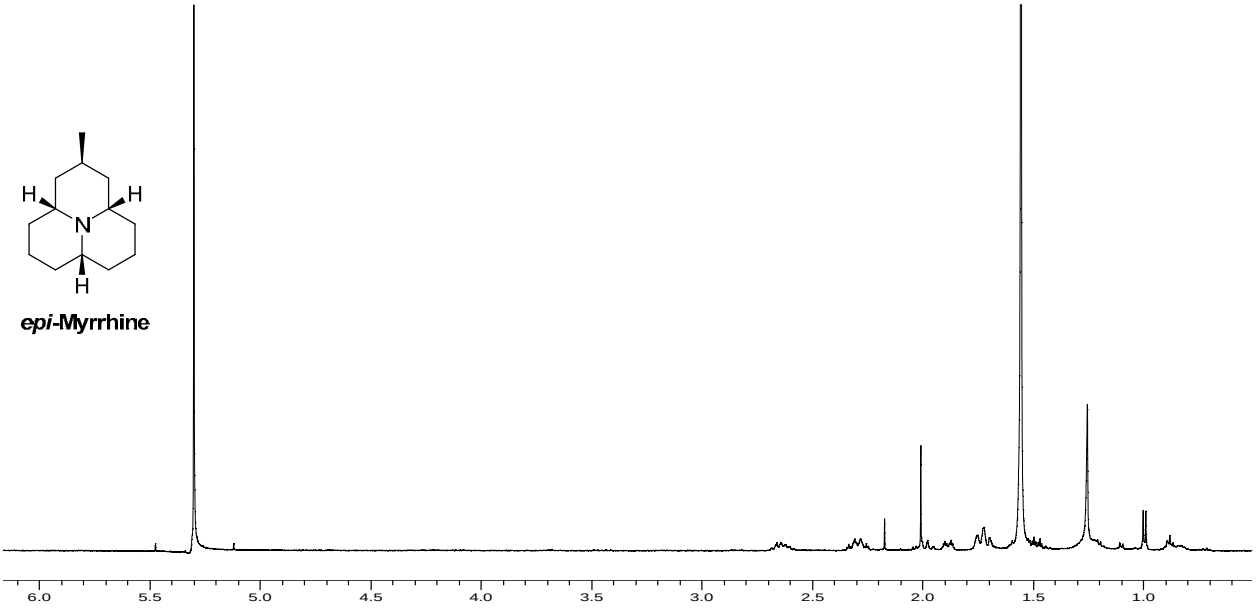

150
140
130
120
110
100
90
80
70
60
50
40
30
20


H
H
N
H

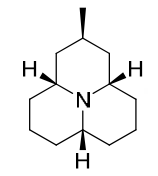
Myrrhine

8.0
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5

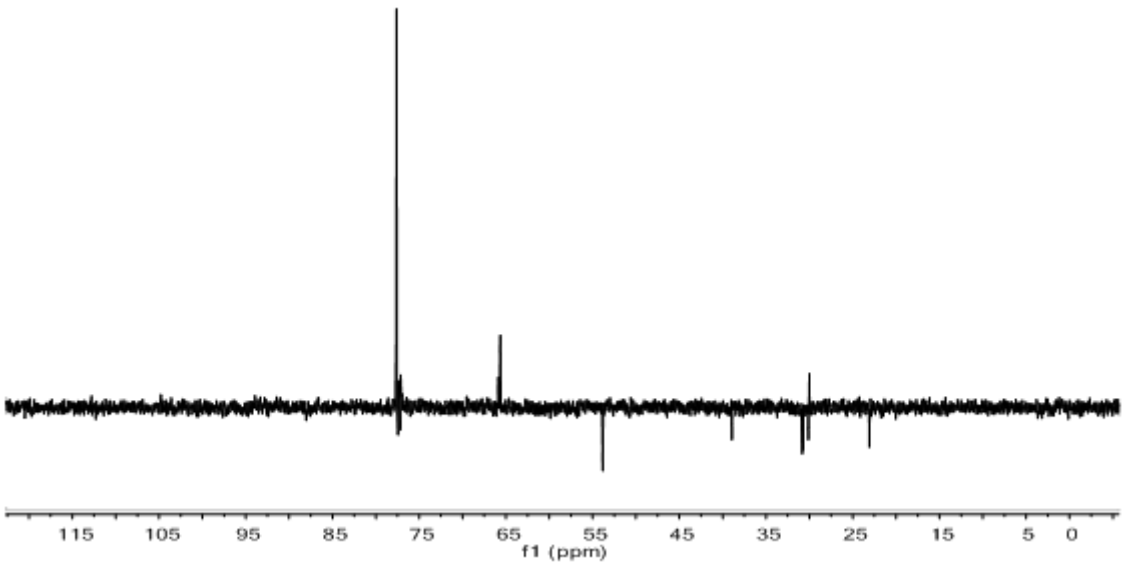

100
90
80
70
60
50
40
30
20

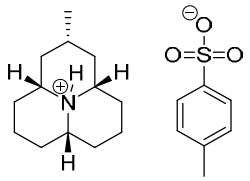


***epi*-Myrrhine**

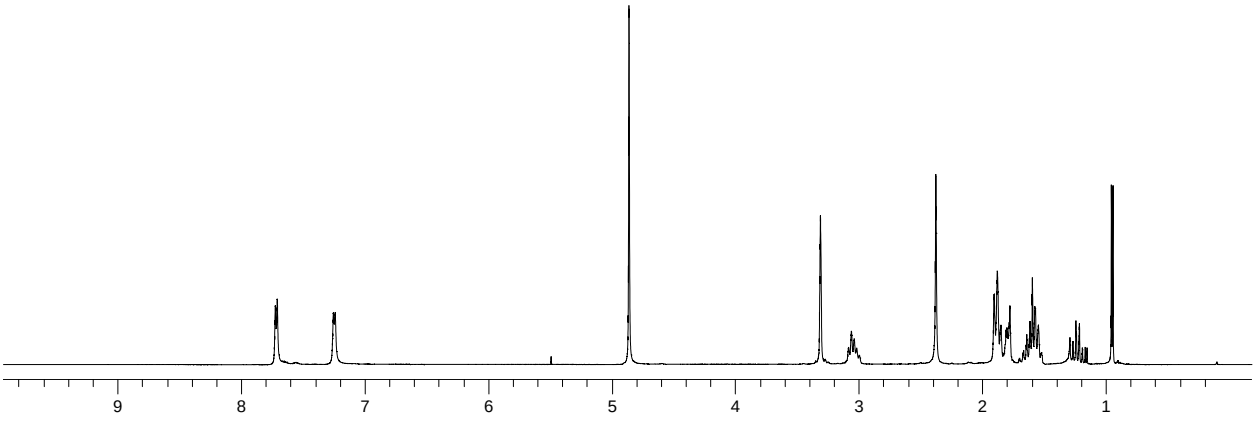


