Pd(II)-Catalyzed Synthesis of Bicyclo[3.2.1] Lactones via Tandem Intramolecular β-C(sp^3)–H Olefination and Lactonization of Free Carboxylic Acids.

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Supporting Information

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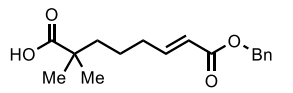
General information

Unless otherwise stated, all reagents were purchased from commercial suppliers and used without further purification. Anhydrous solvents were obtained from the solvent purification system produced by *J*C Meyer Solvent Systems. Analytical thin-layer chromatography (TLC) was performed on Merck Millipore precoated (0.25 mm thickness) silica gel plates with F254 fluorescent indicator. TLC plates were visualized by exposure to ultraviolet light (UV) and/or submersion in aqueous potassium permanganate solution ($KMnO_4$), followed by brief heating on a hot plate (120 °C, 10–15 s). Flash-column chromatography was performed employing silica gel (32-63 μm particle size) supplied by Dynamic Adsorbents. Proton nuclear magnetic resonance spectra (^{1}H NMR) were recorded on Bruker DRX-600 instrument (600 MHz). Chemical shifts are expressed in parts per million (ppm, δ scale) downfield from tetramethylsilane and are referenced to residual protium in the NMR solvent ($CHCl_3$, δ 7.26). Data are represented as follows: chemical shift, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet and/or multiple resonances, b = broad, app = apparent), coupling constant, *J*, in Hertz (Hz) AND integration. Proton-decoupled carbon nuclear magnetic resonance spectra (^{13}C NMR) were recorded on Bruker DRX-600 instrument (150 MHz). Chemical shifts are expressed in parts per million (ppm, δ scale) downfield from tetramethylsilane and are referenced to the carbon resonances of the solvent ($CDCl_3$, δ 77.2). High-resolution mass spectra (HRMS) were recorded on an Agilent Mass spectrometer using ESI-TOF (electrospray ionization-time of flight).

Substrate structures.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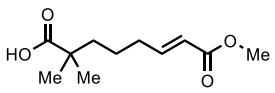
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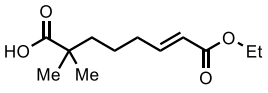
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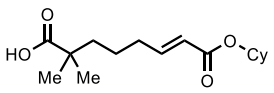
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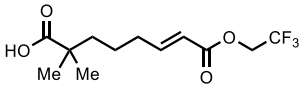
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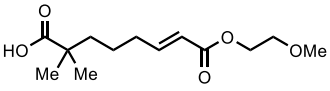
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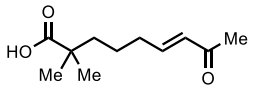
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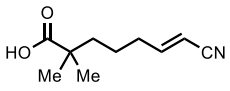
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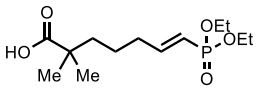
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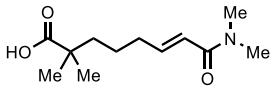
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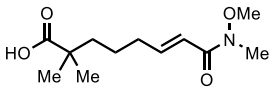
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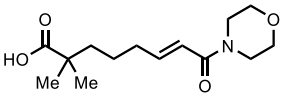
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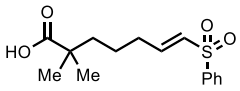
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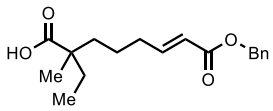
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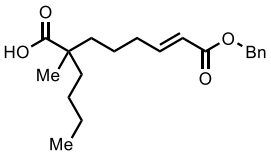
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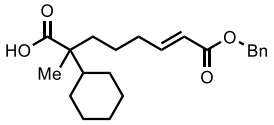
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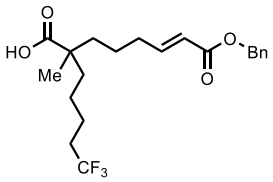
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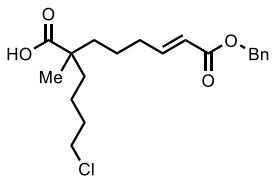
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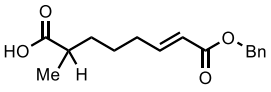
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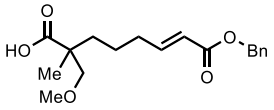
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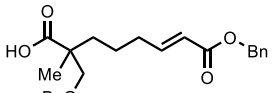
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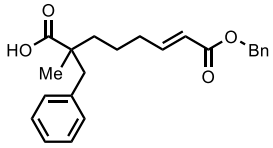
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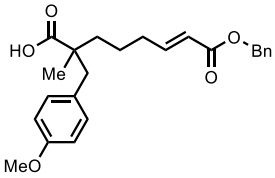
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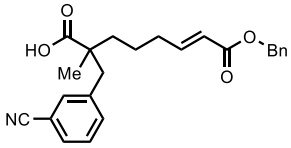
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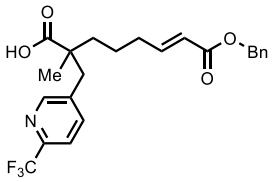
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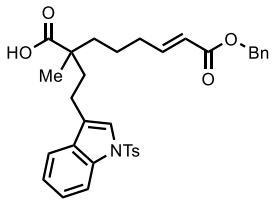
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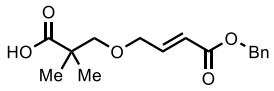
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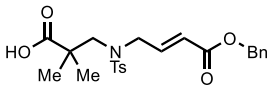
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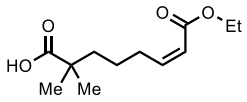
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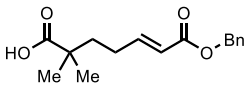
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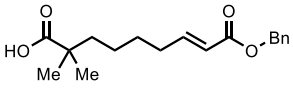
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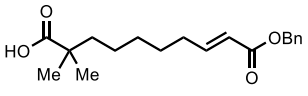
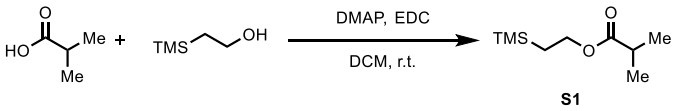

16-S.M.

Experimental Section.

General Procedure A: Preparation of Substrates **10a-10m**, **14-S.M., 15-S.M., 16-S.M.**

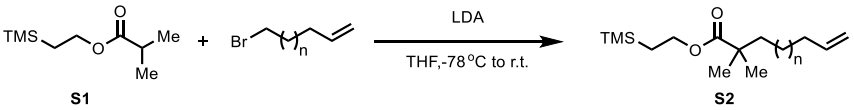
*Synthesis of the ester **S1**:*



S1

4-Dimethylaminopyridine (2.0 equiv.) and 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (2.0 equiv.) were added in sequence to a solution of the isobutyric acid (1.0 equiv.) and 2-(trimethylsilyl)ethanol (1.5 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was stirred at 23 °C for 15 hours. The product mixture was then diluted sequentially with dichloromethane and saturated aqueous ammonium chloride solution. The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane and washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by a flash-column chromatography to provide the corresponding ester **S1** as a colorless oil. (^{1}H NMR matched the previously reported data[1])

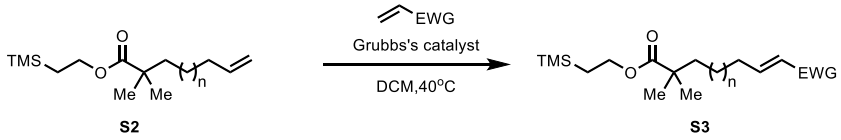
*Synthesis of the alkylated ester **S2**:*



S1 **S2**

A solution of *n*-butyllithium in hexanes (2.50 M, 1.20 equiv.) was added dropwise via syringe over 30 min to a solution of diisopropylamine (1.25 equiv.) in tetrahydrofuran (0.2 M) at –78 °C. The resulting solution was stirred for 45 min at –78 °C. A solution of the ester **S1** (1.0 equiv.) in tetrahydrofuran was then added dropwise via syringe over 15 min at –78 °C. Upon completion of the addition, the reaction mixture was stirred for 1 hour at –78 °C. Alkyl bromide (1.3 equiv.) was then added dropwise via syringe at –78 °C. The reaction mixture was allowed to slowly warm to 23 °C overnight. The warmed product mixture was diluted sequentially with water and ethyl acetate. The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate. The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was eluted over a short plug of silica gel with 20% ethyl acetate–hexanes to provide the corresponding doubly methylated ester **S2** as a colorless oil, which was used directly in the next step without any further purification.

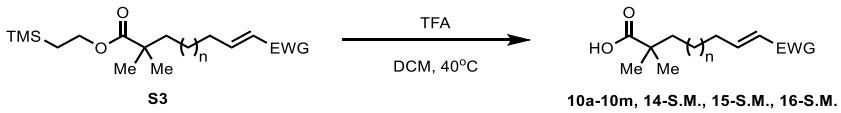
*Synthesis of **S3** via olefin cross-metathesis:*



S2 **S3**

Hoveyda–Grubbs-II catalyst (3 mol%) was added to a solution of the alkylated ester **S2** (nominally, 1.0 equiv.) and acrylate (1.5 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30 min. The cooled product mixture was concentrated, and the residue obtained was the acrylate **S3** obtained in this way was used directly in the next step without further purification.

*Synthesis of the linear substrate **10a-10m, 14-S.M., 15-S.M., 16-S.M.**:*

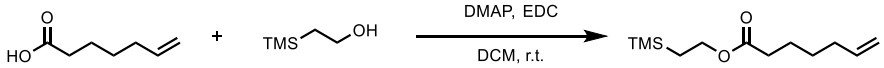


S3 **10a-10m, 14-S.M., 15-S.M., 16-S.M.**

Trifluoroacetic acid (6.5 equiv.) was added to a solution of the **S3** (nominally, 1.0 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30 min. The cooled product mixture was concentrated and the residue obtained was purified by a flash-column chromatography to provide the corresponding linear substrate **10a-10m, 14-S.M., 15-S.M., 16-S.M.** as colorless oils.

General Procedure B: Preparation of Substrates **12a-12m**

*Synthesis of the ester **S4**:*

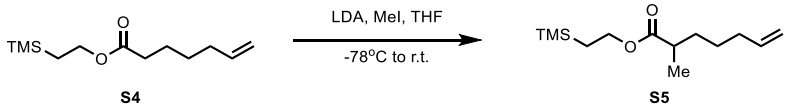


S4

4-Dimethylaminopyridine (2.0 equiv.) and 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (2.0 equiv.) were added in sequence to a solution of the hept-6-enoic acid (1.0 equiv.) and 2-(trimethylsilyl)ethanol (1.5 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was stirred at 23 °C for 15 hours. The product mixture was then diluted sequentially with dichloromethane and saturated aqueous ammonium chloride solution. The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane and washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by a flash-column chromatography to provide the corresponding ester **S4** as a colorless oil.

^{1}H NMR (600 MHz, $CDCl_3$) δ 5.79 (ddt, J = 16.9, 10.2, 6.7 Hz, 1H), 5.11 – 4.84 (m, 2H), 4.24 – 4.00 (m, 2H), 2.28 (t, J = 7.5 Hz, 2H), 2.12 – 1.98 (m, 2H), 1.69 – 1.60 (m, 2H), 1.42 (tt, J = 9.9, 6.6 Hz, 2H), 1.03 – 0.86 (m, 2H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 174.0, 138.6, 114.8, 62.6, 34.5, 33.5, 28.5, 24.6, 17.5, -1.3. HRMS (ESI-TOF) Calcd for $C_{12}H_{25}O_2Si^+$ $[M+H]^+$: 229.1624, found: 229.1627.

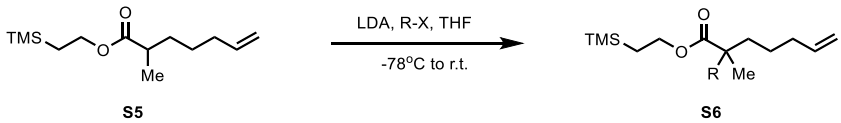
*Synthesis of the methylated ester **S5**:*



S4 **S5**

A solution of *n*-butyllithium in hexanes (2.50 M, 1.20 equiv.) was added dropwise via syringe over 30 min to a solution of diisopropylamine (1.25 equiv.) in tetrahydrofuran (0.2 M) at –78 °C. The resulting solution was stirred for 45 min at –78 °C. A solution of the ester **S4** (1.0 equiv.) in tetrahydrofuran was then added dropwise via syringe over 15 min at –78 °C. Upon completion of the addition, the reaction mixture was stirred for 1 hour at –78 °C. Iodomethane (1.3 equiv.) was then added dropwise via syringe at –78 °C. The reaction mixture was allowed to slowly warm to 23 °C overnight. The warmed product mixture was diluted sequentially with water and ethyl acetate. The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate. The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was eluted over a short plug of silica gel with 20% ethyl acetate–hexanes to provide the corresponding methylated ester **S5** as a colorless oil, which was used directly in the next step without any further purification.

*Synthesis of the doubly alkylated ester **S6**:*

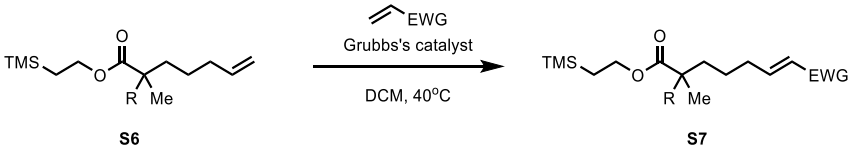


S5 **S6**

A solution of *n*-butyllithium in hexanes (2.50 M, 1.20 equiv.) was added dropwise via syringe over 30 min to a solution of diisopropylamine (1.25 equiv.) in tetrahydrofuran (0.2 M) at –78 °C. The resulting solution was stirred for 45 min at –78 °C. A solution of the methylated ester **S5** (nominally, 1.0 equiv.) in tetrahydrofuran was then added dropwise via syringe over 15 min at –78 °C. Upon completion of the addition, the reaction mixture was stirred for 1 hour at –78 °C. Alkyl halide (1.3 equiv.) was then added dropwise via syringe at –78 °C. The reaction mixture was allowed to slowly warm to 23 °C overnight. The warmed product mixture was diluted sequentially with water and ethyl acetate. The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate. The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was eluted over

a short plug of silica gel with 20% ethyl acetate–hexanes to provide the corresponding doubly alkylated ester **S6** as a colorless oil, which was used directly in the next step without any further purification.

*Synthesis of **S7** via olefin cross-metathesis:*



S6 **S7**

Hoveyda–Grubbs-II catalyst (3 mol%) was added to a solution of the doubly alkylated ester **S6** (nominally, 1.0 equiv.) and acrylate (1.5 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated, and the residue obtained was the acrylate **S7** obtained in this way was used directly in the next step without further purification.

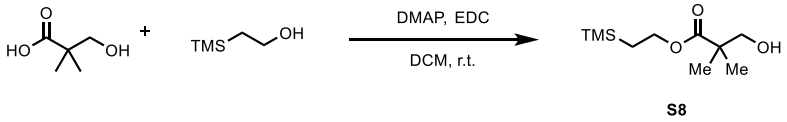
*Synthesis of the linear substrate **12a-12m**:*

S7 **12a-12m**

Trifluoroacetic acid (6.5 equiv.) was added to a solution of the **S7** (nominally, 1.0 equiv.) in dichloromethane (0.2 M) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated, and the residue obtained was purified by a flash-column chromatography to provide the corresponding linear substrate **12a-12m** as a colorless oil.

Synthetic Procedure for Preparation of Substrate **12n**.

*Synthesis of the alcohol **S8**:*

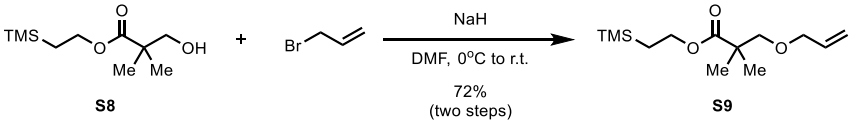


S8

4-Dimethylaminopyridine (2.40 g, 16.9 mmol, 2.0 equiv.) and 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (3.20 g, 16.9 mmol, 2.0 equiv.) were added in sequence to a solution of the 3-hydroxy-2,2-dimethylpropanoic acid (1.0 g, 8.45 mmol, 1.0 equiv.) and 2-(trimethylsilyl)ethanol (2.4 mL, 16.9 mmol, 2.0 equiv.) in dichloromethane (42 mL) at 23 °C. The reaction mixture was stirred at 23 °C for 15 hours. The product mixture was then diluted sequentially with dichloromethane (100 mL) and saturated aqueous ammonium chloride solution (50 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane (100 mL) and

washed with saturated aqueous sodium chloride solution (100 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The alcohol **S8** obtained in this way was used directly in the next step without further purification.

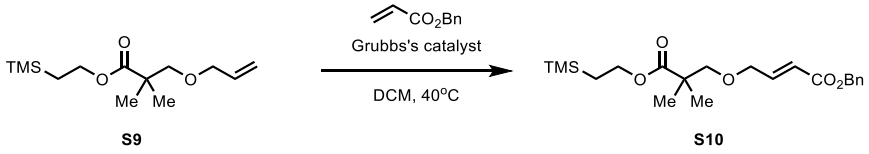
*Synthesis of the olefin **S9**:*



Sodium hydride (0.39 g, 10.2 mmol, 1.2 equiv.) was added to a solution of the alcohol **S8** (nominally, 8.45 mmol, 1.0 equiv.) in dimethylformamide (45 mL) at 0 °C. The reaction mixture was stirred at 0 °C for 30 min. Allyl bromide (1.10 ml, 15.7 mmol, 1.5 equiv.) was slowly added to the reaction mixture via syringe at 0 °C. The reaction mixture was allowed to slowly warm up to room temperature over 4 hours. The product mixture was then diluted sequentially with dichloromethane (100 mL) and saturated aqueous ammonium chloride solution (50 mL) and water (50 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane (100 mL) and the combined organic layer was sequentially washed with water (100 mL) and saturated aqueous sodium chloride solution (100 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography (eluting with 5% ethyl acetate–hexanes) to provide the olefin **S9** as a colorless oil (1.57 g, 72% over two steps).

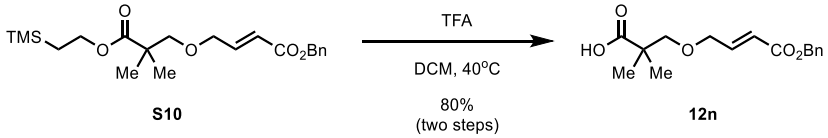
^{1}H NMR (600 MHz, $CDCl_3$): δ 5.98 – 5.71 (m, 1H), 5.24 (dt, *J* = 17.3, 1.7 Hz, 1H), 5.14 (dt, *J* = 10.4, 1.6 Hz, 1H), 4.28 – 4.07 (m, 2H), 3.97 (dt, *J* = 5.5, 1.5 Hz, 2H), 3.42 (s, 2H), 1.18 (s, 6H), 1.05 – 0.84 (m, 2H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 176.9, 135.1, 116.7, 77.1, 72.4, 62.9, 43.6, 22.7, 17.4, -1.2. HRMS (ESI-TOF) Calcd for $C_{13}H_{26}NaO_3Si^+$ $[M+Na]^+$: 281.1549, found: 281.1547.

*Synthesis of the acrylate **S10**:*



Hoveyda–Grubbs-II catalyst (50.0 mg, 0.097 mmol, 5 mol%) was added to a solution of the olefin **S9** (0.5 g, 1.94 mmol, 1.0 equiv.) and acrylate (0.44 mL, 2.90 mmol, 1.5 equiv.) in dichloromethane (8.0 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated, and the residue obtained was the acrylate **S10** obtained in this way was used directly in the next step without further purification.

*Synthesis of the substrate **12n**:*

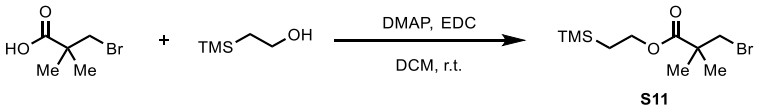


Trifluoroacetic acid (0.96 mL, 12.6 mmol, 6.5 equiv.) was added to a solution of the acrylate **S10** (nominally, 1.94 mmol, 1.0 equiv.) in dichloromethane (9.7 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated, and the residue obtained was purified by a flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide the corresponding linear substrate **12n** as a colorless oil (0.45 g, 80% over two steps).

Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.43 – 7.29 (m, 5H), 6.97 (dt, *J* = 15.7, 4.2 Hz, 1H), 6.11 (dt, *J* = 15.7, 2.1 Hz, 1H), 5.19 (s, 2H), 4.16 (dd, *J* = 4.2, 2.1 Hz, 2H), 3.49 (s, 2H), 1.23 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 181.5, 166.2, 144.9, 136.1, 128.7, 128.4, 128.4, 121.1, 77.4, 70.2, 66.4, 43.5, 22.4. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_5^-$ [M-H]$^-$: 291.1232, found: 291.1231

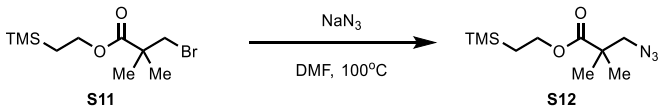
Synthetic Procedure for Preparation of Substrate **12*o***.

*Synthesis of the ester **S11**:*



4-Dimethylaminopyridine (4.0 g, 33.1 mmol, 2.0 equiv.) and 1-Ethyl-3-(3-dimethylaminopropyl)carbodiimide (6.30 g, 33.1 mmol, 2.0 equiv.) were added in sequence to a solution of the 3-bromo-2,2-dimethylpropanoic acid (3.0 g, 16.6 mmol, 1.0 equiv.) and 2-(trimethylsilyl)ethanol (4.71 mL, 33.14 mmol, 2.0 equiv.) in dichloromethane (82 mL) at 23 °C. The reaction mixture was stirred at 23 °C for 15 hours. The product mixture was then diluted sequentially with dichloromethane (100 mL) and saturated aqueous ammonium chloride solution (100 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane (100 mL) and washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The ester **S11** obtained in this way was used directly in the next step without further purification.

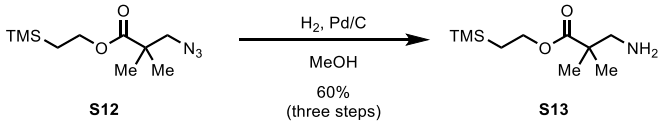
*Synthesis of the azide **S12**:*



Sodium azide (2.15 g, 33.2 mmol, 2.0 equiv.) was added to a solution of the ester **S11** (nominally, 16.6 mmol, 1.0 equiv.) in dimethylformamide (82 mL) at 23 °C. The reaction mixture was

subsequently placed in an oil bath that had been preheated to 100 °C. The reaction mixture was stirred at 100 °C for 15 hours. The product mixture was then allowed to cool to 23 °C over 30 min. The cooled product mixture was then diluted sequentially with dichloromethane (100 mL) and saturated aqueous ammonium chloride solution (100 mL) and water (50 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane (100 mL). The combined organic layers were subsequently washed with water (100 mL) and with saturated aqueous sodium chloride solution (100 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The azide **S12** obtained in this way was used directly in the next step without further purification.

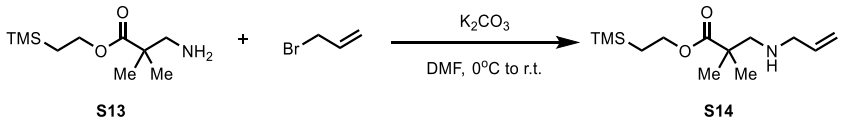
*Synthesis of the free amine **S13**:*



Palladium on carbon (370 mg) was added to a solution of the azide **S12** (nominally, 16.6 mmol, 1 equiv.) in methanol (82 mL) at 23 °C. The reaction vessel was then purged with dihydrogen and placed then pressurized to 1 atm via a hydrogen filled balloon. The reaction mixture was stirred for 15 hours at 23 °C. The reaction vessel was then slowly vented, and the product mixture was diluted with ethyl acetate (20 mL) and the diluted solution was filtered through a pad of Celite. The filtrate was concentrated, and the residue obtained purified by a flash-column chromatography (eluting with 10% methanol–ethyl acetate) to provide the amine **S13** as a colorless oil (2.10 g, 60% over three steps).

^{1}H NMR (600 MHz, $CDCl_3$) δ 4.34 – 4.00 (m, 2H), 2.74 (s, 2H), 1.39 (s, 2H), 1.16 (s, 6H), 1.04 – 0.88 (m, 2H), 0.05 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.6, 62.9, 51.7, 44.6, 23.1, 17.5, -1.2. HRMS (ESI-TOF) Calcd for $C_{10}H_{24}NO_2Si^+$ $[M+H]^+$: 218.1576, found: 218.1573

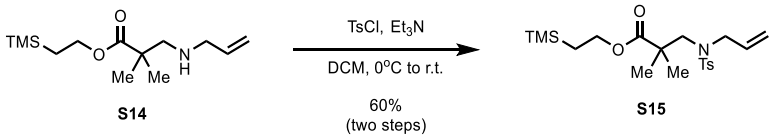
*Synthesis of the allyl amine **S14**:*



Potassium carbonate (2.0 g, 14.5 mmol, 30 equiv.) was added to a solution of the free amine **S13** (1.05 g, 4.83 mmol, 1.0 equiv.) in acetonitrile (25 mL) at 0 °C. The reaction mixture was stirred at 0 °C for 30 min. Allyl bromide (0.50 ml, 5.8 mmol, 1.2 equiv.) was slowly added to the reaction mixture via syringe at 0 °C. The reaction mixture was allowed to slowly warm up to room temperature over 6 hours. The product mixture was then diluted sequentially with ethyl acetate (50 mL) and saturated aqueous ammonium chloride solution (30 mL) and water (50 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate (50 mL) and the combined organic layer was sequentially washed with saturated aqueous sodium chloride solution (50 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was

concentrated. The allyl amine **S14** obtained in this way was used directly in the next step without further purification.

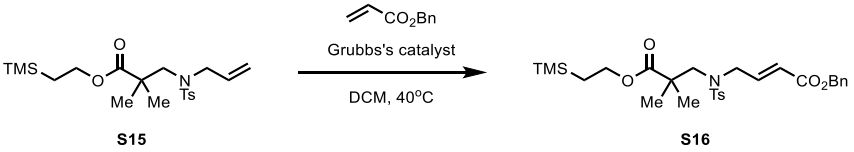
*Synthesis of the tosyl protected amine **S15**:*



p-Methylbenzenesulfonyl chloride (1.37 g, 7.30 mmol, 1.5 equiv.) was added to a solution of the allyl amine **S14** (nominally, 4.83 mmol, 1.0 equiv.) and triethylamine (1.70 mL, 12.1 mmol, 2.5 equiv.) in dichloromethane (26 mL) at 0 °C. The reaction mixture was stirred at 0 °C for 1 hour and then at 23 °C for 2 hours. The product mixture was then diluted sequentially with dichloromethane (50 mL) and saturated aqueous ammonium chloride solution (300 mL). The diluted product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with dichloromethane (50 mL) and washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The filtrate was concentrated, and the residue obtained purified by a flash-column chromatography (eluting with 10% ethyl acetate–hexanes) to provide the tosyl amine **S15** as a colorless oil (1.20 g, 60% over two steps).

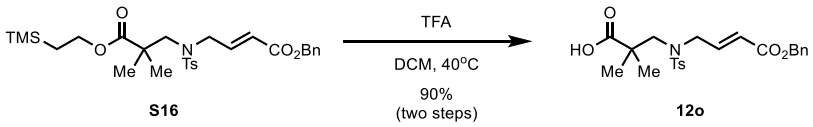
^{1}H NMR (600 MHz, $CDCl_3$) δ 7.85 – 7.54 (m, 2H), 7.29 (dt, *J* = 7.9, 0.8 Hz, 2H), 5.45 (ddt, *J* = 17.5, 9.9, 6.3 Hz, 1H), 5.20 – 4.91 (m, 2H), 4.29 – 3.95 (m, 2H), 3.74 (dd, *J* = 6.3, 1.4 Hz, 2H), 3.38 (s, 2H), 2.42 (s, 3H), 1.24 (s, 6H), 1.04 – 0.86 (m, 2H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.2, 143.5, 137.3, 133.0, 129.9, 127.6, 119.0, 63.3, 55.1, 51.9, 43.4, 24.0, 21.7, 17.5, -1.3. HRMS (ESI-TOF) Calcd for $C_{20}H_{33}NNaO_4SSi^+$ $[M+Na]^+$: 434.1797, found: 434.1794

*Synthesis of the acrylate **S16**:*



Hoveyda–Grubbs-II catalyst (80.0 mg, 0.097 mmol, 5 mol%) was added to a solution of the tosyl amine **S15** (0.60 g, 1.92 mmol, 1.0 equiv.) and acrylate (0.44 mL, 2.90 mmol, 1.5 equiv.) in dichloromethane (8.0 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated, and the residue obtained was the acrylate **S16** obtained in this way was used directly in the next step without further purification.

*Synthesis of the substrate **12o**:*

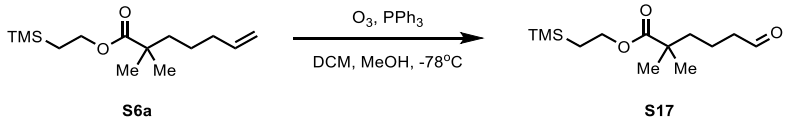


Trifluoroacetic acid (0.96 mL, 12.5 mmol, 6.5 equiv.) was added to a solution of the acrylate **S16** (nominally, 1.92 mmol, 1.0 equiv.) in dichloromethane (10 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30 min. The cooled product mixture was concentrated, and the residue obtained was purified by a flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide the corresponding linear substrate **12o** as a colorless oil (0.77 g, 90% over two steps).

Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.69 – 7.64 (m, 2H), 7.42 – 7.30 (m, 5H), 7.28 – 7.26 (m, 2H), 6.62 (dt, *J* = 15.7, 6.0 Hz, 1H), 5.84 (dt, *J* = 15.7, 1.6 Hz, 1H), 5.12 (s, 2H), 3.90 (dd, *J* = 6.0, 1.7 Hz, 2H), 3.37 (s, 2H), 2.38 (s, 3H), 1.26 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.2, 165.6, 144.0, 143.2, 136.4, 135.9, 130.0, 128.7, 128.4, 128.3, 127.5, 123.9, 66.5, 56.3, 50.5, 43.4, 23.8, 21.7. HRMS (ESI-TOF) Calcd for $C_{23}H_{26}NO_6S^-$ [M-H]$^-$: 444.1481, found: 444.1482

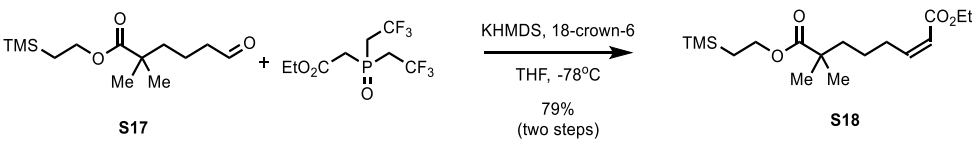
Synthetic Procedure for Preparation of (*Z*)-**10c**:

*Synthesis of the aldehyde **S17**:*



Ozone was passed through a solution of the olefin **S6a** (0.30 g, 1.16 mmol, 1 equiv.) in dichloromethane (30 mL) and methanol (4.0 mL) at –78 °C until a dark blue color persisted. Dioxygen was then passed through the solution to remove any unreacted ozone, resulting in a colorless solution. Triphenylphosphne (0.455 g, 1.74 mmol, 1.50 equiv.) was then added in one portion. The cooling bath was removed, and the mixture was allowed to warm to 23 °C over 1 hour. The warmed product mixture was concentrated and the residue obtained was flushed through a short pad of silica (eluting with 25% ethyl acetate–hexanes) to provide the aldehyde **S17** as a colorless oil that was used in the subsequent step without further purification.

*Synthesis of the (Z)-acrylate **S18**:*



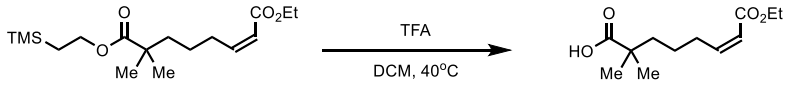
A solution of potassium bis(trimethylsilyl)amide (1.0M, 1.51 mL, 1.51 mmol, 1.30 equiv.) in was added via a syringe to a solution of ethyl 2-(bis(2,2,2-trifluoroethyl)phosphoryl)acetate (0.35 mL, 1.51 mmol, 1.3 equiv.) and 18-crown-6 (1.53 g, 5.81 mmol, 5.0 equiv.) in tetrahydrofuran (12 mL)

at –78 °C. The reaction mixture was stirred at –78 °C for 1 hour. The aldehyde **S17** (nominally, 1.16 mmol, 1.0 equiv.) in tetrahydrofuran (4.0 mL) was then added via syringe to the reaction mixture at –78 °C. The reaction mixture was stirred for –78 °C for 2 hours. The product mixture was then allowed warm to 23 °C over 30 min. The warmed product mixture was diluted sequentially with saturated aqueous ammonium chloride solution (20 mL), water (10 mL), and ethyl acetate (500 mL). The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The organic layer was washed with saturated aqueous sodium chloride solution (30 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by flash-column chromatography (eluting with 10% ether–hexanes) to furnish the (Z)-acrylate **S18** as a yellow oil (0.30 g, 79% over two steps).

^{1}H NMR (600 MHz) analysis of the unpurified product mixture indicated the presence of 19:1 (Z/E) mixture of isomers.

^{1}H NMR (600 MHz, $CDCl_3$) δ 6.18 (dt, *J* = 11.5, 7.4 Hz, 1H), 5.76 (d, *J* = 11.5 Hz, 1H), 4.35 – 3.96 (m, 4H), 2.63 (qd, *J* = 7.4, 1.8 Hz, 2H), 1.57 – 1.51 (m, 2H), 1.42 – 1.33 (m, 2H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.15 (s, 6H), 1.05 – 0.90 (m, 2H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.2, 166.6, 150.1, 120.2, 62.7, 59.9, 42.2, 40.4, 29.4, 25.3, 24.6, 17.4, 14.4, -1.1. HRMS (ESI-TOF) Calcd for $C_{17}H_{32}NaO_4Si^+$ $[M+Na]^+$: 351.1968, found: 351.1968

*Synthesis of the (Z)-***10c***:*

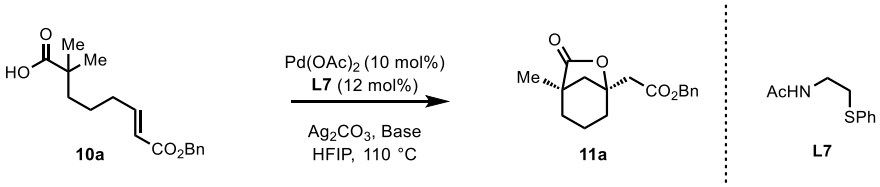


Trifluoroacetic acid (0.42 mL, 5.84 mmol, 6.5 equiv.) was added to a solution of the (Z)-acrylate **S18** (0.30 g, 0.914 mmol, 1.0 equiv.) in dichloromethane (4 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated and the residue obtained was purified by a flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide the corresponding linear substrate (*Z*)-**10c** as a colorless oil (0.20 g, 95%).

Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.19 (dt, *J* = 11.5, 7.5 Hz, 1H), 5.77 (dt, *J* = 11.5, 1.7 Hz, 1H), 4.16 (q, *J* = 7.1 Hz, 2H), 2.65 (qd, *J* = 7.4, 1.8 Hz, 2H), 1.65 – 1.54 (m, 2H), 1.50 – 1.37 (m, 2H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.20 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.0, 166.6, 149.9, 120.3, 60.0, 42.2, 40.1, 29.3, 25.1, 24.5, 14.4. HRMS (ESI-TOF) Calcd for $C_{12}H_{19}O_4^-$ $[M-H]^-$: 227.1283, found: 227.1282

Reaction Optimization Tables.

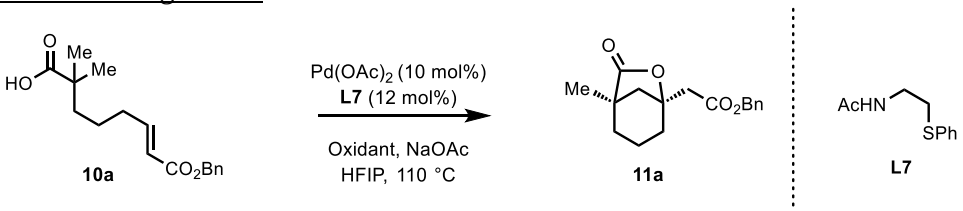
Table S1. Base Investigation.[a,b]



Entry	base	Yield
1	Li_2CO_3	62%
2	LiF	45%
3	NaOAc	87%
4	Na_2CO_3	74%
5	Na_2HPO_4	77%
6	$Na_2HPO_4 \cdot 7H_2O$	58%
7	K_2HPO_4	52%
8	$KHCO_3$	48%
9	CsOAc	63%

[a]Reaction conditions: substrate **10a** (0.1 mmol), $Pd(OAc)_2$ (10 mol%), ligand (12 mol%), base (1.0 equiv.), Ag_2CO_3 (2.0 equiv.), HFIP (1.0 mL), 110 °C, 15 h. [b]The yields were determined by ^1H NMR analysis of the crude product using dibromomethane as the internal standard.

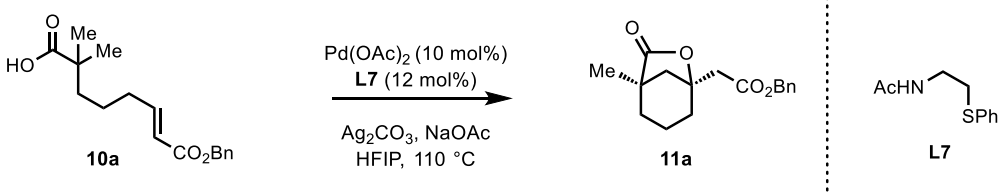
Table S2. Oxidant Investigation.[a,b]



Entry	Oxidant	Yield
1	Ag_2CO_3	87%
2	AgOAc	62%
3	Ag_2O	57%
4	AgTFA	trace
5	$Cu(OAc)_2$	21%
6	BQ	11%
7	$NaIO_4$	7%
8	TBHP (70% in water)	33%
9	$Na_2CO_3 \cdot 1.5H_2O_2$	13%

[a]Reaction conditions: substrate **10a** (0.1 mmol), $Pd(OAc)_2$ (10 mol%), ligand (12 mol%), NaOAc (1.0 equiv.), Oxidant (2.0 equiv.),HFIP (1.0 mL), 110 °C, 15 h. [b]The yields were determined by ^1H NMR analysis of the crude product using dibromomethane as the internal standard.

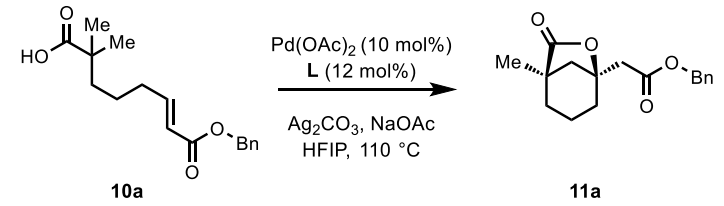
Table S3. Palladium source and loading Investigation.[a,b]

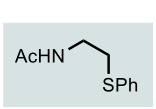


Entry	Deviation from standard conditions	Yield
1	none	87%
2	$Pd(TFA)_2$ instead of $Pd(OAc)_2$	50%
3	$Pd(PhCN)_2Cl_2$ instead of $Pd(OAc)_2$	80%
4	$Pd(MeCN)_2Cl_2$ instead of $Pd(OAc)_2$	76%
5	5 mol% $Pd(OAc)_2$ instead of 10 mol% $Pd(OAc)_2$	66%
6	3 mol% Pd(OAc)2 instead of 10 mol% Pd(OAc)2	32%

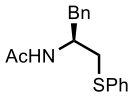
[a]Reaction conditions: substrate **10a** (0.1 mmol), $Pd(OAc)_2$ (10 mol%), ligand (12 mol%), NaOAc (1.0 equiv.), Ag_2CO_3 (2.0 equiv.), HFIP (1.0 mL), 110 °C, 15 h. [b]The yields were determined by ^1H NMR analysis of the crude product using dibromomethane as the internal standard.

Table S4. Investigation of the substitution effects around the thioether ligand..[a,b]

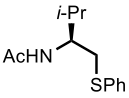




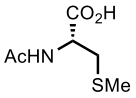
L7, 86%



L9, 65%;
(ee 6%)



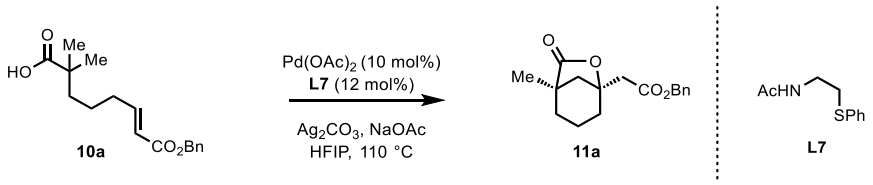
L10, 52%;
(ee 8%)



L11, 21%

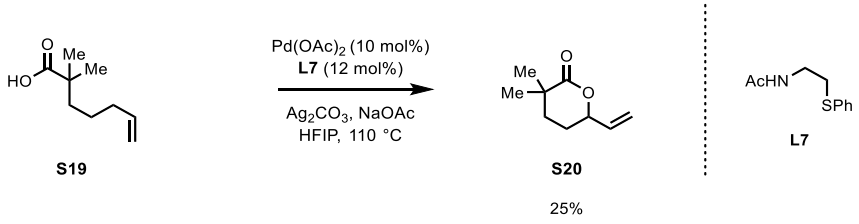
[a]Reaction conditions: substrate **10a** (0.1 mmol), $Pd(OAc)_2$ (10 mol%), ligand (12 mol%), NaOAc (1.0 equiv.), Ag_2CO_3 (2.0 equiv.), HFIP (1.0 mL), 110 °C, 15 h. [b]The yields were determined by ^1H NMR analysis of the crude product using dibromomethane as the internal standard.

General Reaction Procedure for the Synthesis of Bicyclo[3.2.1] Lactones.



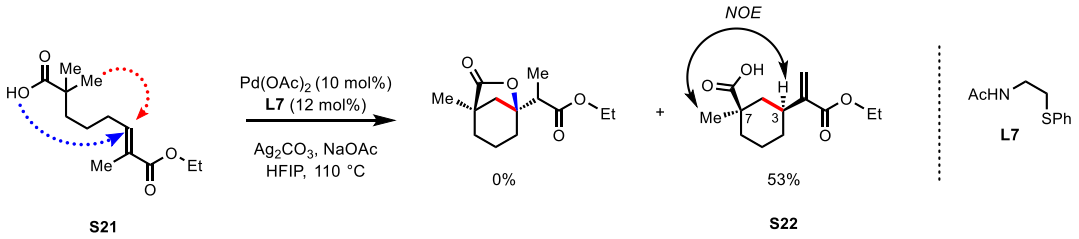
General procedure C: A screw-capped culture tube was sequentially charged with $Pd(OAc)_2$ (2.20 mg, 10.0 μmol, 0.10 equiv.), ligand (**L7**) (2.30 mg, 12.0 μmol, 0.12 equiv.), sodium acetate (8.20 mg, 0.10 mmol, 1.0 equiv.), silver carbonate (55.2 mg, 0.2 mmol, 2.0 equiv.), the free carboxylic acid **10** or **12** (0.1 mmol, 1.0 equiv.), and HFIP (1.0 mL) at 23 °C. The reaction vessel was sealed, and the mixture was allowed to stir for 10 min at 23 °C. The reaction vessel was then placed into a heat block that had been preheated to 110 °C. The reaction mixture was allowed to stir for 15 hours at 110 °C. After being allowed to cool to room temperature, the product mixture was diluted with DCM and filtered through a pad of Celite. The filtrate was concentrated and the residue obtained was purified by flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide the desired bicyclo[3.2.1] lactone product **11** or **13**.

Reaction Procedure for the Side Reaction through Allylic C-H functionalization



A screw-capped culture tube was sequentially charged with $Pd(OAc)_2$ (2.20 mg, 10.0 μmol, 0.10 equiv.), ligand (**L7**) (2.30 mg, 12.0 μmol, 0.12 equiv.), sodium acetate (8.20 mg, 0.10mmol, 1.0 equiv.), silver carbonate (55.2 mg, 0.2 mmol, 2.0 equiv.), the free carboxylic acid **S19** (15.6 mg, 0.1 mmol, 1.0 equiv.), and HFIP (1.0 mL) at 23 °C. The reaction vessel was sealed, and the mixture was allowed to stir for 10 min at 23 °C. The reaction vessel was then placed into a heat block that had been preheated to 110 °C. The reaction mixture was allowed to stir for 15 hours at 110 °C. After being allowed to cool to room temperature, the product mixture was diluted with DCM and filtered through a pad of Celite. The filtrate was concentrated, and the residue obtained was purified by flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide 25% yield of the undesired allylic C-H functionalization product **S20.** (^{1}H NMR matched the previously reported data[2])

Reaction Procedure for the tri-substituted olefin substrate S21



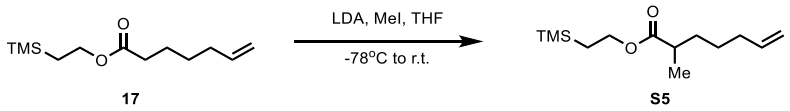
A screw-capped culture tube was sequentially charged with $Pd(OAc)_2$ (2.20 mg, 10.0 μmol, 0.10 equiv.), ligand (**L7**) (2.30 mg, 12.0 μmol, 0.12 equiv.), sodium acetate (8.20 mg, 0.10mmol, 1.0 equiv.), silver carbonate (55.2 mg, 0.2 mmol, 2.0 equiv.), the free carboxylic acid **S21** (24.2 mg, 0.1 mmol, 1.0 equiv.), and HFIP (1.0 mL) at 23 °C. The reaction vessel was sealed, and the mixture was allowed to stir for 10 min at 23 °C. The reaction vessel was then placed into a heat block that had been preheated to 110 °C. The reaction mixture was allowed to stir for 15 hours at 110 °C. After being allowed to cool to room temperature, the product mixture was diluted with DCM and filtered through a pad of Celite. The filtrate was concentrated, and the residue obtained was purified by flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide 53% yield of the unlactonized exocyclic unsaturated ester product **S22.**

The relative stereochemistry of the product **S22** was established by NOE analysis. Correlations between C3 hydrogen and C7 methyl substituent support the relative assignment shown.

^{1}H NMR (600 MHz, $CDCl_3$) δ 6.17 (s, 1H), 5.51 (d, J = 1.6 Hz, 1H), 4.21 (qd, J = 7.1, 1.5 Hz, 2H), 2.84 – 2.51 (m, 1H), 1.82 (dt, J = 10.1, 4.2 Hz, 2H), 1.77 – 1.69 (m, 2H), 1.68 – 1.48 (m, 3H), 1.32 (s, 3H), 1.30 (t, J = 7.1 Hz, 3H), 1.10 (qd, J = 12.6, 3.3 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.6, 167.3, 145.5, 122.8, 60.8, 42.6, 39.3, 33.7, 33.4, 31.7, 21.6, 20.1, 14.3.

Synthesis of the 6,6,5-Tricyclic Lactone 24.

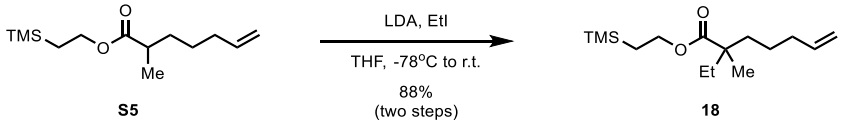
*Synthesis of the ester **S21**:*



17 **S5**

A solution of *n*-butyllithium in hexanes (2.50 M, 6.32 mL, 15.7 mmol, 1.20 equiv.) was added dropwise via syringe over 30 min to a solution of diisopropylamine (2.32 mL, 16.5 mmol, 1.25 equiv.) in tetrahydrofuran (66 mL) at –78 °C. The resulting solution was stirred for 45 min at –78 °C. A solution of the ester **17** (3.0 g, 13.2 mmol, 1.0 equiv.) in tetrahydrofuran (5.0 mL) was then added dropwise via syringe over 15 min at –78 °C. Upon completion of the addition, the reaction mixture was stirred for 1 hour at –78 °C. Iodomethane (1.23 mL, 19.8 mmol, 1.5equiv.) was then added dropwise via syringe at –78 °C. The reaction mixture was allowed to slowly warm to 23 °C overnight. The warmed product mixture was diluted sequentially with water (50 mL) and ethyl acetate (50 mL). The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate (50 mL). The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The ester **S5** obtained in this way used in the subsequent step without further purification.