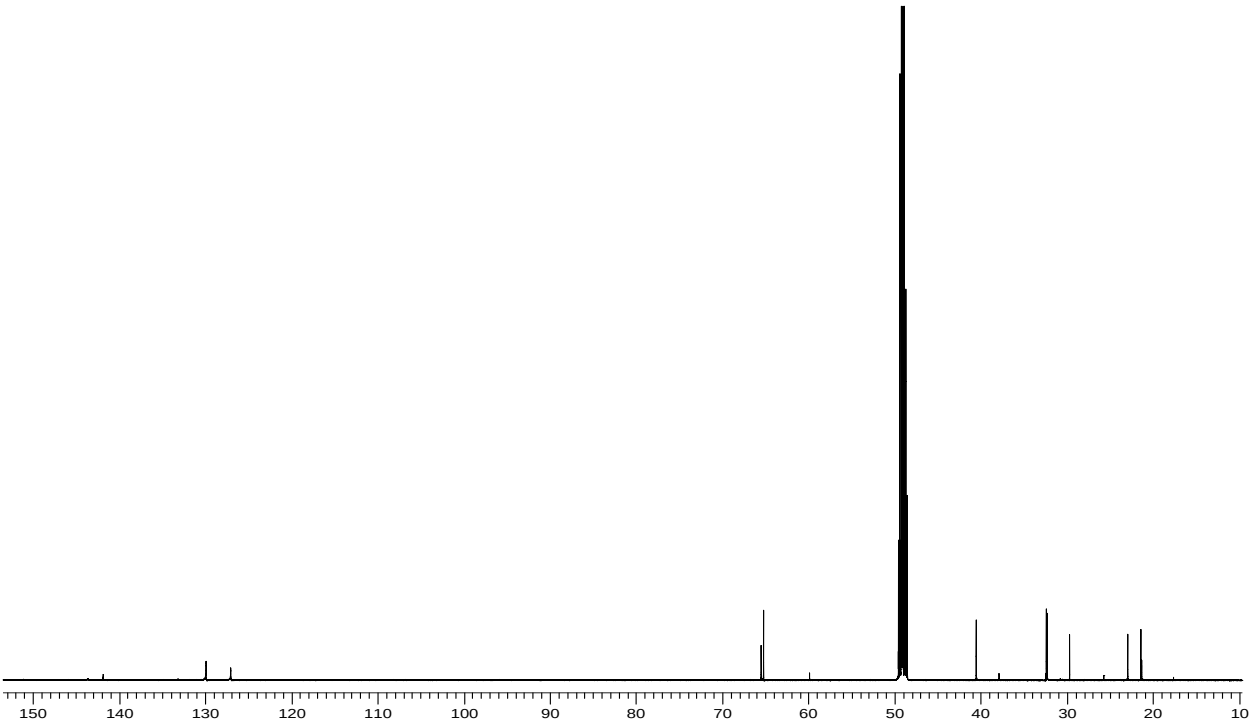
***epi*-Myrrhine**

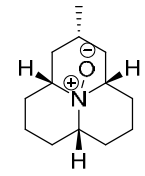




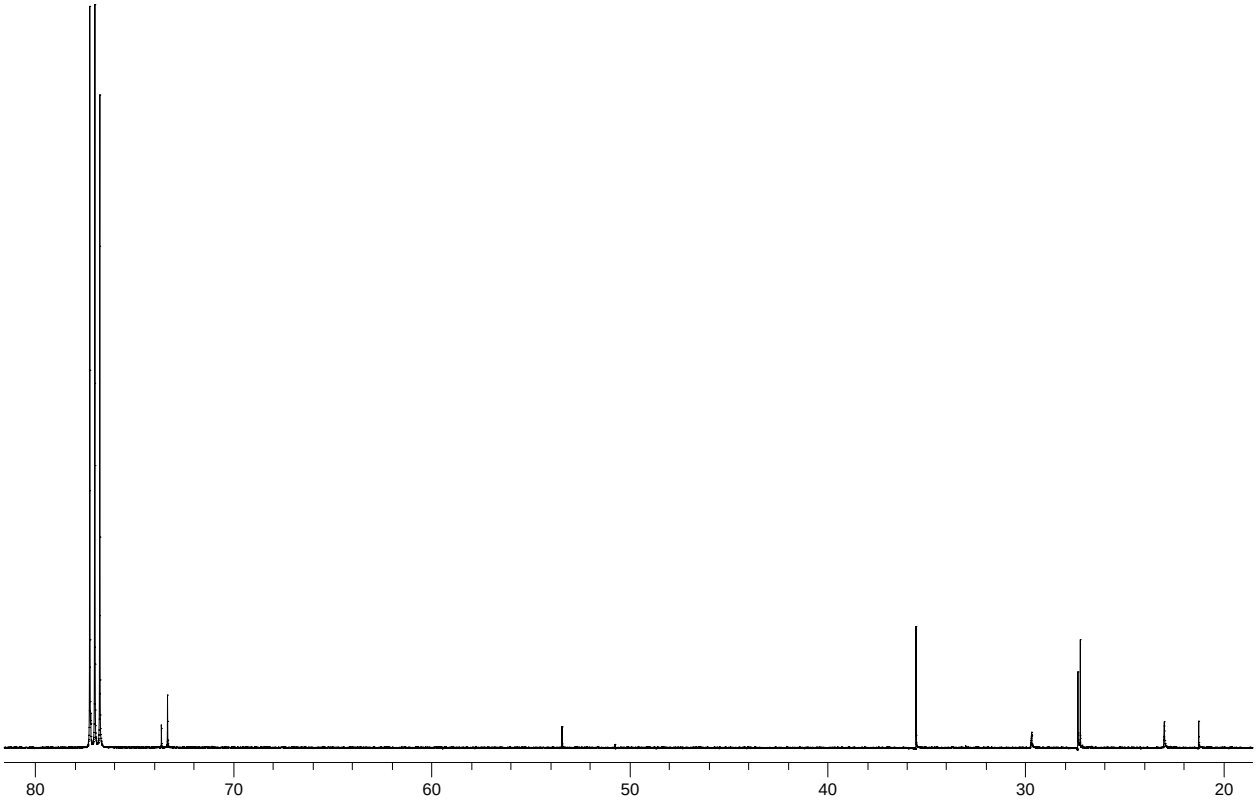
Myrrhine-*p*TsOH

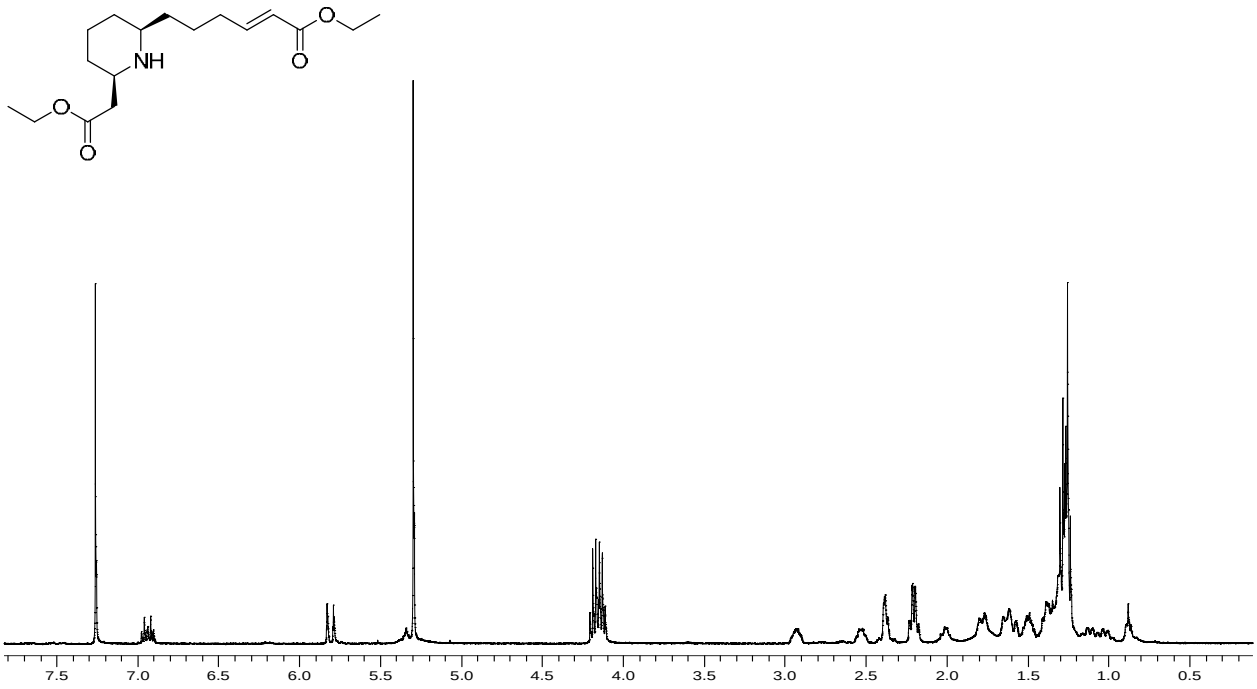


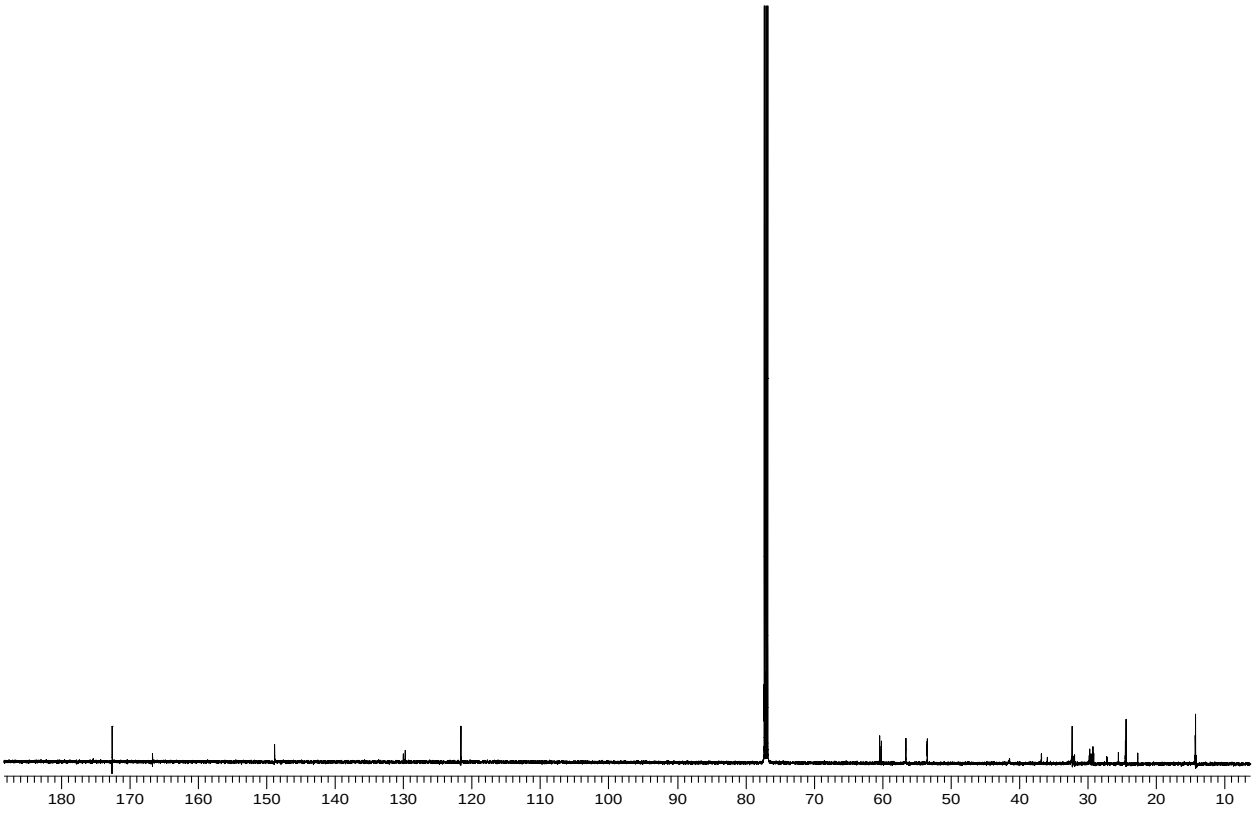




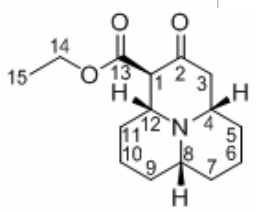
Myrrhine *N*-oxide



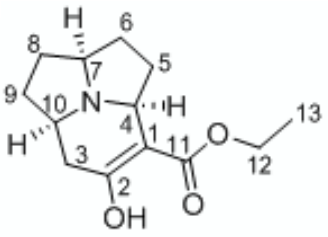

NH
O
O
O
O
7.5
7.0
6.5
6.0
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5


180
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10

NOESY spectra

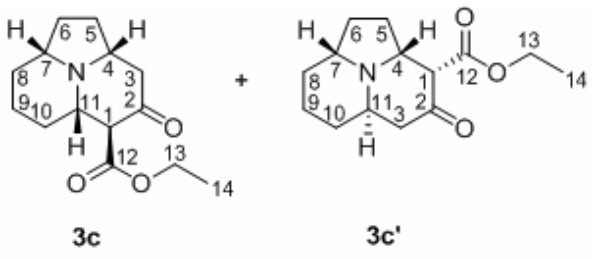


3a

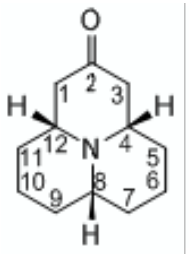

H
6
8
5
7
9
10
N
H
4
1
11
O
13
H
3
12
2
O
OH

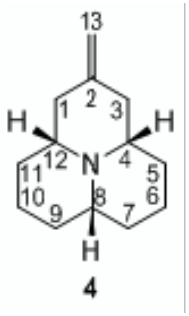
***cis*-3b**

H-7
H-10
H-4
H-3A
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
f1 (ppm)
4.2
3.6
3.0
2.4
1.8
1.2
f2 (ppm)


3c
3c'

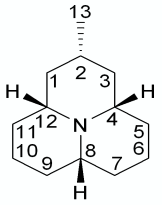
H-1
H-1
H-11
H-3A
H-4
H-3B
H-7
3c'
3c
3c
3c
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
f2 (ppm)
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
f1 (ppm)