*Synthesis of the doubly alkylated ester **18**:*

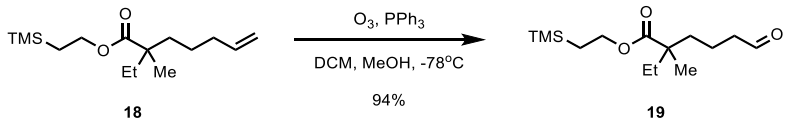


S5 **18**

A solution of *n*-butyllithium in hexanes (2.50 M, 6.32 mL, 15.7 mmol, 1.20 equiv.) was added dropwise via syringe over 30 min to a solution of diisopropylamine (2.32 mL, 16.5 mmol, 1.25 equiv.) in tetrahydrofuran (66 mL) at –78 °C. The resulting solution was stirred for 45 min at –78 °C. A solution of the ester **S5** (nominally, 13.2 mmol, 1.0 equiv.) in tetrahydrofuran (5.0 mL) was then added dropwise via syringe over 15 min at –78 °C. Upon completion of the addition, the reaction mixture was stirred for 1 hour at –78 °C. Ethyl iodide (1.60 mL, 19.8 mmol, 1.5 equiv.) was then added dropwise via syringe at –78 °C. The reaction mixture was allowed to slowly warm to 23 °C overnight. The warmed product mixture was diluted sequentially with water (50 mL) and ethyl acetate (50 mL). The resulting biphasic mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate (50 mL). The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution. The washed organic layer was dried over sodium sulfate. The dried solution was filtered and the filtrate was concentrated. The residue obtained was purified by flash column chromatography (eluting with 4 % ethyl acetate–hexanes) to provide the doubly alkylated ester **18** as a colorless oil (3.14 g, 88% over two steps).

^{1}H NMR (600 MHz, $CDCl_3$) δ 5.78 (ddt, *J* = 16.9, 10.2, 6.6 Hz, 1H), 5.09 – 4.80 (m, 2H), 4.26 – 4.02 (m, 2H), 2.05 – 1.96 (m, 2H), 1.70 – 1.62 (m, 2H), 1.48 – 1.29 (m, 3H), 1.30 – 1.18 (m, 1H), 1.09 (s, 3H), 1.01 – 0.93 (m, 2H), 0.81 (t, *J* = 7.5 Hz, 3H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.6, 138.7, 114.7, 62.4, 46.2, 38.6, 34.4, 32.1, 24.1, 20.7, 17.5, 9.1, -1.4. HRMS (ESI-TOF) Calcd for $C_{15}H_{31}O_2Si^+$ $[M+H]^+$: 271.2093, found: 271.2091

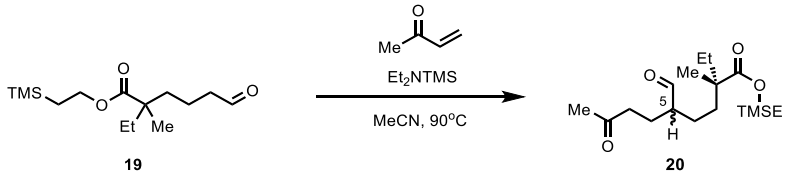
*Synthesis of the aldehyde **19**:*



Ozone was passed through a solution of the olefin **18** (3.0g g, 11.1 mmol, 1 equiv.) in dichloromethane (150 mL) and methanol (20 mL) at –78 °C until a dark blue color persisted. Dioxygen was then passed through the solution to remove any unreacted ozone, resulting in a colorless solution. Triphenylphosphine (4.38 g, 16.7 mmol, 1.50 equiv.) was then added in one portion. The cooling bath was removed, and the mixture was allowed to warm to 23 °C over 1 hour. The warmed product mixture was concentrated, and the residue obtained was flushed through a short pad of silica (eluting with 15% ethyl acetate–hexanes) to provide the aldehyde **19** as a colorless oil (2.84 g, 94%).

^{1}H NMR (600 MHz, $CDCl_3$) δ 9.75 (t, *J* = 1.7 Hz, 1H), 4.30 – 3.91 (m, 2H), 2.41 (tq, *J* = 6.3, 2.0 Hz, 2H), 1.70 – 1.59 (m, 3H), 1.53 – 1.37 (m, 3H), 1.12 (s, 3H), 1.03 – 0.94 (m, 2H), 0.82 (t, *J* = 7.5 Hz, 3H), 0.05 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 202.5, 177.4, 62.7, 46.2, 44.4, 38.2, 32.1, 20.9, 17.6, 17.5, 9.0, -1.4. HRMS (ESI-TOF) Calcd for $C_{14}H_{29}O_3Si^+$ $[M+H]^+$: 273.1886, found: 273.1887

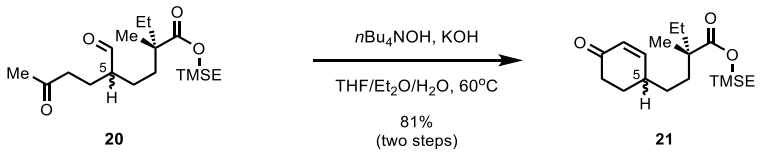
*Synthesis of the Michael adduct **20**:*



Diethylamino(trimethyl)silane (0.35 mL, 1.84 mmol, 0.2 equiv.) was added to a solution of the aldehyde **19** (2.50 g, 9.18 mmol, 1.0 equiv.) and methyl vinyl ketone (1.15 mL, 13.8 mmol, 1.5 equiv.) in acetonitrile (466 mL) at 23 °C. The reaction flask was equipped with a reflux condenser and placed into an oil bath that had been preheated to 90 °C. The reaction was stirred at 90 °C for 48 hours. The product mixture was allowed to cool to 23 °C over 30 min. The cooled product mixture concentrated to provide the Michael adduct **20** that was used in the subsequent step without further purification.

^{1}H NMR (600 MHz) analysis of the unpurified product mixture indicated the presence of 1:1 mixture of diastereomer at the C5 position of product **20**.

*Synthesis of the unsaturated enone **21**:*

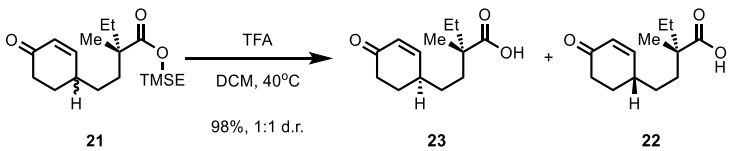


Potassium hydroxide (0.1 M, 88.3 mL, 8.83 mmol, 0.9 equiv.) was added to a solution of the Michael adduct **20** (nominally, 9.18 mmol, 1.0 equiv.) and tetrabutylammonium hydroxide (40% aqueous, 150 mL) in mixture of tetrahydrofuran (120 mL), diethyl ether (40 mL), and water (40 mL) at 23 °C. The reaction flask was equipped with a reflux condenser and placed into an oil bath that had been preheated to 60 °C. The reaction was stirred at 60 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30 min. The cooled resulting biphasic product mixture was transferred to a separatory funnel and the layers that formed were separated. The aqueous layer was extracted with ethyl acetate (2 × 100 mL). The organic layers were combined, and the combined organic layers were washed with saturated aqueous sodium chloride solution (100 mL). The washed organic layer was dried over sodium sulfate. The dried solution was filtered, and the filtrate was concentrated. The residue obtained was purified by flash column chromatography (eluting with 10 % ethyl acetate–hexanes) to provide the unsaturated ketone **21**, as an inseparable mixture of C5 diastereomers (2.40 g, 81% over two steps).

^{1}H NMR (600 MHz) analysis of the unpurified product mixture indicated the presence of 1:1 mixture of diastereomers at the C5 position.

^{1}H NMR (600 MHz, $CDCl_3$) δ 6.83 (dtd, *J* = 10.2, 2.5, 1.4 Hz, 1H), 5.96 (ddt, *J* = 10.2, 2.5, 0.9 Hz, 1H), 4.36 – 3.95 (m, 2H), 2.54 – 2.43 (m, 1H), 2.39 – 2.27 (m, 2H), 2.10 (dddd, *J* = 13.7, 6.3, 5.1, 3.9 Hz, 1H), 1.82 – 1.56 (m, 3H), 1.54 – 1.32 (m, 4H), 1.11 (s, 3H), 1.00 – 0.93 (m, 2H), 0.83 (t, *J* = 7.5 Hz, 3H), 0.04 (s, 9H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 199.9, 177.4, 154.9, 154.8, 129.3, 129.3, 62.7, 46.1, 46.1, 37.1, 37.0, 36.6, 36.6, 36.1, 36.0, 32.2, 32.1, 29.7, 29.6, 28.7, 28.7, 20.9, 20.9, 17.6, 9.0, 9.0, -1.4. HRMS (ESI-TOF) Calcd for $C_{18}H_{32}NaO_3Si^+$ $[M+Na]^+$: 347.2018, found: 347.2019

*Synthesis of the annulation precursor **23**:*



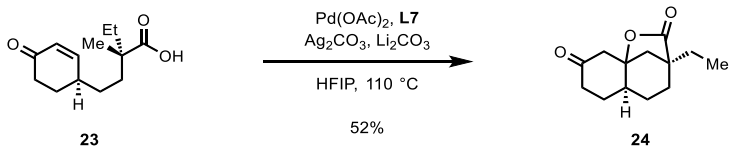
Trifluoroacetic acid (3.0 mL, 39.8 mmol, 6.5 equiv.) was added to a solution of the unsaturated ketone **21** (2.0 g, 6.12 mmol, 1.0 equiv.) in dichloromethane (31 mL) at 23 °C. The reaction mixture was subsequently placed in an oil bath that had been preheated to 40 °C. The reaction

mixture was stirred at 40 °C for 15 hours. The product mixture was allowed to cool to 23 °C over 30min. The cooled product mixture was concentrated and the residue obtained was purified by a flash-column chromatography (eluting with 20% ethyl acetate–hexanes) to provide the corresponding linear substrate **23** and **22** as a colorless oils (combined mass 1.34 g, combined 98%; ^{1}H NMR analysis of the purified product mixture indicated the presence of 1:1 mixture of diastereomers)To obtain analytically pure samples of **23** and **22**, the two diastereomers were separated using supercritical fluid chromatography.

23: ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.85 (dd, *J* = 10.1, 2.3 Hz, 1H), 5.98 (dd, *J* = 10.1, 2.4 Hz, 1H), 2.49 (dt, *J* = 16.9, 4.8 Hz, 1H), 2.41 – 2.28 (m, 2H), 2.10 (dt, *J* = 10.3, 4.6 Hz, 1H), 1.80 – 1.62 (m, 3H), 1.61 – 1.43 (m, 3H), 1.37 (ddt, *J* = 14.7, 11.3, 4.8 Hz, 1H), 1.15 (s, 3H), 0.88 (t, *J* = 7.4 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 200.1, 183.5, 154.9, 129.3, 46.1, 37.0, 36.5, 35.6, 31.9, 29.5, 28.6, 20.8, 9.0. HRMS (ESI-TOF) Calcd for $C_{13}H_{19}O_3^-$ [M-H]$^-$: 223.1334, found: 223.1332

22: ^{1}H NMR (600 MHz, Chloroform-d) δ 6.85 (ddd, *J* = 10.1, 2.7, 1.4 Hz, 1H), 5.99 (ddd, *J* = 10.2, 2.5, 0.8 Hz, 1H), 2.50 (dddd, *J* = 16.8, 5.1, 4.3, 0.9 Hz, 1H), 2.40 – 2.29 (m, 2H), 2.12 (dqd, *J* = 13.3, 4.9, 1.5 Hz, 1H), 1.87 – 1.63 (m, 3H), 1.59 – 1.49 (m, 2H), 1.49 – 1.39 (m, 2H), 1.16 (s, 3H), 0.89 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 200.0, 182.9, 154.8, 129.3, 46.1, 37.1, 36.6, 35.7, 31.9, 29.6, 28.7, 20.8, 9.0. HRMS (ESI-TOF) Calcd for $C_{13}H_{19}O_3^-$ [M-H]$^-$: 223.1334, found: 223.1336

*Synthesis of the 6,6,5-Tricyclic Lactone **24** via Tandem Intramolecular β-C(sp^3)–H Olefination and Lactonization:*



A screw-capped culture tube was sequentially charged with $Pd(OAc)_2$ (4.50 mg, 20.0 μmol, 0.20 equiv.), ligand (**L7**) (4.70 mg, 24.0 μmol, 0.24 equiv.), lithium carbonate (14.8 mg, 0.20 mmol, 2.0 equiv.), silver carbonate (55.2 mg, 0.2 mmol, 2.0 equiv.), the free carboxylic acid annulation precursor **23** (22.4 mg, 0.1 mmol, 1.0 equiv.), and HFIP (1.0 mL) at 23 °C. The reaction vessel was sealed, and the mixture was allowed to stir for 10 min at 23 °C. The reaction vessel was then placed into a heat block that had been preheated to 110 °C. The reaction mixture was allowed to stir for 15 hours at 110 °C. After being allowed to cool to room temperature, the product mixture was diluted with DCM and filtered through a short pad of celite. The filtrate was concentrated, and the residue obtained was purified by flash-column chromatography (eluting with 2% methanol–dichloromethane) to provide the desired 6,6,5-tricyclic lactone **24** as a colorless oil (11.6 mg, 52%).

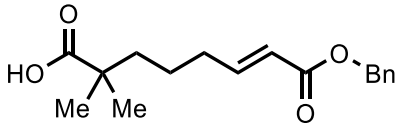
^{1}H NMR (600 MHz, $CDCl_3$) δ 2.65 – 2.54 (m, 2H), 2.47 (ddt, *J* = 14.7, 4.3, 2.3 Hz, 1H), 2.38 – 2.29 (m, 1H), 2.07 – 1.87 (m, 4H), 1.79 (d, *J* = 11.5 Hz, 1H), 1.75 – 1.57 (m, 5H), 1.44 – 1.33 (m, 1H), 0.91 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 206.5, 179.1, 85.4, 49.7, 47.9, 46.1, 40.4, 39.0, 32.4, 28.8, 26.7, 26.7, 8.8. HRMS (ESI-TOF) Calcd for $C_{13}H_{19}O_3^+$ [M+H]$^+$: 223.1334, found: 223.1337

References:

[1] Wang, Z.; Wu, J.; Lamine, W.; Li, B.; Sotiropoulos, J.-M.; Chrostowska, A.; Miqueu, K.; Liu, S.-Y., C–Boron Enolates Enable Palladium Catalyzed Carboboration ofInternal 1,3-Enynes. *Angew. Chem. Int. Ed.* **2021**, *60*, 21231–21236.
[2] Bischop, M.; Pietruszka, J., Synthesis of Vinyllactones via Allylic Oxidation of Alkenoic Acids. *Synlett* **2011**, *18*, 2689-2692.

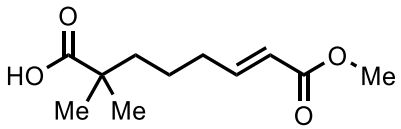
Characterization of Substrates and Products.

Substrate:



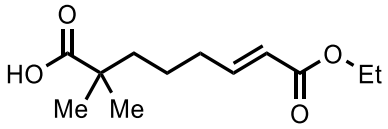
10a

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 – 7.28 (m, 5H), 7.00 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.6 Hz, 1H), 5.18 (s, 2H), 2.20 (qd, *J* = 7.2, 1.6 Hz, 2H), 1.68 – 1.50 (m, 2H), 1.46 (tdd, *J* = 9.7, 7.2, 4.5 Hz, 2H), 1.20 (s, 6H).^{13}C NMR (151 MHz, $CDCl_3$) δ 184.2, 166.6, 149.5, 136.2, 128.7, 128.3, 128.3, 121.4, 66.2, 42.2, 40.0, 32.7, 25.1, 23.5. HRMS (ESI-TOF) Calcd for $C_{17}H_{21}O_4^-$ [M-H]$^-$: 289.1440, found: 289.1432



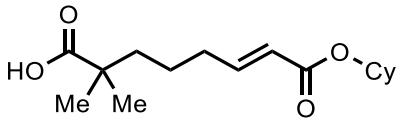
10b

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.95 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.83 (dt, *J* = 15.7 Hz, 1.6 Hz, 1H), 3.73 (s, 3H), 2.24 – 2.14 (m, 2H), 1.63 – 1.52 (m, 2H), 1.47 (ddd, *J* = 9.2, 7.2, 5.8 Hz, 2H), 1.20 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.4, 167.2, 149.1, 121.4, 51.6, 42.1, 40.0, 32.6, 25.1, 23.5. HRMS (ESI-TOF) Calcd for $C_{11}H_{17}O_4^-$ [M-H]$^-$: 213.1127, found: 213.1123



10c

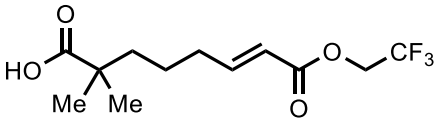
Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.93 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.82 (dt, *J* = 15.7 Hz, 1.6Hz, 1H), 4.18 (q, *J* = 7.1 Hz, 2H), 2.19 (qd, *J* = 7.2, 1.6 Hz, 2H), 1.67 – 1.50 (m, 2H), 1.46 (ddd, *J* = 9.2, 7.3, 5.8 Hz, 2H), 1.28 (t, *J* = 7.1 Hz, 3H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.5, 166.8, 148.8, 121.8, 60.3, 42.2, 40.0, 32.6, 25.1, 23.5, 14.4.HRMS (ESI-TOF) Calcd for $C_{12}H_{19}O_4^-$ [M-H]$^-$: 227.1283, found: 227.1278



10d

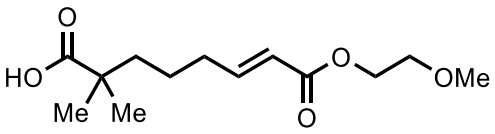
Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.20 (s, 1H), 6.93 (dt, *J* = 15.6, 6.8 Hz, 1H), 5.81 (dt, *J* = 15.6, 1.6 Hz, 1H), 4.81 (tt, *J* = 9.2, 3.9 Hz, 1H),

2.19 (qd, *J* = 7.3, 1.6 Hz, 2H), 2.00 – 1.80 (m, 2H), 1.79 – 1.67 (m, 2H), 1.64 – 1.50 (m, 3H), 1.52 – 1.32 (m, 6H), 1.31 – 1.23 (m, 1H), 1.20 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.3, 166.4, 148.5, 122.2, 72.7, 72.6, 42.2, 40.0, 32.6, 32.6, 32.6, 31.8, 31.8, 25.6, 25.1, 23.9, 23.6. HRMS (ESI-TOF) Calcd for $C_{16}H_{25}O_4^-$ [M-H]$^-$: 281.1753, found: 281.1751



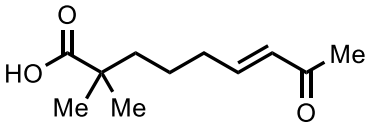
10e

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.08 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.89 (dt, *J* = 15.7, 1.6 Hz, 1H), 4.51 (q, *J* = 8.5 Hz, 2H), 2.24 (qd, *J* = 7.1, 1.6 Hz, 2H), 1.65 – 1.52 (m, 2H), 1.52 – 1.43 (m, 2H), 1.21 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.0, 164.8, 151.9, 151.9, 126.0, 124.1, 122.3, 120.5, 119.8, 60.7, 60.5, 60.2, 60.0, 42.2, 40.0, 32.8, 25.1, 23.4. HRMS (ESI-TOF) Calcd for $C_{12}H_{16}F_3O_4^-$ [M-H]$^-$: 281.1001, found: 281.0995



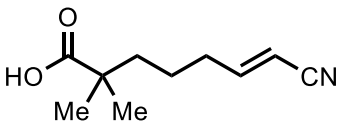
10f

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.98 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.87 (dt, *J* = 15.6, 1.6 Hz, 1H), 4.45 – 4.17 (m, 2H), 3.65 – 3.52 (m, 2H), 3.40 (s, 3H), 2.20 (qd, *J* = 7.2, 1.6 Hz, 2H), 1.61 – 1.52 (m, 2H), 1.50 – 1.40 (m, 2H), 1.20 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.4, 166.7, 149.5, 121.4, 70.7, 63.5, 59.2, 42.2, 40.0, 32.6, 25.1, 23.5. HRMS (ESI-TOF) Calcd for $C_{13}H_{21}O_5^-$ [M-H]$^-$: 257.1389, found: 257.1387



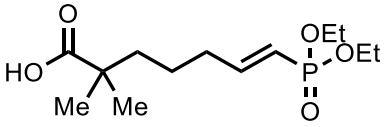
10g

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.78 (dt, *J* = 16.0, 6.8 Hz, 1H), 6.07 (dt, *J* = 15.9, 1.5 Hz, 1H), 2.24 (s, 3H), 2.21 (td, *J* = 7.1, 1.6 Hz, 2H), 1.59 – 1.52 (m, 2H), 1.51 – 1.42 (m, 2H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 199.0, 184.4, 148.0, 131.6, 42.2, 40.0, 32.9, 27.0, 25.1, 23.6. HRMS (ESI-TOF) Calcd for $C_{11}H_{17}O_3^-$ [M-H]$^-$: 197.1178, found: 197.1174



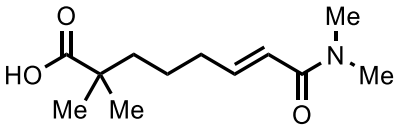
10h

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.70 (dt, *J* = 16.3, 6.9 Hz, 1H), 5.35 (dt, *J* = 16.4, 1.7 Hz, 1H), 2.23 (qd, *J* = 7.1, 1.7 Hz, 2H), 1.61 – 1.50 (m, 2H), 1.50 – 1.39 (m, 2H), 1.21 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.6, 155.5, 117.6, 100.3, 42.1, 39.7, 33.7, 25.2, 23.2. HRMS (ESI-TOF) Calcd for $C_{10}H_{14}NO_2^-$ [M-H]$^-$: 180.1025, found: 180.1021



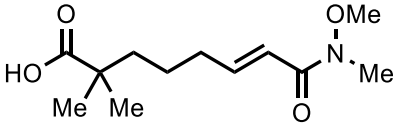
10i

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.77 (ddt, *J* = 22.1, 17.1 Hz, 6.5Hz, 1H), 5.65 (ddt, *J* = 21.2, 17.2, 1.6 Hz, 1H), 4.08 (dqd, *J* = 8.0, 7.1, 2.3 Hz, 4H), 2.22 (qt, *J* = 6.8, 1.9 Hz, 2H), 1.61 – 1.51 (m, 2H), 1.51 – 1.38 (m, 2H), 1.32 (td, *J* = 7.1, 0.5 Hz, 6H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.3, 153.7, 117.7, 116.5, 61.9, 61.9, 42.1, 40.0, 34.6, 34.5, 25.2, 23.4, 16.5, 16.5. HRMS (ESI-TOF) Calcd for $C_{13}H_{24}O_5P^-$ [M-H]$^-$: 291.1361, found: 291.1358



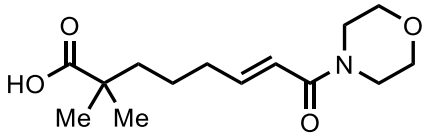
10j

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.85 (dt, *J* = 15.1, 6.9 Hz, 1H), 6.24 (dt, *J* = 15.1, 1.6 Hz, 1H), 3.07 (s, 3H), 3.00 (s, 3H), 2.19 (qd, *J* = 7.1, 1.5 Hz, 2H), 1.60 – 1.50 (m, 2H), 1.45 (tdd, *J* = 9.6, 7.2, 4.6 Hz, 2H), 1.18 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.1, 167.3, 146.2, 120.4, 42.1, 40.1, 37.6, 36.0, 32.9, 25.2, 23.9. HRMS (ESI-TOF) Calcd for $C_{12}H_{20}NO_3^-$ [M-H]$^-$: 226.1443, found: 226.1440



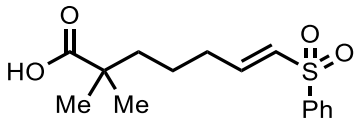
10k

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.95 (dt, *J* = 15.4, 7.0 Hz, 1H), 6.52 – 6.29 (m, 1H), 3.70 (s, 3H), 3.24 (s, 3H), 2.23 (qd, *J* = 7.2, 1.6 Hz, 2H), 1.70 – 1.51 (m, 2H), 1.52 – 1.35 (m, 2H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.7, 167.1, 147.5, 119.0, 61.8, 42.1, 40.1, 32.9, 32.5, 25.1, 23.8. HRMS (ESI-TOF) Calcd for Calcd for $C_{12}H_{20}NO_4^-$ [M-H]$^-$: 242.1392, found: 242.1396



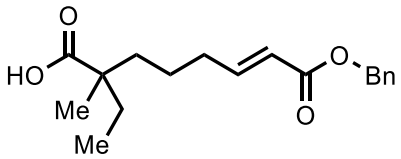
10l

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 6.88 (dt, *J* = 15.1, 6.9 Hz, 1H), 6.21 (dt, *J* = 15.1, 1.6 Hz, 1H), 3.69 (s, 6H), 3.56 (s, 2H), 2.21 (qd, *J* = 7.2, 1.6 Hz, 2H), 1.65 – 1.53 (m, 2H), 1.52 – 1.40 (m, 2H), 1.20 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 181.9, 165.8, 146.6, 119.7, 66.9, 46.1, 42.3, 42.0, 39.9, 32.8, 25.1, 23.6. HRMS (ESI-TOF) Calcd for $C_{14}H_{22}NO_4^-$ [M-H]$^-$: 268.1549, found: 268.1550



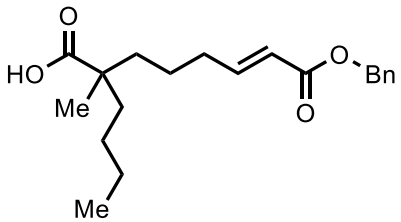
10m

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.88 (dd, *J* = 8.4, 1.3 Hz, 2H), 7.68 – 7.56 (m, 1H), 7.57 – 7.44 (m, 2H), 6.97 (dt, *J* = 15.1, 6.8 Hz, 1H), 6.33 (dt, *J* = 15.0, 1.6 Hz, 1H), 2.24 (qd, *J* = 7.1, 1.6 Hz, 2H), 1.59 – 1.51 (m, 2H), 1.47 (qd, *J* = 6.6, 6.1, 2.5 Hz, 2H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.9, 146.6, 140.8, 133.4, 130.9, 129.4, 127.8, 42.1, 39.8, 31.9, 25.1, 23.2. HRMS (ESI-TOF) Calcd for $C_{15}H_{19}O_4S^-$ [M-H]$^-$: 295.1004, found: 295.1001



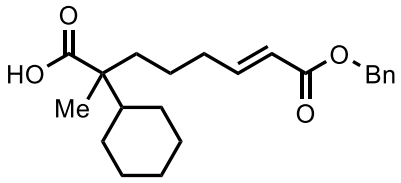
12a

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 – 7.27 (m, 5H), 7.00 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.6 Hz, 1H), 5.18 (s, 2H), 2.28 – 2.06 (m, 2H), 1.82 – 1.58 (m, 2H), 1.59 – 1.36 (m, 4H), 1.13 (s, 3H), 0.87 (t, *J* = 7.5 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.7, 166.6, 149.5, 136.2, 128.7, 128.3, 128.3, 121.4, 66.2, 46.1, 38.1, 32.7, 31.8, 23.2, 20.7, 9.0. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_4^-$ [M-H]$^-$: 303.1596, found: 303.1593



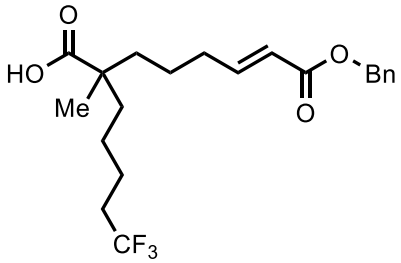
12b

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 9.81 (s, 1H), 7.43 – 7.29 (m, 5H), 7.00 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.18 (s, 2H), 2.20 (ddt, *J* = 8.2, 2.9, 1.6 Hz, 2H), 1.74 – 1.56 (m, 2H), 1.53 – 1.36 (m, 4H), 1.36 – 1.22 (m, 3H), 1.22 – 1.15 (m, 1H), 1.14 (s, 3H), 0.89 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.0, 166.6, 149.6, 136.2, 128.7, 128.3, 121.4, 121.4, 66.2, 45.8, 38.9, 38.5, 32.7, 26.7, 23.3, 23.2, 21.2, 14.1. HRMS (ESI-TOF) Calcd for $C_{20}H_{27}O_4^-$ [M-H]$^-$: 331.1909, found: 331.1904



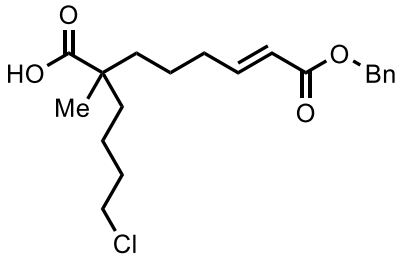
12c

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.46 – 7.28 (m, 5H), 6.99 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.87 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.18 (s, 2H), 2.19 (dtt, *J* = 20.3, 8.7, 6.9 Hz, 2H), 1.92 – 1.72 (m, 2H), 1.72 – 1.56 (m, 4H), 1.56 – 1.42 (m, 3H), 1.41 – 1.29 (m, 1H), 1.30 – 1.17 (m, 2H), 1.16 – 1.06 (m, 2H), 1.04 (s, 3H), 0.98 (td, *J* = 12.5, 3.4 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.7, 166.6, 149.6, 136.2, 128.7, 128.3, 128.3, 121.4, 66.2, 49.6, 45.5, 36.8, 32.8, 28.6, 27.1, 26.9, 26.9, 26.7, 23.4, 16.7. HRMS (ESI-TOF) Calcd for $C_{22}H_{29}O_4^-$ [M-H]$^-$: 357.2066, found: 357.2062



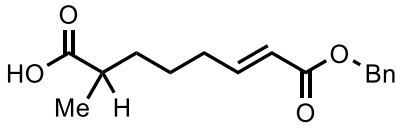
12d

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 – 7.29 (m, 5H), 6.99 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.6 Hz, 1H), 5.17 (s, 2H), 2.37 – 2.14 (m, 2H), 2.12 – 1.97 (m, 2H), 1.74 – 1.61 (m, 2H), 1.59 – 1.50 (m, 2H), 1.50 – 1.35 (m, 5H), 1.33 – 1.23 (m, 1H), 1.15 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.1, 166.5, 149.3, 136.2, 130.0, 128.7, 128.4, 128.3, 126.3, 124.5, 121.6, 120.0, 66.3, 45.6, 38.6, 38.6, 33.9, 33.7, 33.5, 33.4, 32.6, 23.8, 23.1, 22.4, 22.4, 22.4, 22.4, 21.2. HRMS (ESI-TOF) Calcd for $C_{21}H_{26}F_3O_4^-$ [M-H]$^-$: 399.1783, found: 399.1773



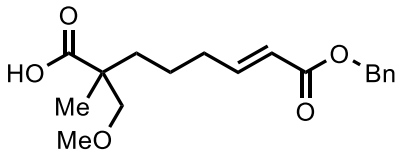
12e

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.43 – 7.28 (m, 5H), 6.99 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.7, 1.6 Hz, 1H), 5.17 (s, 2H), 3.53 (td, *J* = 6.6, 0.6 Hz, 2H), 2.20 (dddt, *J* = 9.8, 6.7, 4.7, 1.7 Hz, 2H), 1.85 – 1.70 (m, 2H), 1.68 – 1.59 (m, 2H), 1.54 – 1.30 (m, 6H), 1.16 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.0, 166.6, 149.4, 136.2, 128.7, 128.4, 128.3, 121.5, 66.2, 45.7, 44.8, 38.5, 38.2, 33.0, 32.7, 23.1, 22.0, 21.3. HRMS (ESI-TOF) Calcd for $C_{20}H_{26}ClO_4^-$ $[M-H]^-$: 365.1520, found: 365.1516



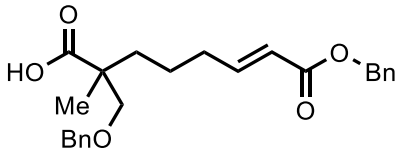
12f

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.48 – 7.28 (m, 5H), 6.99 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.7, 1.6 Hz, 1H), 5.17 (s, 2H), 2.60 – 2.38 (m, 1H), 2.22 (qd, *J* = 7.0, 1.6 Hz, 2H), 1.76 – 1.63 (m, 1H), 1.57 – 1.35 (m, 3H), 1.19 (d, *J* = 7.0 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.4, 166.6, 149.4, 136.2, 128.7, 128.3, 128.3, 121.5, 66.2, 39.3, 33.0, 32.2, 25.7, 17.0. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_4^-$ $[M-H]^-$: 275.1283, found: 275.1281



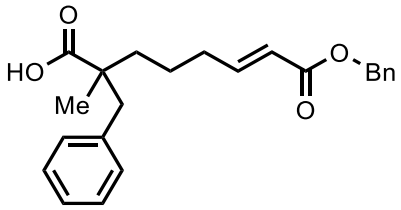
12g

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.44 – 7.29 (m, 5H), 6.98 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.6 Hz, 1H), 5.17 (s, 2H), 3.46 (d, *J* = 9.0 Hz, 1H), 3.37 (s, 3H), 3.39 – 3.34 (m, 1H), 2.20 (qt, *J* = 6.9, 1.8 Hz, 2H), 1.71 – 1.59 (m, 1H), 1.56 – 1.37 (m, 3H), 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.8, 166.5, 149.3, 136.3, 128.7, 128.4, 128.3, 121.5, 77.7, 66.2, 59.6, 46.8, 35.3, 32.7, 22.8, 19.8. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_5^-$ $[M-H]^-$: 319.1545, found: 319.1541



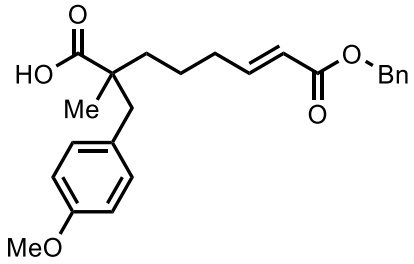
12h

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.27 (m, 10H), 6.96 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.86 (dt, *J* = 15.7 Hz, 1.6Hz, 1H), 5.17 (s, 2H), 4.54 (d, *J* = 1.8 Hz, 2H), 3.52 (d, *J* = 8.9 Hz, 1H), 3.44 (d, *J* = 8.9 Hz, 1H), 2.18 (dtdd, *J* = 8.4, 6.9, 2.8, 1.6 Hz, 2H), 1.68 (ddd, *J* = 13.5, 12.0, 5.0 Hz, 1H), 1.53 (ddd, *J* = 13.4, 12.3, 4.7 Hz, 1H), 1.47 – 1.35 (m, 2H), 1.22 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 180.1, 166.5, 149.3, 137.8, 136.3, 128.7, 128.6, 128.4, 128.3, 127.9, 127.8, 121.5, 74.8, 73.6, 66.2, 46.9, 35.3, 32.6, 22.8, 20.0. HRMS (ESI-TOF) Calcd for $C_{24}H_{27}O_5^-$ $[M-H]^-$: 395.1858, found: 395.1851



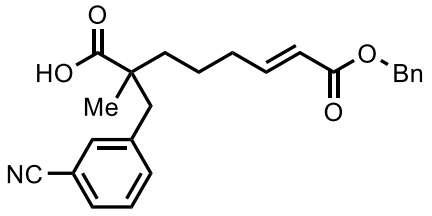
12i

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 – 7.28 (m, 5H), 7.29 – 7.17 (m, 3H), 7.17 – 7.10 (m, 2H), 7.00 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.18 (s, 2H), 3.02 (d, *J* = 13.4 Hz, 1H), 2.74 (d, *J* = 13.4 Hz, 1H), 2.33 – 2.06 (m, 2H), 1.84 – 1.66 (m, 1H), 1.61 – 1.35 (m, 3H), 1.11 (s, 3H). ^{13}C NMR (151 MHz, $CDCl^3$) δ 183.0, 166.5, 149.4, 137.2, 136.2, 130.3, 128.7, 128.4, 128.3, 128.2, 126.8, 121.5, 66.2, 47.3, 45.2, 38.6, 32.6, 23.4, 20.8. HRMS (ESI-TOF) Calcd for $C_{23}H_{25}O_4^-$ $[M-H]^-$: 365.1753, found: 365.1751



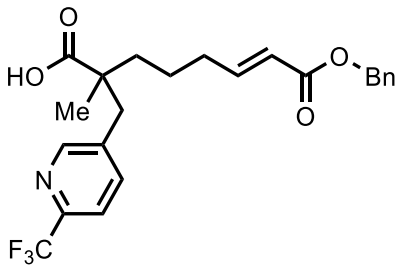
12j

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.40 – 7.29 (m, 5H), 7.08 – 7.03 (m, 2H), 7.00 (dt, *J* = 15.7, 6.9 Hz, 1H), 6.87 – 6.63 (m, 2H), 5.88 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.18 (s, 2H), 3.77 (s, 3H), 2.96 (d, *J* = 13.6 Hz, 1H), 2.69 (d, *J* = 13.5 Hz, 1H), 2.29 – 2.09 (m, 2H), 1.84 – 1.65 (m, 1H), 1.61 – 1.36 (m, 3H), 1.10 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.2, 166.5, 158.5, 149.4, 136.3, 131.3, 129.3, 128.7, 128.3, 128.3, 121.5, 113.7, 66.2, 55.3, 47.3, 44.5, 38.5, 32.7, 23.4, 20.8. HRMS (ESI-TOF) Calcd for $C_{24}H_{27}O_5^-$ $[M-H]^-$: 395.1858, found: 395.1854



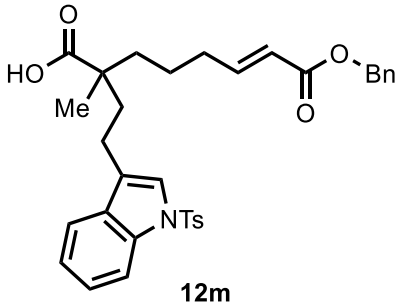
12k

Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.51 (dt, *J* = 7.1, 1.7 Hz, 1H), 7.44 (d, *J* = 1.7 Hz, 1H), 7.40 – 7.30 (m, 7H), 7.00 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.89 (dt, *J* = 15.7, 1.5 Hz, 1H), 5.18 (s, 2H), 3.08 (d, *J* = 13.5 Hz, 1H), 2.75 (d, *J* = 13.5 Hz, 1H), 2.37 – 2.10 (m, 2H), 1.75 (dd, *J* = 12.0, 8.8 Hz, 1H), 1.60 – 1.41 (m, 3H), 1.12 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.1, 166.5, 149.0, 138.8, 136.2, 134.8, 133.7, 130.7, 129.1, 128.7, 128.4, 128.3, 121.7, 118.9, 112.4, 66.3, 47.2, 44.5, 38.8, 32.5, 23.2, 20.7. HRMS (ESI-TOF) Calcd for $C_{24}H_{24}NO_4^-$ [M-H]$^-$: 390.1705, found: 390.1706



12l

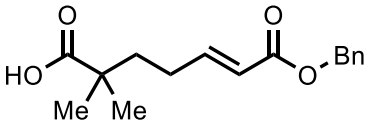
Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.59 (d, *J* = 2.1 Hz, 1H), 7.68 (dd, *J* = 8.1, 2.1 Hz, 1H), 7.63 (dd, *J* = 8.1, 0.8 Hz, 1H), 7.48 – 7.30 (m, 5H), 7.00 (dt, *J* = 15.6, 6.9 Hz, 1H), 5.90 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.18 (s, 2H), 3.17 (d, *J* = 13.5 Hz, 1H), 2.77 (d, *J* = 13.5 Hz, 1H), 2.35 – 2.17 (m, 2H), 1.90 – 1.69 (m, 1H), 1.66 – 1.40 (m, 3H), 1.13 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 180.2, 166.5, 151.1, 149.0, 146.8, 146.5, 146.3, 146.1, 139.4, 136.9, 136.2, 128.7, 128.4, 128.4, 124.4, 122.6, 121.7, 120.7, 120.3, 120.3, 120.3, 120.2, 118.9, 66.3, 47.2, 42.2, 39.1, 32.4, 23.3, 20.8. HRMS (ESI-TOF) Calcd for $C_{23}H_{23}F_3NO_4^-$ [M-H]$^-$: 434.1579, found: 434.1572



12m

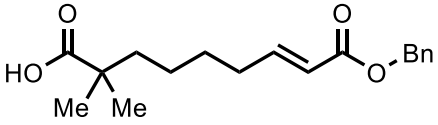
Prepared according to general procedure B: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.96 (dt, *J* = 8.3, 0.9 Hz, 1H), 7.82 – 7.62 (m, 2H), 7.46 (dt, *J* = 7.8, 1.1 Hz, 1H), 7.43 – 7.27 (m, 7H), 7.24 – 7.14 (m, 3H), 6.99 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.88 (dt, *J* = 15.6, 1.5 Hz, 1H), 5.17 (s, 2H), 2.67 (dddd, *J* = 14.7, 12.5, 4.9, 1.1 Hz, 1H), 2.60 (dddd, *J* = 14.7, 12.4, 4.6, 1.2 Hz, 1H), 2.32 (s, 3H), 2.25 – 2.17 (m, 2H), 2.06 (ddd, *J* = 13.5, 12.4, 4.7 Hz, 1H), 1.81 (ddd, *J* = 13.5, 12.4, 4.9 Hz, 1H),

1.77 – 1.68 (m, 1H), 1.64 – 1.40 (m, 3H), 1.28 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 182.7, 166.5, 149.2, 144.9, 136.2, 135.5, 135.4, 130.9, 129.9, 128.7, 128.3, 128.3, 126.9, 124.8, 123.2, 122.8, 122.5, 121.6, 119.5, 113.9, 66.2, 45.8, 38.7, 38.2, 32.6, 23.1, 21.7, 21.3, 20.4. HRMS (ESI-TOF) Calcd for $C_{33}H_{34}NO_6S^-$ [M-H]$^-$: 572.2107, found: 572.2111



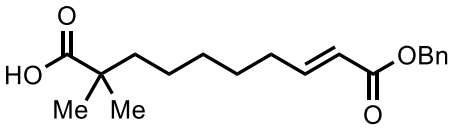
14-S.M.

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.46 – 7.29 (m, 5H), 7.01 (dt, *J* = 15.7, 6.8 Hz, 1H), 5.89 (dt, *J* = 15.7, 1.6 Hz, 1H), 5.17 (s, 2H), 2.26 – 2.15 (m, 2H), 1.79 – 1.63 (m, 2H), 1.23 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.1, 166.5, 149.2, 136.2, 128.7, 128.3, 121.3, 66.2, 42.0, 38.4, 27.9, 25.0. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_4^-$ [M-H]$^-$: 275.1283, found: 275.1282



15-S.M.

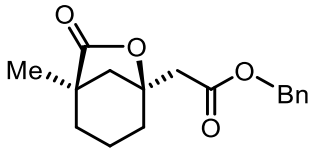
Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 – 7.32 (m, 5H), 7.02 (dt, *J* = 15.7, 6.9 Hz, 1H), 5.89 (dt, *J* = 15.6, 1.6 Hz, 1H), 5.20 (s, 2H), 2.28 – 2.18 (m, 2H), 1.64 – 1.53 (m, 2H), 1.47 (p, *J* = 7.5 Hz, 2H), 1.38 – 1.28 (m, 2H), 1.21 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 183.8, 166.7, 149.9, 136.3, 128.7, 128.3, 128.3, 121.2, 66.2, 42.2, 40.3, 32.2, 28.5, 25.1, 24.6. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_4^-$ [M-H]$^-$: 303.1596, found: 303.1597



16-S.M.