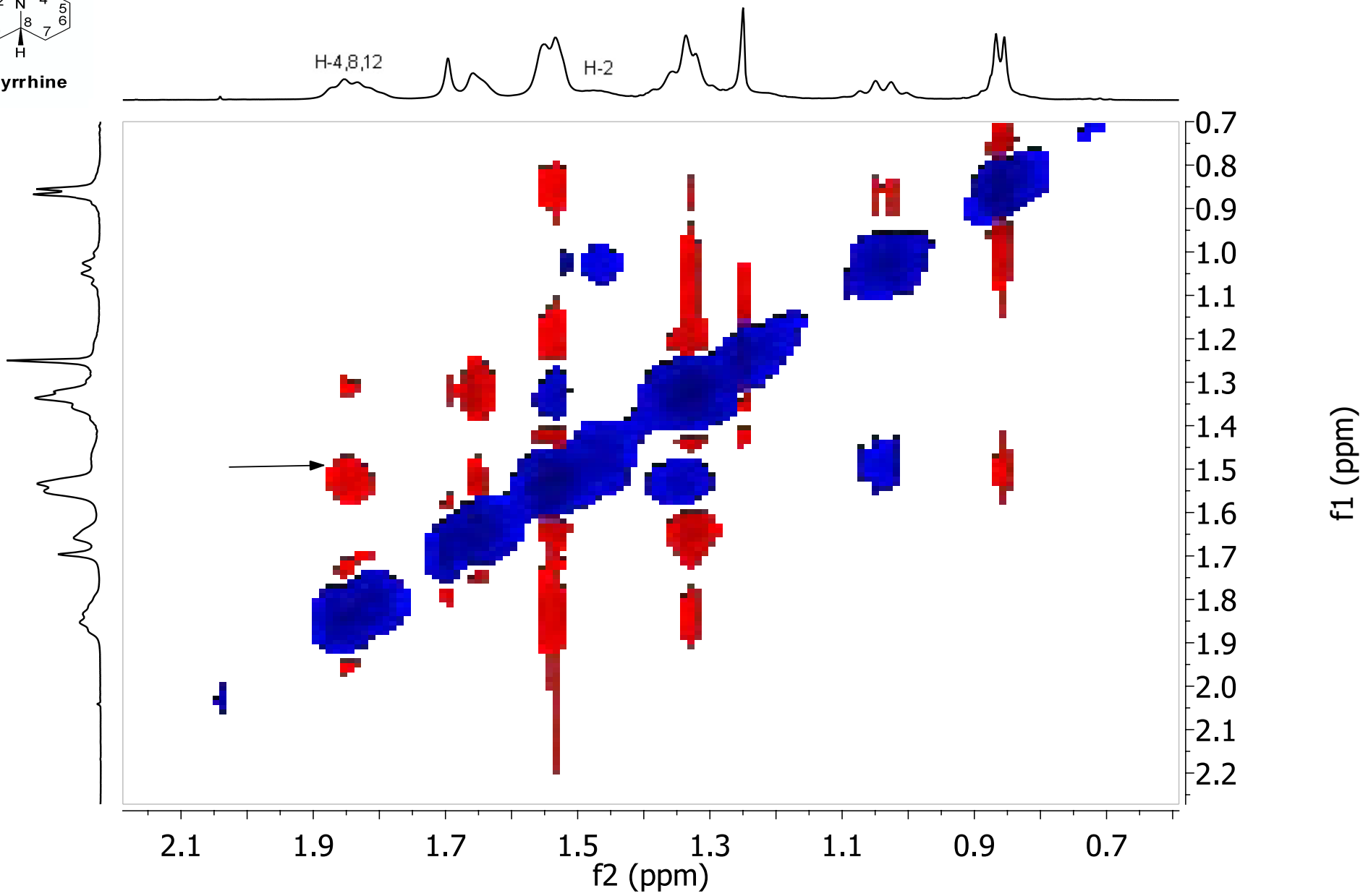

13
2
1
3
H
H
12
N
4
11
5
10
9
8
7
6
H

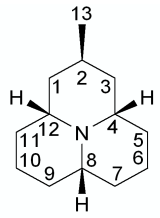
4

H-13
H-1A,1B,2A,2B
H-4,8,12
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
f1 (ppm)
4.6
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
f2 (ppm)