Prepared according to general procedure A: Colorless Oil. ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.45 – 7.28 (m, 5H), 7.00 (dt, *J* = 15.1, 6.9 Hz, 1H), 5.86 (dq, *J* = 15.6, 1.3 Hz, 1H), 5.17 (s, 2H), 2.19 (q, *J* = 7.2 Hz, 2H), 1.49 (dt, *J* = 31.8, 8.0 Hz, 4H), 1.34 – 1.23 (m, 4H), 1.19 (s, 6H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 184.4, 166.7, 150.1, 136.3, 128.7, 128.3, 128.3, 121.1, 66.2, 42.2, 40.4, 32.3, 29.7, 27.9, 25.1, 24.7. HRMS (ESI-TOF) Calcd for $C_{19}H_{25}O_4^-$ [M-H]$^-$: 317.1753, found: 317.1757

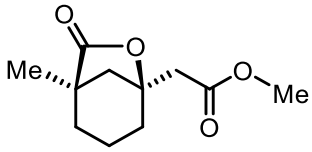
Products:



11a

Benzyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11a)

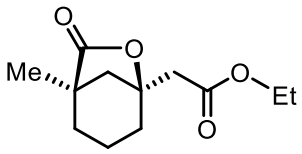
Following the general procedure, **11a** was obtained as a colorless oil, 24.8mg (86% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.45 – 7.30 (m, 5H), 5.14 (s, 2H), 2.83 (d, *J* = 15.0 Hz, 1H), 2.77 (d, *J* = 15.0 Hz, 1H), 2.14 (dt, *J* = 11.6, 2.3 Hz, 1H), 1.92 (d, *J* = 11.6 Hz, 1H), 1.89 – 1.85 (m, 1H), 1.85 – 1.77 (m, 1H), 1.75 – 1.63 (m, 3H), 1.48 – 1.37 (m, 1H), 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.6, 169.1, 135.6, 128.8, 128.6, 128.5, 82.0, 66.8, 48.0, 44.7, 43.8, 33.8, 31.9, 20.8, 19.6. HRMS (ESI-TOF) Calcd for $C_{17}H_{21}O_4^+$ $[M+H]^+$: 289.1440, found: 289.1437



11b

Methyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11b)

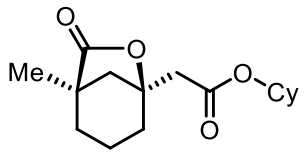
Following the general procedure, **11b** was obtained as a colorless oil, 15.5mg (73% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.70 (s, 3H), 2.80 (d, *J* = 15.1 Hz, 1H), 2.73 (d, *J* = 15.1 Hz, 1H), 2.27 – 2.06 (m, 1H), 1.97 (d, *J* = 11.6 Hz, 1H), 1.91 – 1.77 (m, 2H), 1.77 – 1.63 (m, 3H), 1.51 – 1.38 (m, 1H), 1.21 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.7, 169.8, 82.0, 52.0, 48.1, 44.7, 43.7, 33.8, 31.9, 20.8, 19.6. HRMS (ESI-TOF) Calcd for $C_{11}H_{17}O_4^+$ $[M+H]^+$: 213.1127, found: 213.1123



11c

Ethyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11c)

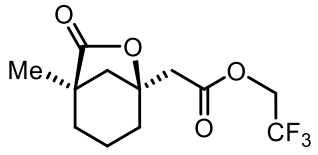
Following the general procedure, **11c** was obtained as a colorless oil, 18.5mg (82% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.15 (q, *J* = 7.1 Hz, 2H), 2.78 (d, *J* = 14.9 Hz, 1H), 2.71 (d, *J* = 15.0 Hz, 1H), 2.16 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.96 (d, *J* = 11.6 Hz, 1H), 1.89 – 1.78 (m, 2H), 1.78 – 1.61 (m, 3H), 1.45 (tq, *J* = 10.6, 5.8, 5.1 Hz, 1H), 1.27 (t, *J* = 7.2 Hz, 3H), 1.21 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.7, 169.3, 82.1, 61.0, 48.1, 44.7, 43.9, 33.8, 31.9, 20.8, 19.6, 14.3. HRMS (ESI-TOF) Calcd for $C_{12}H_{19}O_4^+$ $[M+H]^+$: 227.1283, found: 227.1281



11d

Cyclohexyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11d)

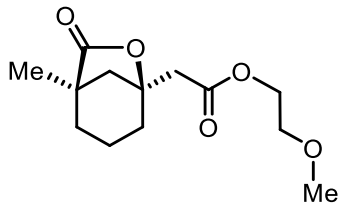
Following the general procedure, **11d** was obtained as a colorless oil, 21.3mg (76% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.77 (tt, *J* = 9.2, 3.9 Hz, 1H), 2.75 (d, *J* = 14.7 Hz, 1H), 2.69 (d, *J* = 14.6 Hz, 1H), 2.17 (dt, *J* = 11.7, 2.3 Hz, 1H), 1.93 (d, *J* = 11.6 Hz, 1H), 1.89 – 1.77 (m, 4H), 1.77 – 1.64 (m, 5H), 1.58 – 1.48 (m, 1H), 1.47 – 1.21 (m, 6H), 1.20 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.7, 168.7, 82.1, 73.5, 73.4, 48.1, 48.0, 48.0, 44.7, 44.4, 44.3, 44.3, 33.8, 33.8, 31.7, 25.4, 23.9, 20.8, 19.6. HRMS (ESI-TOF) Calcd for $C_{16}H_{25}O_4^+$ $[M+H]^+$: 281.1753, found: 281.1750



11e

2,2,2-Trifluoroethyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11e)

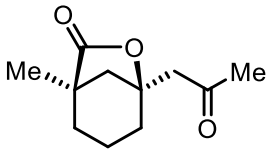
Following the general procedure, **11e** was obtained as a colorless oil, 22.1mg (79% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.50 (qd, *J* = 8.4, 1.0 Hz, 2H), 2.89 (d, *J* = 15.2 Hz, 1H), 2.84 (d, *J* = 15.2 Hz, 1H), 2.23 – 2.12 (m, 1H), 1.94 (d, *J* = 11.5 Hz, 1H), 1.92 – 1.80 (m, 2H), 1.79 – 1.63 (m, 3H), 1.53 – 1.39 (m, 1H), 1.22 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.3, 167.6, 125.6, 123.8, 122.0, 120.1, 81.4, 60.9, 60.6, 60.4, 60.1, 47.9, 44.7, 43.2, 33.8, 31.9, 20.8, 19.6. HRMS (ESI-TOF) Calcd for $C_{12}H_{16}F_3O_4^+$ $[M+H]^+$: 281.1001, found: 281.0997



11f

2-Methoxyethyl 2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(11f)

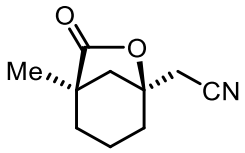
Following the general procedure, **11f** was obtained as a colorless oil, 20.0mg (78% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.37 – 4.10 (m, 2H), 3.59 (dd, *J* = 4.9, 4.4 Hz, 2H), 3.38 (s, 3H), 2.83 (d, *J* = 15.1 Hz, 1H), 2.76 (d, *J* = 15.1 Hz, 1H), 2.17 (dt, *J* = 11.6, 2.3 Hz, 1H), 1.96 (d, *J* = 11.6 Hz, 1H), 1.92 – 1.78 (m, 2H), 1.77 – 1.58 (m, 3H), 1.51 – 1.35 (m, 1H), 1.21 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.7, 169.2, 81.9, 70.5, 63.9, 59.1, 48.0, 44.7, 43.8, 33.9, 31.8, 20.9, 19.6. HRMS (ESI-TOF) Calcd for $C_{13}H_{21}O_4^+$ $[M+H]^+$: 257.1389, found: 257.1382



11g

(1*R*,5*S*)-1-Methyl-5-(2-oxopropyl)-6-oxabicyclo[3.2.1]octan-7-one(11g)

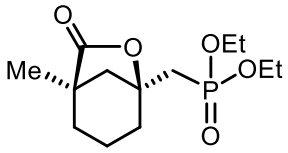
Following the general procedure, **11g** was obtained as a colorless oil, 16.1mg (82% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.89 (d, *J* = 15.9 Hz, 1H), 2.82 (d, *J* = 15.9 Hz, 1H), 2.21 (s, 3H), 2.04 – 1.99 (m, 2H), 1.88 – 1.78 (m, 1H), 1.79 – 1.73 (m, 2H), 1.73 – 1.63 (m, 2H), 1.51 – 1.37 (m, 1H), 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 205.3, 179.8, 82.5, 51.9, 48.0, 44.5, 33.8, 32.0, 31.8, 20.8, 19.6. HRMS (ESI-TOF) Calcd for $C_{11}H_{17}O_3^+$ $[M+H]^+$: 197.1178, found: 197.1182



11h

2-((1*R*,5*S*)-1-Methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetonitrile(11h)

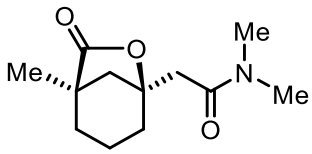
Following the general procedure, **11h** was obtained as a colorless oil, 15.8mg (88% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 2.80 (d, *J* = 16.9 Hz, 1H), 2.76 (d, *J* = 16.9 Hz, 1H), 2.16 (dt, *J* = 11.3, 2.4 Hz, 1H), 2.02 – 1.84 (m, 3H), 1.81 – 1.62 (m, 3H), 1.52 – 1.39 (m, 1H), 1.26 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.5, 115.3, 80.0, 47.5, 45.1, 33.6, 32.0, 28.1, 20.7, 19.5. HRMS (ESI-TOF) Calcd for $C_{10}H_{14}NO_2^+$ $[M+H]^+$: 180.1025, found: 180.1022



11i

Diethyl (((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)methyl)phosphonate(11i)

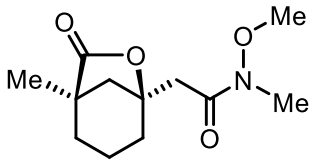
Following the general procedure, **11i** was obtained as a colorless oil, 23.5mg (81% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 4.18 – 4.05 (m, 4H), 2.33 (dd, *J* = 19.5, 15.2 Hz, 1H), 2.27 – 2.14 (m, 2H), 2.01 (d, *J* = 11.7 Hz, 1H), 1.94 – 1.77 (m, 3H), 1.69 (dddd, *J* = 13.3, 9.0, 6.4, 2.6 Hz, 2H), 1.51 – 1.39 (m, 1H), 1.34 (t, *J* = 7.1 Hz, 6H), 1.20 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.6, 82.0, 81.9, 62.1, 62.1, 62.0, 48.7, 48.7, 44.9, 36.8, 35.9, 33.7, 33.0, 33.0, 20.8, 19.8, 16.6, 16.6, 16.5, 16.5. HRMS (ESI-TOF) Calcd for $C_{13}H_{24}O_5P^+$ $[M+H]^+$: 291.1361, found: 291.1360



11j

N,N-Dimethyl-2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetamide(11j)

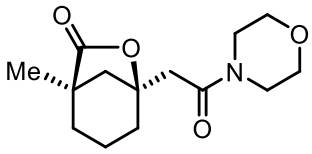
Following the general procedure, **11j** was obtained as a colorless oil, 12.8mg (57% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.05 (s, 3H), 2.94 (s, 3H), 2.78 (s, 2H), 2.19 – 2.00 (m, 2H), 1.92 – 1.75 (m, 3H), 1.74 – 1.65 (m, 2H), 1.52 – 1.41 (m, 1H). 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 180.1, 168.6, 83.8, 48.1, 44.5, 42.4, 38.2, 35.6, 33.9, 32.3, 20.8, 19.7. HRMS (ESI-TOF) Calcd for $C_{12}H_{20}NO_3^+$ $[M+H]^+$: 226.1443, found: 226.1440



11k

N-Methoxy-N-methyl-2-((1*R*,5*S*)-1-methyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetamide(11k)

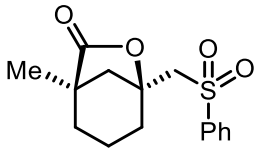
Following the general procedure, **11k** was obtained as a colorless oil, 15.4mg (64% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.71 (s, 3H), 3.18 (s, 3H), 3.00 – 2.79 (m, 2H), 2.17 (dt, *J* = 11.8, 2.1 Hz, 1H), 2.07 (d, *J* = 11.7 Hz, 1H), 1.89 – 1.77 (m, 3H), 1.73 – 1.63 (m, 2H), 1.52 – 1.39 (m, 1H), 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 180.0, 169.9, 83.2, 61.5, 48.2, 44.6, 40.7, 33.9, 32.1, 32.0, 20.8, 19.7. HRMS (ESI-TOF) Calcd for $C_{12}H_{20}NO_4^+$ $[M+H]^+$: 242.1392 , found: 242.1390



11l

(1*R*,5*S*)-1-Methyl-5-(2-morpholino-2-oxoethyl)-6-oxabicyclo[3.2.1]octan-7-one(11l)

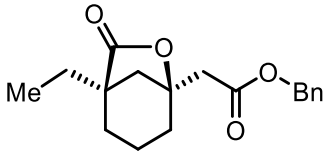
Following the general procedure, **11l** was obtained as a colorless oil, 14.2mg (53% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 3.81 – 3.59 (m, 5H), 3.59 – 3.45 (m, 3H), 2.83 (d, *J* = 14.8 Hz, 1H), 2.73 (d, *J* = 14.8 Hz, 1H), 2.19 – 2.12 (m, 1H), 2.01 (d, *J* = 11.8 Hz, 1H), 1.89 – 1.74 (m, 3H), 1.74 – 1.64 (m, 2H), 1.51 – 1.42 (m, 1H), 1.20 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.8, 167.1, 83.3, 67.0, 66.9, 47.9, 47.1, 44.5, 42.2, 42.0, 33.9, 32.6, 20.8, 19.7. HRMS (ESI-TOF) Calcd for $C_{14}H_{22}NO_4^+$ $[M+H]^+$: 268.1549, found: 268.1550



11m

(1*R*,5*S*)-1-Methyl-5-((phenylsulfonyl)methyl)-6-oxabicyclo[3.2.1]octan-7-one(11m)

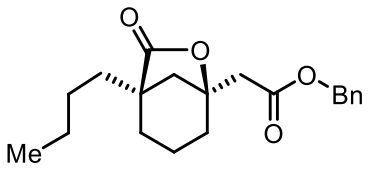
Following the general procedure, **11m** was obtained as a white solid, 22.9mg (78% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.96 – 7.91 (m, 2H), 7.78 – 7.65 (m, 1H), 7.63 – 7.56 (m, 2H), 3.55 (d, *J* = 14.2 Hz, 1H), 3.48 (d, *J* = 14.2 Hz, 1H), 2.39 (dt, *J* = 11.8, 2.4 Hz, 1H), 2.16 (d, *J* = 11.9 Hz, 1H), 2.08 – 1.90 (m, 2H), 1.92 – 1.81 (m, 1H), 1.77 – 1.63 (m, 2H), 1.54 – 1.41 (m, 1H), 1.21 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.7, 140.5, 134.3, 129.6, 128.0, 81.1, 63.7, 47.9, 44.4, 33.6, 32.6, 20.7, 19.6. HRMS (ESI-TOF) Calcd for $C_{15}H_{19}O_4S^+$ $[M+H]^+$: 295.1004, found: 295.1005



13a

Benzyl 2-((1*R*,5*S*)-1-ethyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13a)

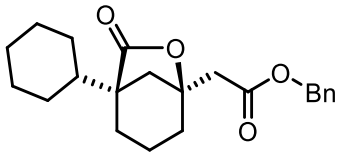
Following the general procedure, **13a** was obtained as a colorless oil, 19.3mg (64% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.30 (m, 5H), 5.14 (d, *J* = 1.7 Hz, 2H), 2.84 (d, *J* = 15.1 Hz, 1H), 2.78 (d, *J* = 15.1 Hz, 1H), 2.20 (dt, *J* = 11.5, 2.5 Hz, 1H), 1.93 – 1.78 (m, 3H), 1.76 – 1.54 (m, 5H), 1.52 – 1.45 (m, 1H), 0.87 (t, *J* = 7.6 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.1, 169.2, 135.6, 128.8, 128.6, 128.5, 82.0, 66.8, 48.9, 44.4, 43.9, 32.3, 31.9, 27.0, 19.5, 8.7. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_4^+$ $[M+H]^+$: 303.1596, found: 303.1593



13b

Benzyl 2-((1*R*,5*S*)-1-butyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13b)

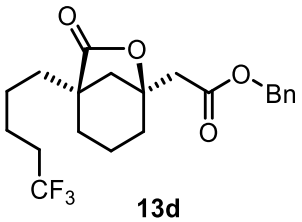
Following the general procedure, **13b** was obtained as a colorless oil, 20.1mg (61% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.30 (m, 5H), 5.14 (d, *J* = 1.9 Hz, 2H), 2.83 (d, *J* = 15.0 Hz, 1H), 2.77 (d, *J* = 15.0 Hz, 1H), 2.19 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.92 – 1.77 (m, 3H), 1.74 – 1.64 (m, 2H), 1.65 – 1.59 (m, 1H), 1.57 – 1.42 (m, 3H), 1.39 – 1.21 (m, 3H), 1.20 – 1.04 (m, 1H), 0.89 (t, *J* = 7.2 Hz, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.3, 169.2, 135.6, 128.8, 128.6, 128.5, 82.0, 66.8, 48.4, 45.0, 43.9, 34.1, 32.3, 32.3, 26.5, 23.2, 19.6, 14.1. HRMS (ESI-TOF) Calcd for $C_{20}H_{27}O_4^+$ $[M+H]^+$: 331.1909, found: 331.1905



13c

Benzyl 2-((1*R*,5*S*)-1-cyclohexyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13c)

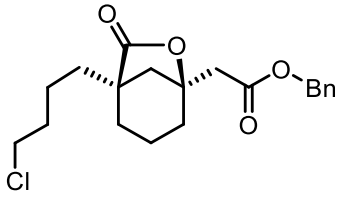
Following the general procedure, **13c** was obtained as a colorless oil, 23.2mg (65% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 – 7.29 (m, 5H), 5.26 – 5.03 (m, 2H), 2.82 (d, *J* = 15.1 Hz, 1H), 2.77 (d, *J* = 15.0 Hz, 1H), 2.24 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.93 – 1.80 (m, 3H), 1.80 – 1.58 (m, 8H), 1.58 – 1.51 (m, 2H), 1.38 – 1.19 (m, 2H), 1.09 (qt, *J* = 13.1, 3.7 Hz, 1H), 0.96 (qd, *J* = 12.4, 3.5 Hz, 1H), 0.82 (qd, *J* = 12.6, 3.6 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.8, 169.2, 135.6, 128.8, 128.6, 128.5, 81.9, 66.8, 52.2, 43.9, 41.7, 40.9, 32.8, 30.7, 28.2, 27.7, 26.7, 26.6, 26.4, 19.7. HRMS (ESI-TOF) Calcd for $C_{22}H_{29}O_4^+$ $[M+H]^+$: 357.2066, found: 357.2063



13d

Benzyl 2-((1*R*,5*S*)-7-oxo-1-(5,5,5-trifluoropentyl)-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13d)

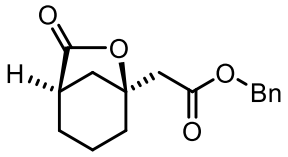
Following the general procedure, **13d** was obtained as a colorless oil, 29.5mg (74% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.31 (m, 5H), 5.14 (d, *J* = 1.1 Hz, 2H), 2.84 (d, *J* = 15.1 Hz, 1H), 2.78 (d, *J* = 15.1 Hz, 1H), 2.21 (dt, *J* = 11.5, 2.4 Hz, 1H), 2.11 – 2.01 (m, 2H), 1.93 – 1.78 (m, 3H), 1.77 – 1.66 (m, 2H), 1.66 – 1.60 (m, 1H), 1.61 – 1.52 (m, 4H), 1.51 – 1.36 (m, 2H), 1.24 (ddd, *J* = 14.5, 12.4, 7.2 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.9, 169.1, 135.6, 130.0, 128.8, 128.6, 128.5, 128.1, 126.3, 124.5, 82.1, 66.8, 48.2, 44.8, 43.8, 33.9, 33.8, 33.7, 33.5, 33.3, 32.3, 32.3, 23.5, 22.4, 22.4, 22.4, 22.3, 19.5. HRMS (ESI-TOF) Calcd for $C_{21}H_{26}F_3O_4^+$ $[M+H]^+$: 399.1783, found: 399.1777



13e

Benzyl 2-((1*S*,5*S*)-1-(4-chlorobutyl)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13e)

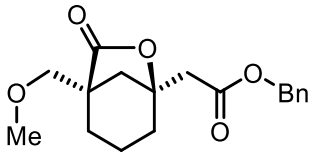
Following the general procedure, **13e** was obtained as a colorless oil, 21.8mg (60% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.54 – 7.27 (m, 5H), 5.14 (d, *J* = 1.9 Hz, 2H), 3.66 – 3.45 (m, 2H), 2.84 (d, *J* = 15.0 Hz, 1H), 2.78 (d, *J* = 15.1 Hz, 1H), 2.21 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.96 – 1.81 (m, 3H), 1.81 – 1.74 (m, 2H), 1.74 – 1.65 (m, 2H), 1.66 – 1.57 (m, 2H), 1.55 – 1.47 (m, 3H), 1.35 – 1.24 (m, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.0, 169.1, 135.6, 128.8, 128.6, 128.5, 82.1, 66.8, 48.3, 44.9, 44.9, 43.8, 33.6, 32.9, 32.3, 32.2, 21.7, 19.5. HRMS (ESI-TOF) Calcd for $C_{20}H_{26}ClO_4^+$ $[M+H]^+$: 365.1520, found: 365.1521



13f

Benzyl 2-((1*R*,5*S*)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13f)

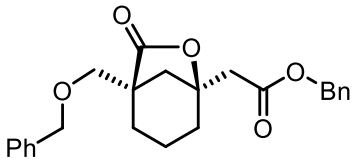
Following the general procedure, **13f** was obtained as a colorless oil, 7.4mg (27% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.43 – 7.30 (m, 5H), 5.14 (d, *J* = 1.7 Hz, 2H), 2.83 (d, *J* = 15.1 Hz, 1H), 2.79 (d, *J* = 15.1 Hz, 1H), 2.76 – 2.72 (m, 1H), 2.34 (ddt, *J* = 10.7, 5.1, 2.3 Hz, 1H), 1.99 – 1.87 (m, 3H), 1.85 – 1.69 (m, 3H), 1.55 (ddt, *J* = 13.5, 7.5, 3.9 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.9, 169.1, 135.6, 128.8, 128.6, 128.5, 84.2, 66.8, 43.9, 41.7, 40.9, 32.6, 26.0, 19.3. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_4^+$ $[M+H]^+$: 275.1283, found: 275.1281



13g

Benzyl 2-((1*R*,5*S*)-1-(methoxymethyl)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13g)

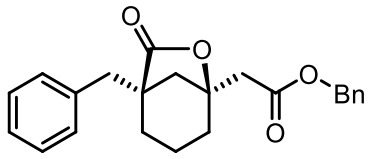
Following the general procedure, **13g** was obtained as a colorless oil, 23.2mg (73% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.43 – 7.29 (m, 5H), 5.14 (s, 2H), 3.53 (d, *J* = 9.5 Hz, 1H), 3.36 (d, *J* = 9.6 Hz, 1H), 3.35 (s, 3H), 2.86 (d, *J* = 15.1 Hz, 1H), 2.80 (d, *J* = 15.1 Hz, 1H), 2.45 (dt, *J* = 11.6, 2.4 Hz, 1H), 2.00 – 1.88 (m, 2H), 1.88 – 1.80 (m, 1H), 1.81 – 1.65 (m, 2H), 1.63 – 1.40 (m, 2H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.5, 169.1, 135.6, 128.8, 128.6, 128.5, 82.4, 73.7, 66.8, 59.6, 49.7, 43.8, 43.3, 32.3, 29.1, 19.1. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_5^+$ $[M+H]^+$: 319.1545, found: 319.1545



13h

Benzyl 2-((1*R*,5*S*)-1-((benzyloxy)methyl)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13h)

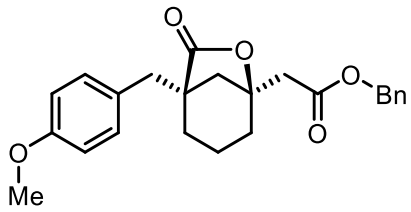
Following the general procedure, **13h** was obtained as a colorless oil, 25.6mg (65% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.40 – 7.27 (m, 10H), 5.14 (s, 1H), 4.57 (d, *J* = 12.1 Hz, 1H), 4.49 (d, *J* = 12.1 Hz, 1H), 3.62 (d, *J* = 9.6 Hz, 1H), 3.45 (d, *J* = 9.6 Hz, 1H), 2.87 (d, *J* = 15.1 Hz, 1H), 2.81 (d, *J* = 15.1 Hz, 1H), 2.49 (dt, *J* = 11.7, 2.4 Hz, 1H), 1.94 (d, *J* = 11.6 Hz, 1H), 1.92 – 1.88 (m, 1H), 1.87 – 1.81 (m, 1H), 1.80 – 1.65 (m, 2H), 1.63 – 1.50 (m, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.5, 169.1, 138.2, 135.6, 128.8, 128.6, 128.5, 128.5, 127.8, 127.7, 82.5, 73.7, 71.3, 66.8, 49.8, 43.8, 43.5, 32.3, 29.2, 19.1. HRMS (ESI-TOF) Calcd for $C_{24}H_{27}O_5^+$ $[M+H]^+$: 395.1858, found: 395.1851



13i

Benzyl 2-((1*S*,5*S*)-1-benzyl-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13i)

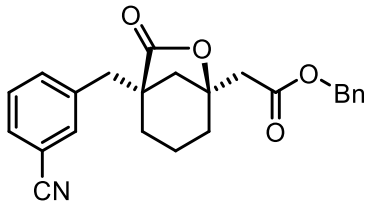
Following the general procedure, **13i** was obtained as a colorless oil, 24.4mg (67% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.41 – 7.30 (m, 5H), 7.30 – 7.26 (m, 2H), 7.25 – 7.19 (m, 1H), 7.16 – 7.08 (m, 2H), 5.26 – 4.90 (m, 2H), 2.97 (d, *J* = 13.8 Hz, 1H), 2.82 (d, *J* = 13.8 Hz, 1H), 2.78 (d, *J* = 15.1 Hz, 1H), 2.71 (d, *J* = 15.1 Hz, 1H), 2.10 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.91 – 1.66 (m, 5H), 1.66 – 1.60 (m, 1H), 1.41 – 1.29 (m, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.8, 169.0, 136.8, 135.6, 130.2, 128.8, 128.6, 128.5, 128.5, 126.8, 82.4, 66.8, 49.5, 45.0, 43.8, 40.8, 32.3, 32.0, 19.4. HRMS (ESI-TOF) Calcd for $C_{23}H_{25}O_4^+$ $[M+H]^+$: 365.1753, found: 365.1755



13j

Benzyl 2-((1*S*,5*S*)-1-(4-methoxybenzyl)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13j)

Following the general procedure, **13j** was obtained as a colorless oil, 22.1mg (56% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 – 7.29 (m, 5H), 7.09 – 7.00 (m, 2H), 6.83 – 6.69 (m, 2H), 5.26 – 4.92 (m, 2H), 3.79 (s, 3H), 2.92 (d, *J* = 14.0 Hz, 1H), 2.78 (d, *J* = 15.1 Hz, 1H), 2.74 (d, *J* = 14.0 Hz, 1H), 2.71 (d, *J* = 15.1 Hz, 1H), 2.08 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.89 – 1.77 (m, 2H), 1.75 (d, *J* = 11.6 Hz, 1H), 1.73 – 1.59 (m, 3H), 1.39 – 1.31 (m, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.8, 169.1, 158.5, 135.6, 131.2, 128.8, 128.8, 128.6, 128.5, 113.9, 82.3, 66.8, 55.4, 49.7, 44.9, 43.9, 39.8, 32.3, 32.1, 19.4. HRMS (ESI-TOF) Calcd for $C_{24}H_{27}O_5^+$ $[M+H]^+$: 395.1858, found: 395.1855

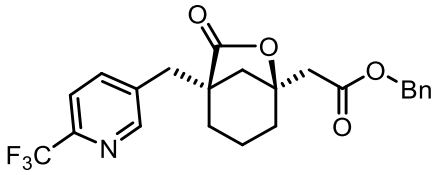


13k

Benzyl 2-((1*S*,5*S*)-1-(3-cyanobenzyl)-7-oxo-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13k)

Following the general procedure, **13k** was obtained as a colorless oil, 23.1mg (59% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.54 (dt, *J* = 6.8, 1.8 Hz, 1H), 7.43 – 7.29 (m, 8H), 5.10 (d, *J* = 3.0 Hz, 2H), 3.02 (d, *J* = 13.9 Hz, 1H), 2.82 (d, *J* = 13.9 Hz, 1H), 2.79 (d, *J* = 15.3 Hz, 1H), 2.71 (d, *J* = 15.3 Hz, 1H), 2.04 (dt, *J* = 11.6, 2.4 Hz, 1H), 1.84 (tdd, *J* = 13.0, 5.7, 2.2 Hz, 2H), 1.77 (d, *J* =

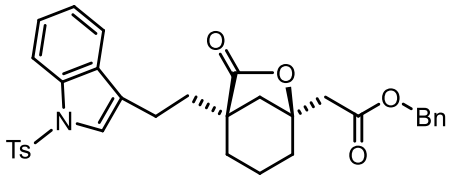
11.5 Hz, 1H), 1.76 – 1.61 (m, 3H), 1.44 – 1.29 (m, 1H). 13C NMR (151 MHz, $CDCl_3$) δ 178.0, 168.9, 138.2, 135.5, 134.8, 133.6, 130.7, 129.4, 128.8, 128.6, 128.5, 118.8, 112.6, 82.5, 66.8, 49.3, 44.6, 43.6, 40.2, 32.5, 31.9, 19.3. HRMS (ESI-TOF) Calcd for $C_{24}H_{24}NO_4^+$ $[M+H]^+$: 390.1705, found: 390.1702



13l

Benzyl 2-((1*S*,5*S*)-7-oxo-1-((6-(trifluoromethyl)pyridin-3-yl)methyl)-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13l)

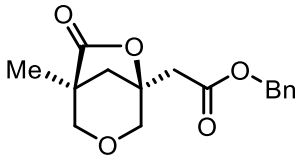
Following the general procedure, **13l** was obtained as a colorless oil, 28.6mg (66% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 8.49 (d, *J* = 2.1 Hz, 1H), 7.80 – 7.65 (m, 1H), 7.60 (dd, *J* = 8.1, 0.8 Hz, 1H), 7.45 – 7.29 (m, 5H), 5.10 (d, *J* = 2.8 Hz, 2H), 3.05 (d, *J* = 14.0 Hz, 1H), 2.89 (d, *J* = 14.0 Hz, 1H), 2.79 (d, *J* = 15.4 Hz, 1H), 2.71 (d, *J* = 15.4 Hz, 1H), 2.06 (dt, *J* = 11.5, 2.4 Hz, 1H), 1.86 (dtd, *J* = 12.5, 5.8, 3.7 Hz, 2H), 1.81 (d, *J* = 11.5 Hz, 1H), 1.79 – 1.65 (m, 3H), 1.39 (dq, *J* = 12.4, 6.2 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.7, 168.8, 151.4, 147.3, 147.1, 146.9, 146.6, 139.1, 135.7, 135.5, 128.8, 128.6, 128.5, 124.4, 122.6, 120.8, 120.4, 120.4, 120.4, 120.3, 119.0, 82.6, 66.8, 49.3, 44.5, 43.5, 37.5, 32.5, 31.9, 19.3. HRMS (ESI-TOF) Calcd for $C_{23}H_{23}F_3NO_4^+$ $[M+H]^+$: 434.1579, found: 434.1572



13m

Benzyl 2-((1*S*,5*S*)-7-oxo-1-((1-((trifluoromethyl)sulfonyl)-1H-indol-3-yl)methyl)-6-oxabicyclo[3.2.1]octan-5-yl)acetate(13m)

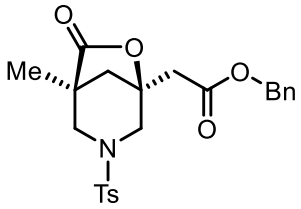
Following the general procedure, **13m** was obtained as a colorless oil, 34.3mg (64% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.98 (dt, *J* = 8.3, 0.9 Hz, 1H), 7.74 (d, *J* = 8.4 Hz, 2H), 7.50 (dt, *J* = 7.8, 1.1 Hz, 1H), 7.42 – 7.34 (m, 4H), 7.33 – 7.28 (m, 3H), 7.25 – 7.16 (m, 3H), 5.15 (d, *J* = 1.2 Hz, 2H), 2.86 (d, *J* = 15.2 Hz, 1H), 2.82 (d, *J* = 15.2 Hz, 1H), 2.70 (dddd, *J* = 14.7, 12.2, 5.2, 1.1 Hz, 1H), 2.54 (dddd, *J* = 14.6, 12.3, 4.6, 1.2 Hz, 1H), 2.36 – 2.34 (m, 1H), 2.33 (s, 3H), 1.98 (ddd, *J* = 14.1, 12.2, 4.7 Hz, 1H), 1.92 (d, *J* = 11.6 Hz, 1H), 1.95 – 1.82 (m, 3H), 1.79 – 1.67 (m, 3H), 1.57 (dd, *J* = 13.2, 6.7 Hz, 1H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 178.7, 169.1, 144.9, 135.6, 135.5, 135.4, 130.9, 130.0, 128.8, 128.6, 128.5, 126.9, 124.9, 123.2, 122.7, 122.6, 119.6, 113.9, 82.2, 66.9, 48.4, 44.7, 43.7, 33.6, 32.4, 32.3, 21.7, 20.0, 19.5. HRMS (ESI-TOF) Calcd for $C_{33}H_{34}NO_4S^+$ $[M+H]^+$: 572.2107, found: 572.2109



13n

Benzyl 2-((1*S*,5*S*)-1-methyl-7-oxo-3,6-dioxabicyclo[3.2.1]octan-5-yl)acetate(13n)

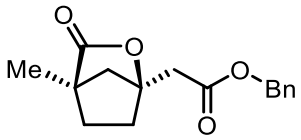
Following the general procedure, **13n** was obtained as a colorless oil, 25.5mg (88% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.42 – 7.32 (m, 5H), 5.14 (s, 2H), 3.78 (dt, *J* = 10.4, 2.8 Hz, 2H), 3.66 (d, *J* = 11.3 Hz, 1H), 3.38 (d, *J* = 10.3 Hz, 1H), 2.80 (s, 2H), 2.28 (dt, *J* = 11.6, 2.6 Hz, 1H), 2.15 (d, *J* = 11.6 Hz, 1H), 1.12 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 177.5, 168.3, 135.3, 128.8, 128.7, 128.6, 79.4, 72.7, 69.8, 67.2, 45.7, 45.2, 39.9, 15.9. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_5^+$ $[M+H]^+$: 291.1232, found: 291.1233



13o

Benzyl 2-((1*S*,5*S*)-1-methyl-7-oxo-3-tosyl-6-oxa-3-azabicyclo[3.2.1]octan-5-yl)acetate(13o)

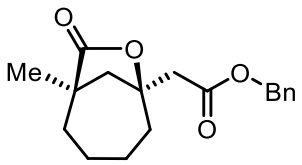
Following the general procedure, **13o** was obtained as a colorless oil, 31.1mg (70% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.70 – 7.54 (m, 2H), 7.42 – 7.28 (m, 7H), 5.12 (s, 2H), 3.77 (dd, *J* = 11.9, 2.0 Hz, 1H), 3.67 (dd, *J* = 11.0, 1.9 Hz, 1H), 2.99 (d, *J* = 11.8 Hz, 1H), 2.87 (d, *J* = 15.7 Hz, 1H), 2.84 (d, *J* = 15.8 Hz, 1H), 2.66 (d, *J* = 11.1 Hz, 1H), 2.43 (s, 3H), 2.21 – 2.09 (m, 1H), 1.94 (d, *J* = 12.0 Hz, 1H), 1.19 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 176.3, 168.2, 144.3, 135.2, 134.1, 130.0, 128.9, 128.8, 128.6, 127.7, 78.2, 67.2, 51.9, 50.0, 45.1, 43.3, 40.9, 21.7, 17.7. HRMS (ESI-TOF) Calcd for $C_{23}H_{26}NO_6S^+$ $[M+H]^+$: 444.1481, found: 444.1488



14

Benzyl 2-((1*S*,4*R*)-4-methyl-3-oxo-2-oxabicyclo[2.2.1]heptan-1-yl)acetate(14)

Following the general procedure, **14** was obtained as a colorless oil, 3.6mg (13% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.50 – 7.31 (m, 5H), 5.17 (s, 2H), 3.00 (d, *J* = 15.6 Hz, 1H), 2.96 (d, *J* = 15.5 Hz, 1H), 2.09 (ddd, *J* = 13.1, 10.8, 4.5 Hz, 1H), 2.02 (dt, *J* = 10.4, 2.4 Hz, 1H), 1.96 (dtd, *J* = 13.4, 5.4, 2.6 Hz, 1H), 1.87 (d, *J* = 10.3 Hz, 1H), 1.85 – 1.72 (m, 2H), 1.36 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 179.4, 169.0, 135.6, 128.8, 128.6, 128.5, 87.2, 66.9, 48.9, 48.8, 38.1, 33.6, 31.6, 14.6. HRMS (ESI-TOF) Calcd for $C_{16}H_{19}O_4^+$ $[M+H]^+$: 275.1283, found: 275.1284



15

benzyl 2-((1*R*,6*S*)-1-methyl-8-oxo-7-oxabicyclo[4.2.1]nonan-6-yl)acetate(15)

Following the general procedure, **15** was obtained as a colorless oil, 24.4mg (81% yield). ^{1}H NMR (600 MHz, $CDCl_3$) δ 7.46 – 7.29 (m, 5H), 5.13 (s, 2H), 2.83 (d, *J* = 15.4 Hz, 1H), 2.76 (d, *J* = 15.5 Hz, 1H), 2.43 (d, *J* = 13.1 Hz, 1H), 2.17 (dt, *J* = 13.2, 1.4 Hz, 1H), 1.95 – 1.77 (m, 3H), 1.71 – 1.59 (m, 3H), 1.58 – 1.45 (m, 2H), 1.23 (s, 3H). ^{13}C NMR (151 MHz, $CDCl_3$) δ 181.7, 169.4, 135.6, 128.8, 128.5, 128.5, 83.3, 66.7, 46.1, 44.6, 42.7, 39.8, 38.5, 25.2, 24.5, 23.5. HRMS (ESI-TOF) Calcd for $C_{18}H_{23}O_4^+$ $[M+H]^+$: 303.1596, found: 303.1595

Crystallographic Analysis of the Sulfone 11m.

The single crystal X-ray diffraction studies were carried out on a Bruker APEX II Ultra CCD diffractometer equipped with Mo Kα radiation (λ = 0.71073). Crystals of the sub*J*ect compound were used as received (grown from DCM/Hexane). A 0.200 x 0.170 x 0.020 mm colorless crystal was mounted on a Cryoloop with Paratone oil. Data were collected in a nitrogen gas stream at 100(2) K using ϕ and ϖ scans. Crystal-to-detector distance was 45 mm using exposure time 8.0 s with a scan width of 0.75°. Data collection was 100.0% complete to 25.242° in *θ*. A total of 27016 reflections were collected covering the indices, -29 < = h < = 31, -12 < = k < = 12, -12 < = l < = 10. 5083 reflections were found to be symmetry independent, with a R_{int} of 0.0601. Indexing and unit cell refinement indicated a *Primitive Monoclinic* lattice. The space group was found to be *P2₁/c*. The data were integrated using the Bruker SAINT software program and scaled using the SADABS software program. Solution by direct methods (SHELXT) produced a complete phasing model consistent with the proposed structure. All nonhydrogen atoms were refined anisotropically by full-matrix least-squares (SHELXL-2014). All carbon bonded hydrogen atoms were placed using a riding model. Their positions were constrained relative to their parent atom using the appropriate HFIX command in SHELXL-2014. Crystallographic data are summarized in Table S4. CCDC deposition number 2122727 contains the supplementary crystallography data for this paper.

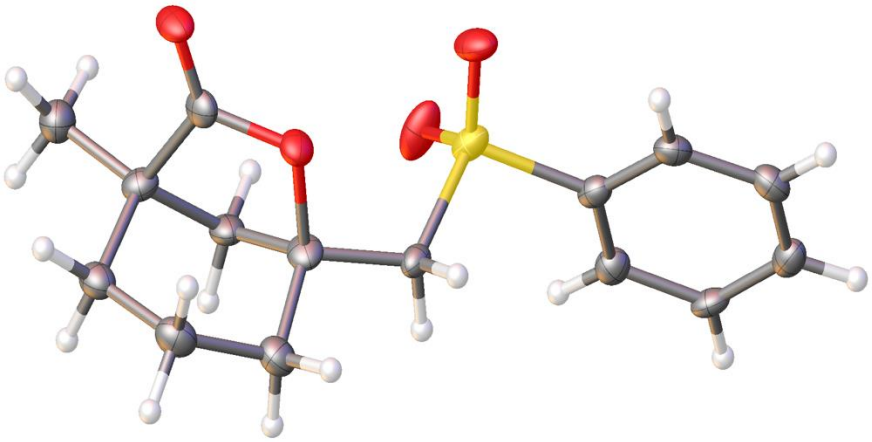
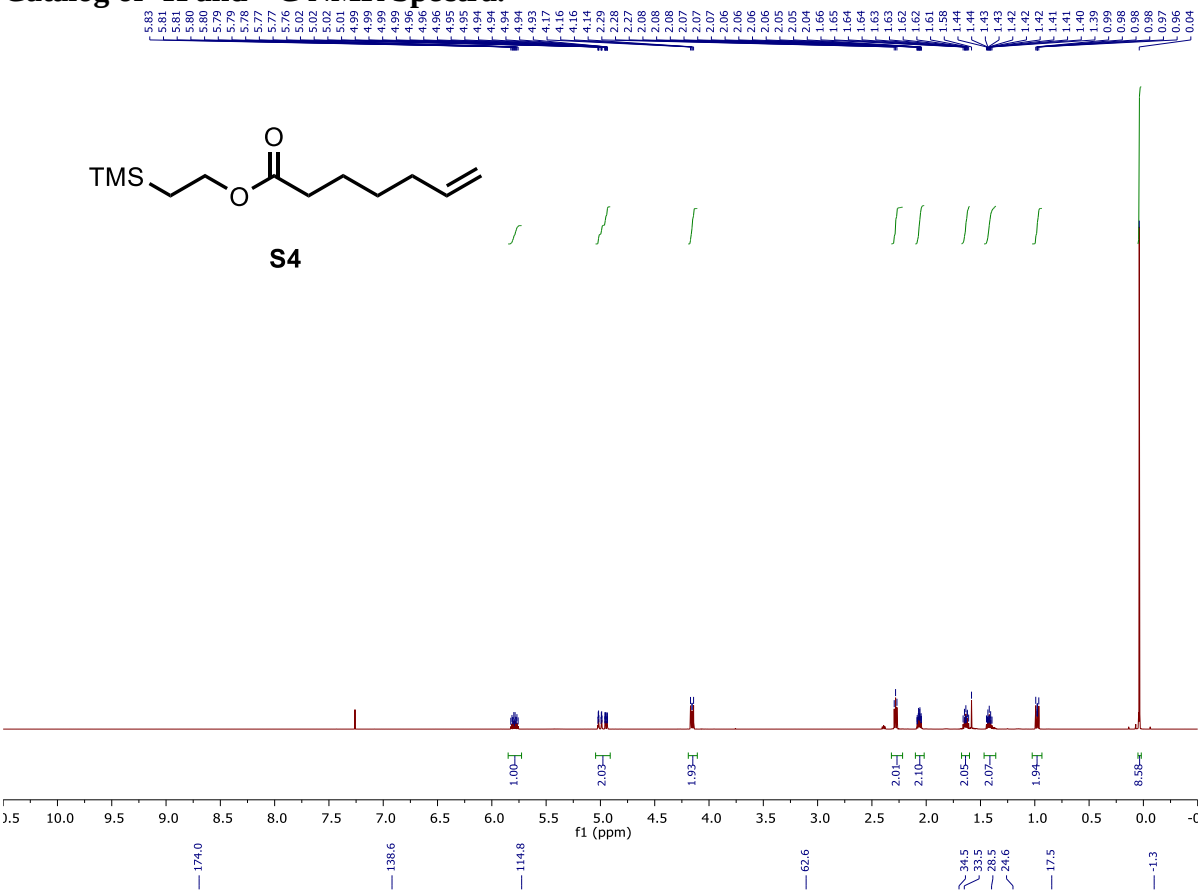


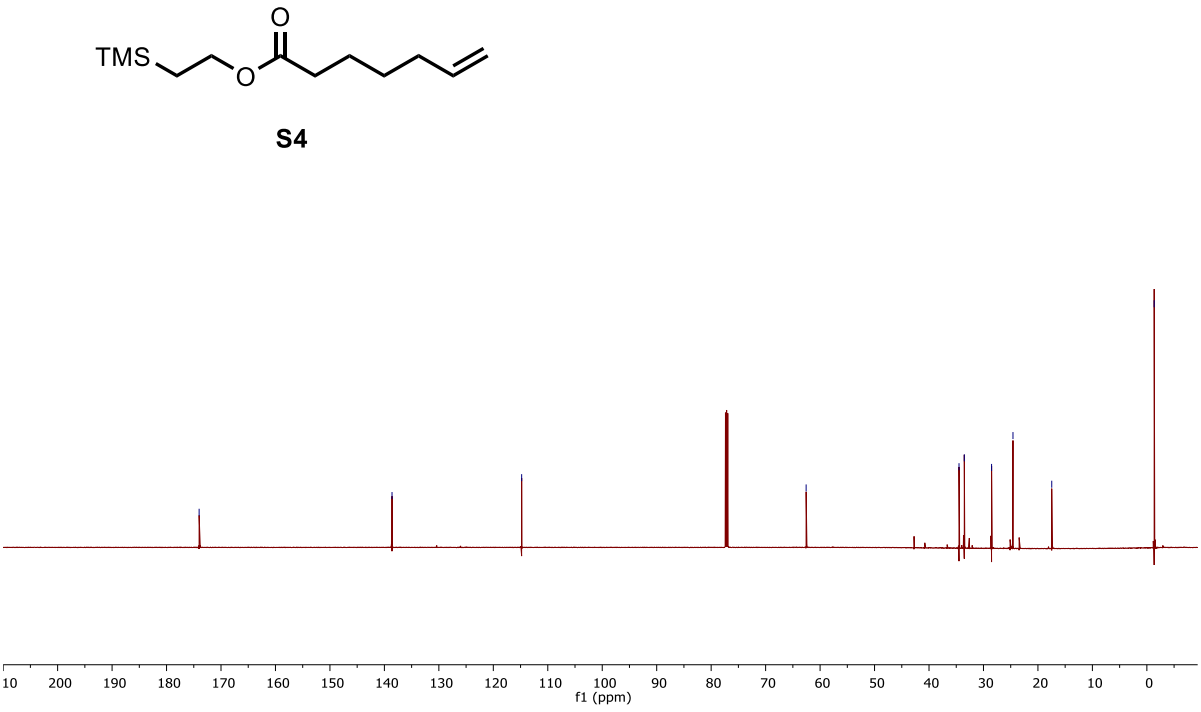
Figure S1. The crystal structure of sulfone **11m**.

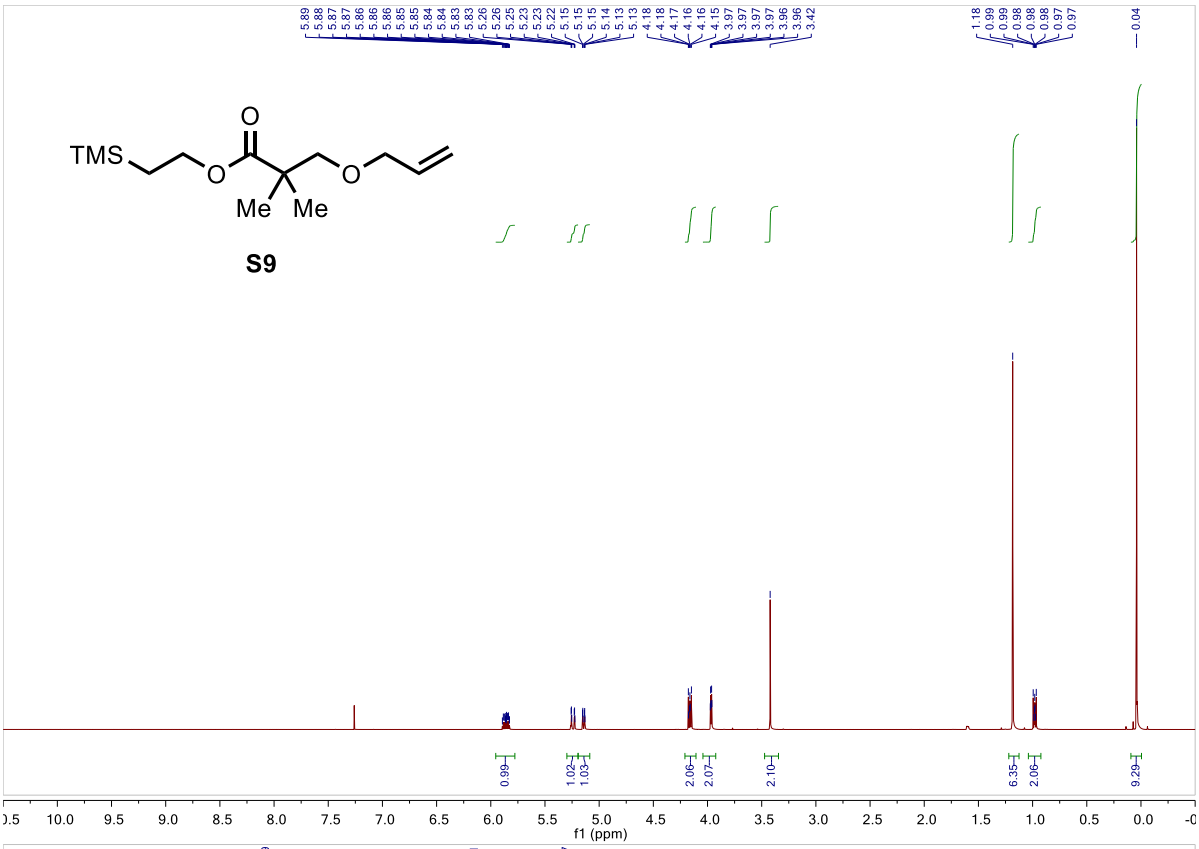
Table S4. Crystal data and structure refinement for sulfone **11m**.