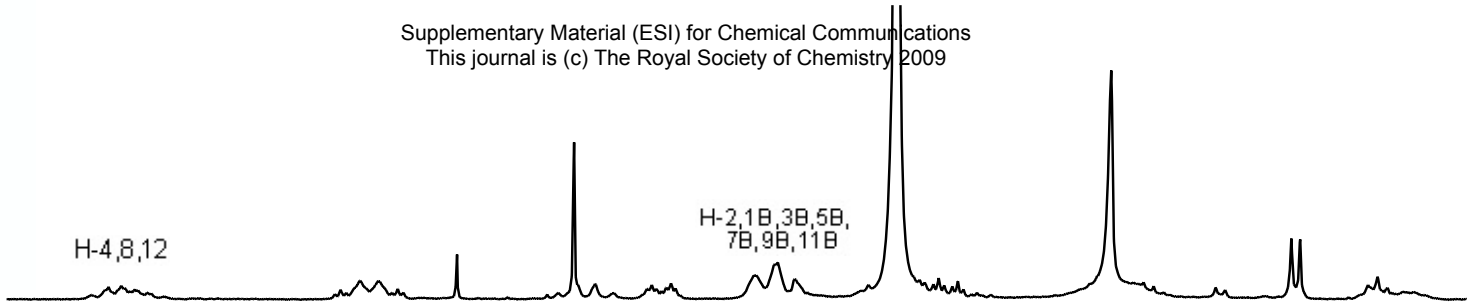

13
2
1
3
H
H
12
N
4
11
5
10
6
9
8
7
H

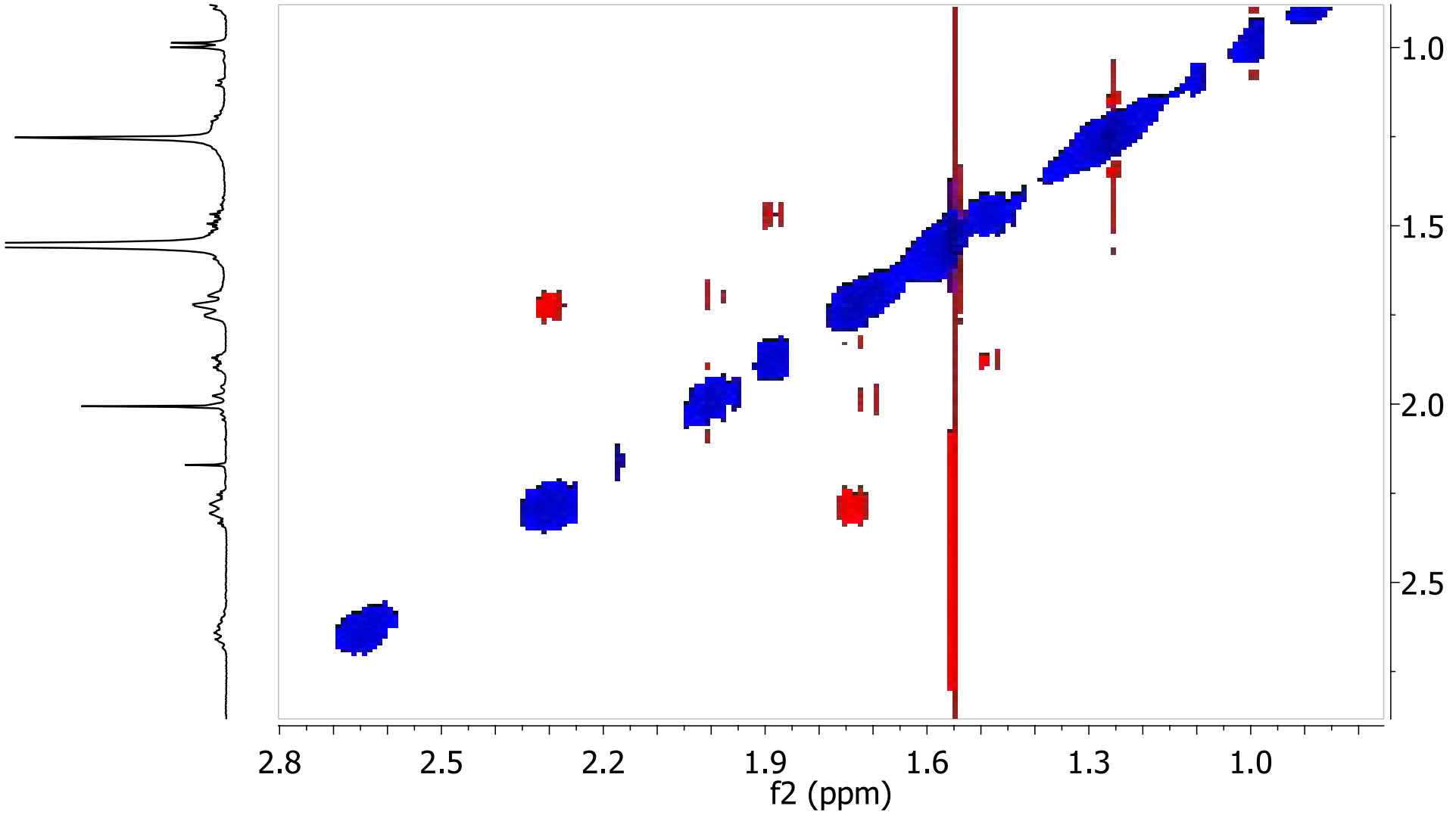
Myrrhine

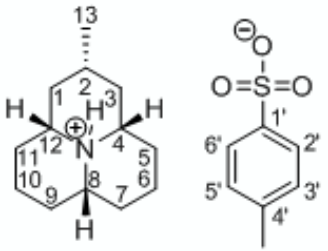

H-4,8,12
H-2
0.7
0.8
0.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2
f1 (ppm)
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
f2 (ppm)



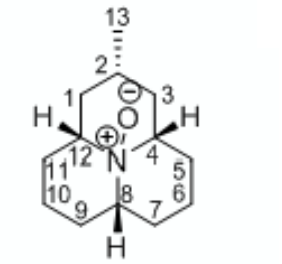
***epi*-Myrrhine**



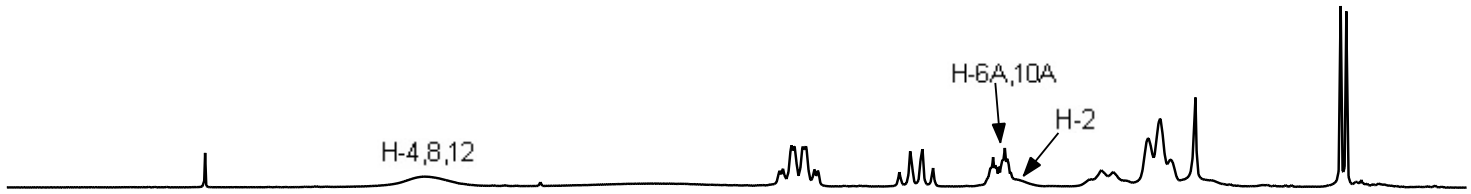


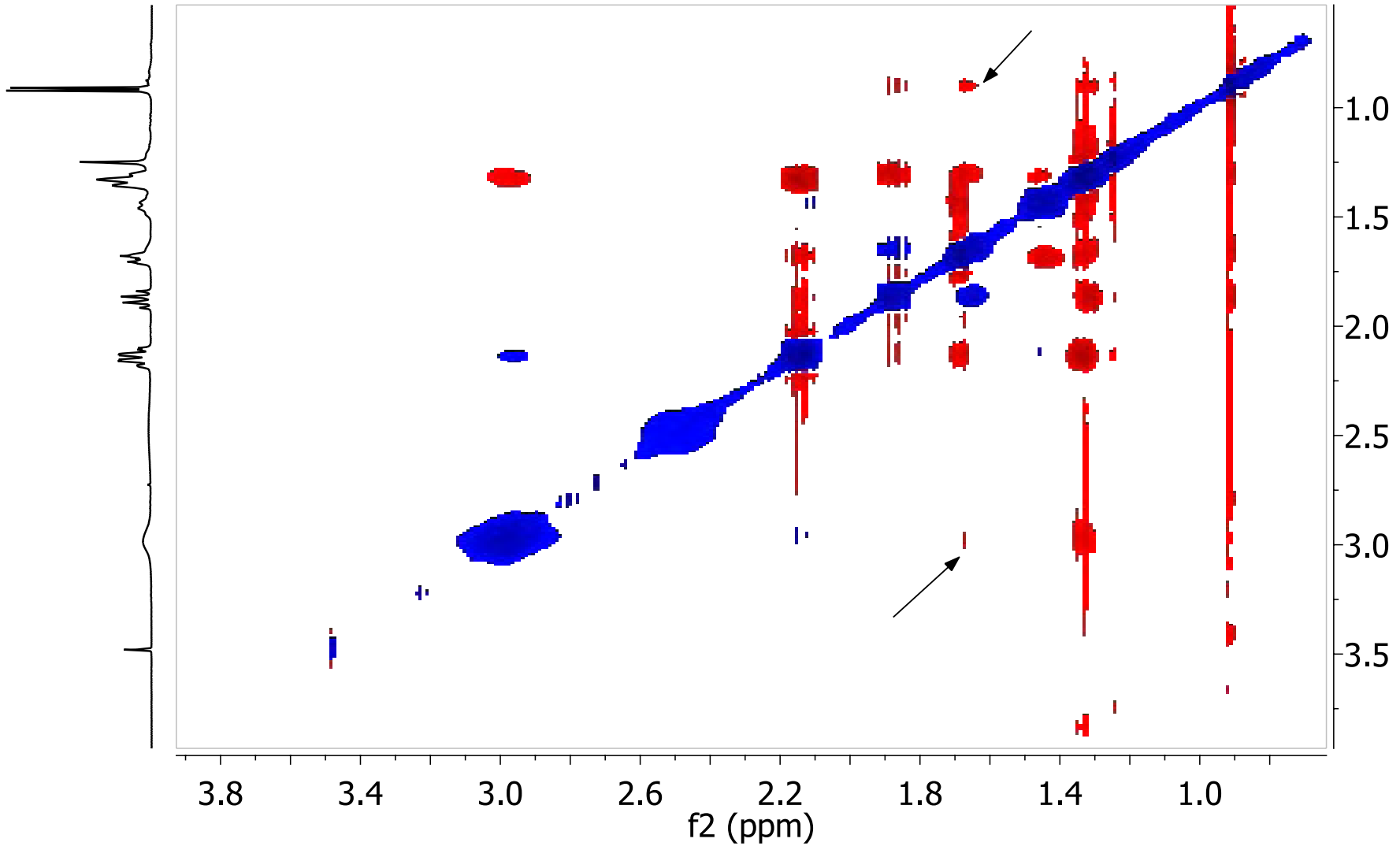


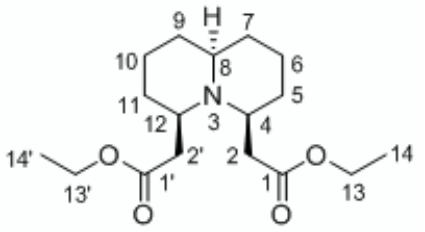
Myrrhine-*p*TsOH



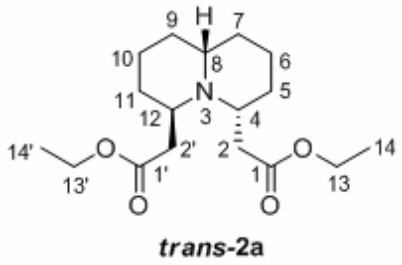
Myrrhine *N*-oxide



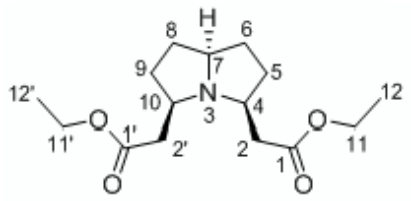




***cis*-2a**

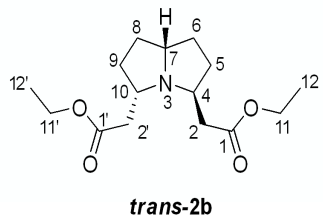


trans-2a


H
8
6
9
7
5
12'
10
N
4
12
3
O
1'
O
11'
2'
2
1
O
O
11

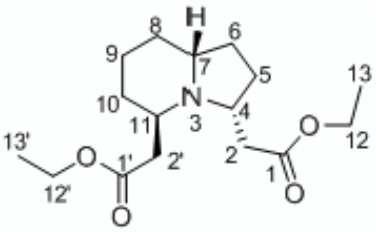
cis-**2b**

H-7
H-4,10
H-5a, 6a,
8a, 9a
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
f1 (ppm)
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
f2 (ppm)