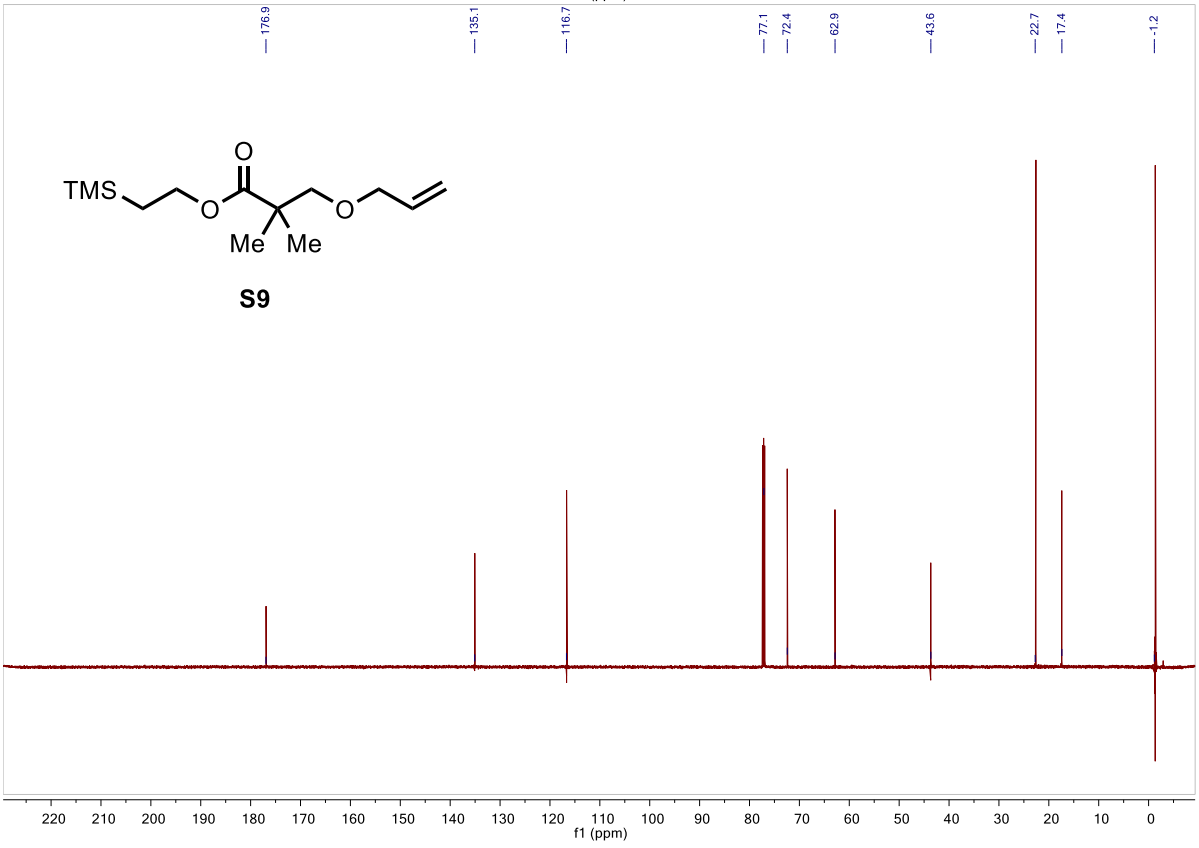
Report date	2021-11-17	
Identification code	yu146	
Empirical formula	C15 H18 O4 S	
Molecular formula	C15 H18 O4 S	
Formula weight	294.35	
Temperature	100.0 K	
Wavelength	0.71073 Å	
Crystal system	Monoclinic	
Space group	P 1 21/c 1	
Unit cell dimensions	a = 26.080(3) Å	α = 90°.
	b = 10.4675(14) Å	β = 101.391(3)°.
	c = 10.3617(12) Å	γ = 90°.
Volume	2772.9(6) $Å^3$	
Z	8	
Density (calculated)	1.410 Mg/m^3	
Absorption coefficient	0.244 mm^{-1}	
F(000)	1248	
Crystal size	0.2 x 0.17 x 0.02 mm^3	
Crystal color, habit	colorless plate	
Theta range for data collection	1.593 to 25.347°.	
Index ranges	-29<=h<=31, -12<=k<=12, -12<=l<=10	
Reflections collected	27016	
Independent reflections	5083 [R(int) = 0.0601]	
Completeness to theta = 25.242°	100.0 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	0.7453 and 0.6629	
Refinement method	Full-matrix least-squares on F^2	
Data / restraints / parameters	5083 / 0 / 364	
Goodness-of-fit on F^2	1.049	
Final R indices [I>2sigma(I)]	R1 = 0.0471, wR2 = 0.0964	
R indices (all data)	R1 = 0.0731, wR2 = 0.1072	
Largest diff. peak and hole	0.349 and -0.423 $e.Å^{-3}$	

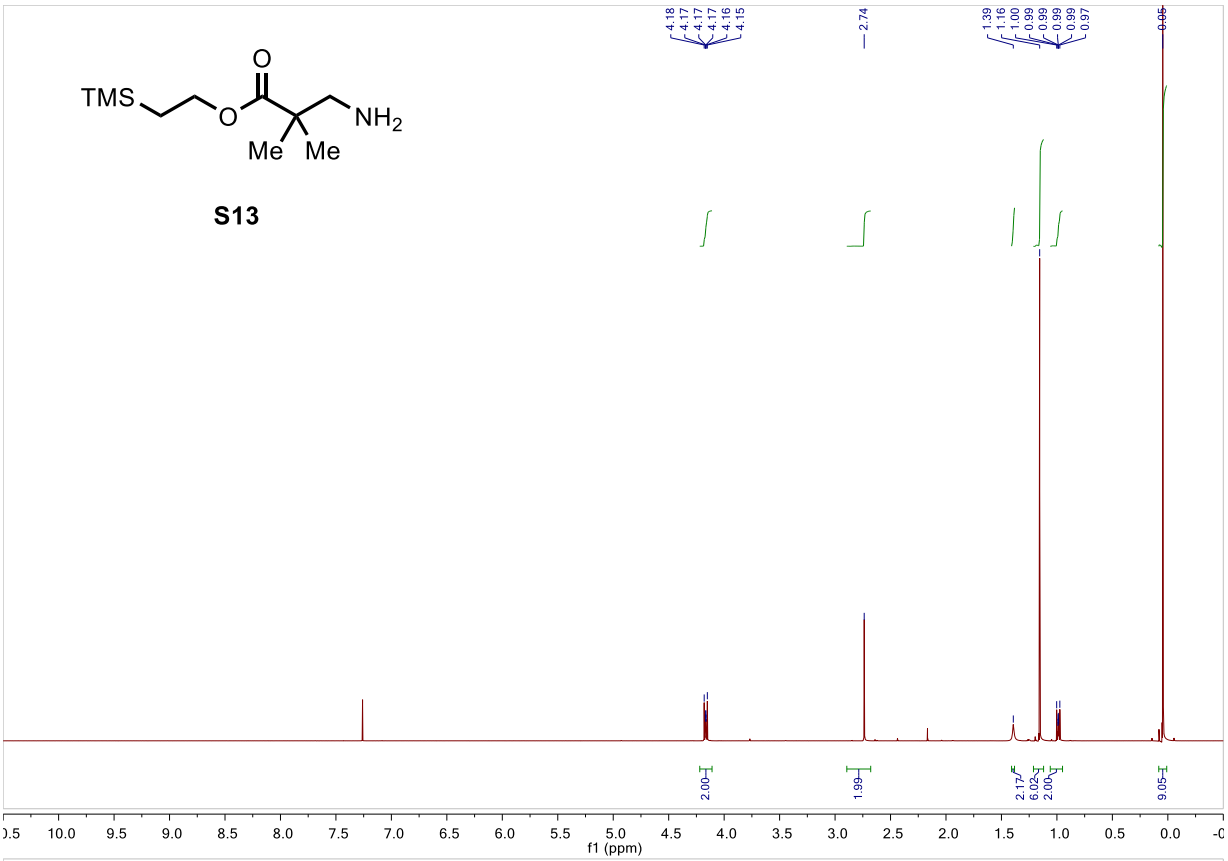
Catalog of ^{1}H and ^{13}C NMR Spectra.






TMS
O
O
O
Me
Me
S9
f1 (ppm)


TMS
O
O
O
Me
Me
S9
f1 (ppm)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O
O
NH2
Me
Me
S13
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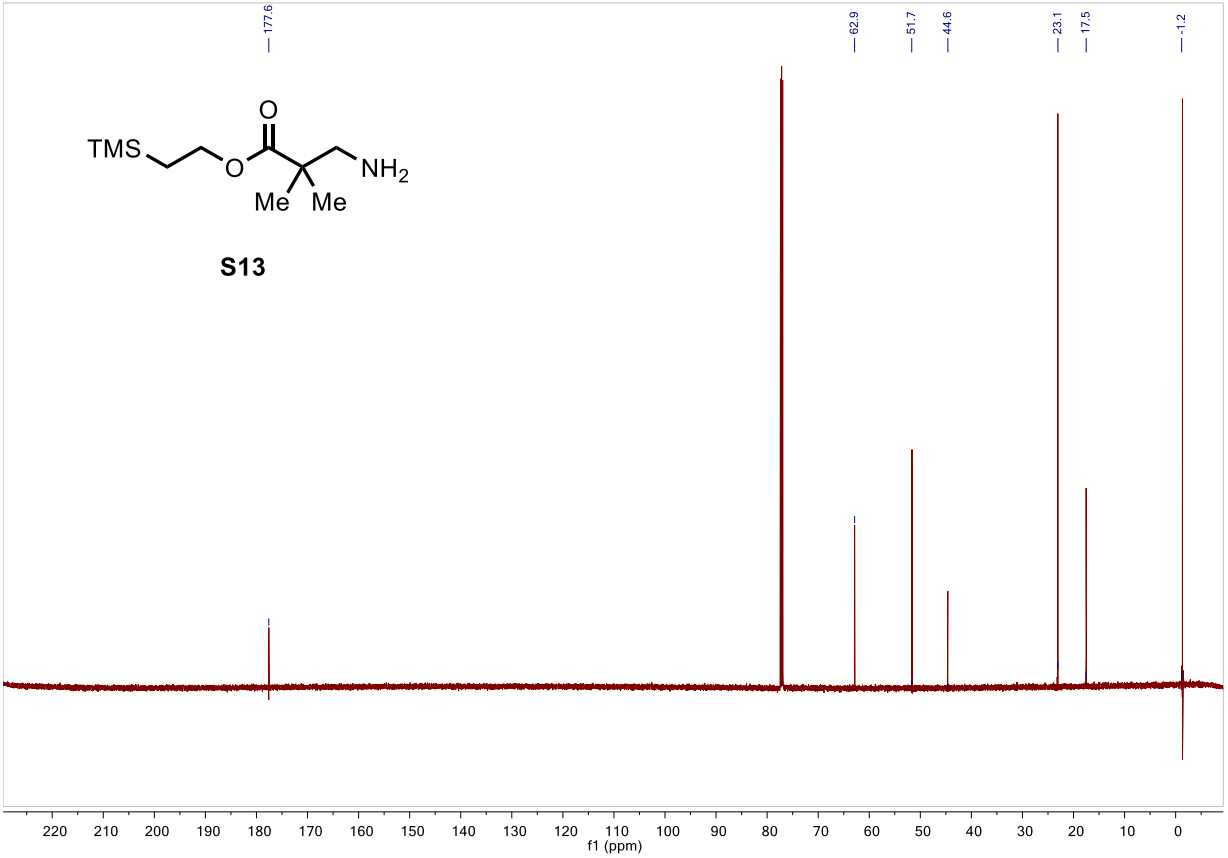
4.17
4.17
4.17
4.16
4.15
2.74
1.39
1.16
1.00
0.99
0.99
0.99
0.97
0.00
2.00
1.99
2.17
6.02
2.00
9.05
f1 (ppm)


TMS
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Me
S13
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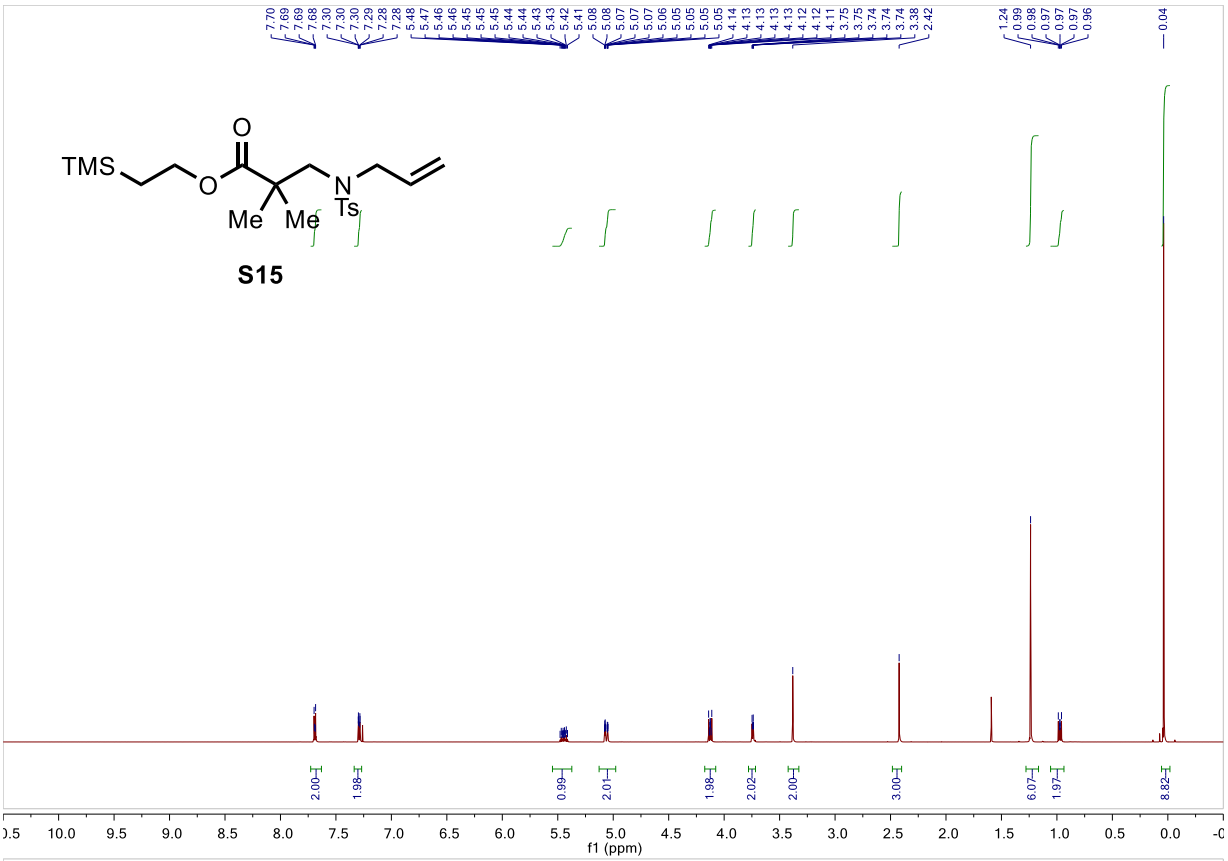
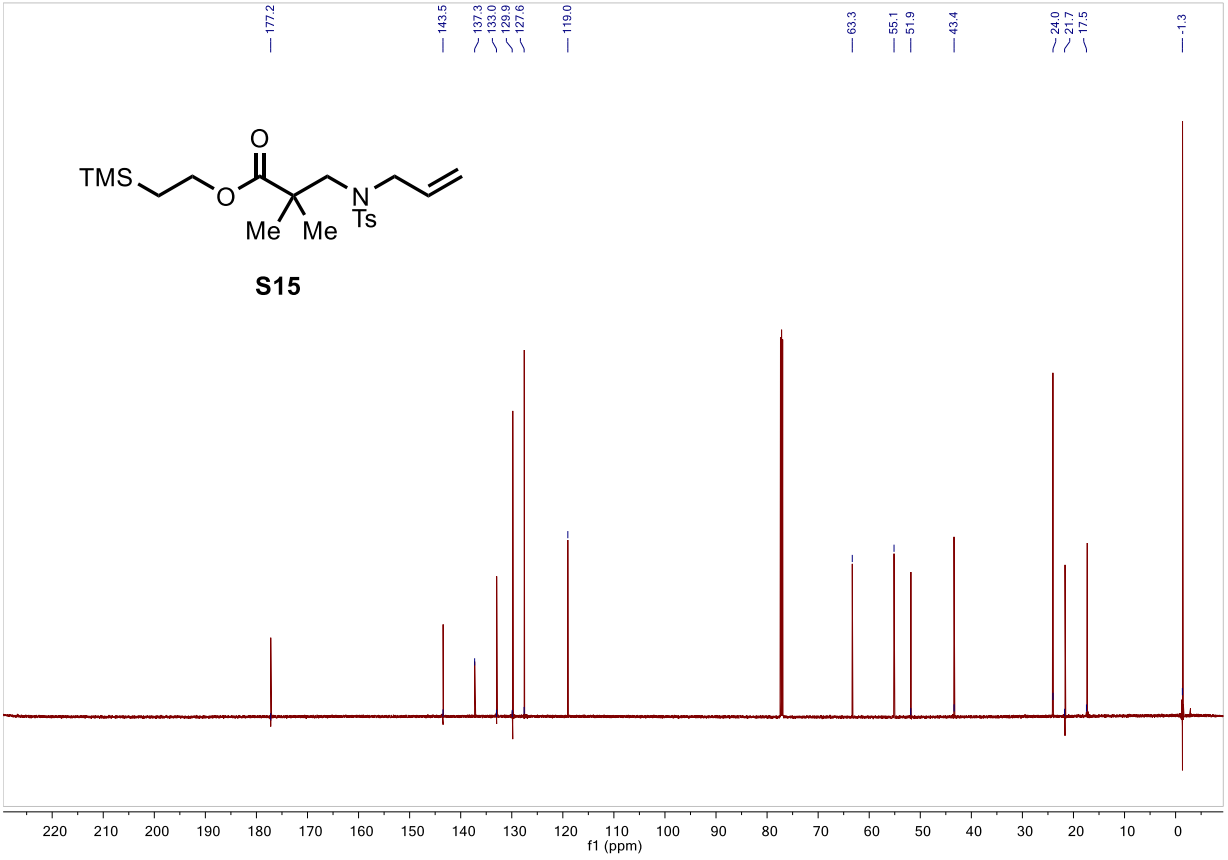
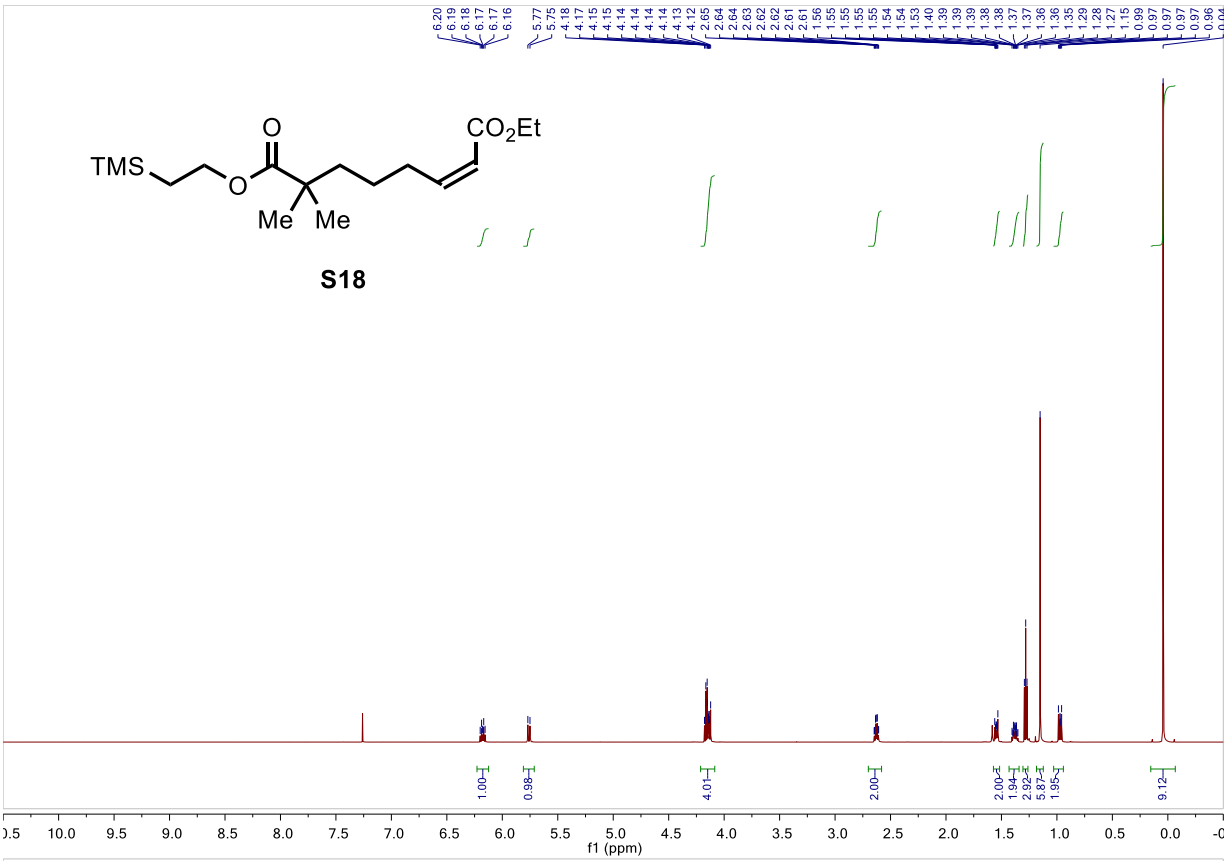
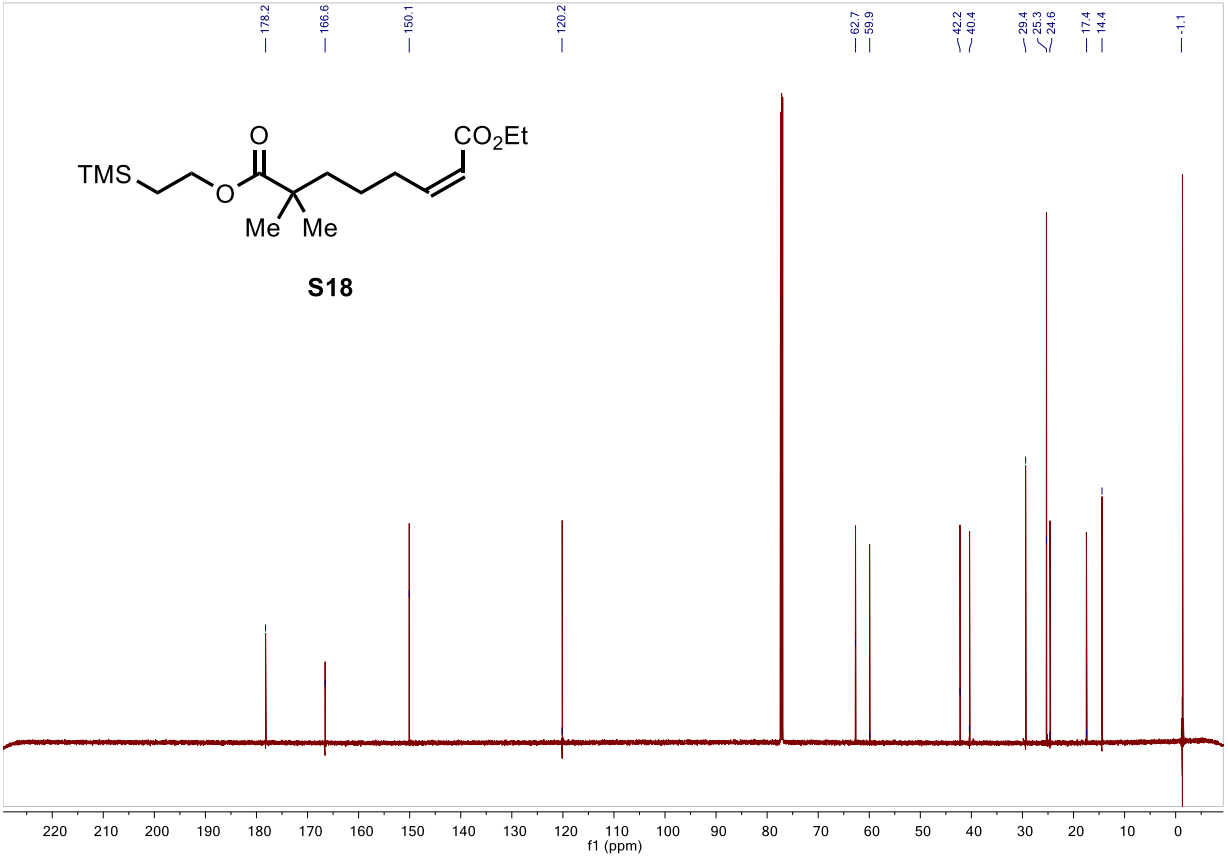
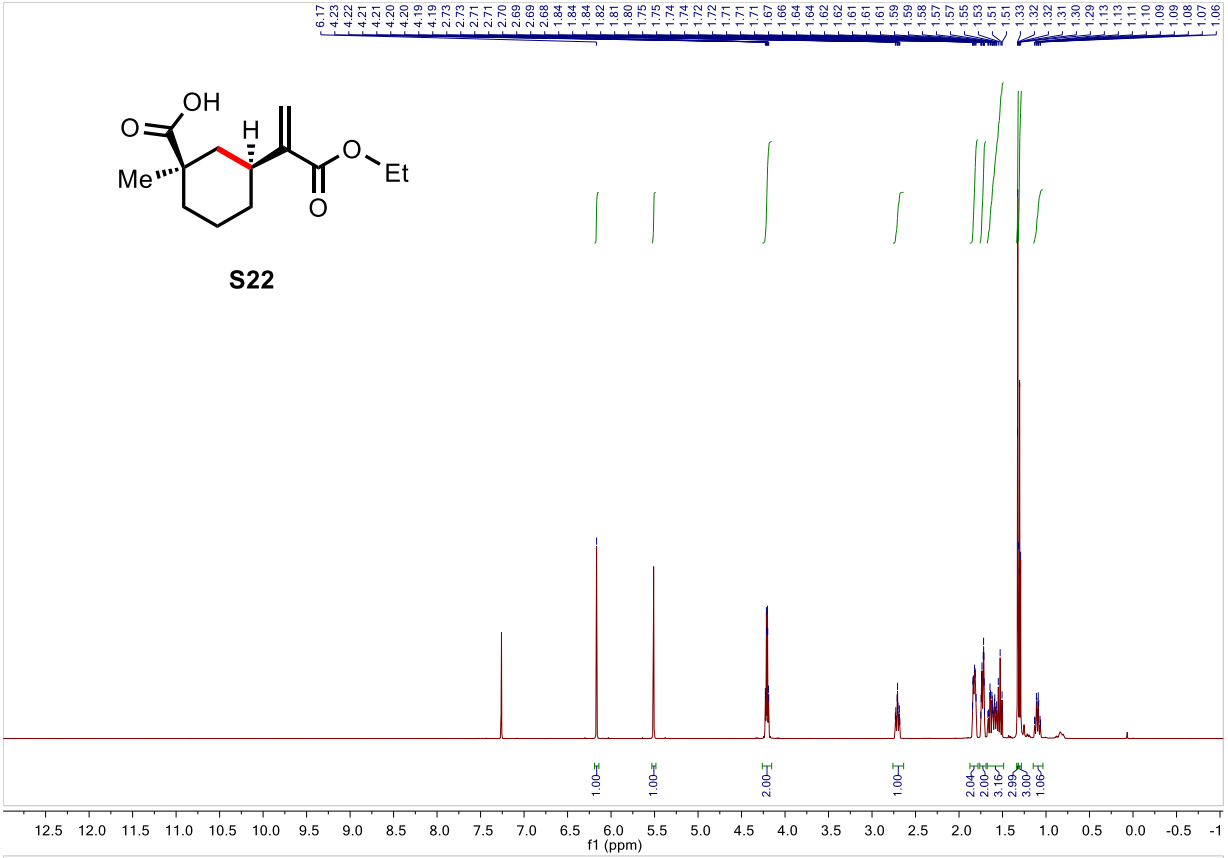
62.9
51.7
44.6
23.1
17.5
-1.2
f1 (ppm)


TMS
O
O
N
Ts
Me
Me
S15
f1 (ppm)

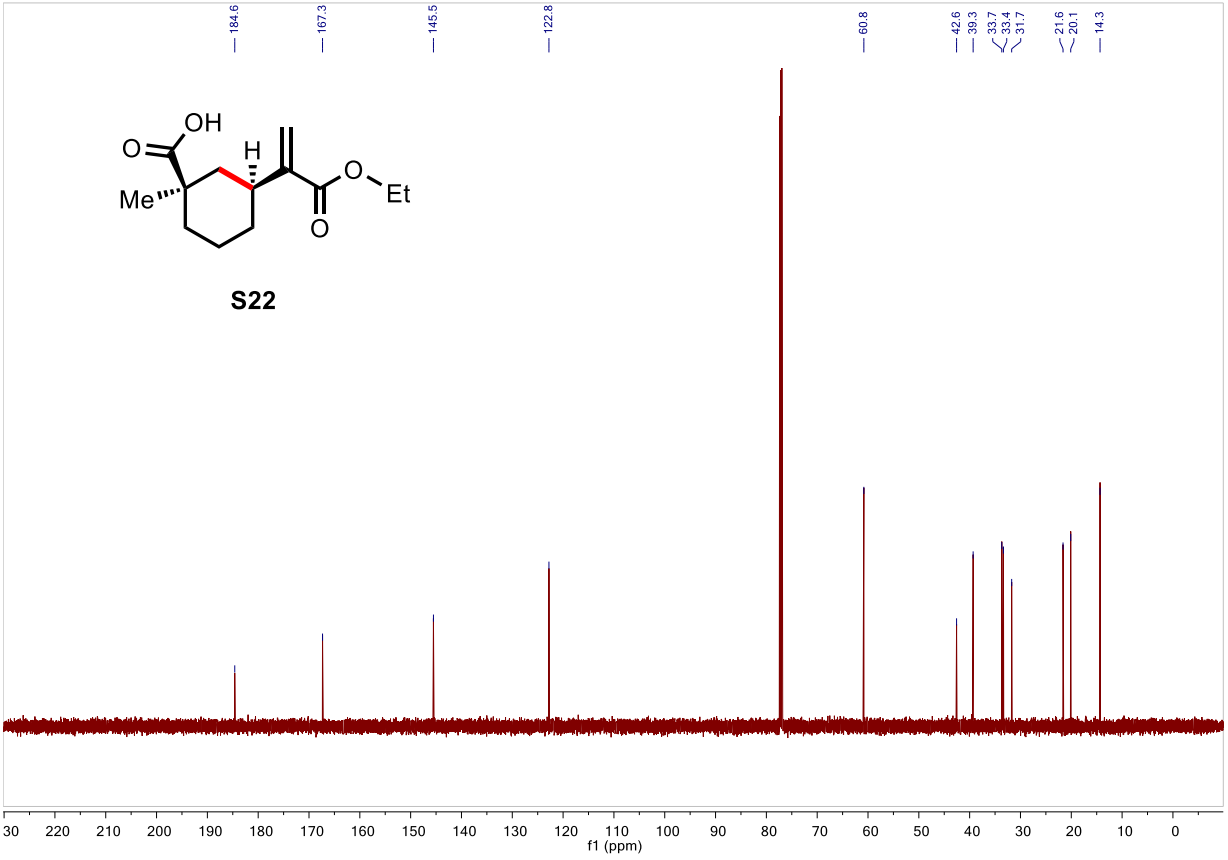

TMS
O
O
N
Ts
Me
Me
S15
f1 (ppm)


TMS
O
O
Me
Me
CO2Et
S18
f1 (ppm)


TMS
O
O
Me
Me
CO2Et
S18
f1 (ppm)

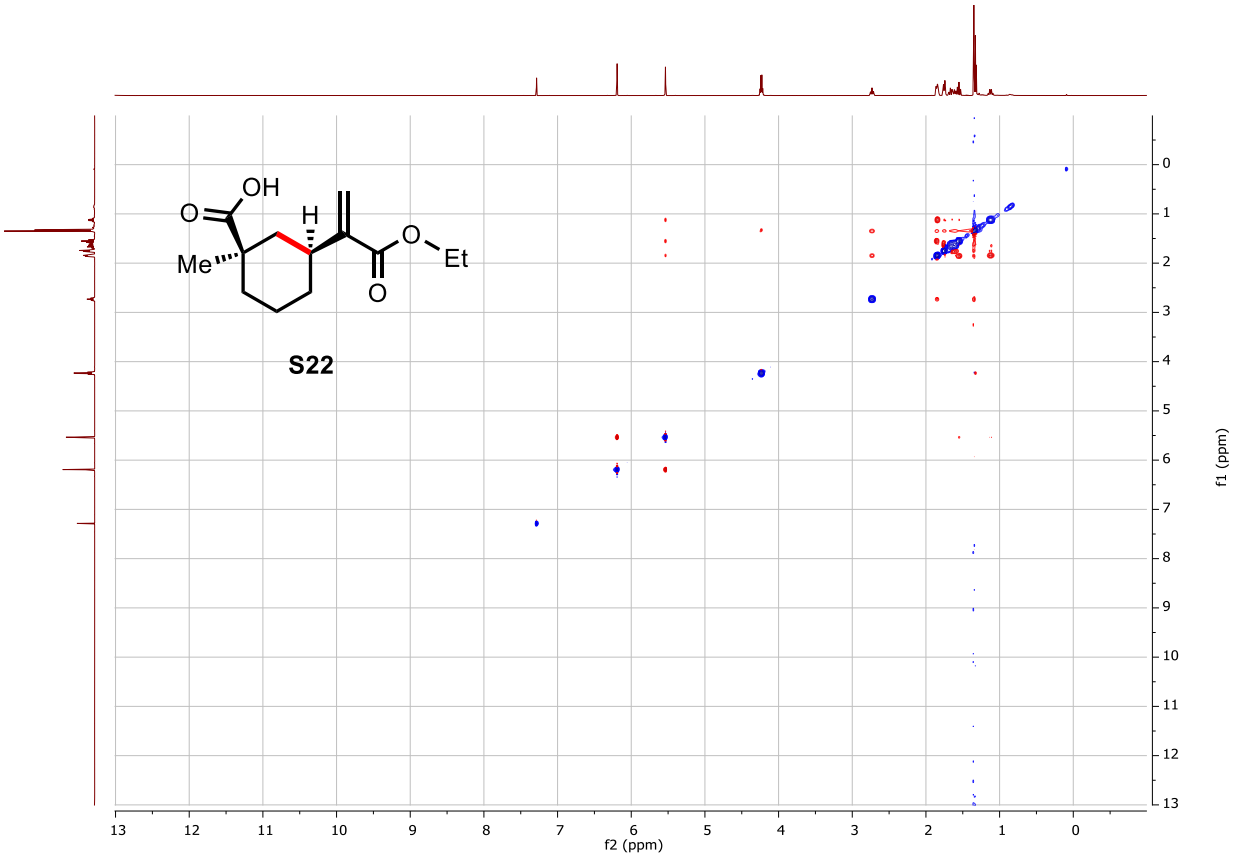


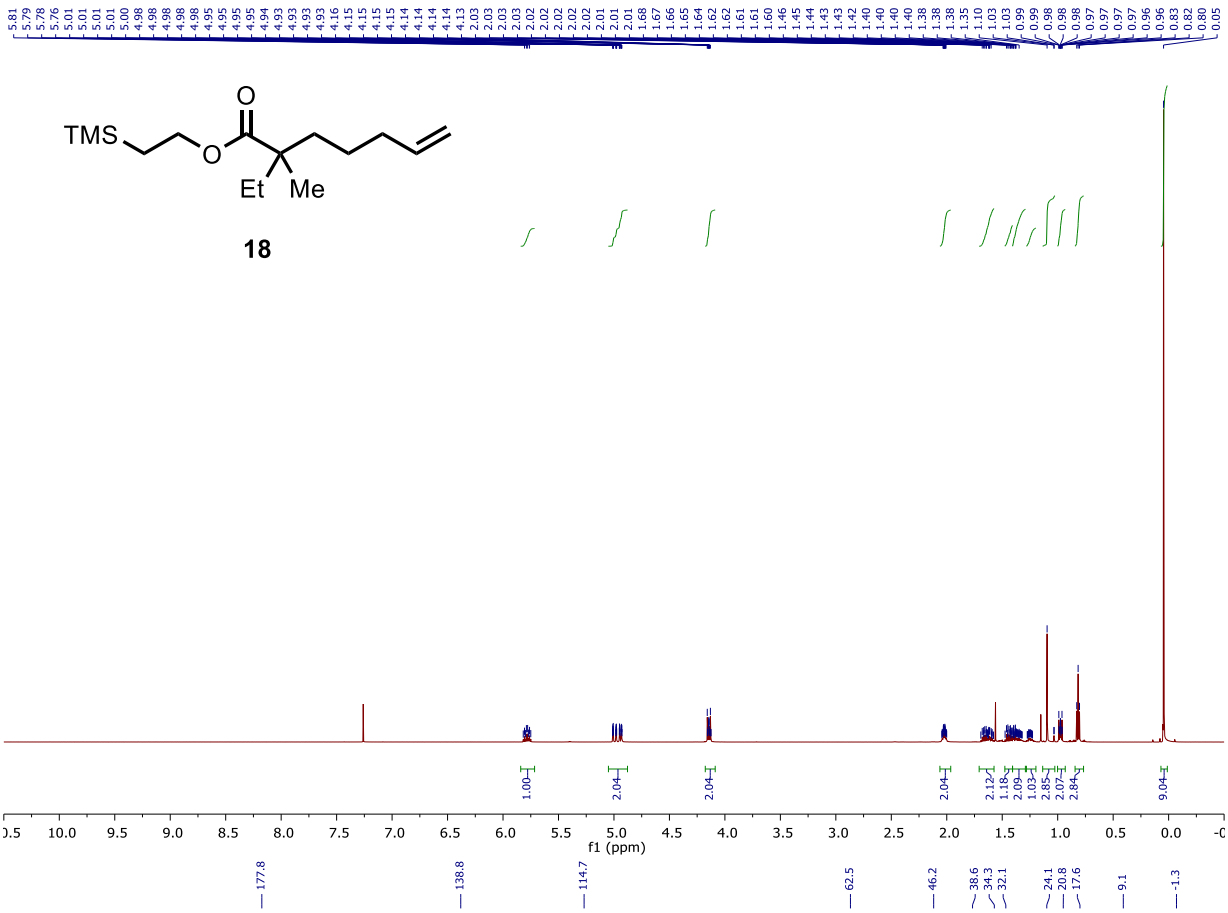
S22

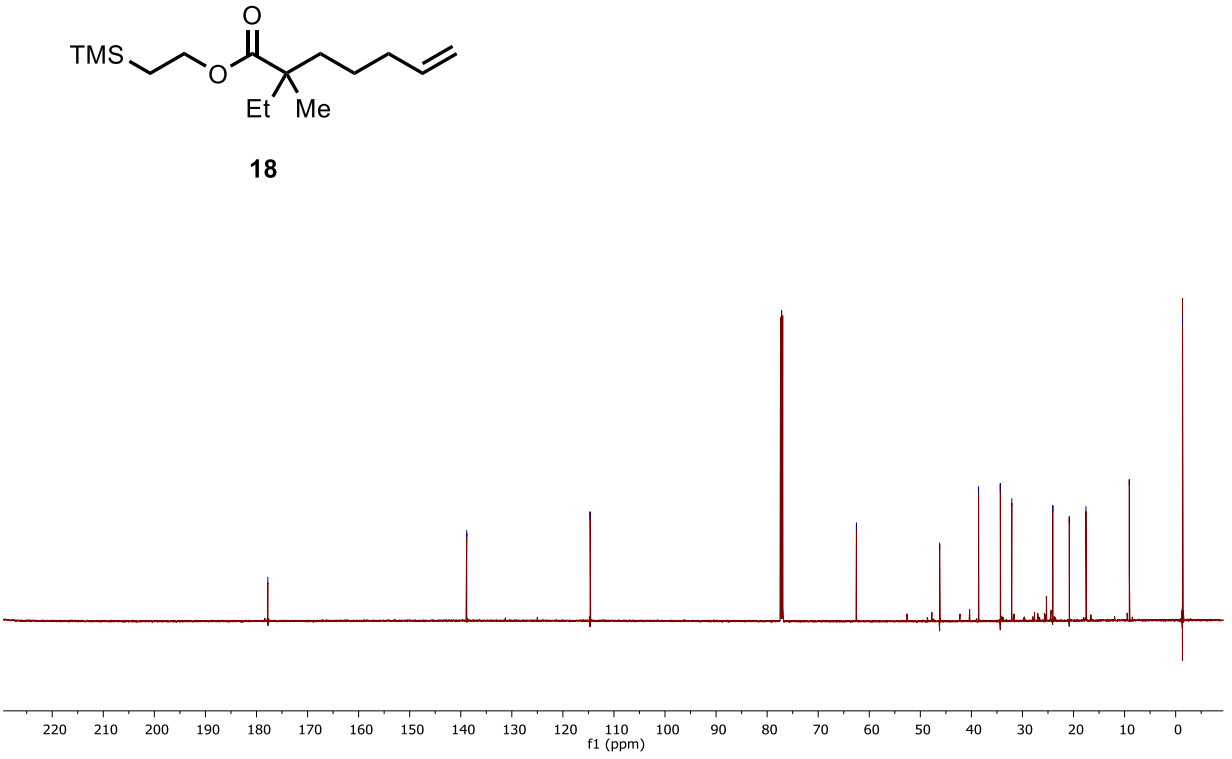


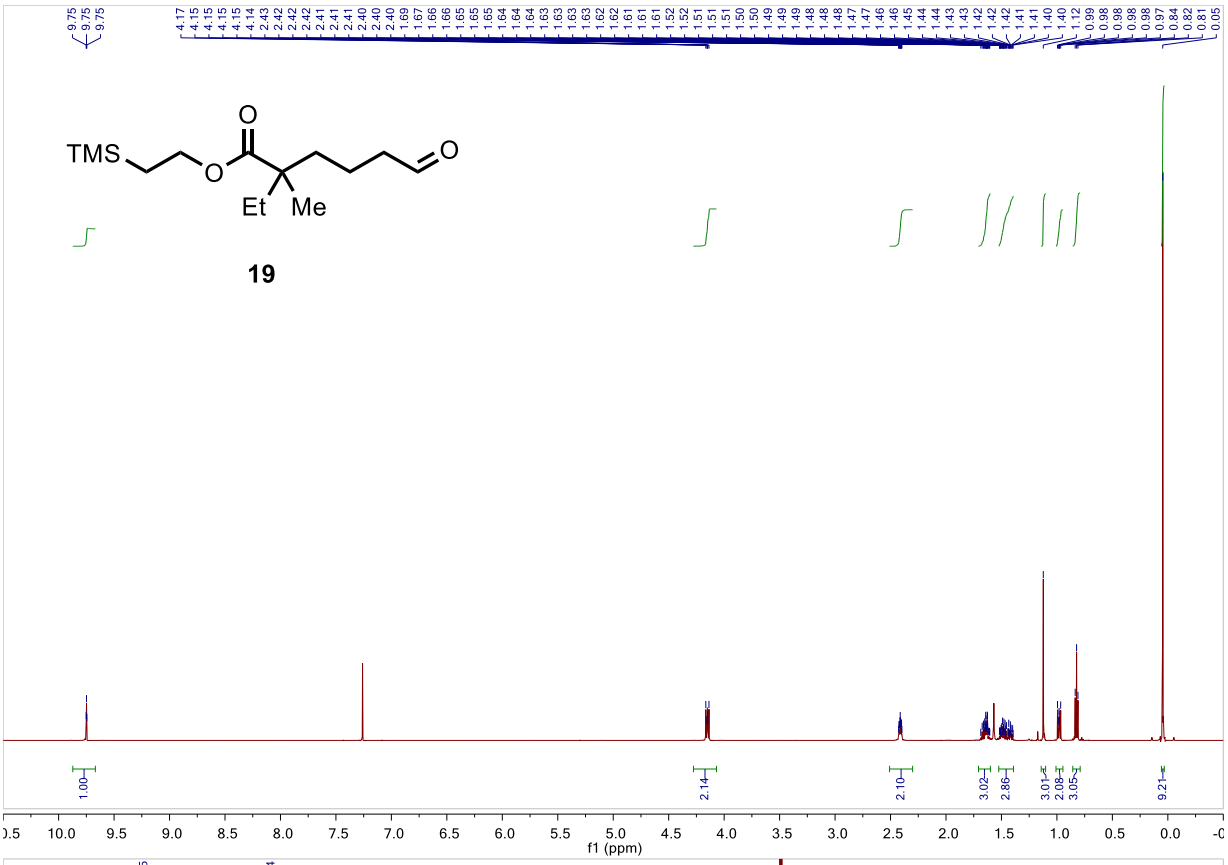
S22

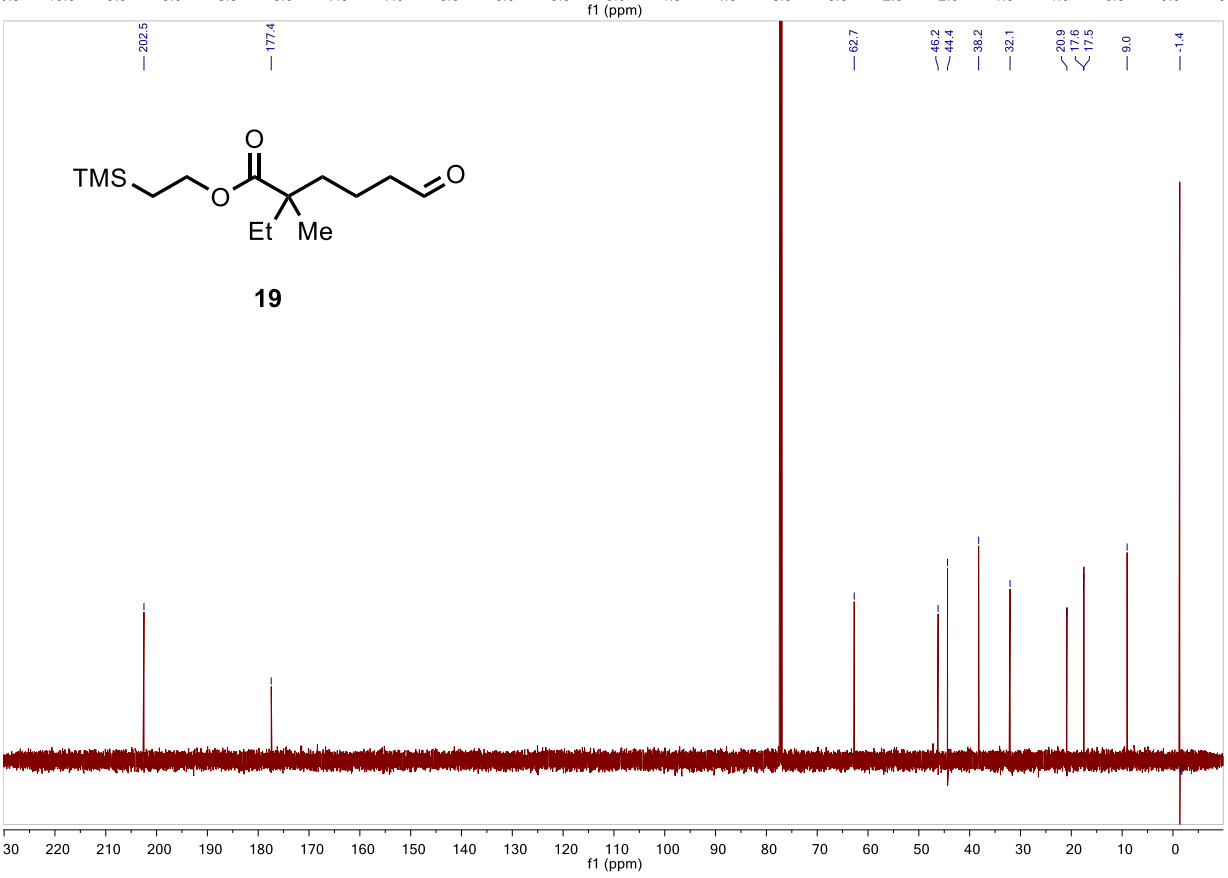
Noesy

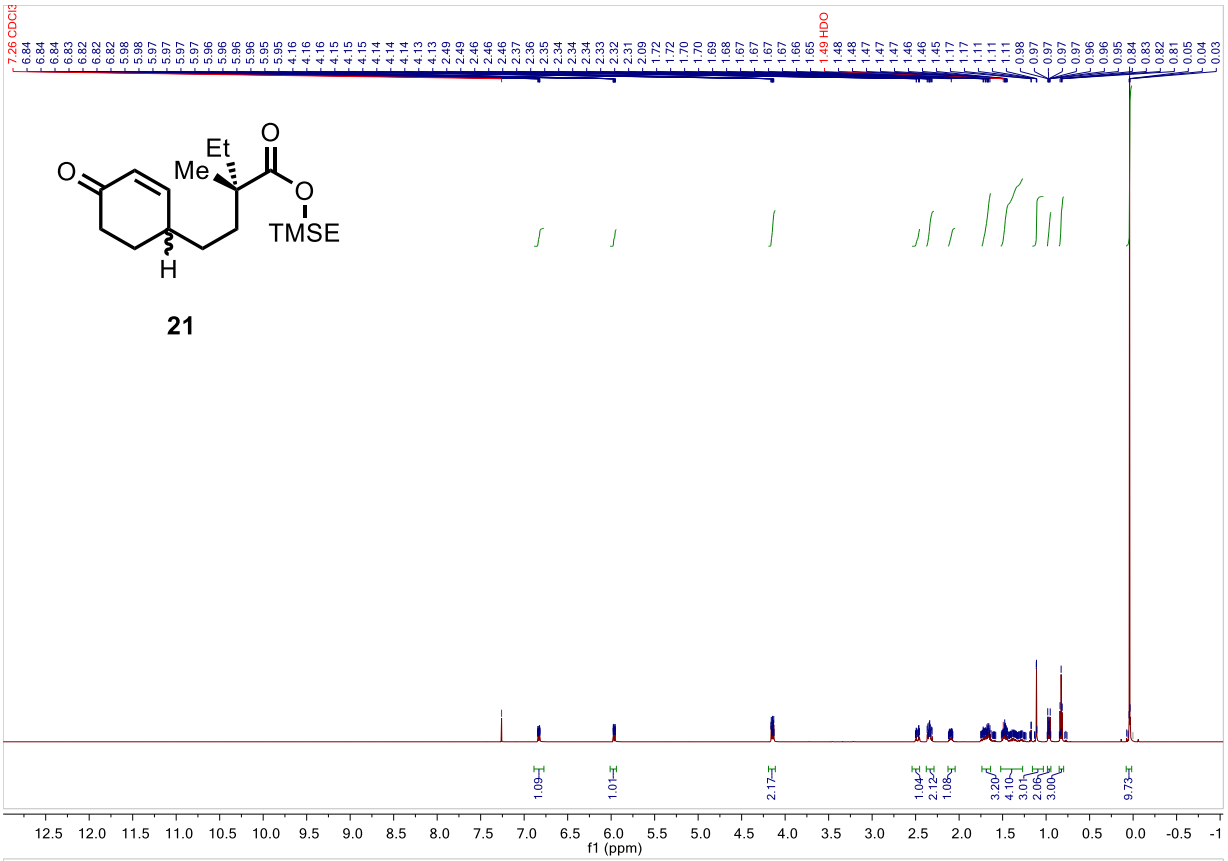



TMS
O
O
Et
Me
18
f1 (ppm)

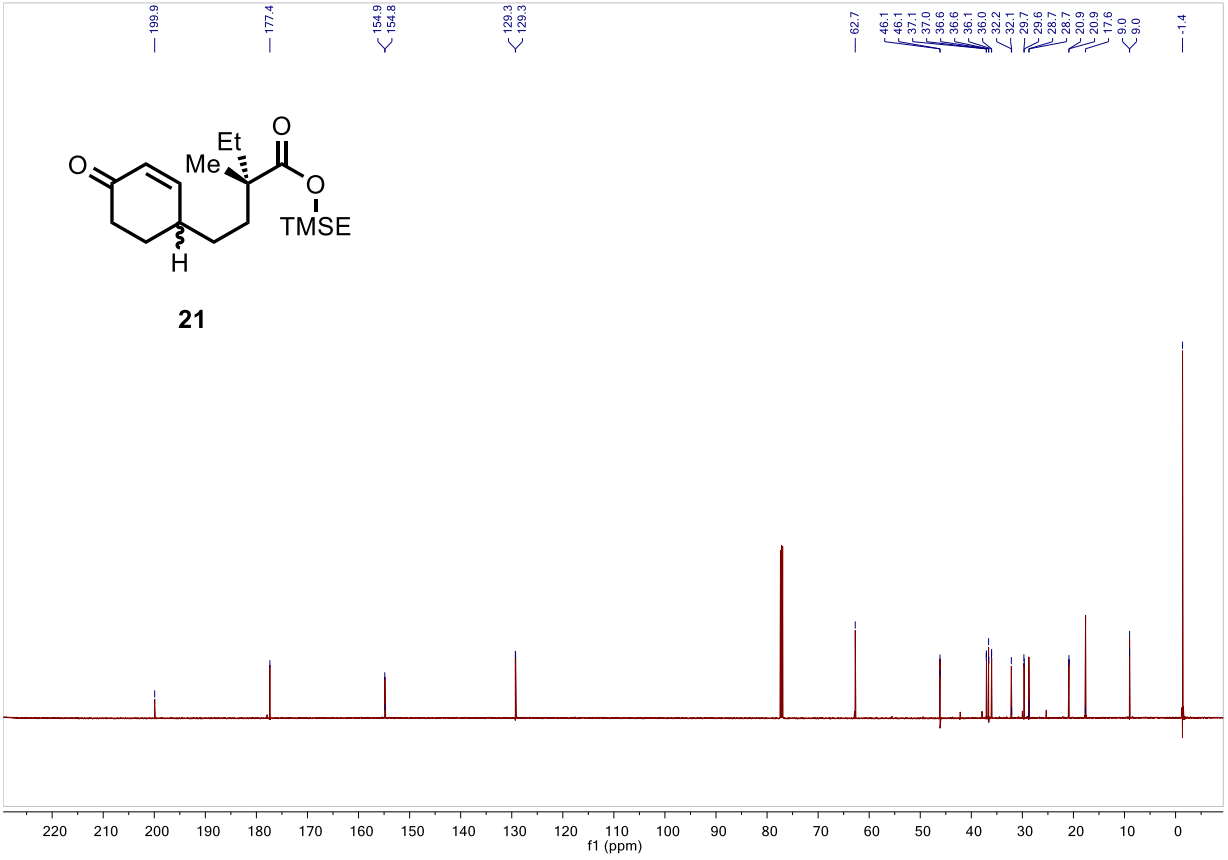

TMS
O
O
Et
Me
18
f1 (ppm)


TMS
O
O
O
Et
Me
19
f1 (ppm)

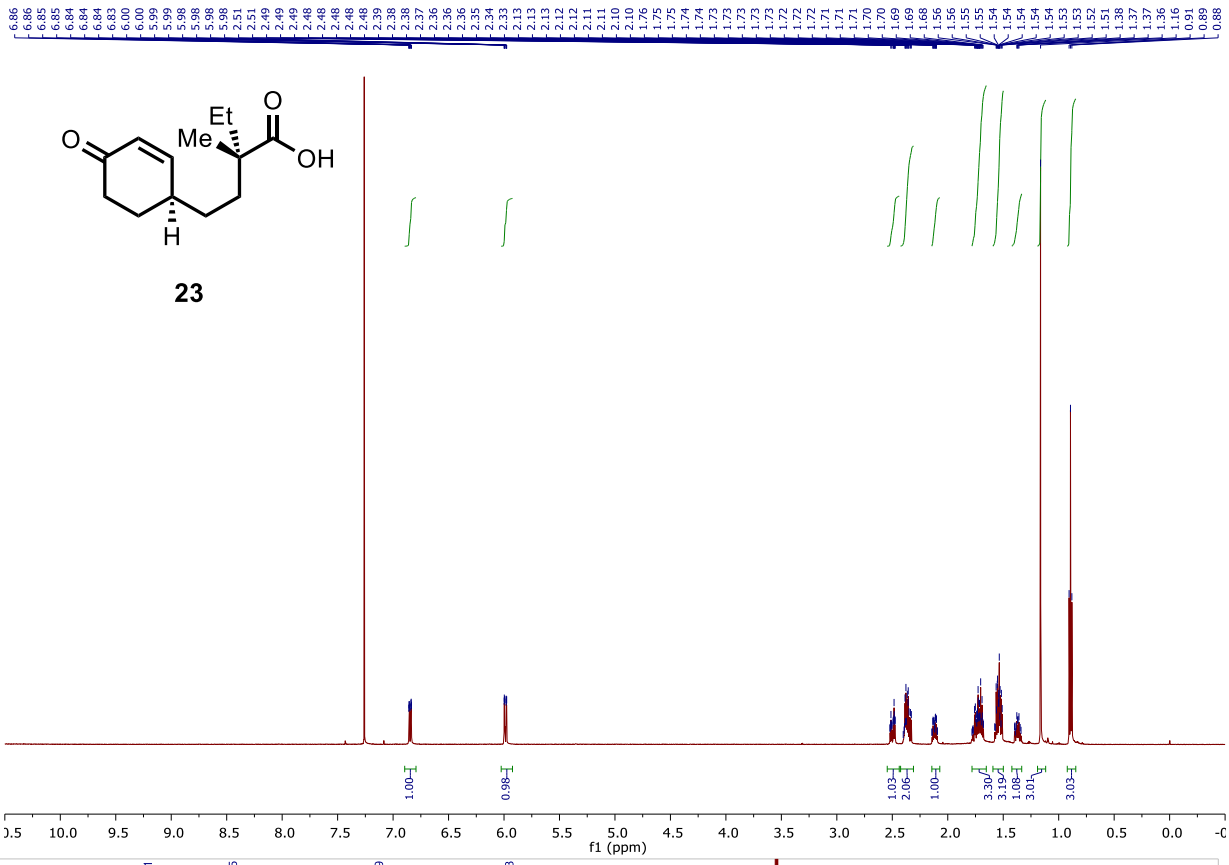

TMS
O
O
O
Et
Me
19
f1 (ppm)

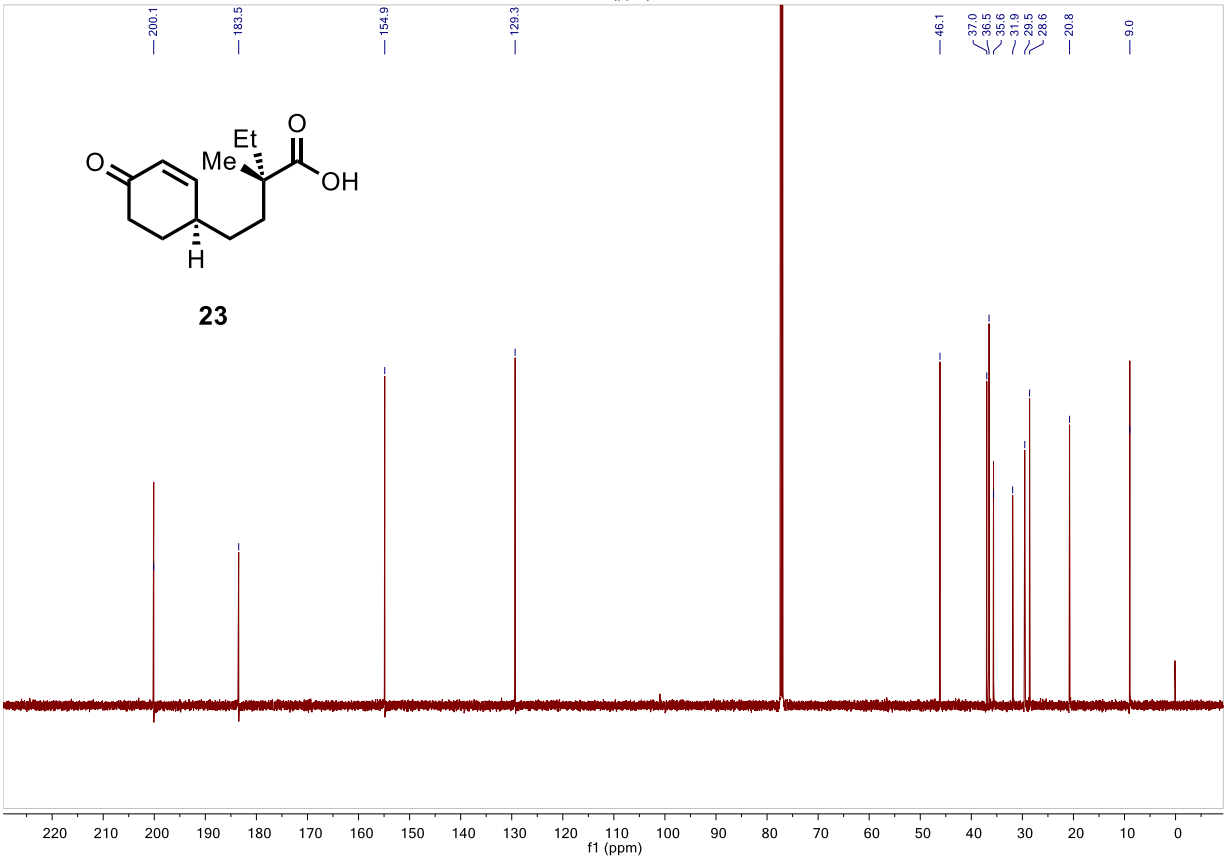


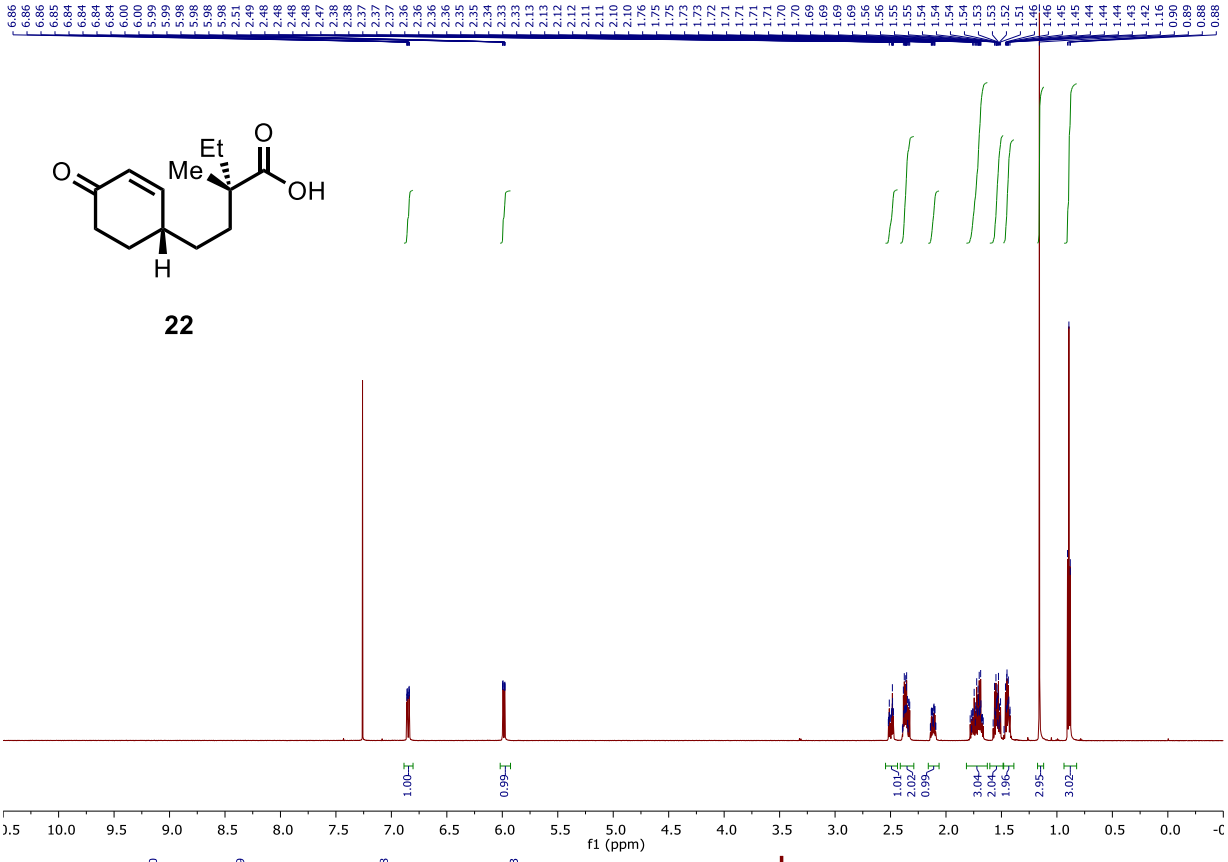
21

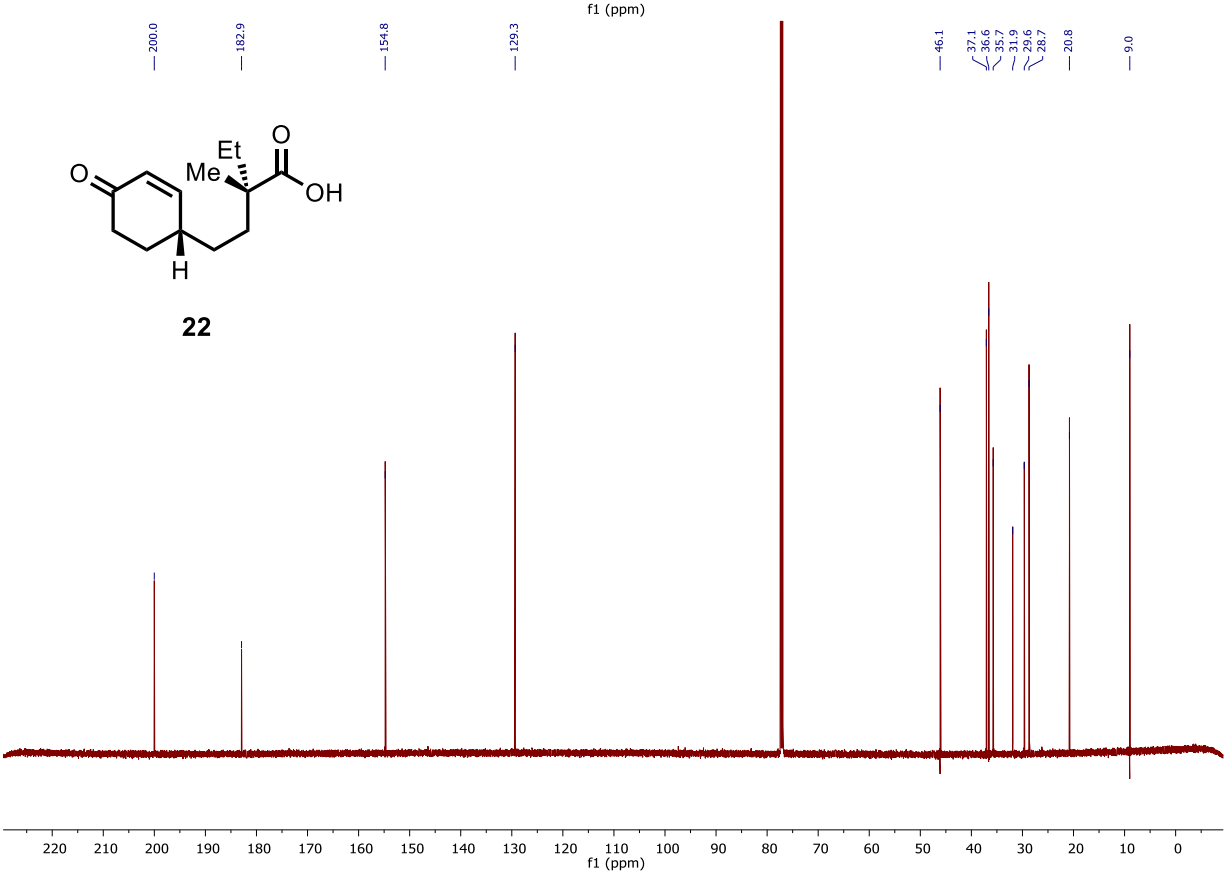


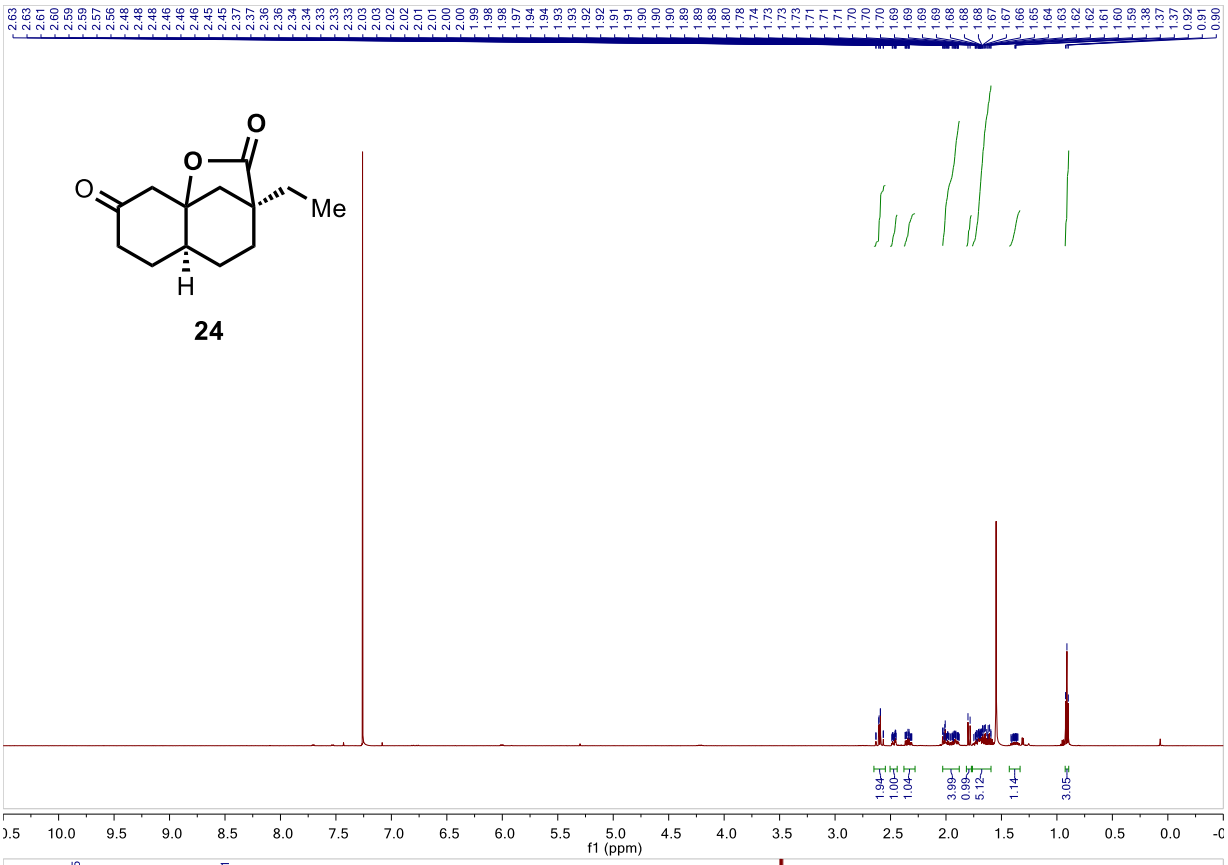
21

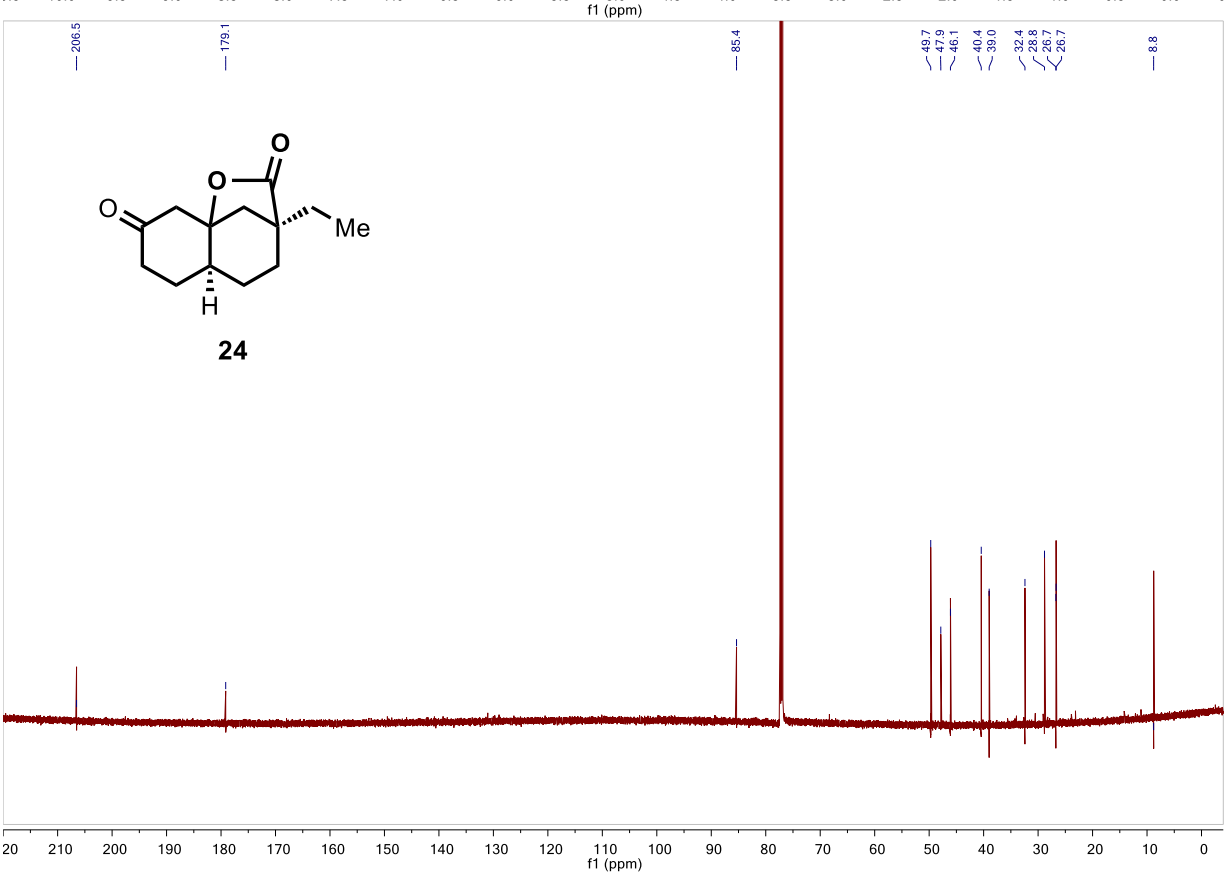

Et
Me
O
OH
O
H
23
f1 (ppm)

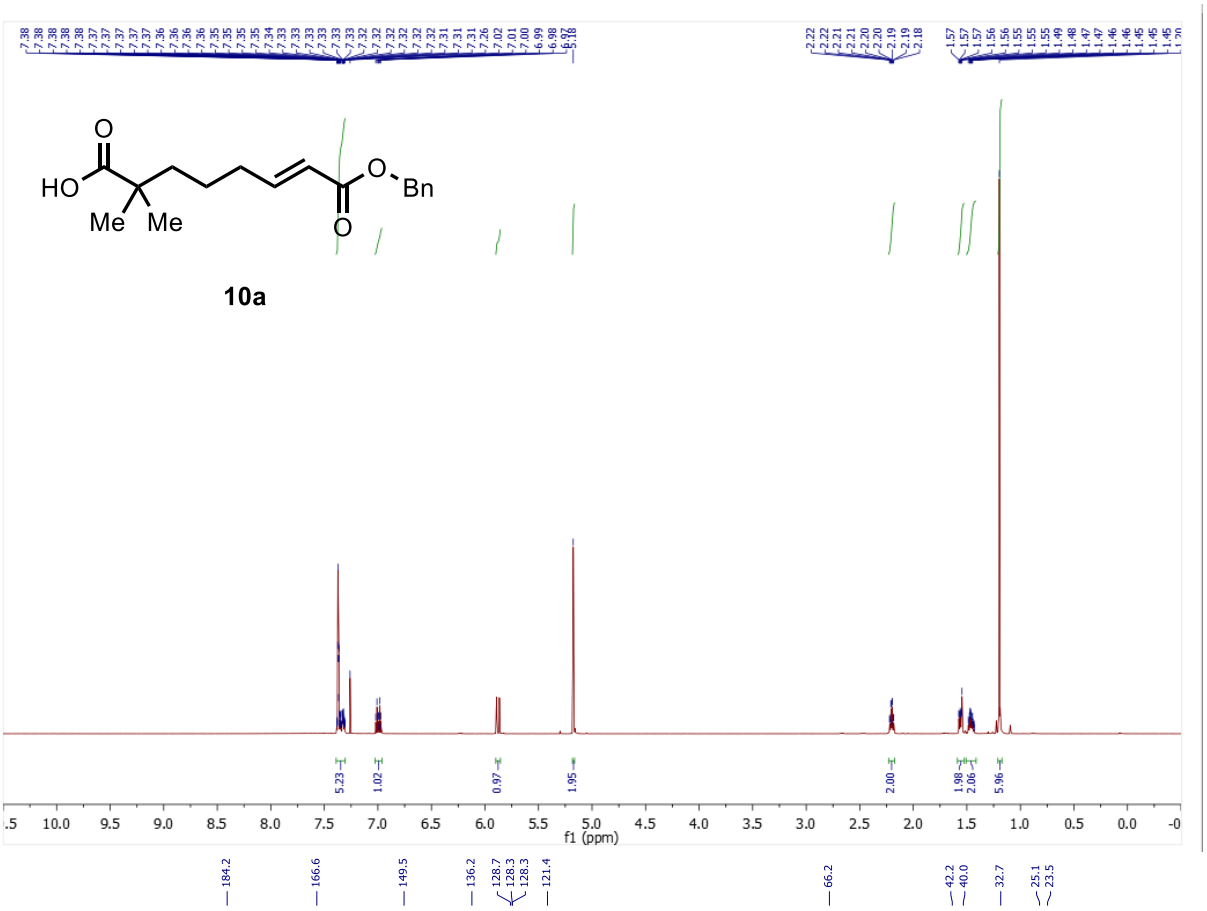

200.1
183.5
154.9
129.3
46.1
37.0
36.5
35.6
31.9
29.5
28.6
20.8
9.0
Et
Me
O
OH
O
H
23
f1 (ppm)


Et
Me
O
OH
O
H
22
f1 (ppm)

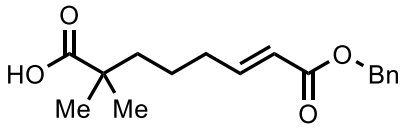

200.0
182.9
154.8
129.3
46.1
37.1
36.6
35.7
31.9
29.6
28.7
20.8
9.0
Et
Me
O
OH
O
H
22
f1 (ppm)


O
O
O
Me
H
24
1.94
1.00
1.04
3.99
0.99
5.12
1.14
3.05
f1 (ppm)

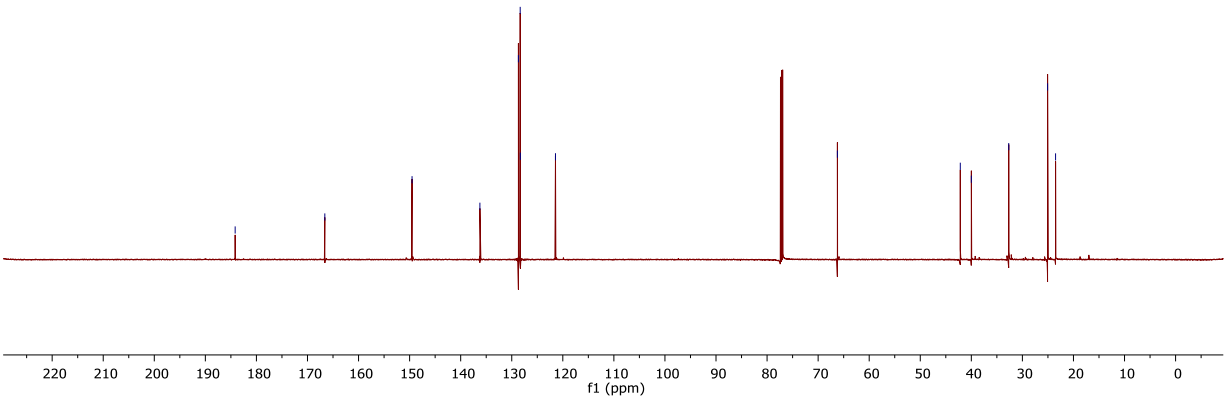

206.5
179.1
85.4
49.7
47.9
46.1
40.4
39.0
32.4
28.8
26.7
26.7
8.8
O
O
O
Me
H
24
f1 (ppm)

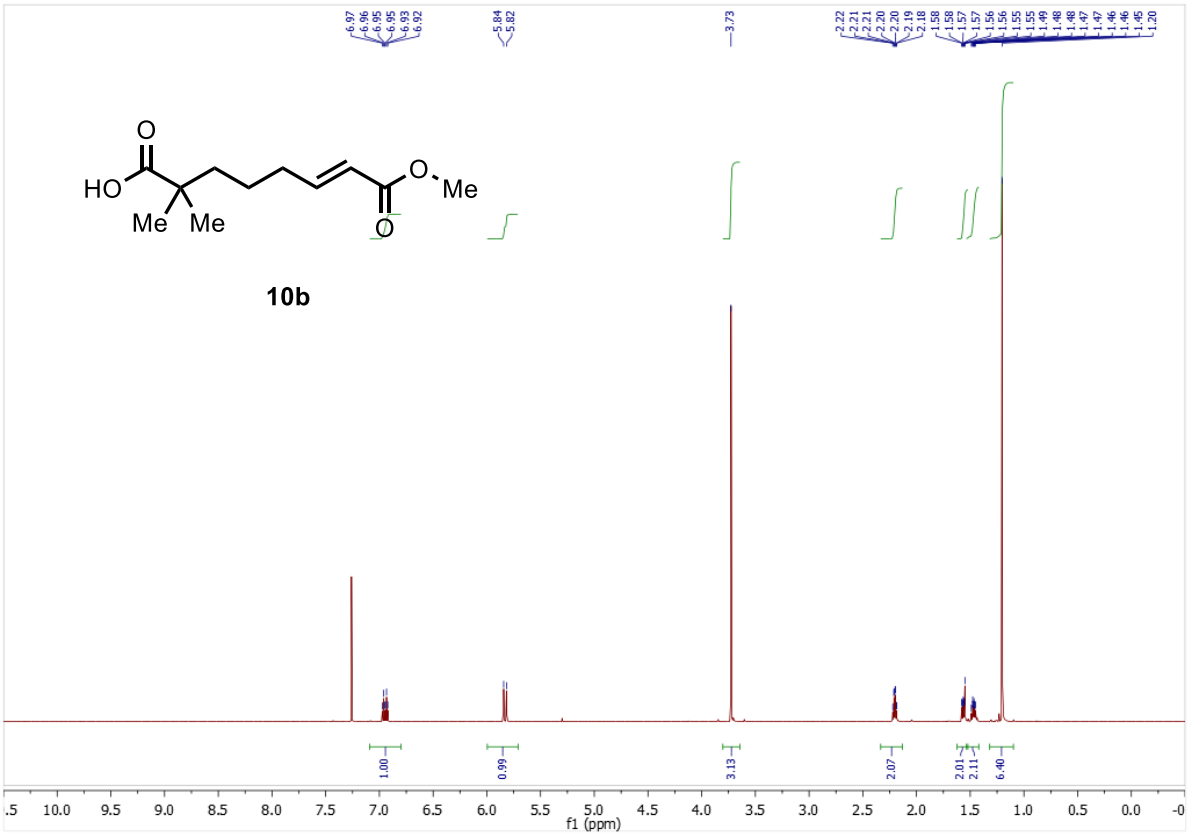


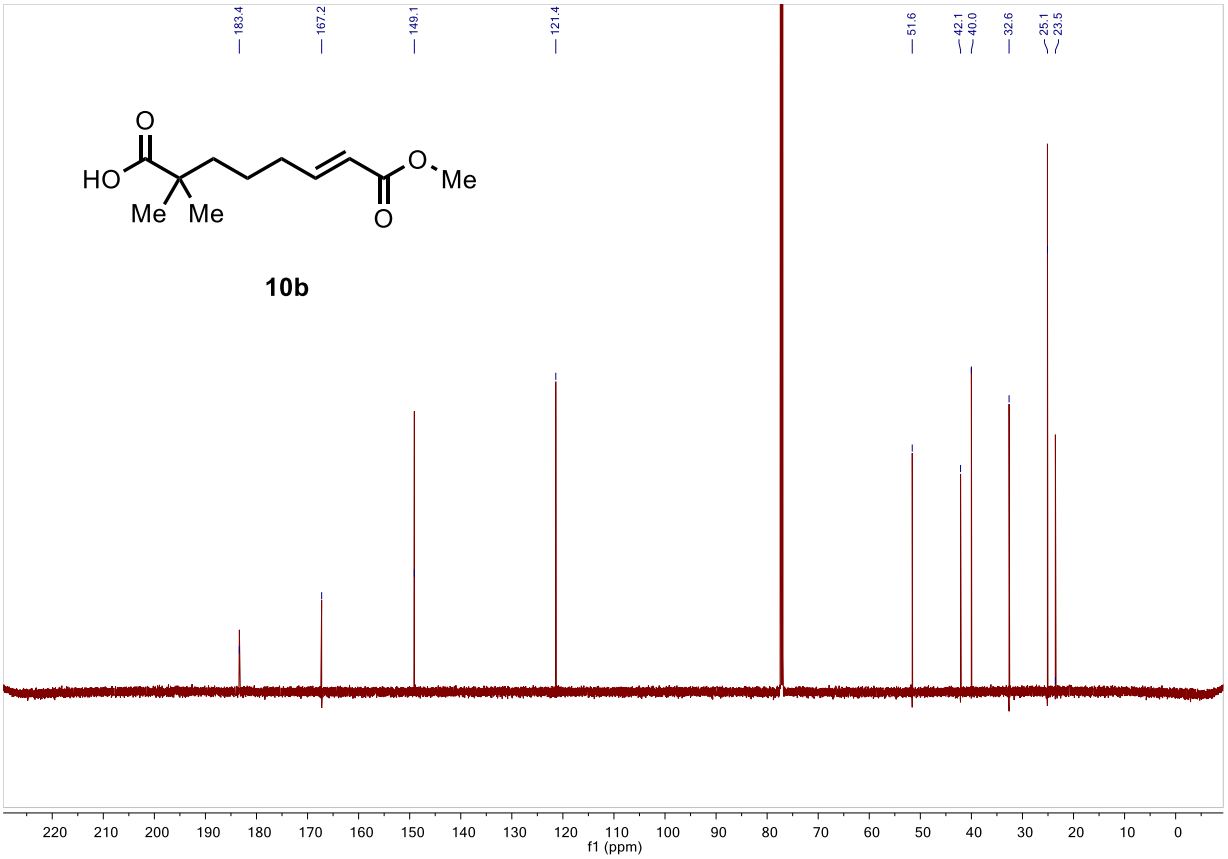
10a

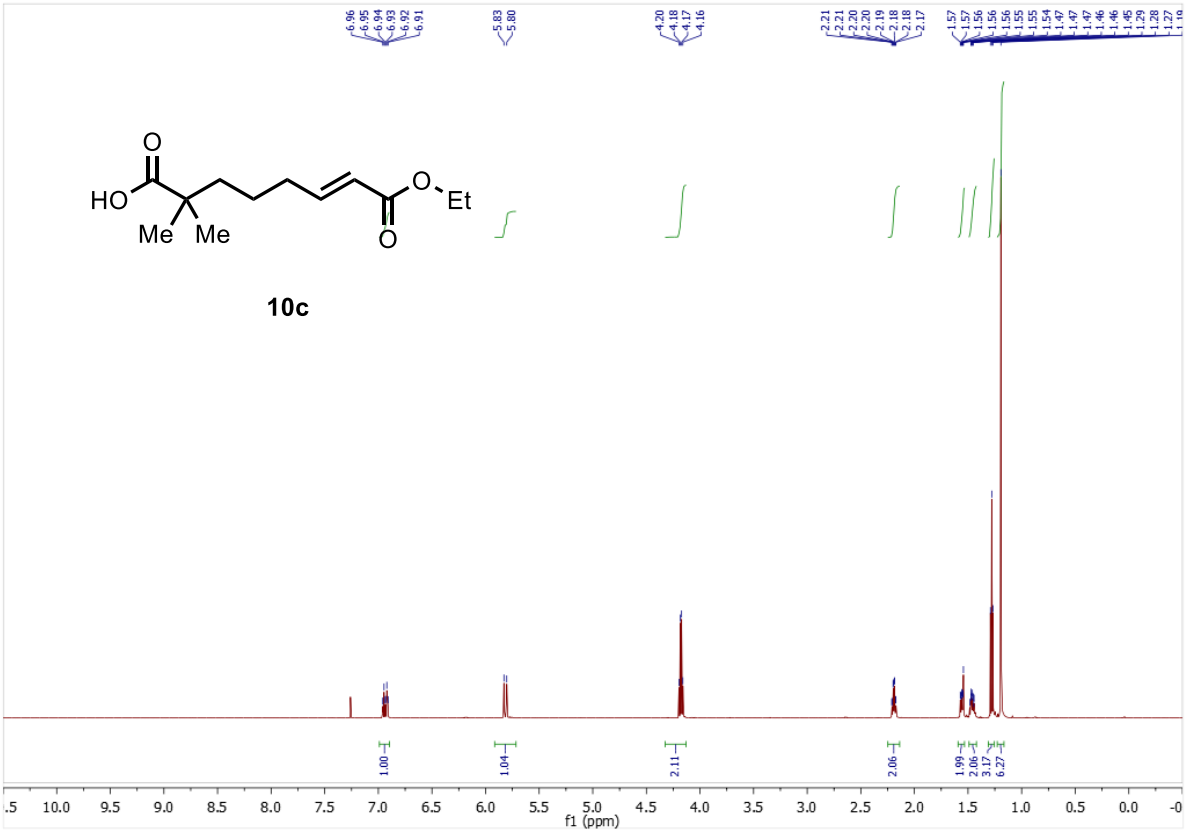


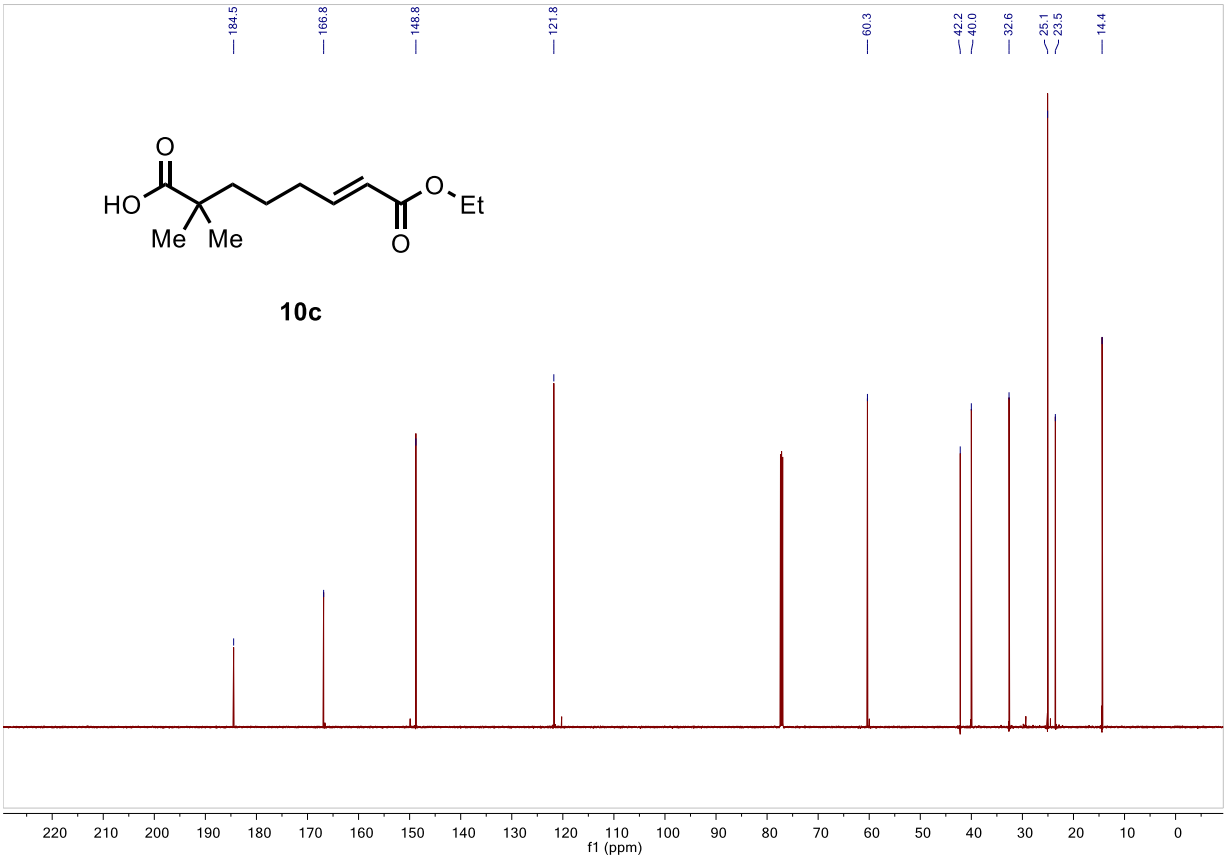
10a

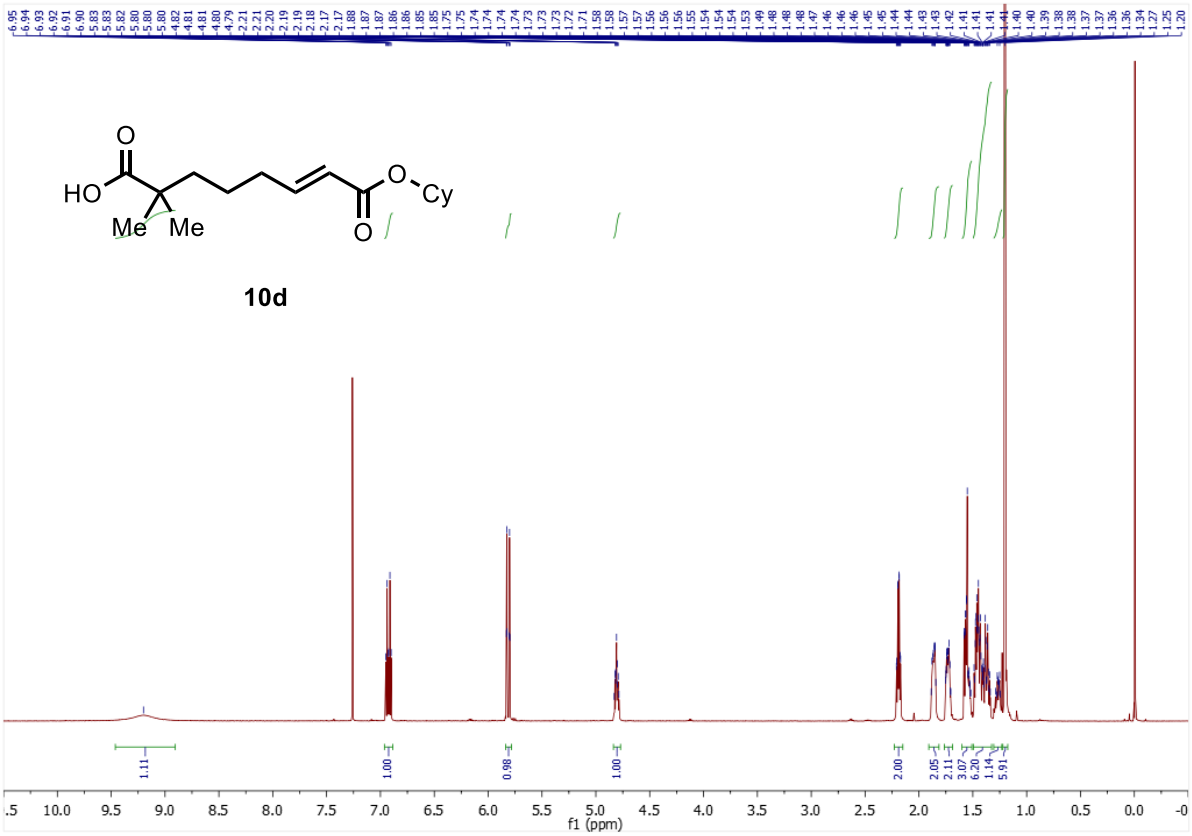


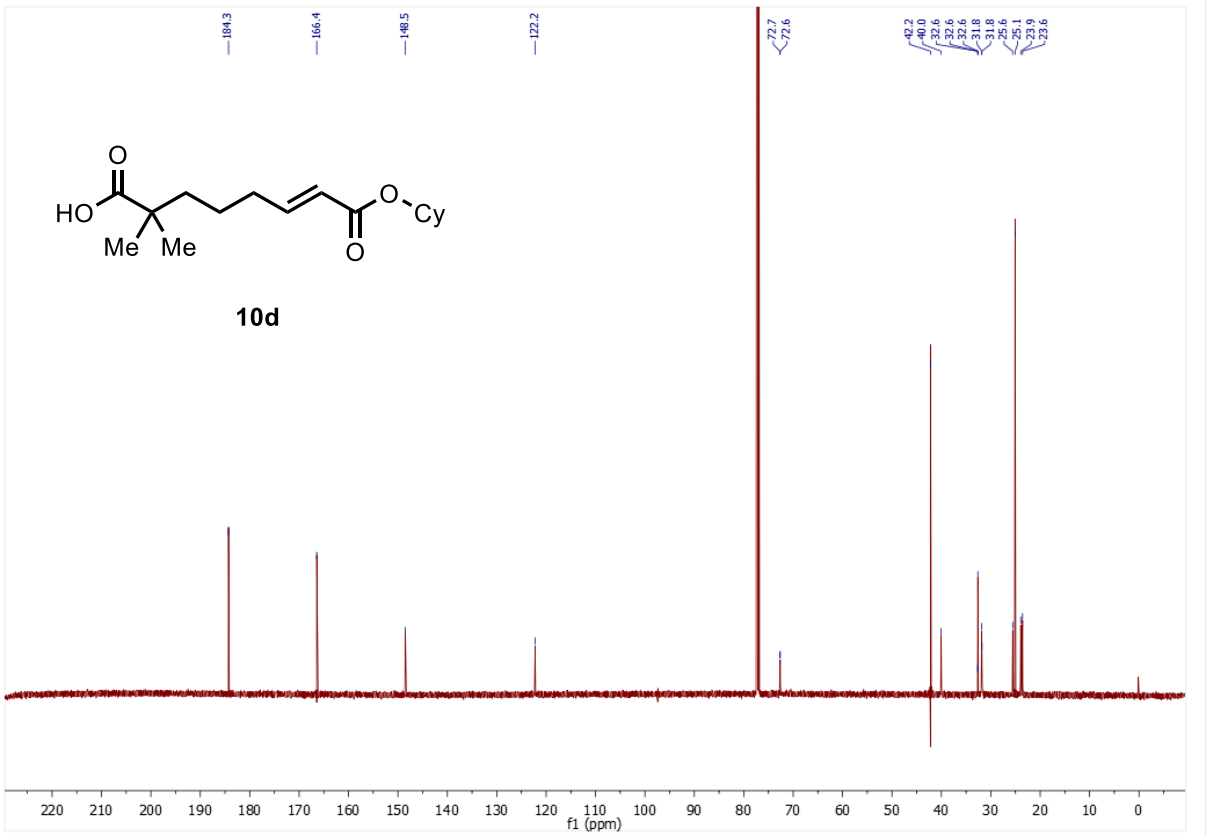

HO
O
Me
Me
O
O
Me
10b
f1 (ppm)