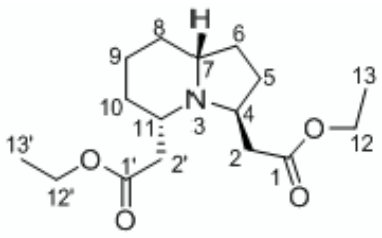

H
8
6
9
7
5
10
N
3
4
12'
12
11'
O
1'
2'
2
1
11
O
O

trans-**2b**

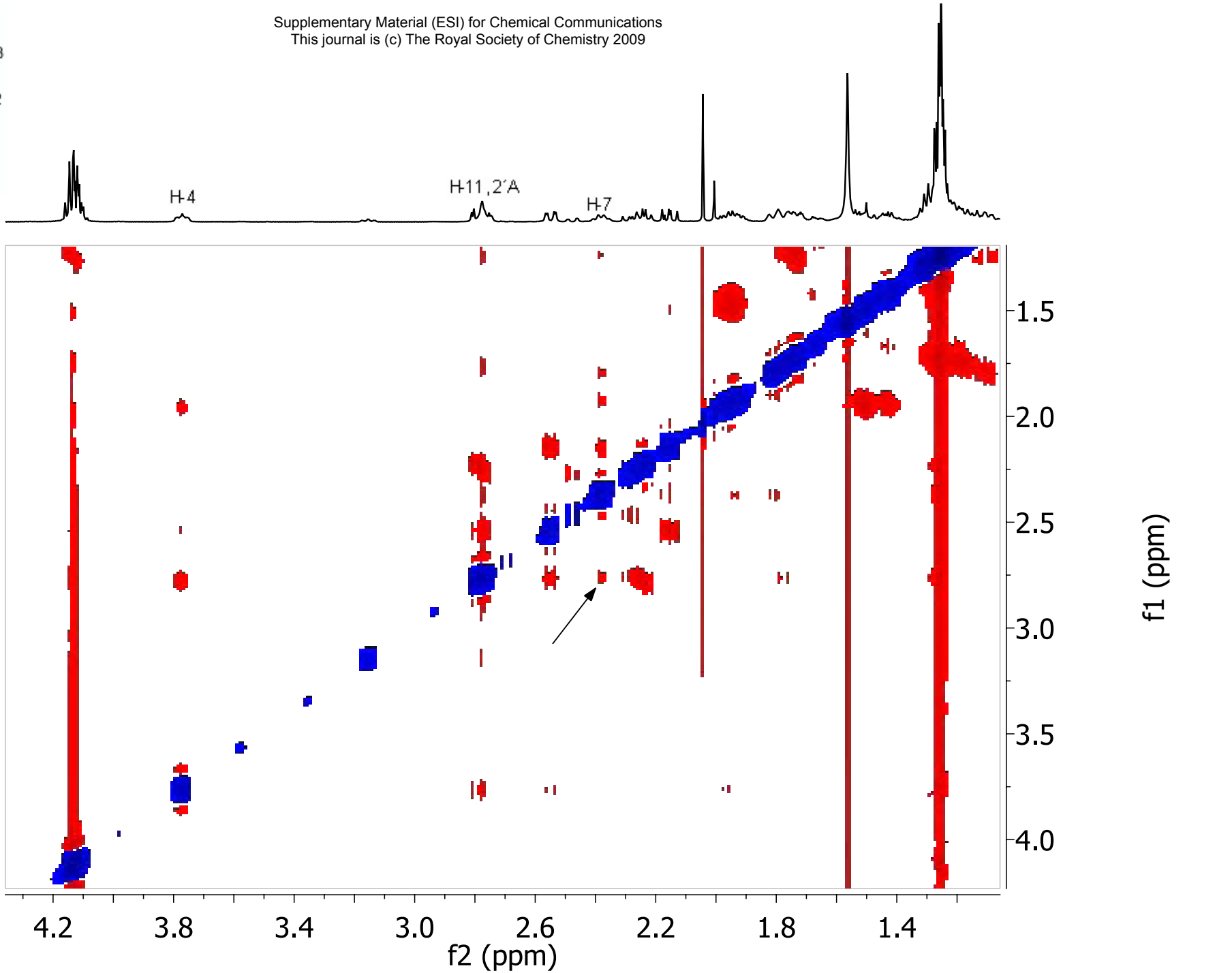
H-7
H-10
H-4
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
f1 (ppm)
4.4
4.0
3.6
3.2
2.8
2.4
2.0
1.6
1.2
f2 (ppm)

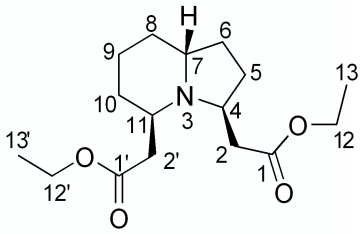


trans-2c



trans-2c'




H
8
6
9
7
5
13
10
N
3
4
11
O
12
13'
O
1'
2'
2
1
12'
O
O

***cis*-2c**

H-4 ,11
H-7
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
f1 (ppm)
4.2
3.8
3.4
3.0
2.6
2.2
1.8
1.4
f2 (ppm)