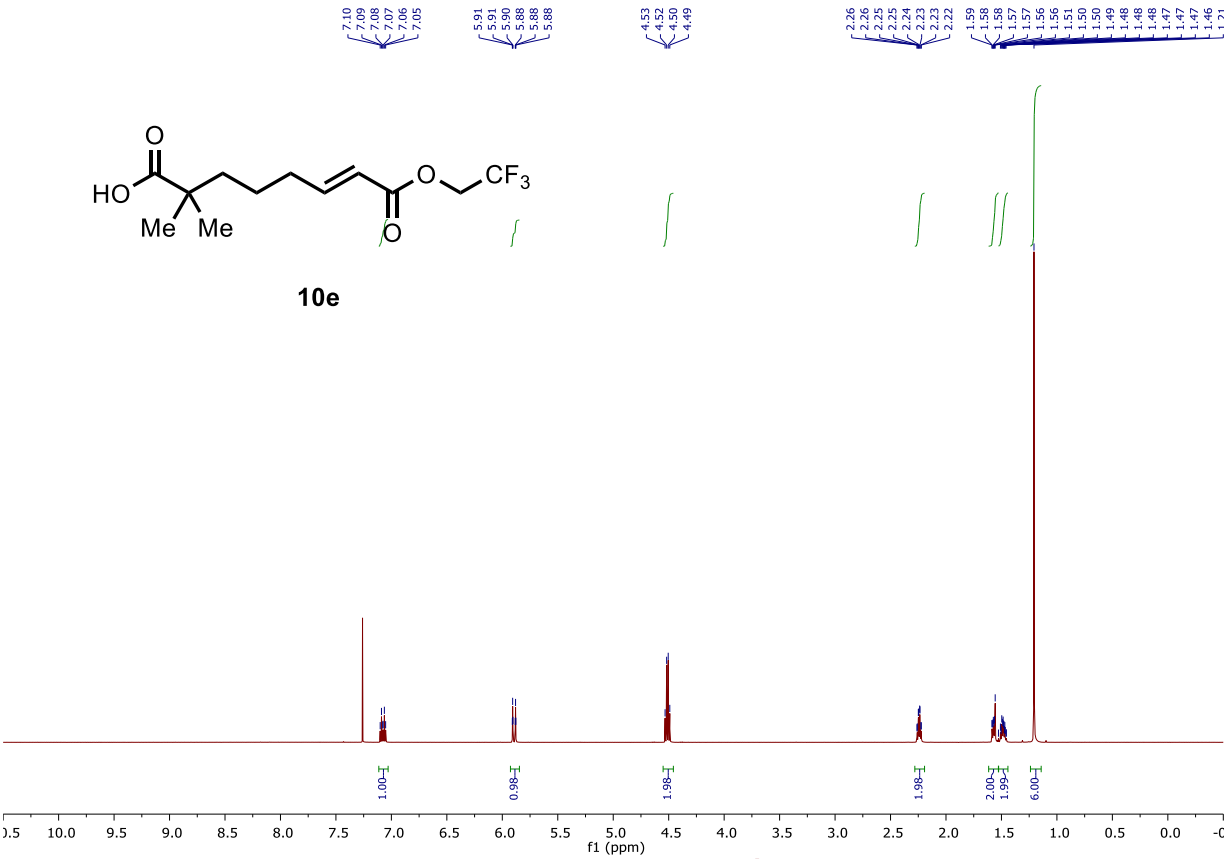

HO
O
Me
Me
O
O
Me
10b
f1 (ppm)


HO
O
Me
Me
O
Et
O
10c
f1 (ppm)

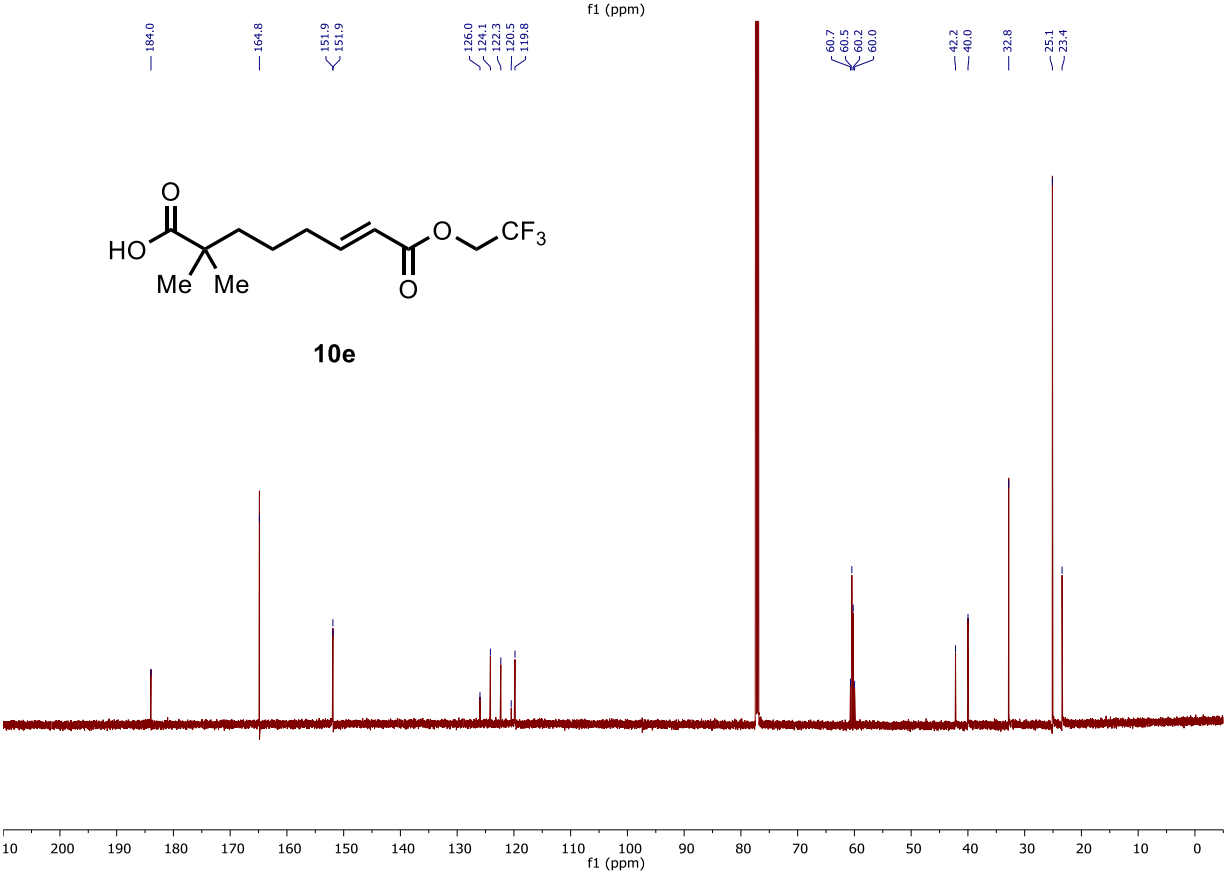

HO
O
Me
Me
O
Et
O
10c
f1 (ppm)


HO
O
Me
Me
O
O
Cy
10d
1.11
1.00
0.98
1.00
2.00
2.05
2.11
3.07
6.20
1.14
5.91
f1 (ppm)

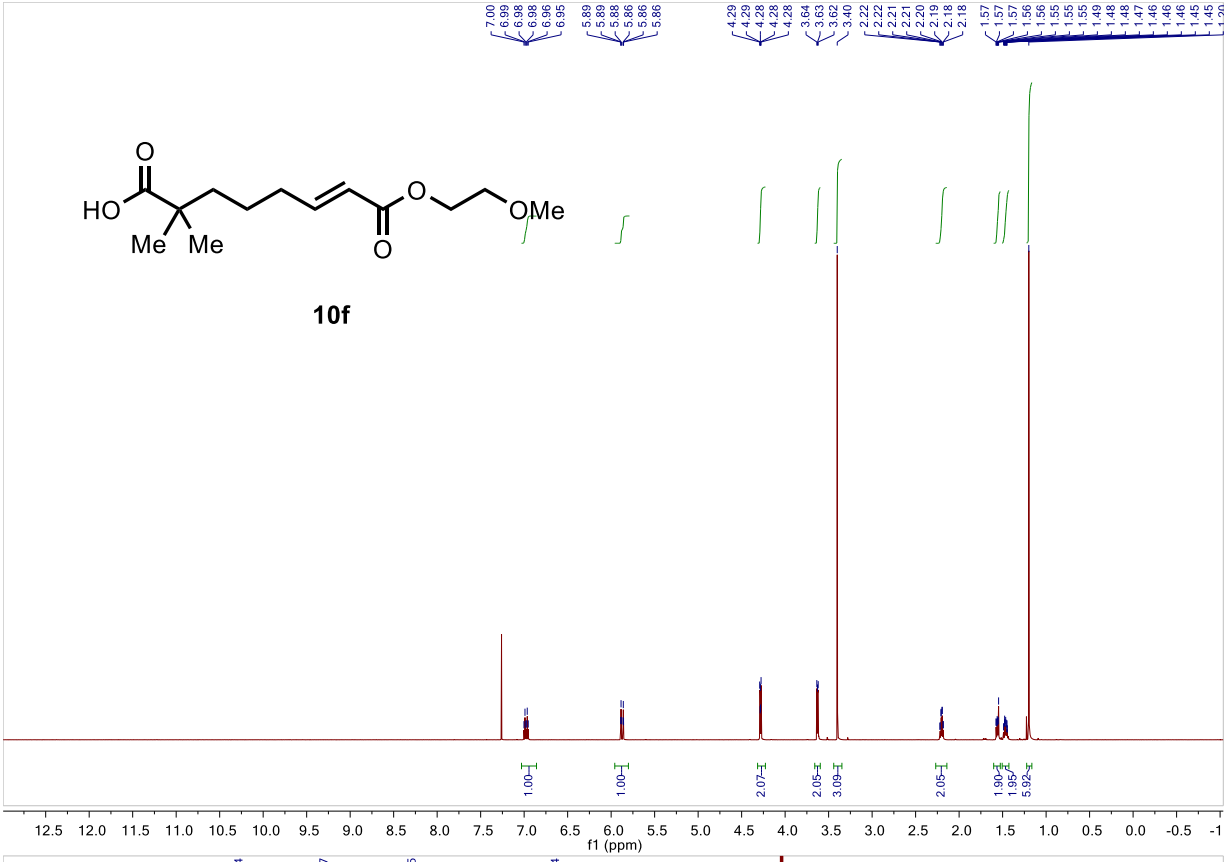

184.3
166.4
148.5
122.2
72.7
72.6
42.2
40.0
32.6
32.6
32.6
31.8
25.6
25.1
23.9
23.6
HO
O
Me
Me
O
O
Cy
10d
f1 (ppm)

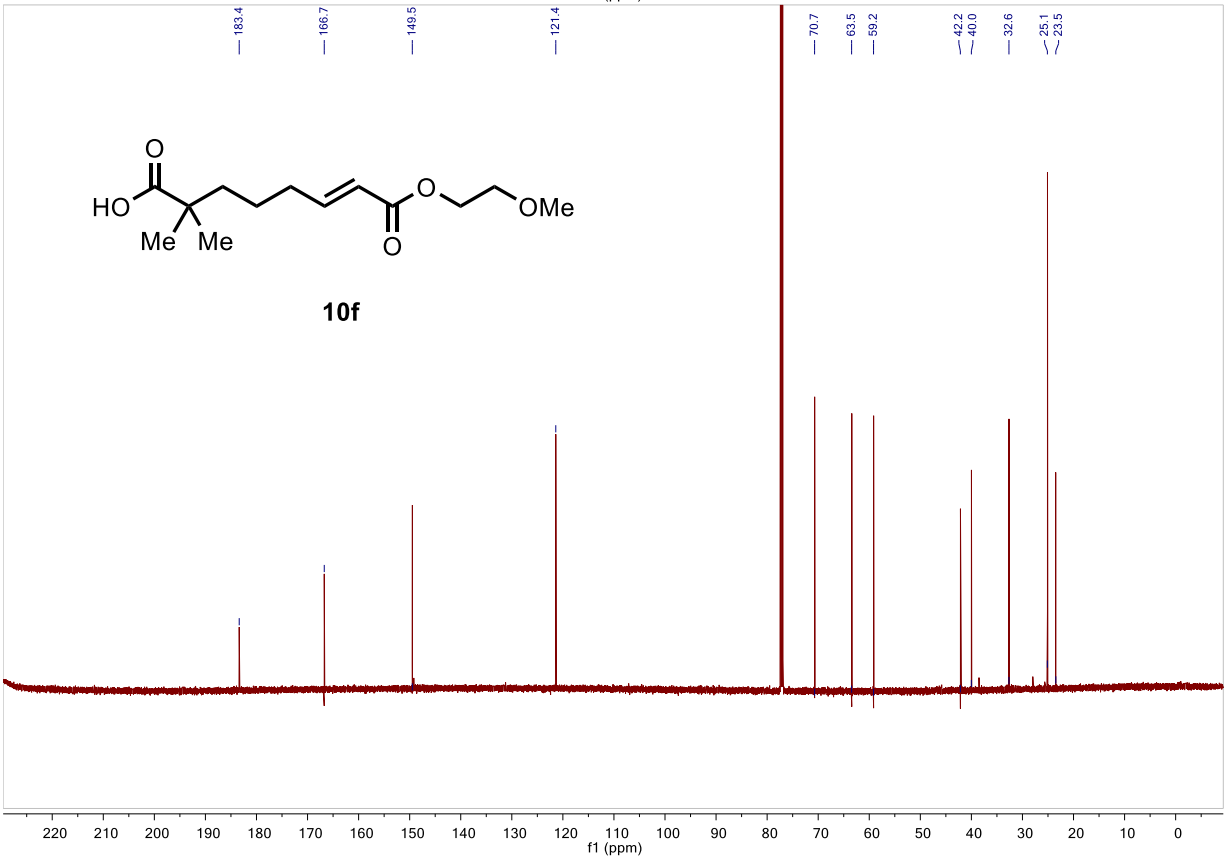


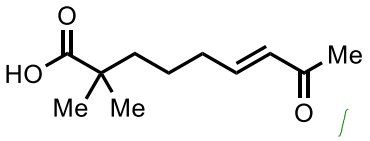
10e



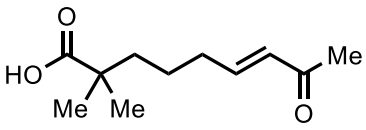
10e


HO
Me Me
O
O
O
OMe
10f
f1 (ppm)

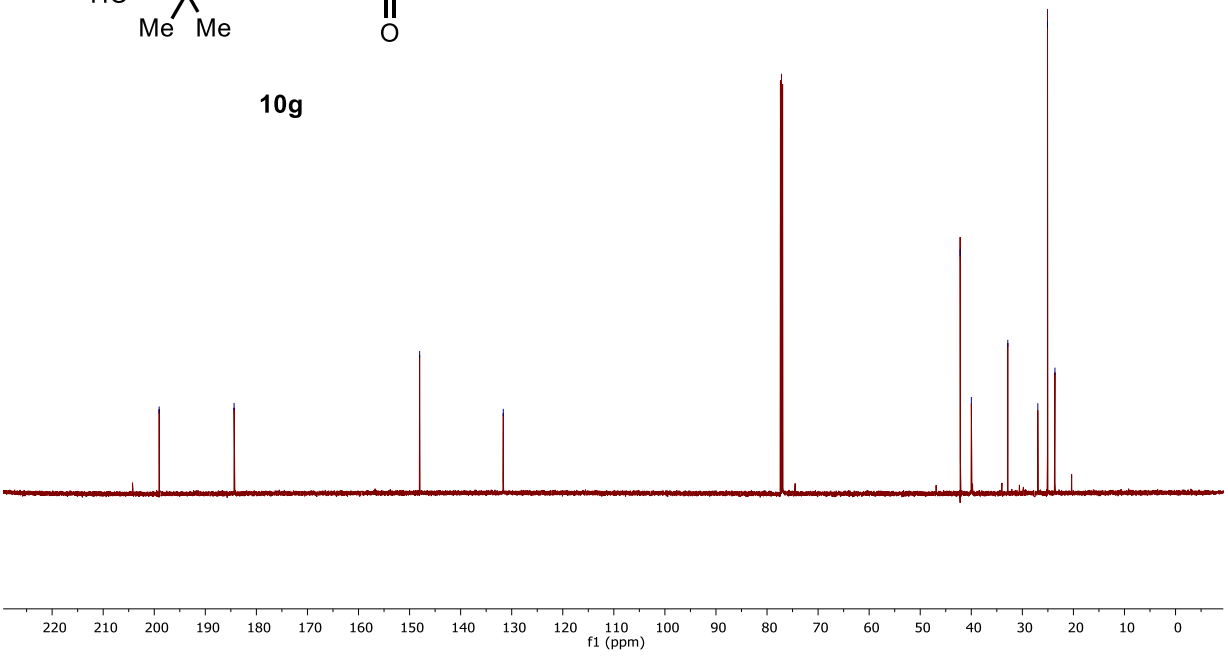

HO
Me Me
O
O
O
OMe
10f
f1 (ppm)

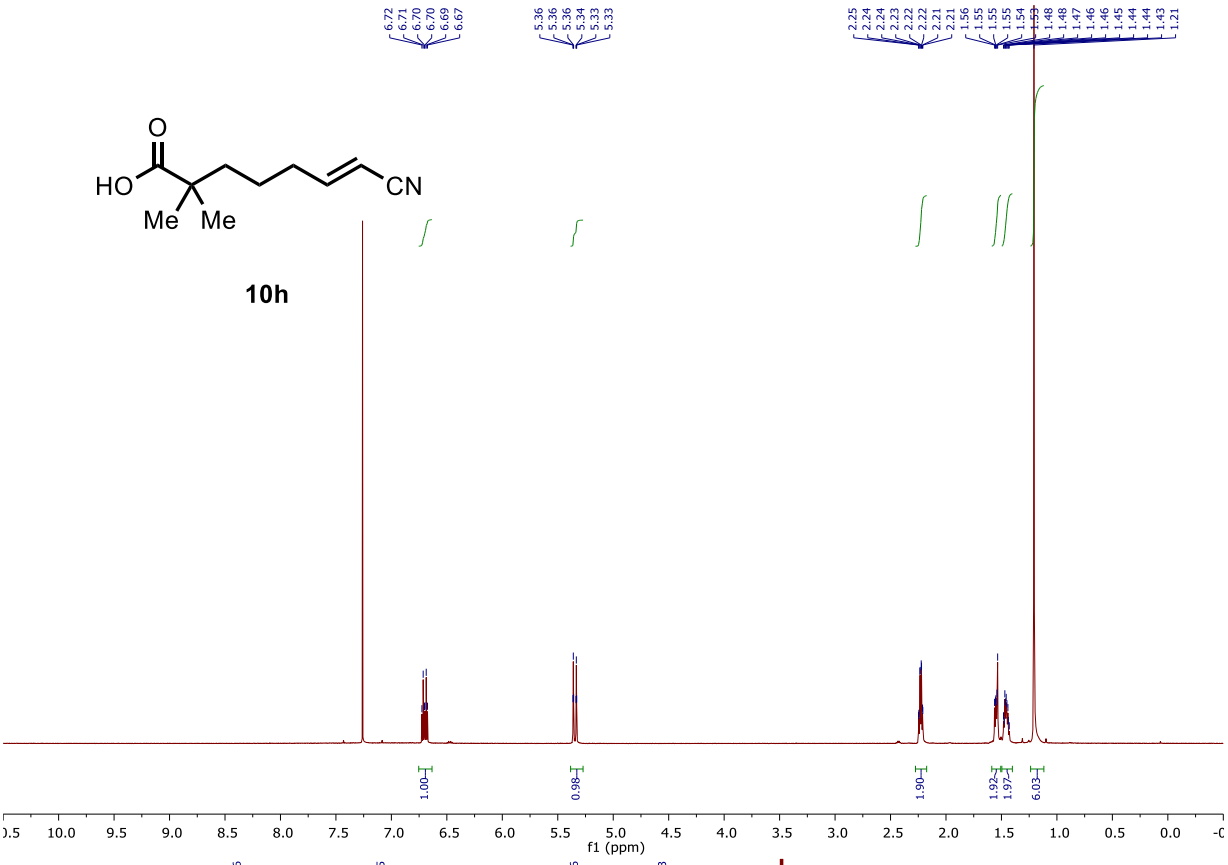


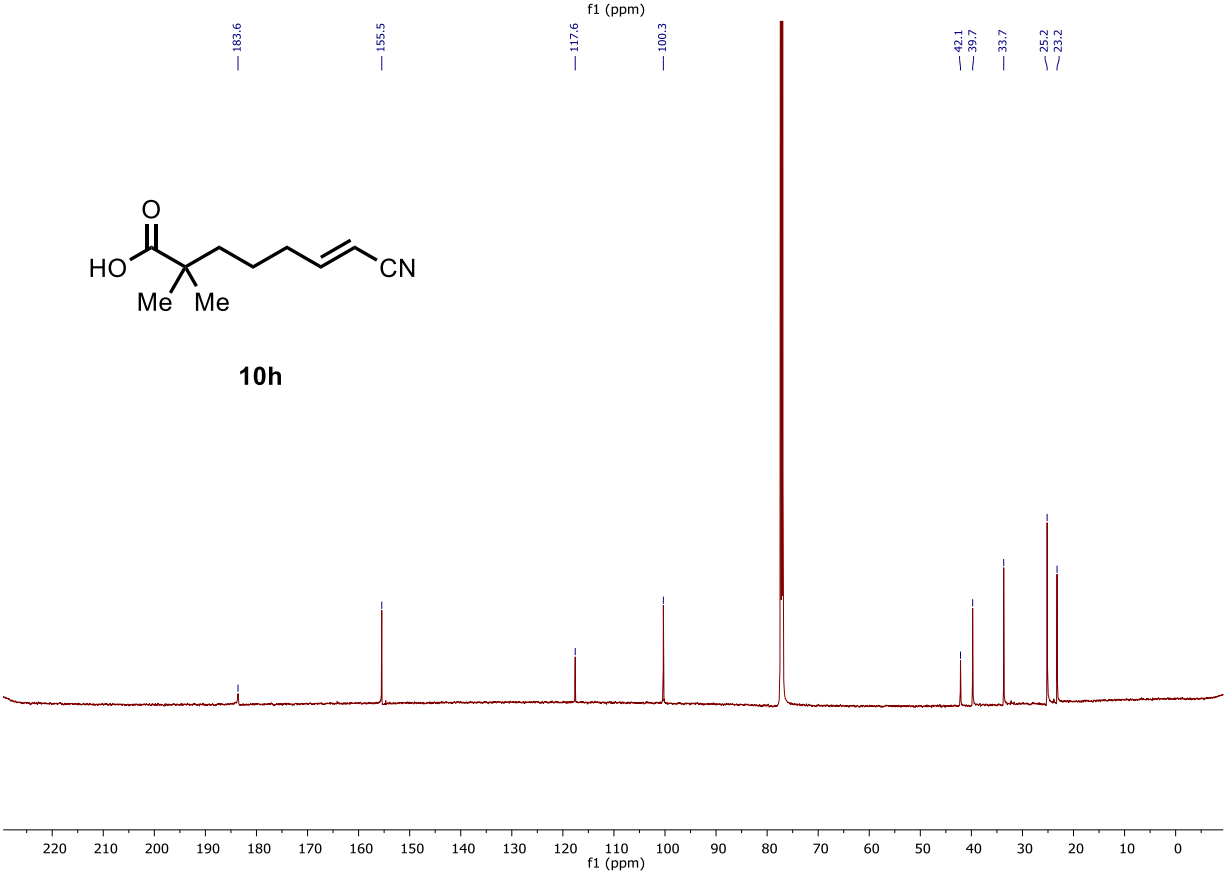
10g

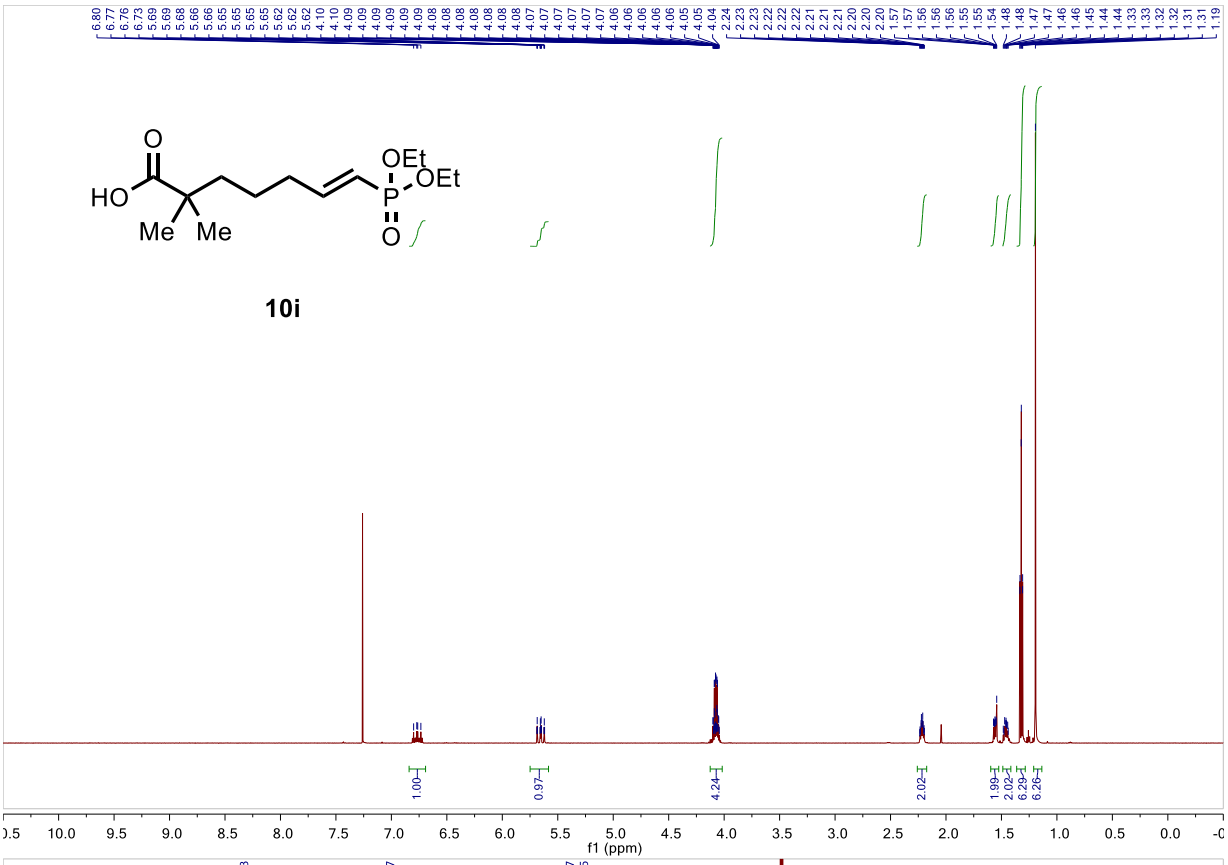


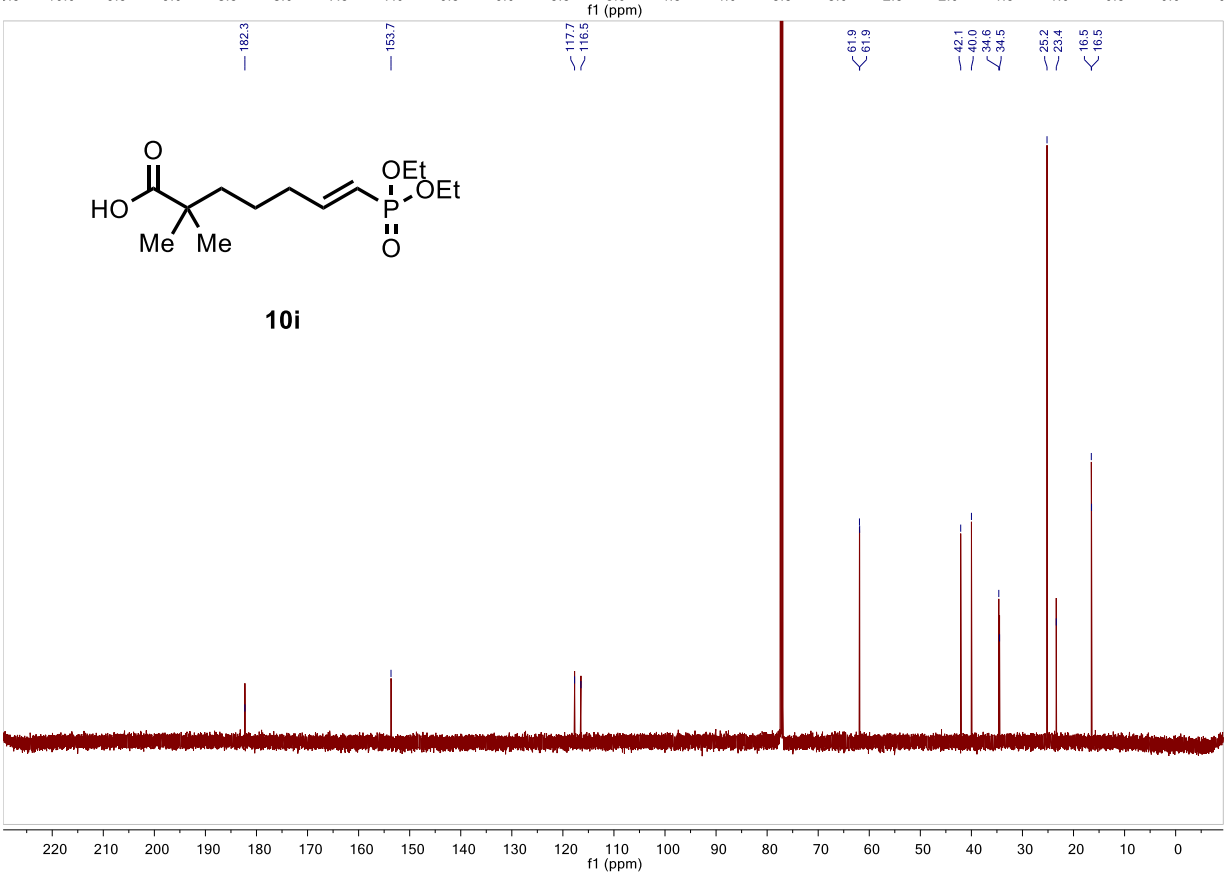
10g

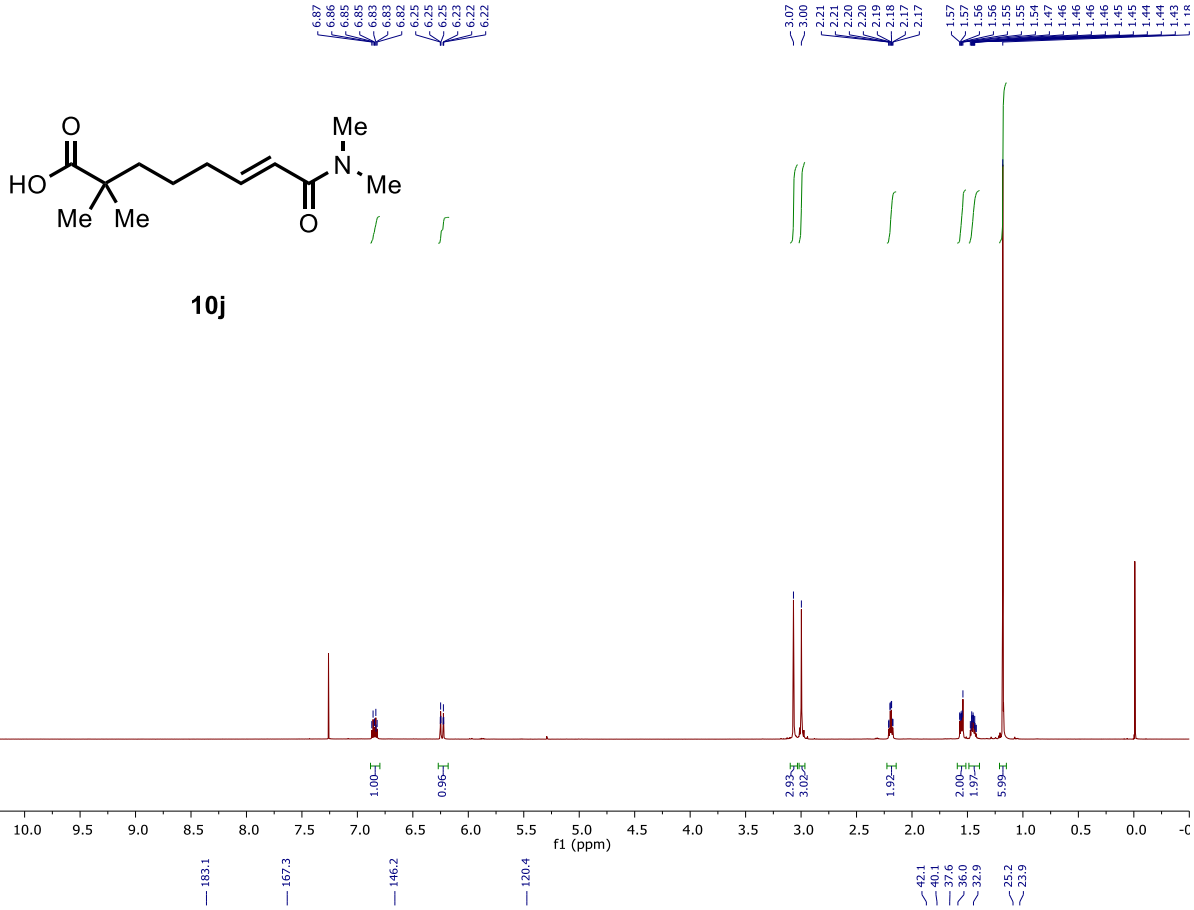


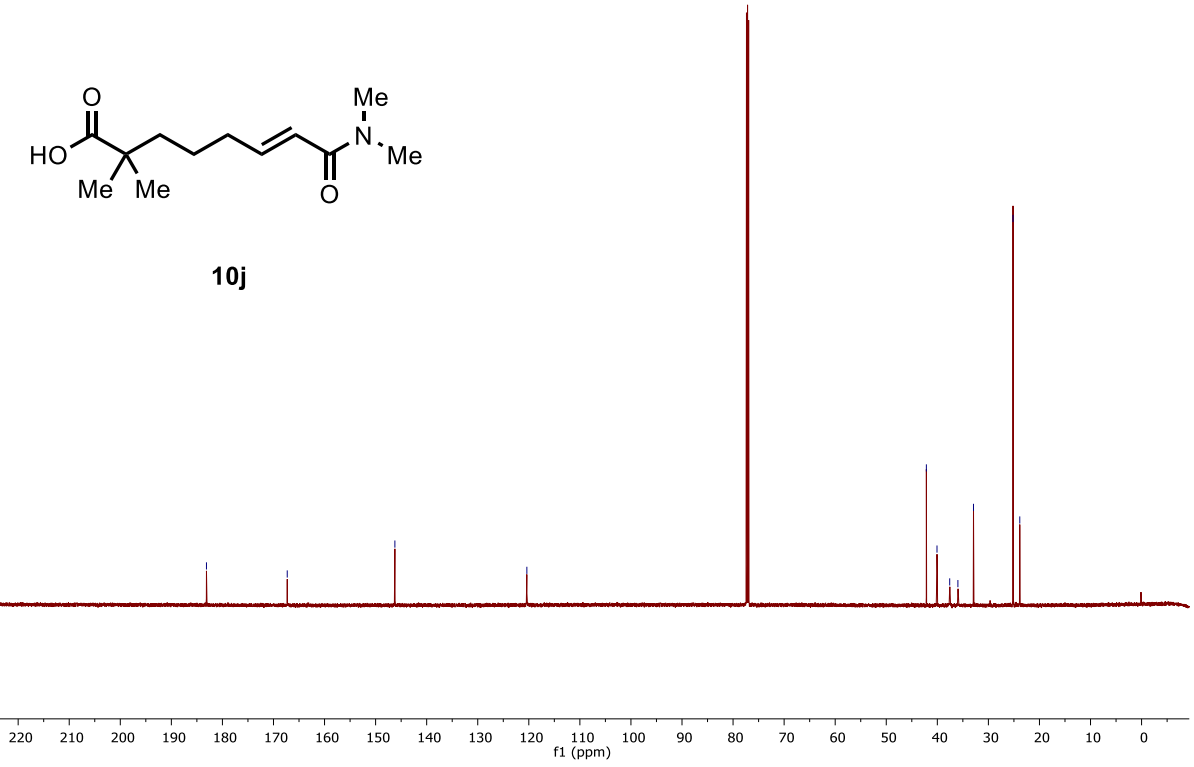

6.72
6.71
6.70
6.70
6.69
6.67
5.36
5.36
5.36
5.34
5.33
5.33
2.25
2.24
2.24
2.23
2.22
2.22
2.21
2.21
1.56
1.55
1.55
1.55
1.54
1.53
1.48
1.48
1.47
1.46
1.46
1.45
1.44
1.44
1.43
1.21
O
HO
CN
Me Me
10h
1.00
0.98
1.90
1.92
1.97
6.03
f1 (ppm)

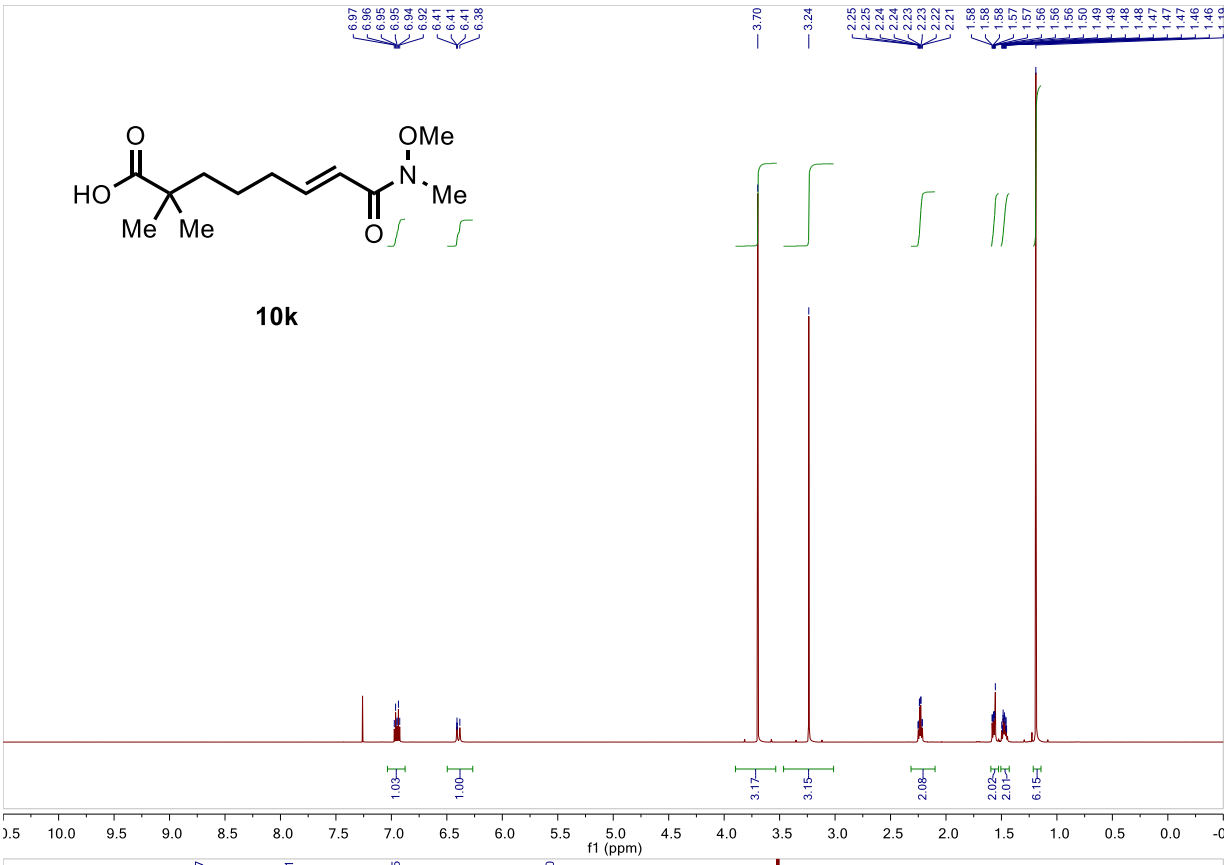

183.6
155.5
117.6
100.3
42.1
39.7
33.7
25.2
23.2
O
HO
CN
Me Me
10h
f1 (ppm)

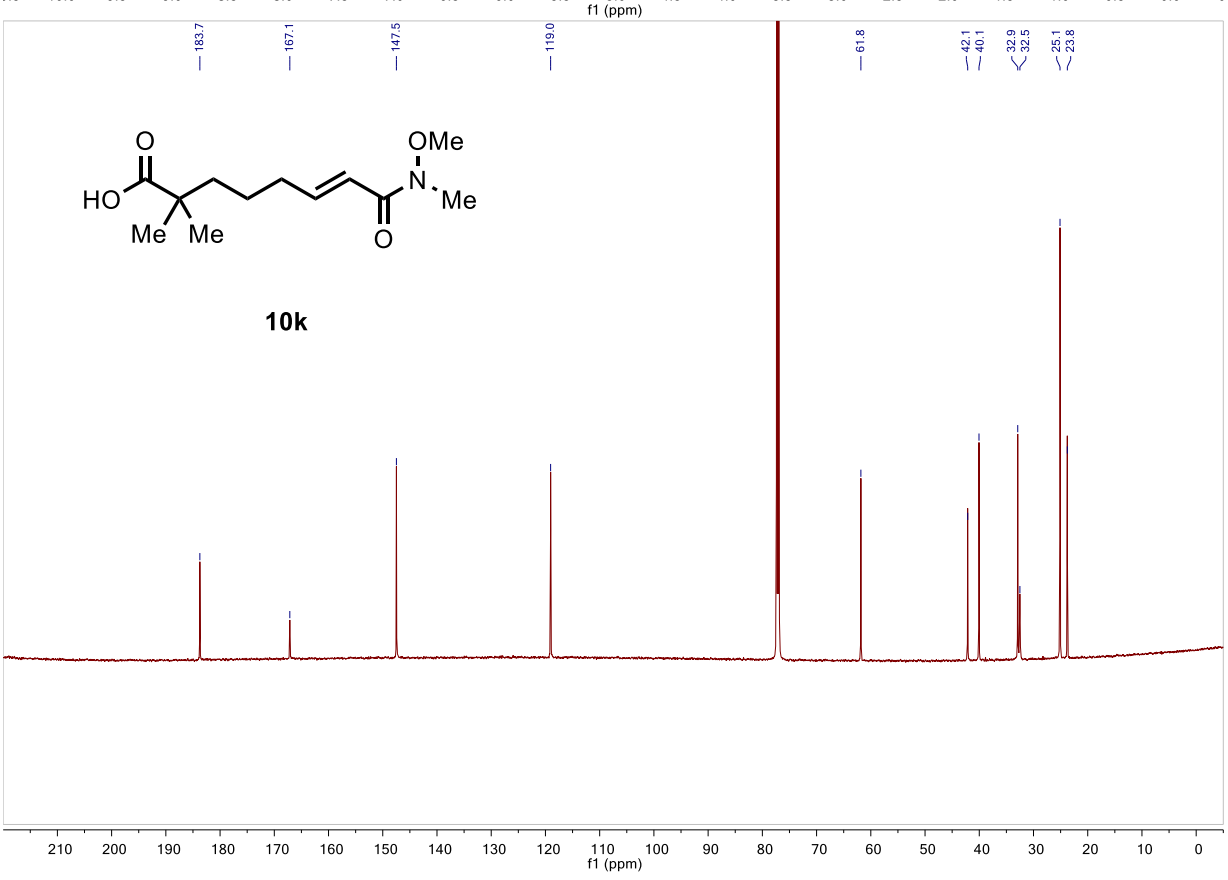

HO
O
Me
Me
OEt
OEt
P
O
10i
f1 (ppm)

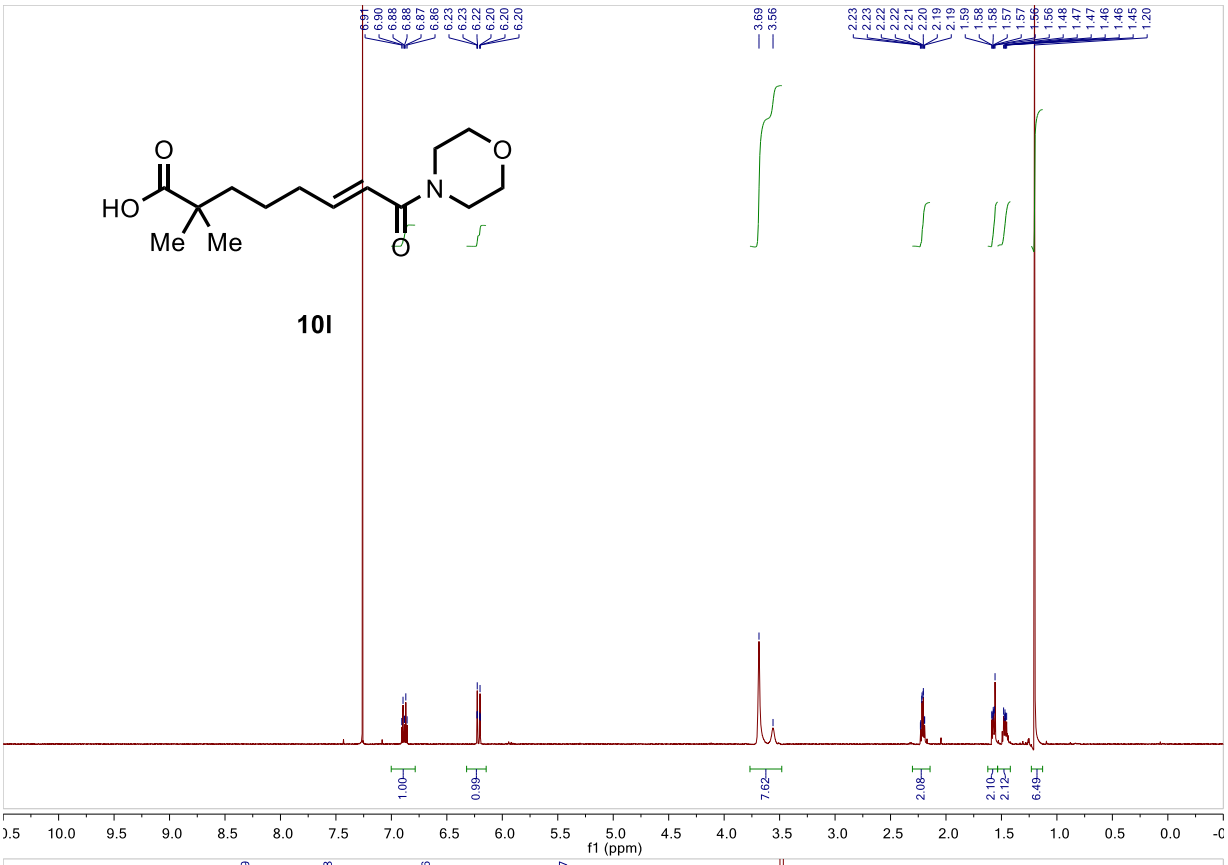

182.3
153.7
117.7
116.5
61.9
61.9
42.1
40.0
34.6
34.5
25.2
23.4
16.5
16.5
HO
O
Me
Me
OEt
OEt
P
O
10i
f1 (ppm)


HO
O
Me
Me
Me
N
Me
O
10j
f1 (ppm)

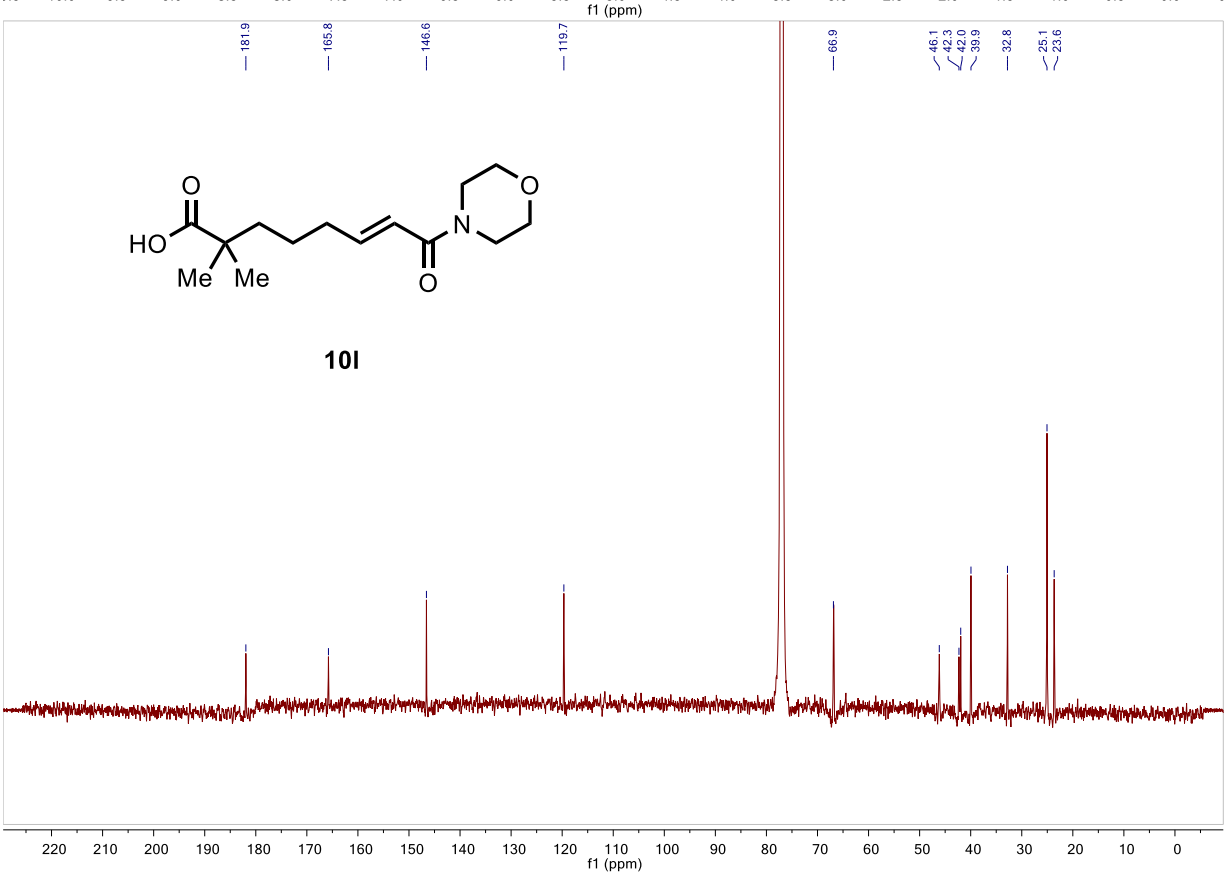

HO
O
Me
Me
Me
N
Me
O
10j
f1 (ppm)


O
HO
Me Me
OMe
N
Me
O
10k
6.97 6.96 6.95 6.95 6.94 6.92 6.41 6.41 6.41 6.38
3.70 3.24
2.25 2.25 2.24 2.24 2.23 2.23 2.22 2.21
1.58 1.58 1.58 1.57 1.57 1.56 1.56 1.56 1.50 1.49 1.49 1.48 1.48 1.47 1.47 1.47 1.46 1.46
1.03 1.00 3.17 3.15 2.08 2.02 2.01 6.15
f1 (ppm)

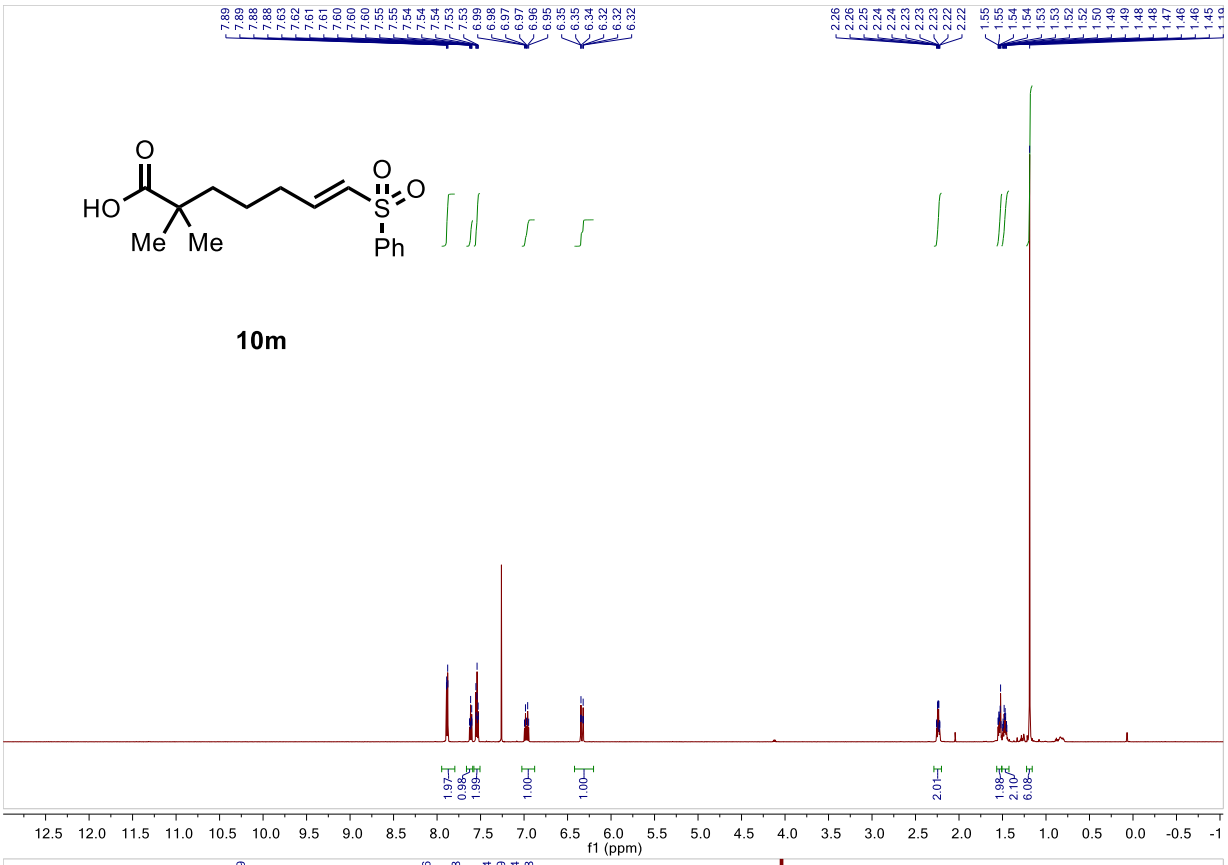

O
HO
Me Me
OMe
N
Me
O
10k
183.7 167.1 147.5 119.0 61.8 42.1 40.1 32.9 32.5 25.1 23.8
f1 (ppm)

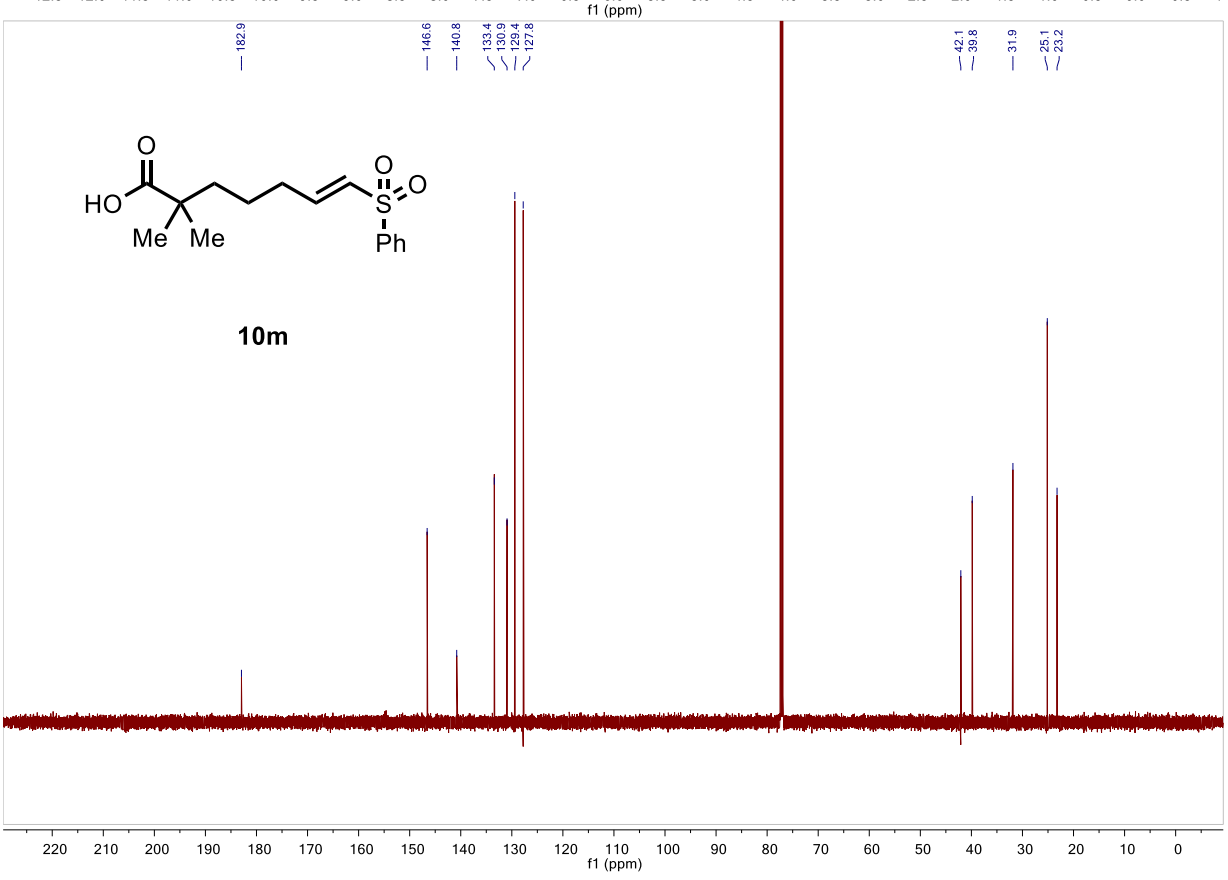

6.91
6.90
6.88
6.88
6.87
6.86
6.23
6.23
6.22
6.20
6.20
6.20
3.69
3.56
2.23
2.23
2.22
2.22
2.21
2.20
2.19
2.19
1.59
1.58
1.58
1.57
1.57
1.56
1.56
1.48
1.47
1.47
1.46
1.46
1.45
1.20
O
HO
Me
Me
N
O
O
1.00
0.99
7.62
2.08
2.10
2.12
6.49
f1 (ppm)

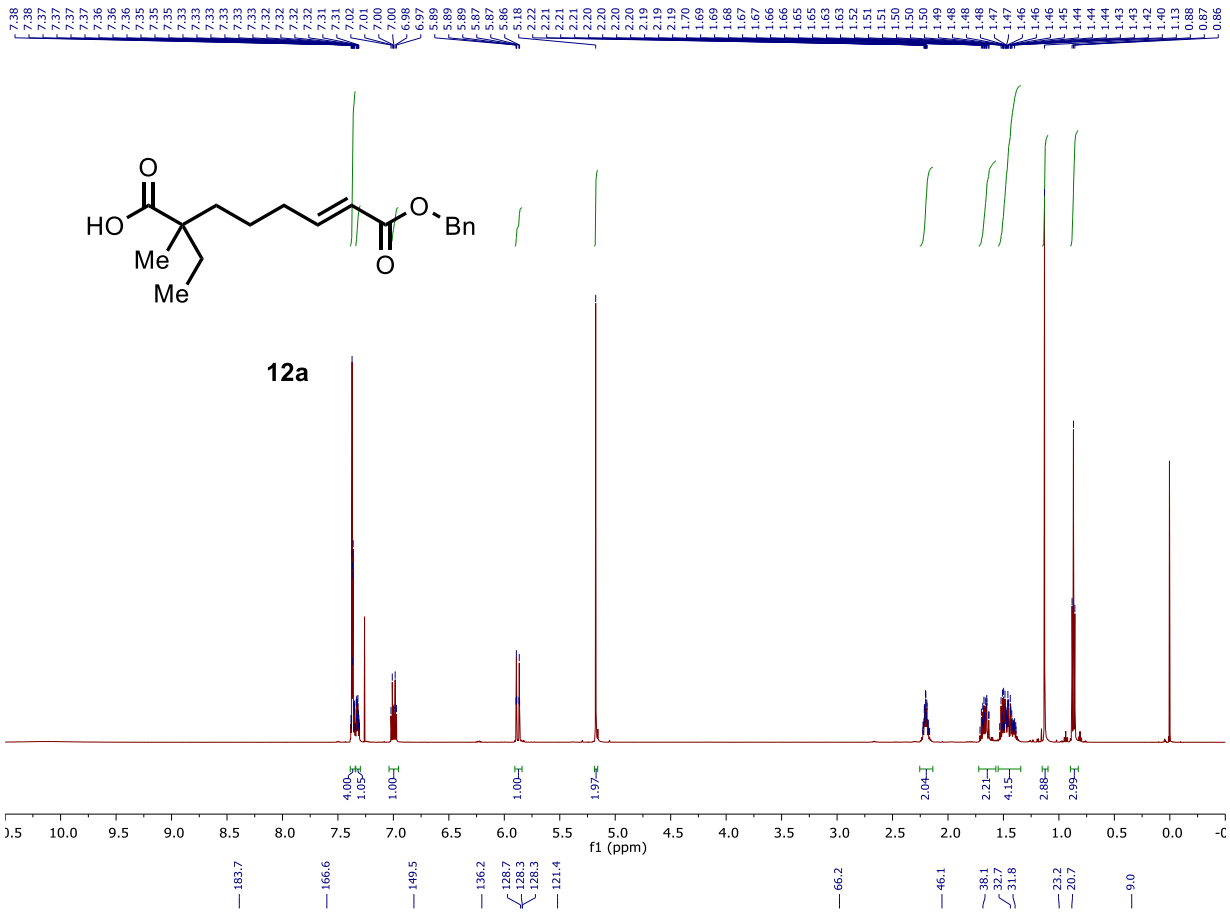
10l

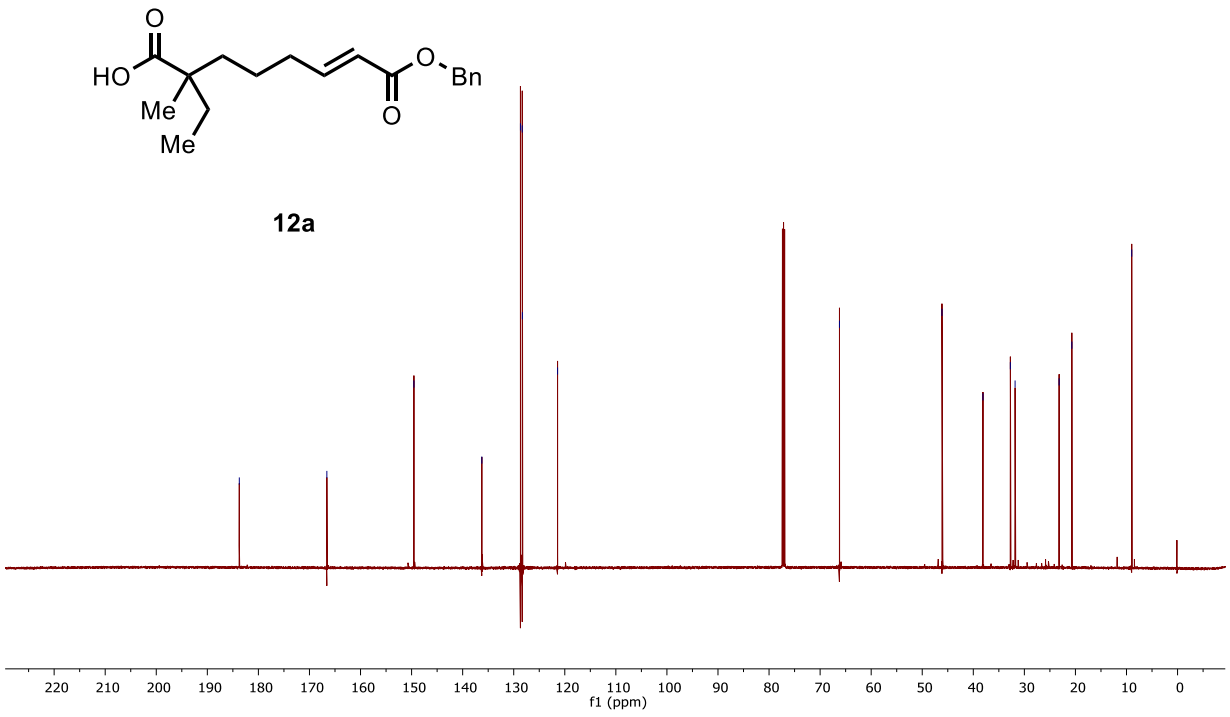

181.9
165.8
146.6
119.7
66.9
46.1
42.3
42.0
39.9
32.8
25.1
23.6
O
HO
Me
Me
N
O
O
f1 (ppm)

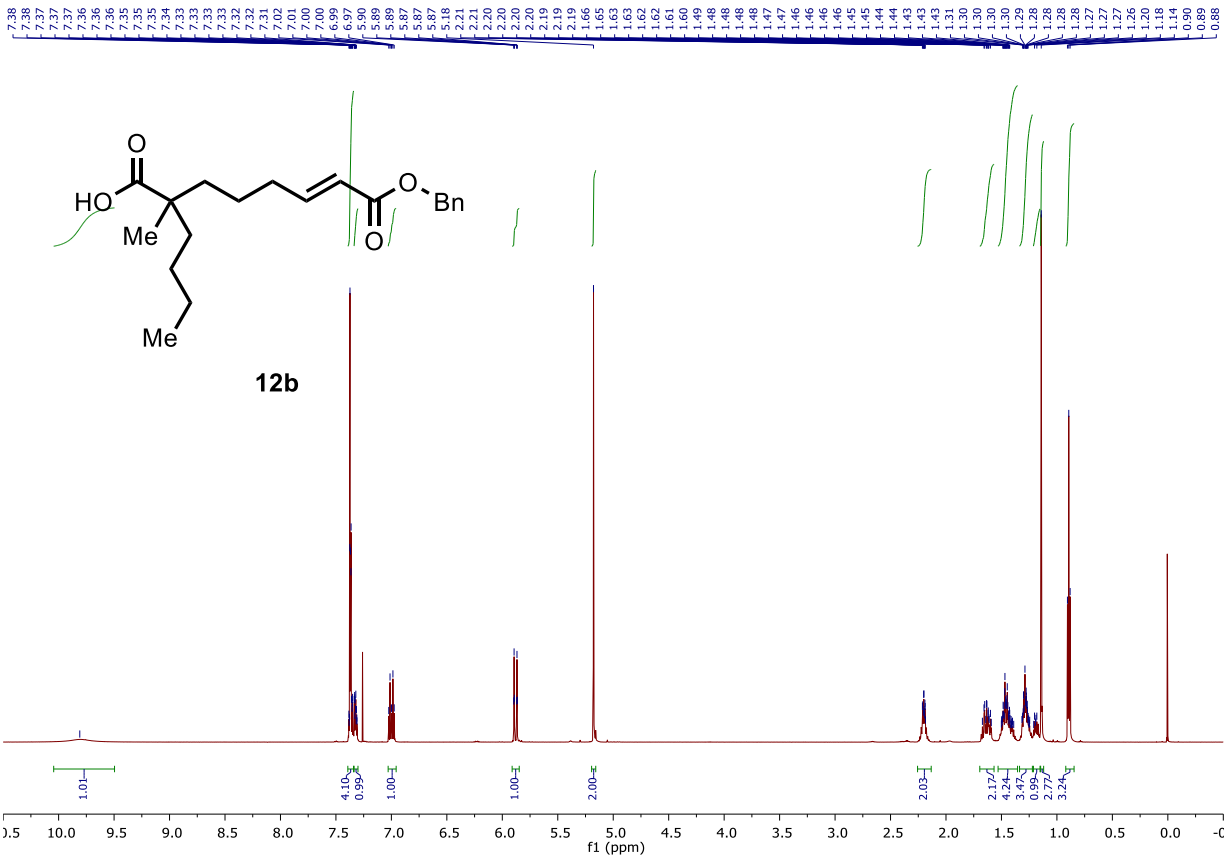
10l

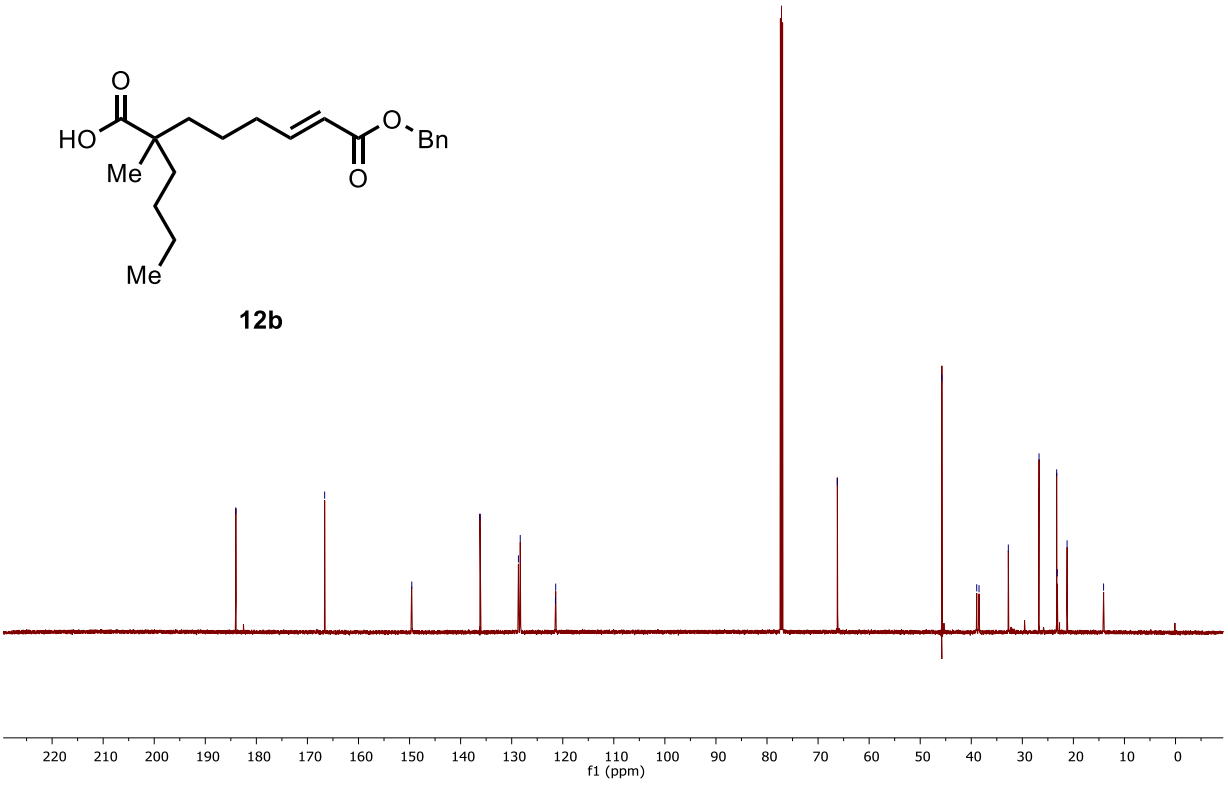

HO
O
Me
Me
S
O
O
Ph
10m
f1 (ppm)

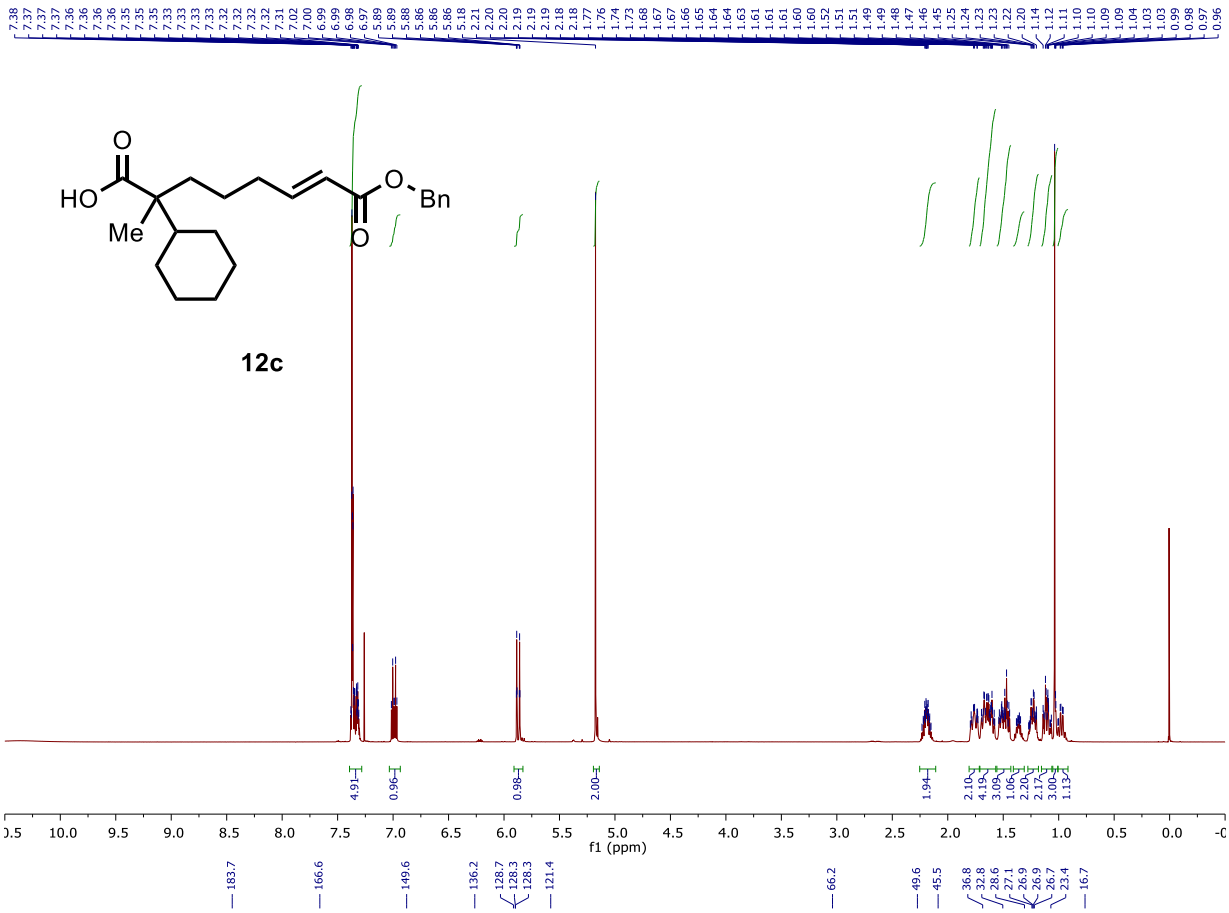

HO
O
Me
Me
S
O
O
Ph
10m
f1 (ppm)

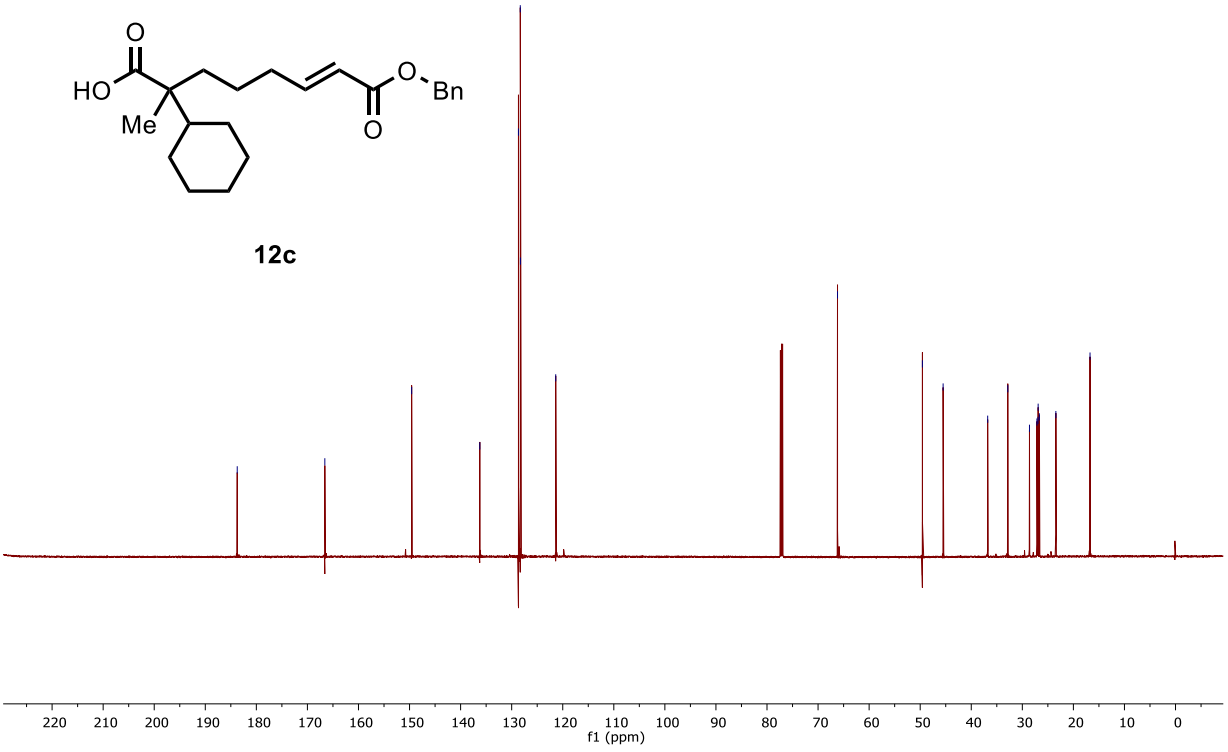

HO
O
Me
Me
O
O
Bn
12a
f1 (ppm)

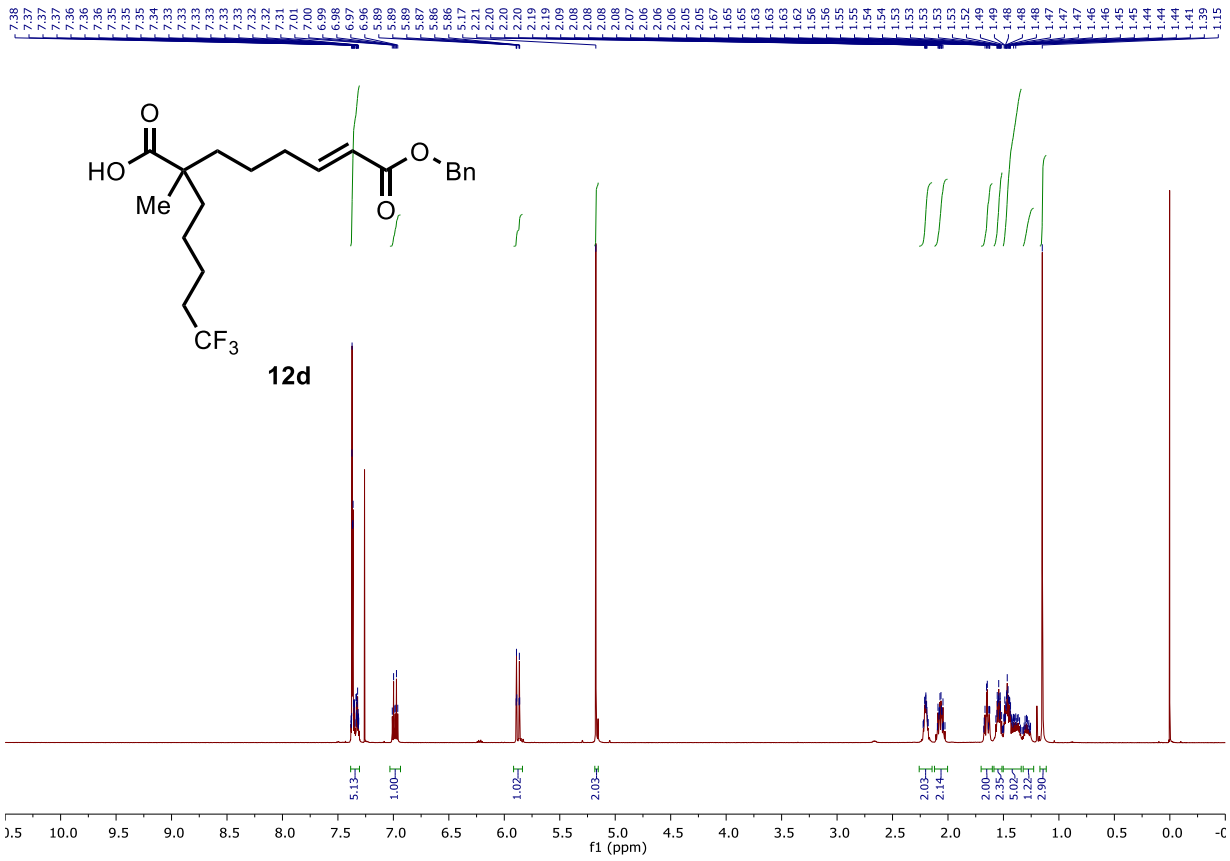

HO
O
Me
Me
O
O
Bn
12a
f1 (ppm)

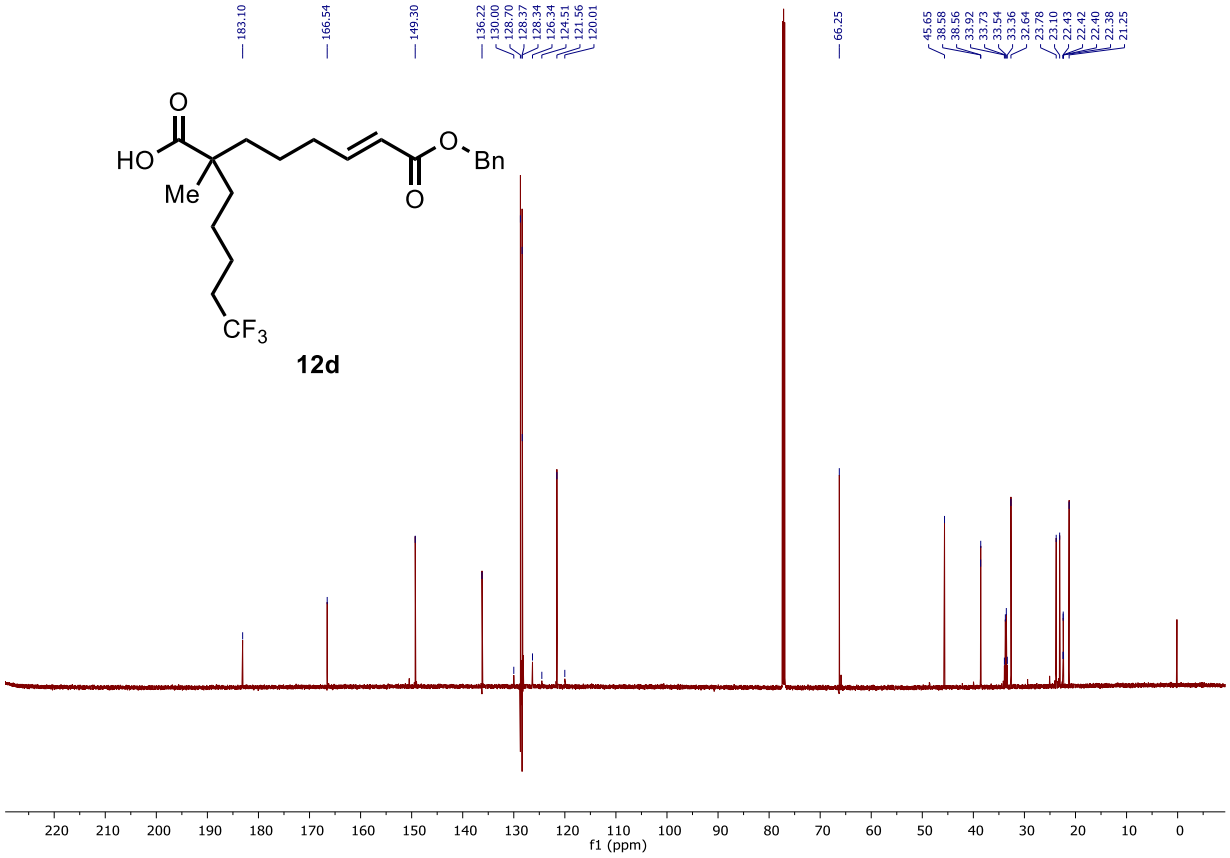

HO
O
Me
Me
O
O
Bn
12b
f1 (ppm)

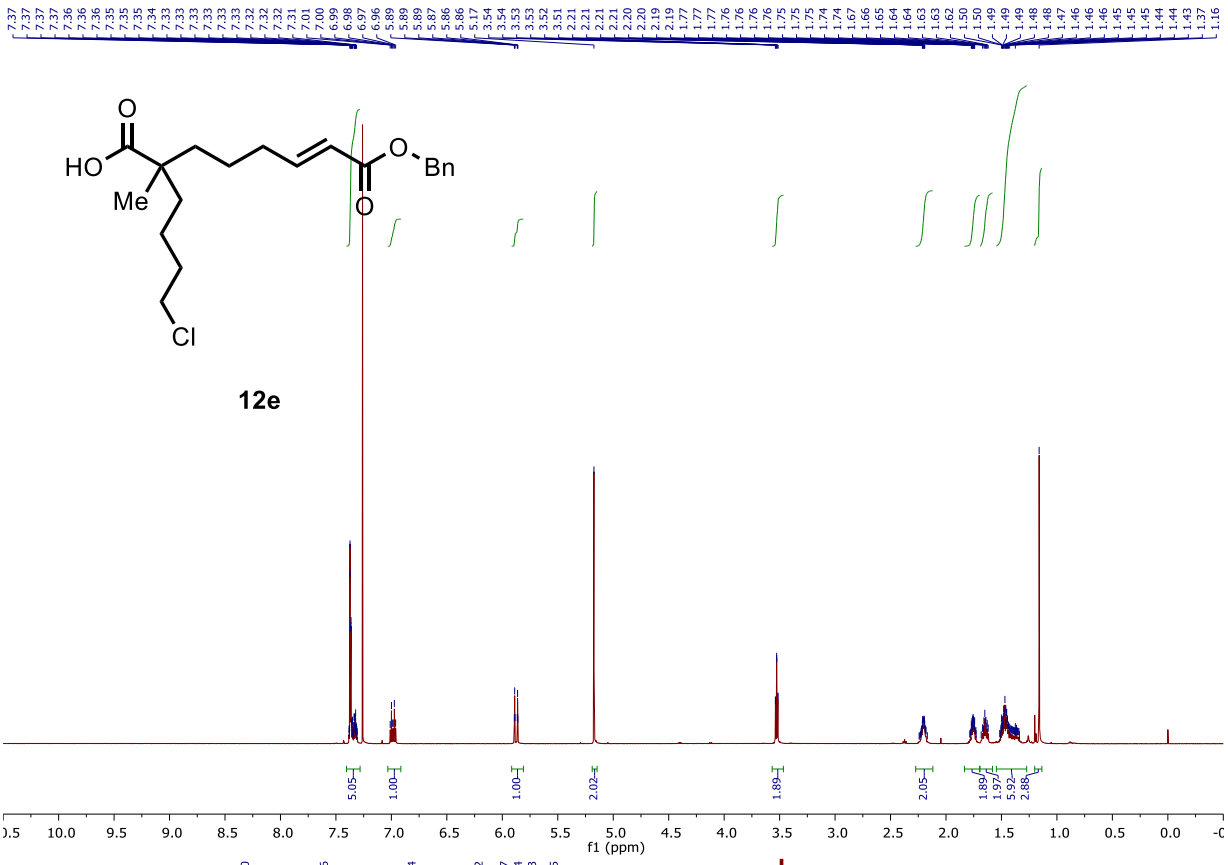

HO
O
Me
Me
O
O
Bn
12b
f1 (ppm)

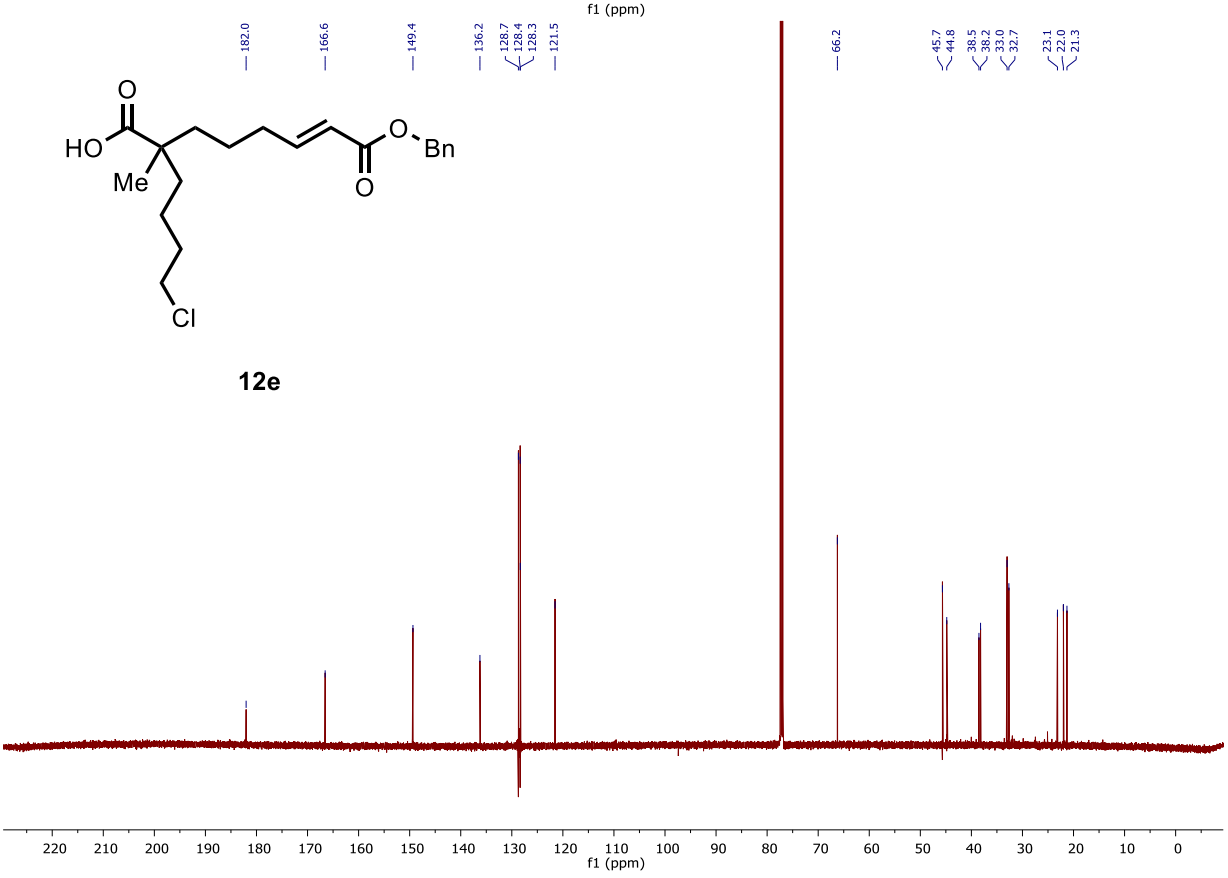

HO
O
Me
O
O
Bn
12c
f1 (ppm)

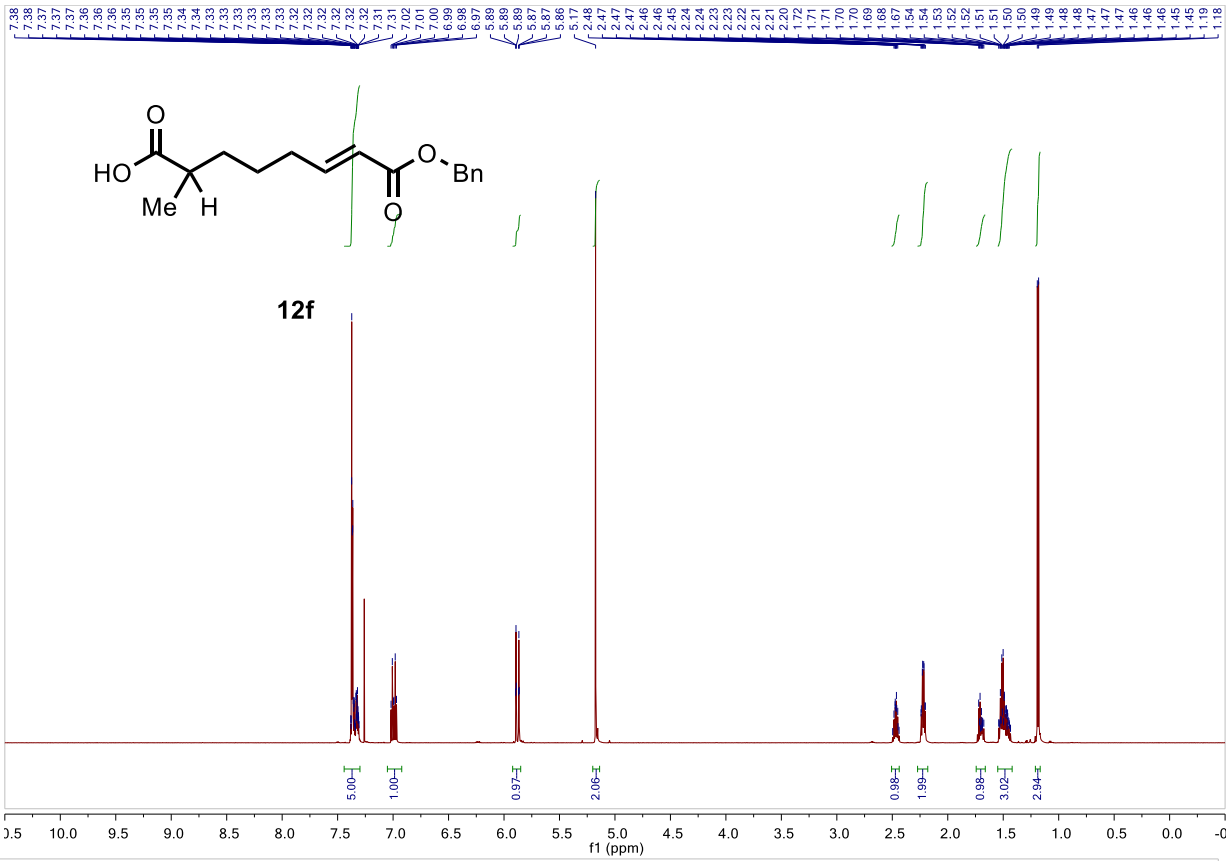

HO
O
Me
O
O
Bn
12c
f1 (ppm)

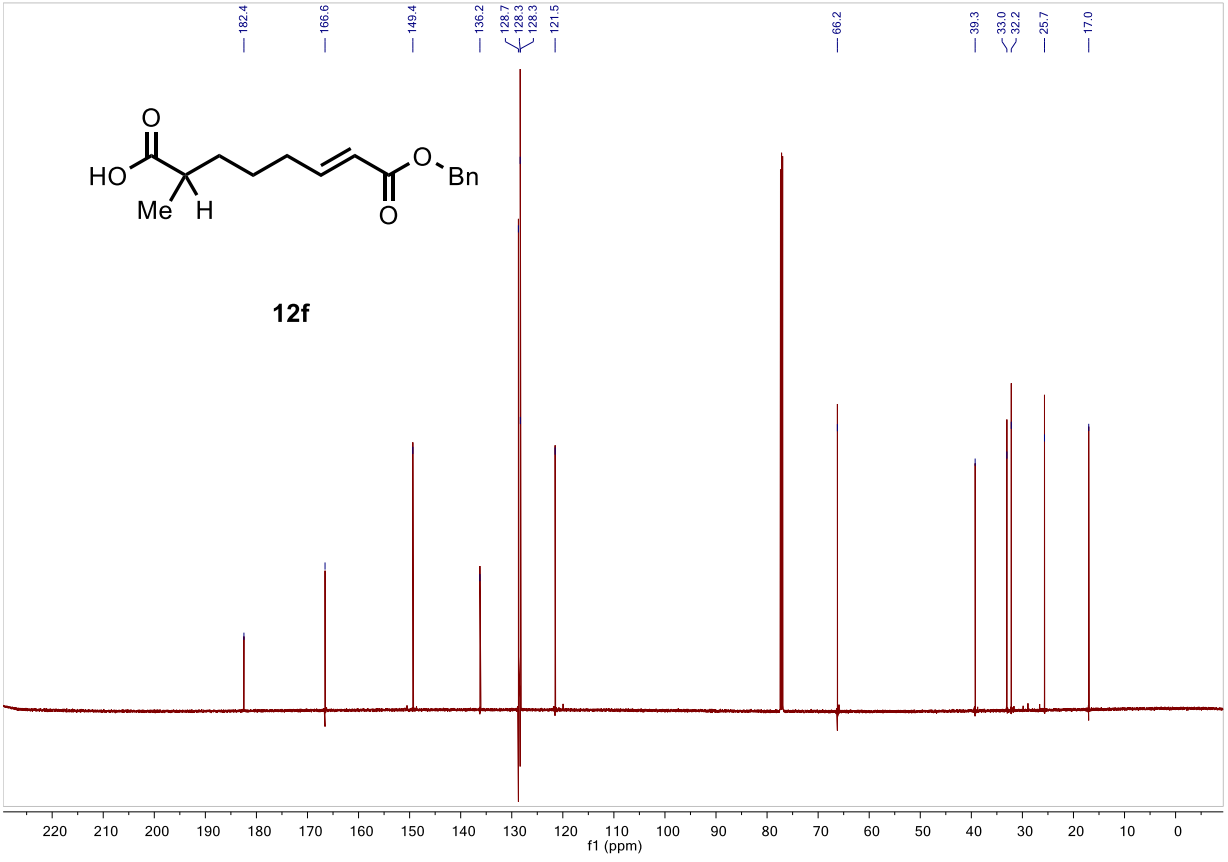

HO
O
Me
O
O
Bn
CF3
12d
f1 (ppm)

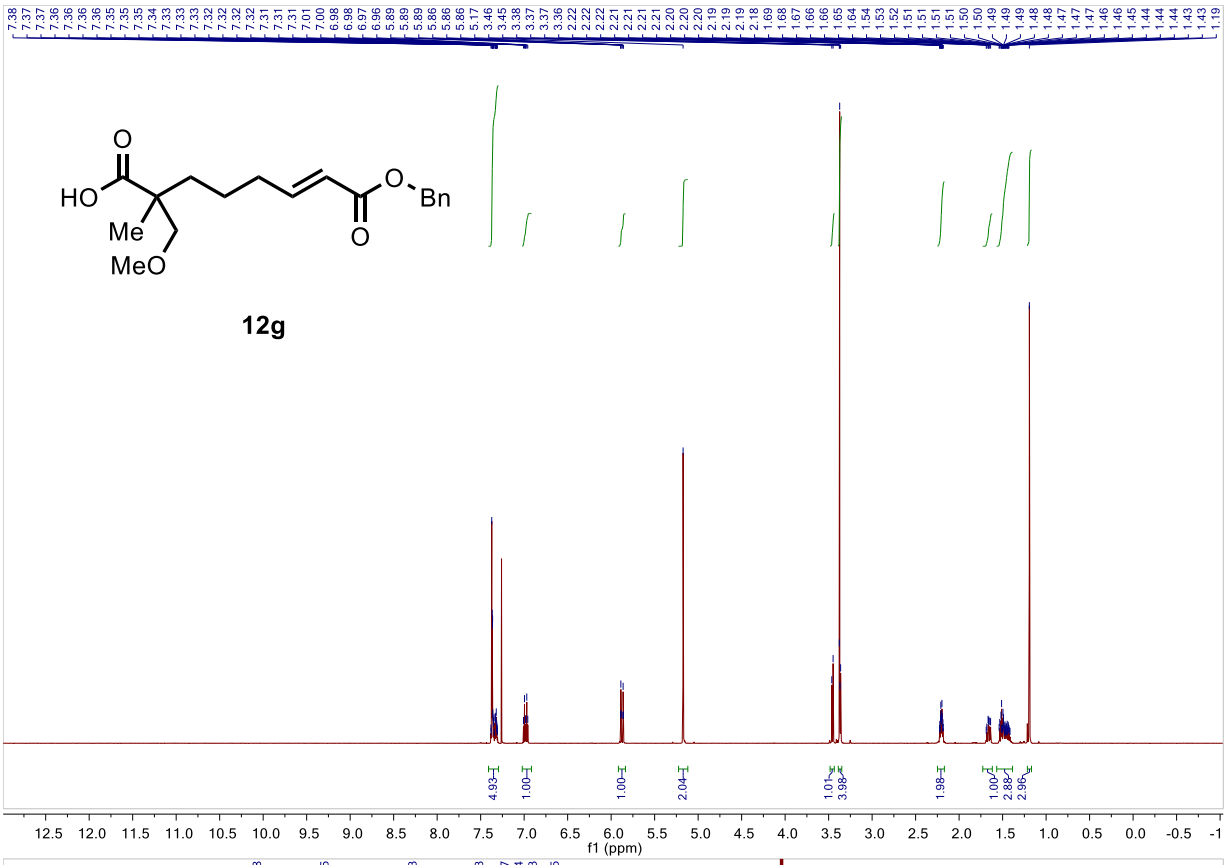

HO
O
Me
O
O
Bn
CF3
12d
f1 (ppm)

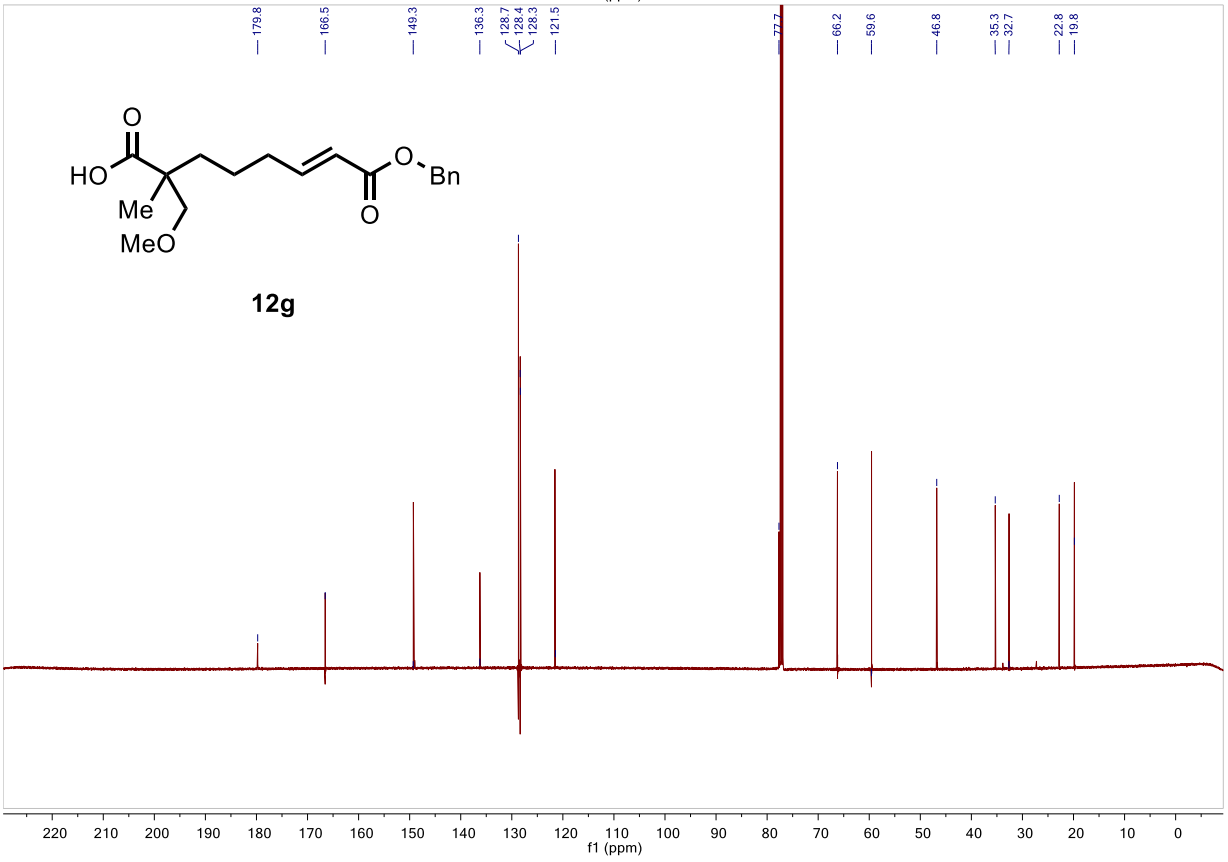

HO
O
Me
O
O
Bn
Cl
12e
5.05
1.00
1.00
2.02
1.89
2.05
1.89
1.97
5.92
2.88
f1 (ppm)

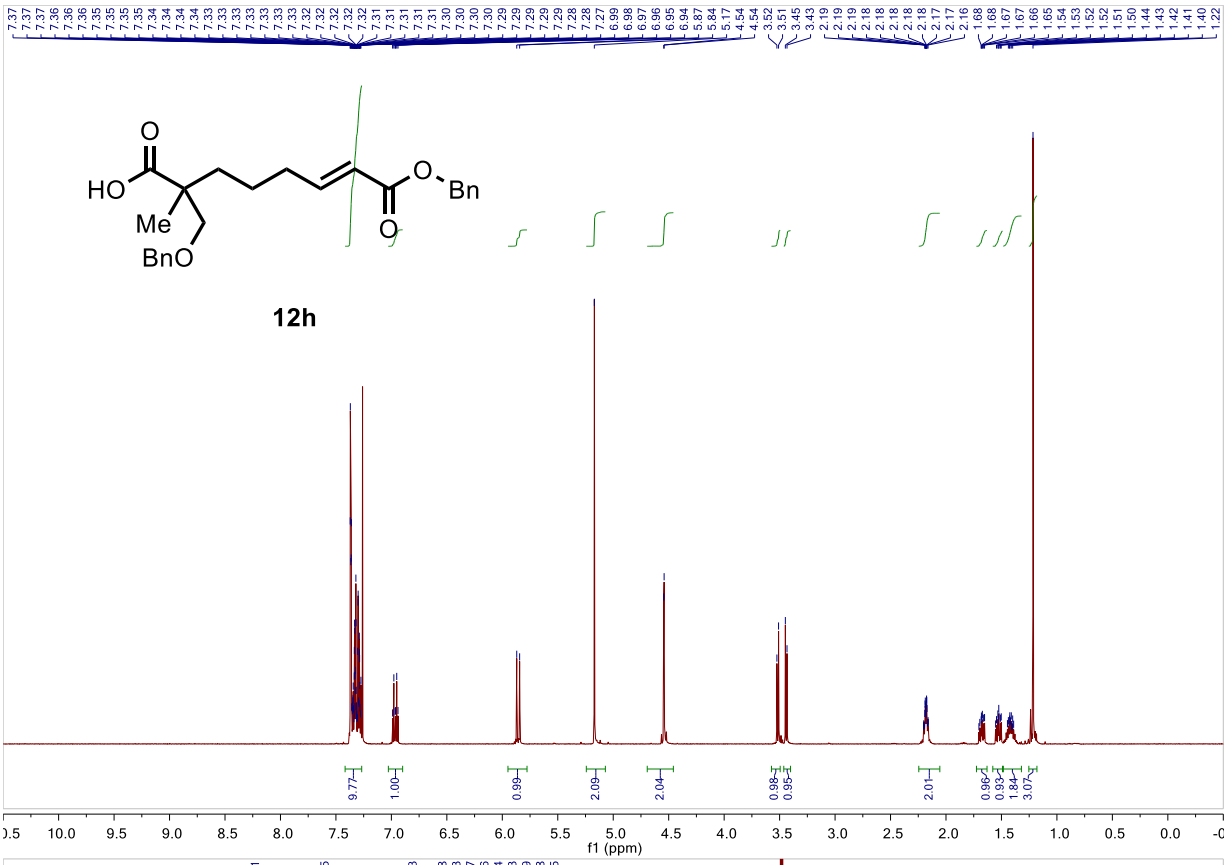

182.0
166.6
149.4
136.2
128.7
128.4
128.3
121.5
66.2
45.7
44.8
38.5
38.2
33.0
32.7
23.1
22.0
21.3
HO
O
Me
O
O
Bn
Cl
12e
f1 (ppm)

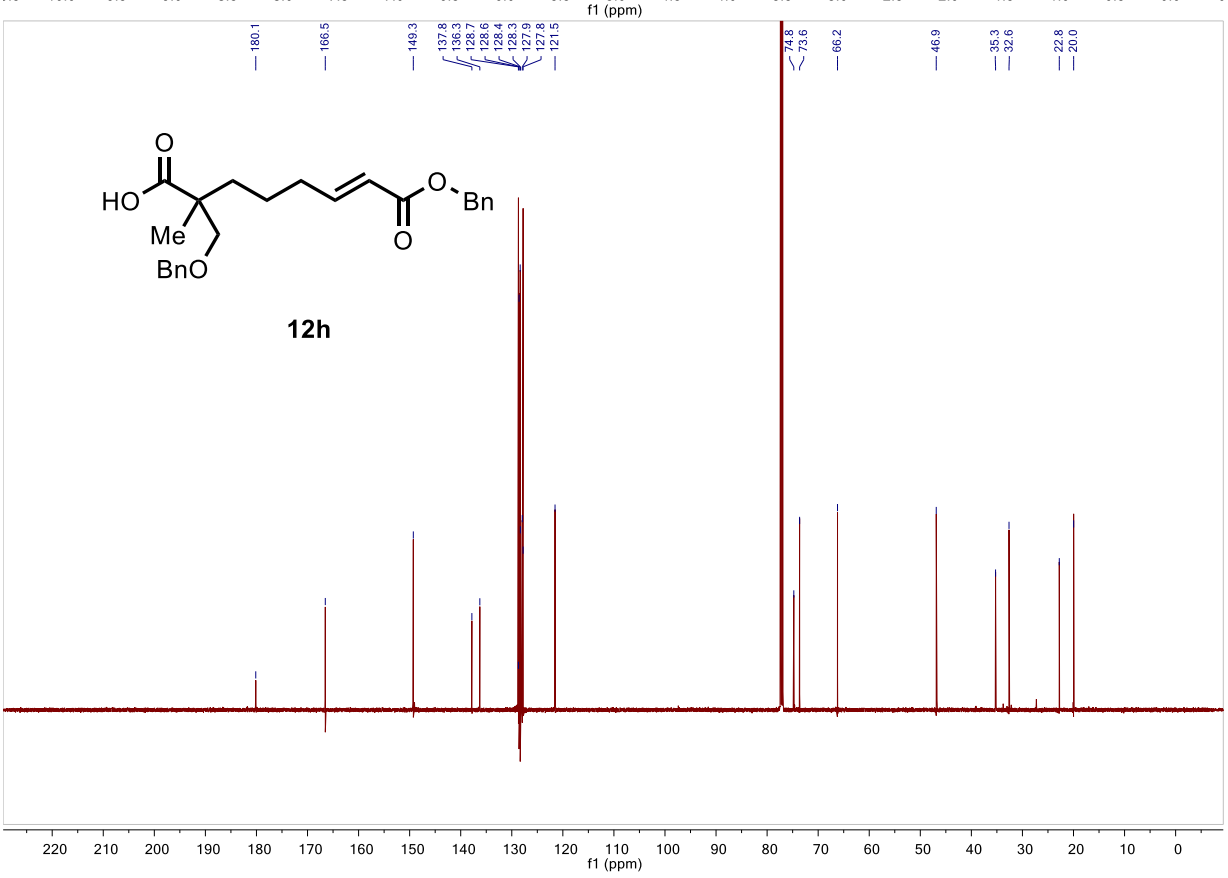

HO
O
Me
H
O
O
Bn
12f
5.00
1.00
0.97
2.06
0.98
1.99
0.98
3.02
2.94
f1 (ppm)

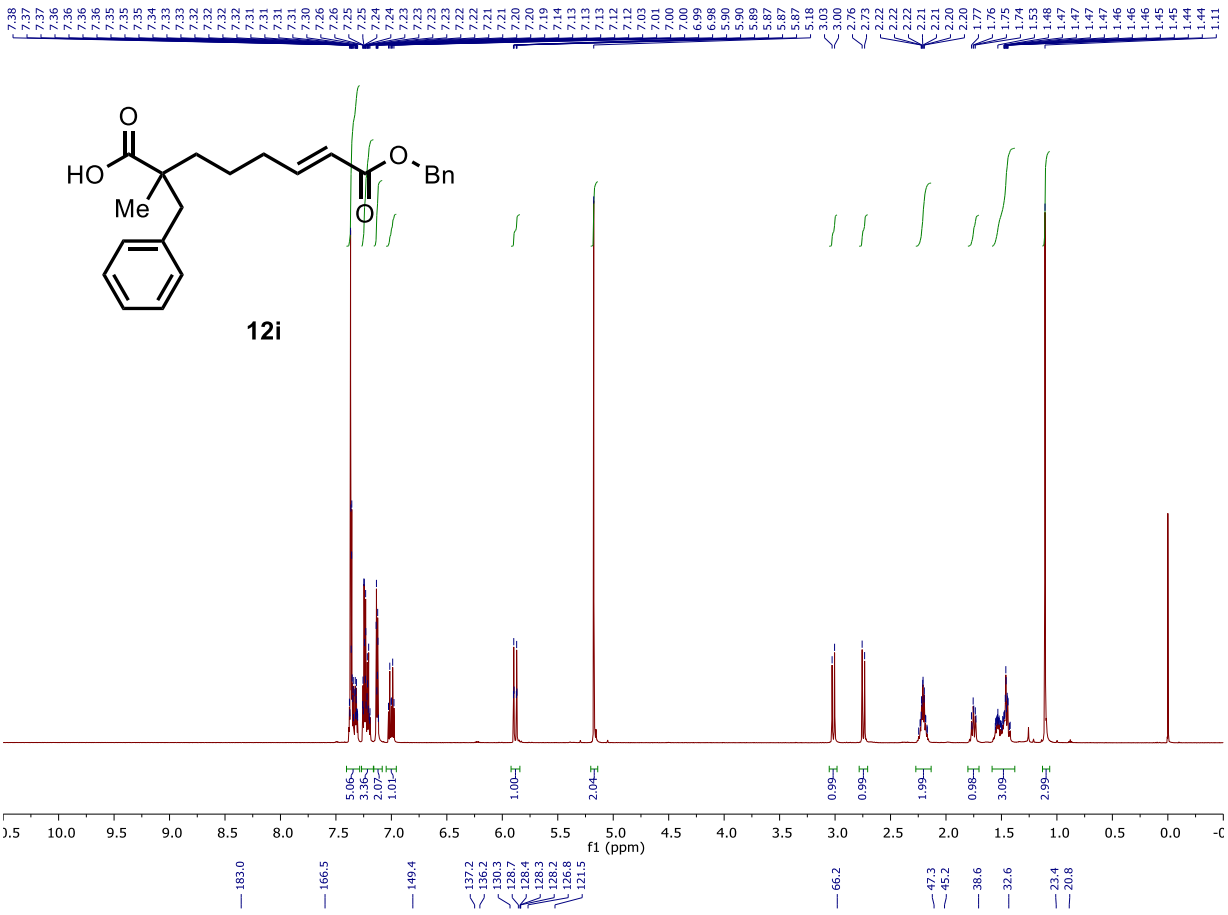

182.4
166.6
149.4
136.2
128.7
128.3
128.3
121.5
66.2
39.3
33.0
32.2
25.7
17.0
HO
O
Me
H
O
O
Bn
12f
f1 (ppm)

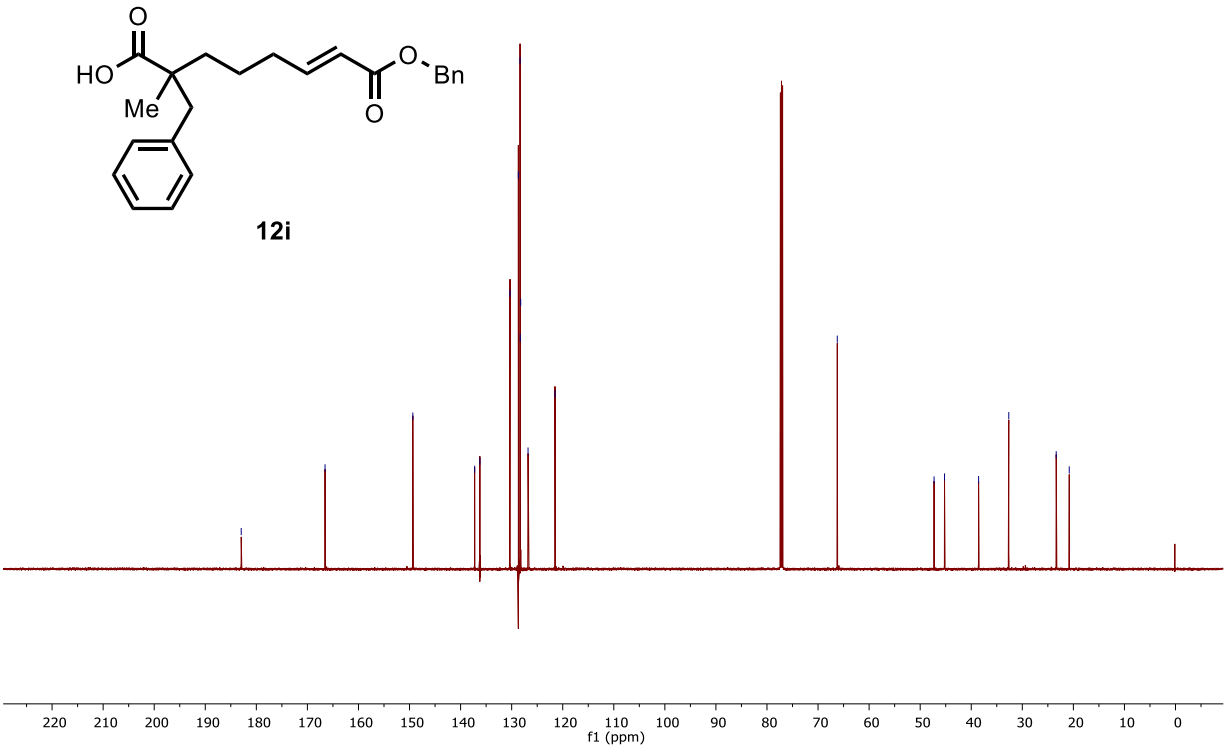

HO
O
O
Bn
Me
MeO
12g
f1 (ppm)

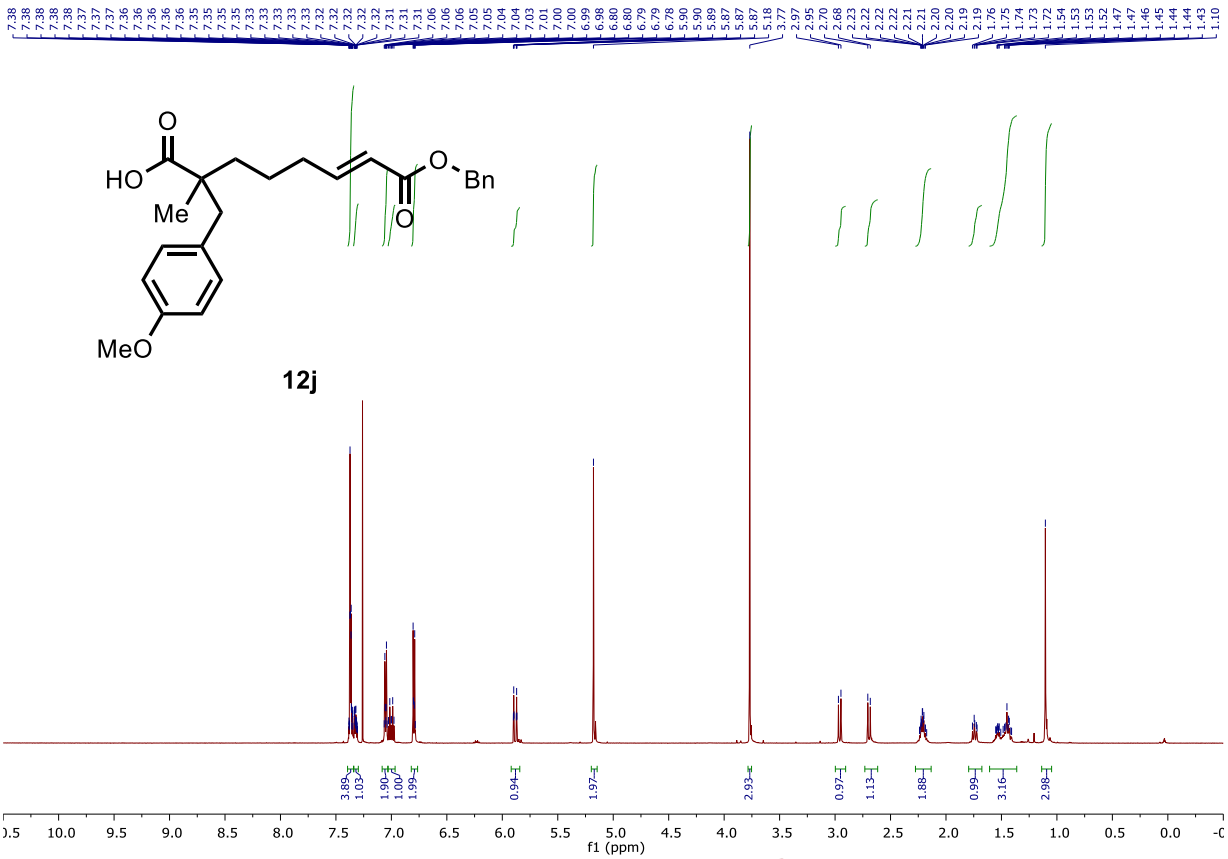

HO
O
O
Bn
Me
MeO
12g
f1 (ppm)

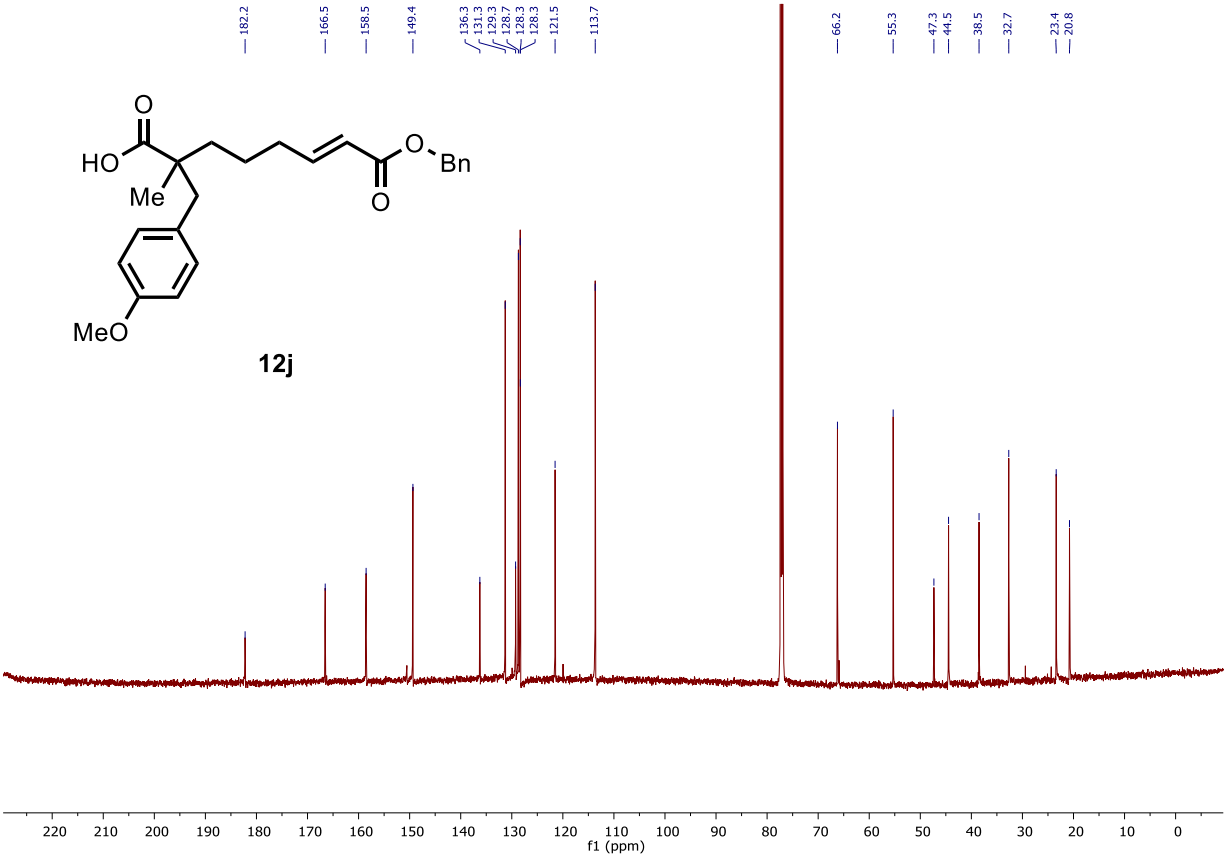

HO
O
Me
BnO
O
O
Bn
12h
9.77
1.00
0.99
2.09
2.04
0.98
0.95
2.01
0.96
0.93
1.84
3.07
f1 (ppm)

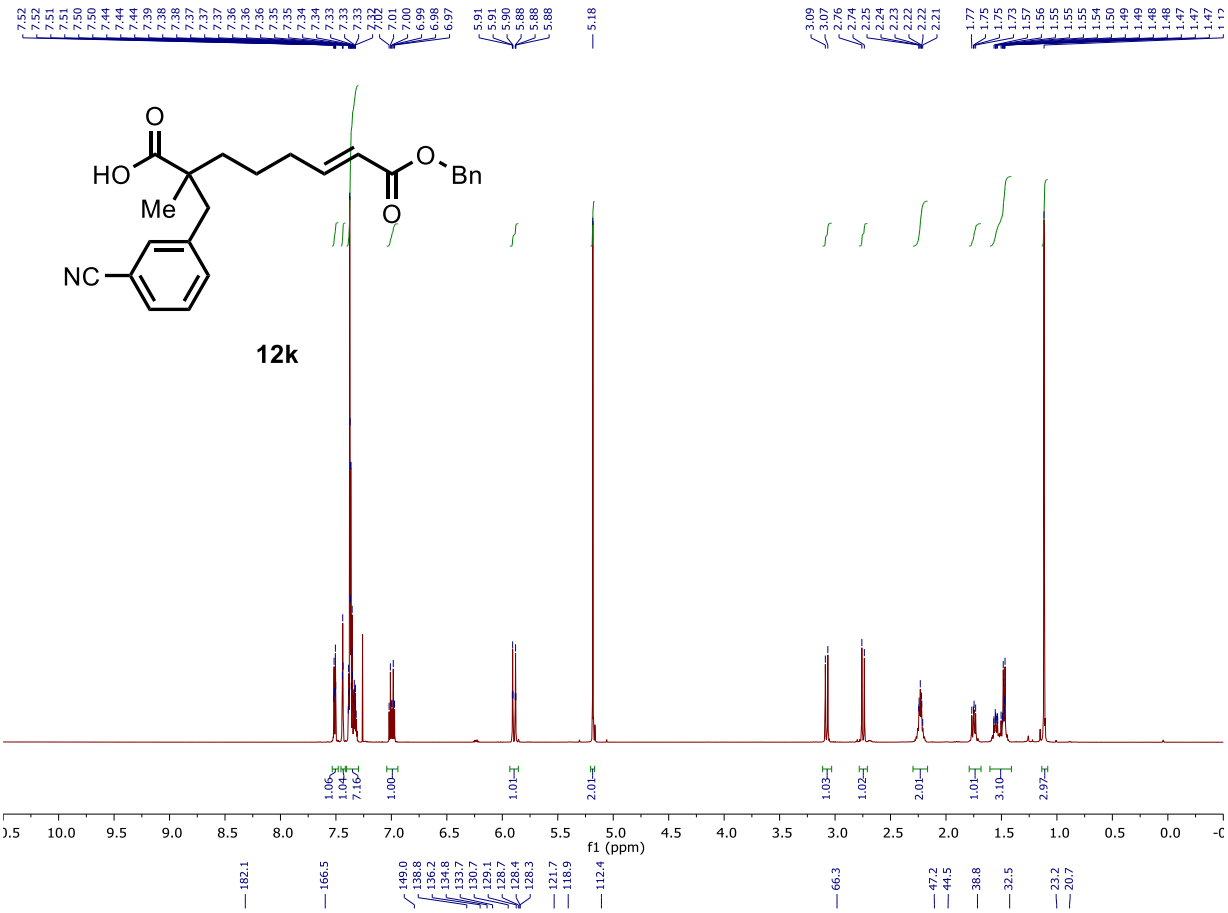

180.1
166.5
149.3
137.8
136.3
128.7
128.6
128.4
128.3
127.9
127.8
121.5
74.8
73.6
66.2
46.9
35.3
32.6
22.8
20.0
HO
O
Me
BnO
O
O
Bn
12h
f1 (ppm)

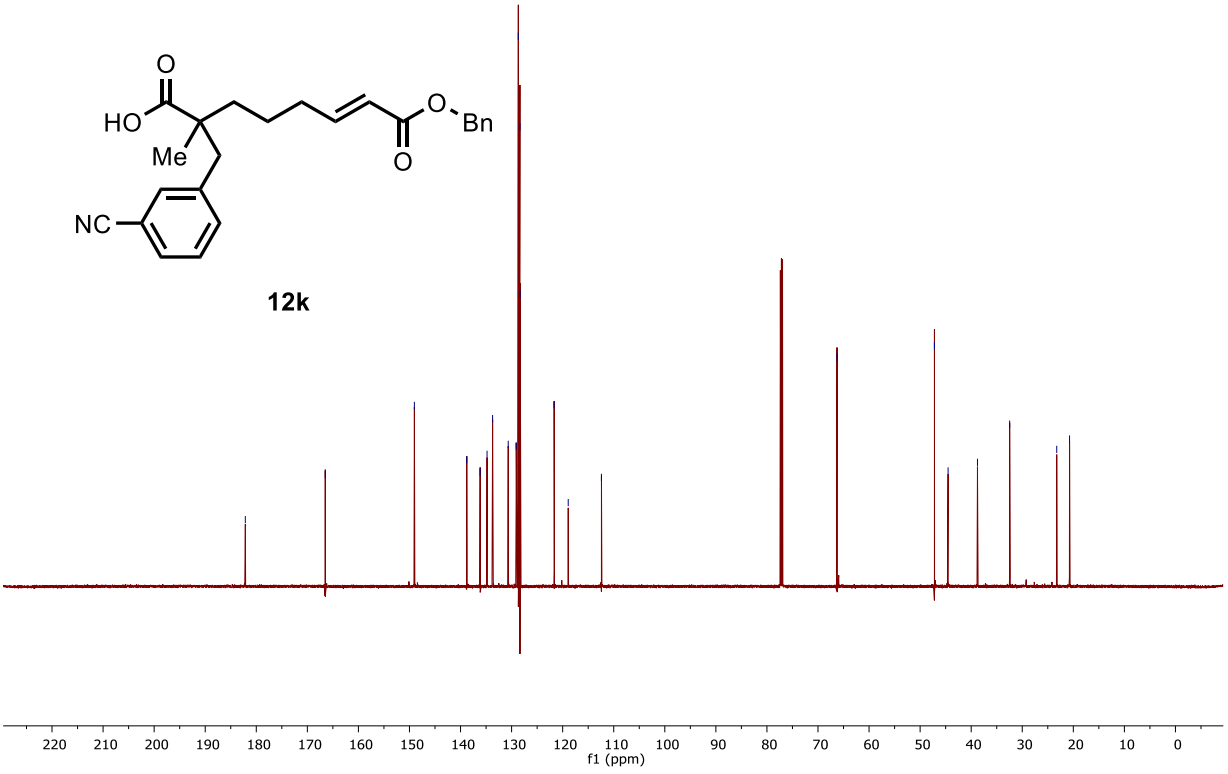

HO
O
Me
O
O
Bn
12i
f1 (ppm)

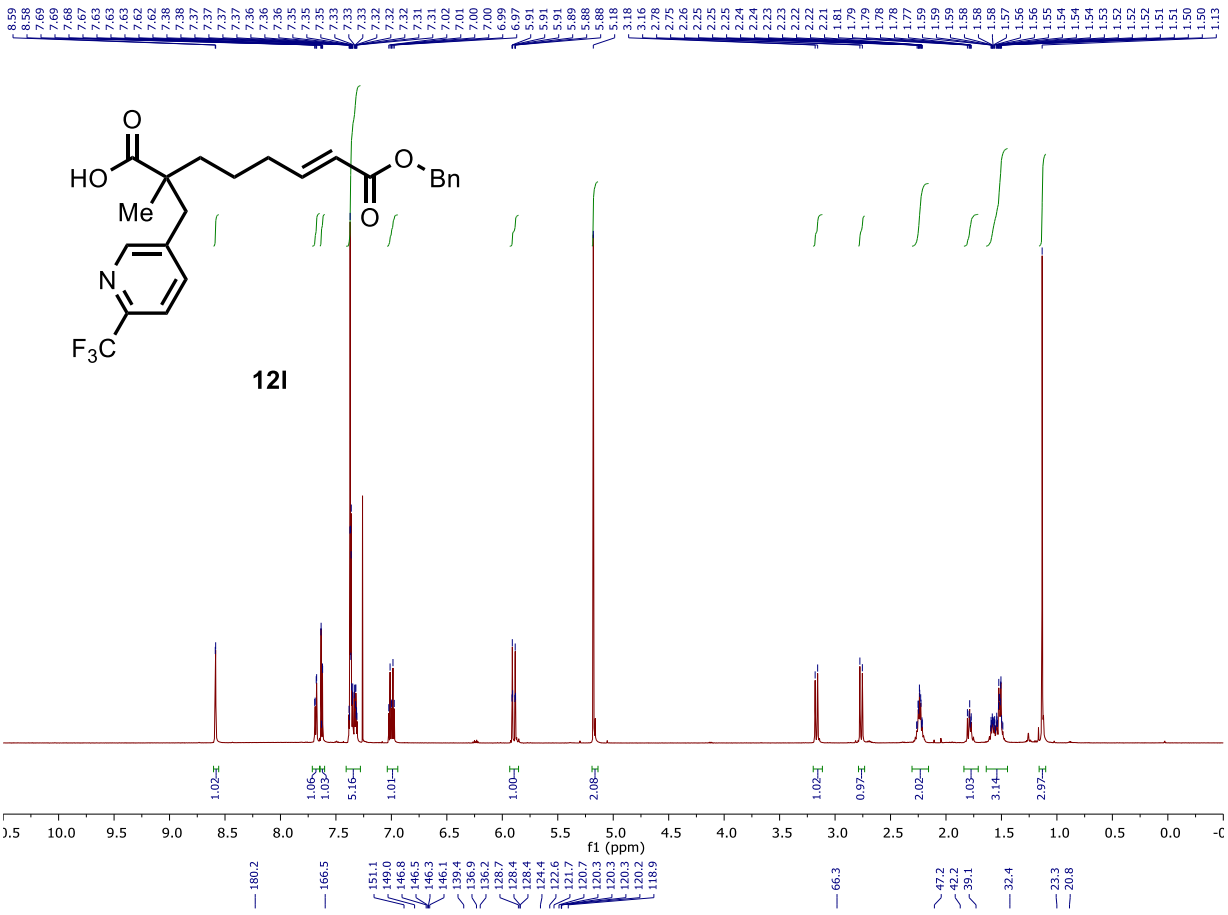

HO
O
Me
O
O
Bn
12i
f1 (ppm)

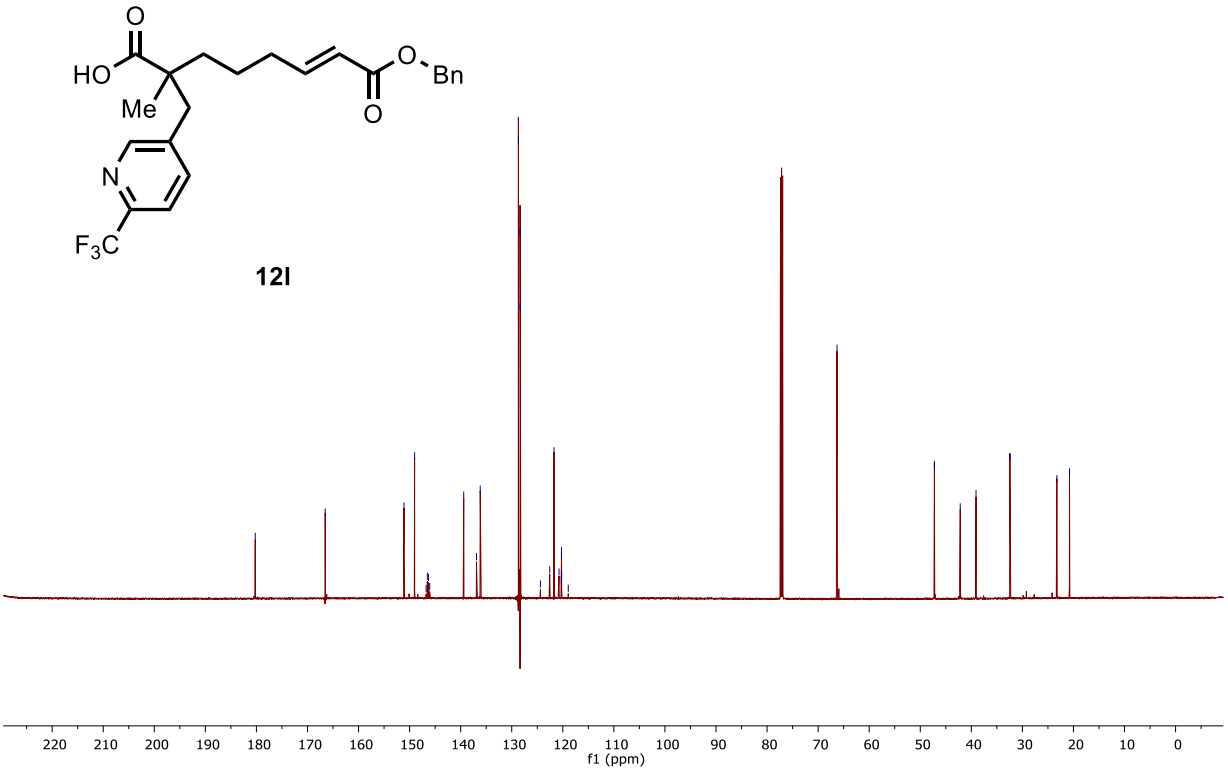

HO
O
Me
O
O
Bn
MeO
12j
f1 (ppm)

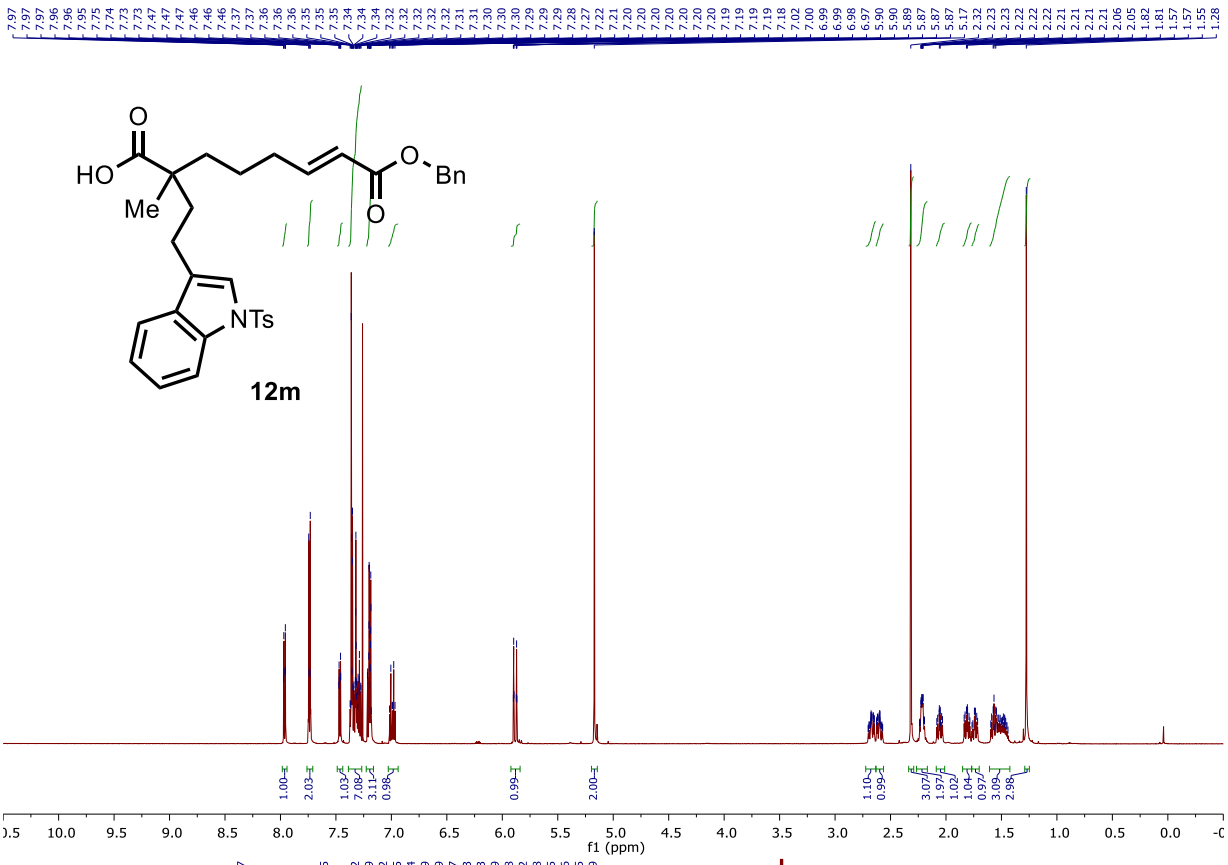

HO
O
Me
O
O
Bn
MeO
12j
f1 (ppm)

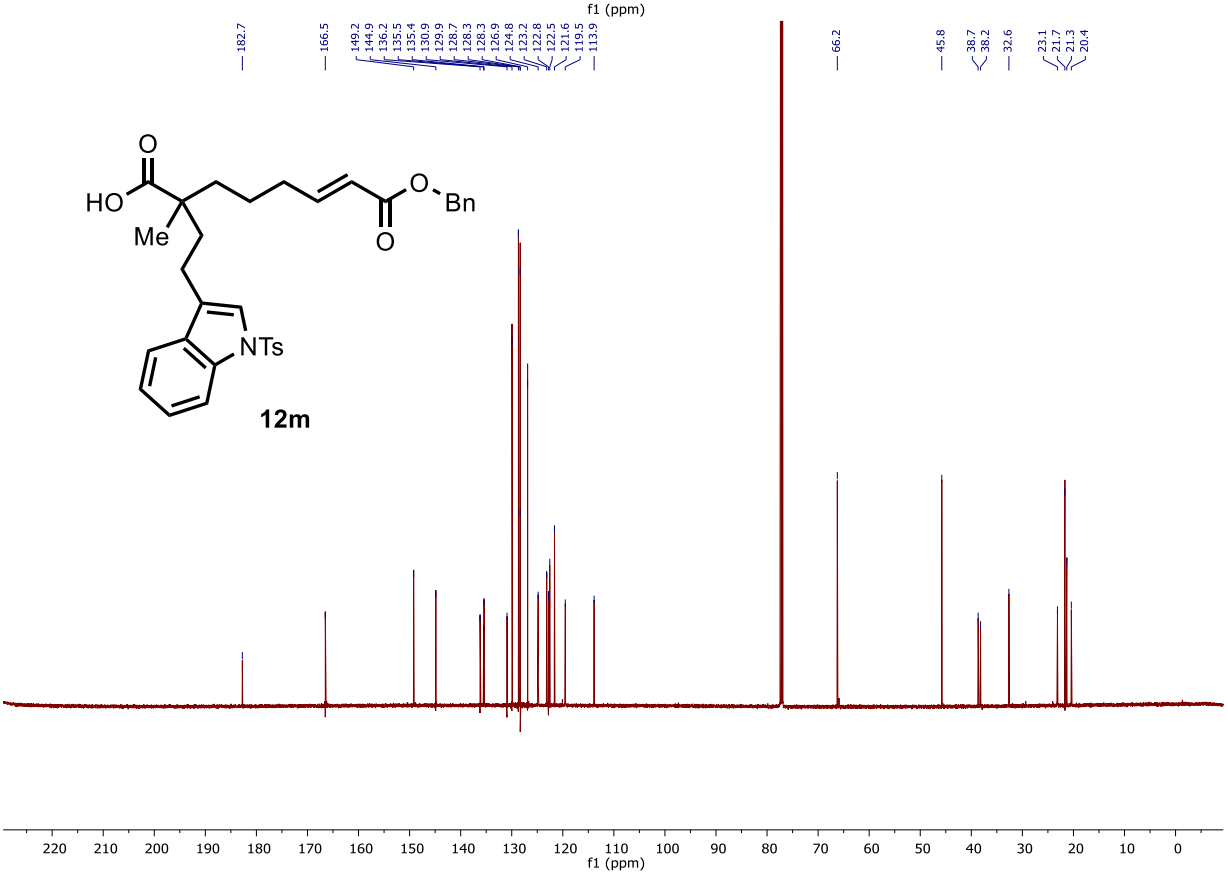

HO
O
Me
O
Bn
O
NC
12k
f1 (ppm)

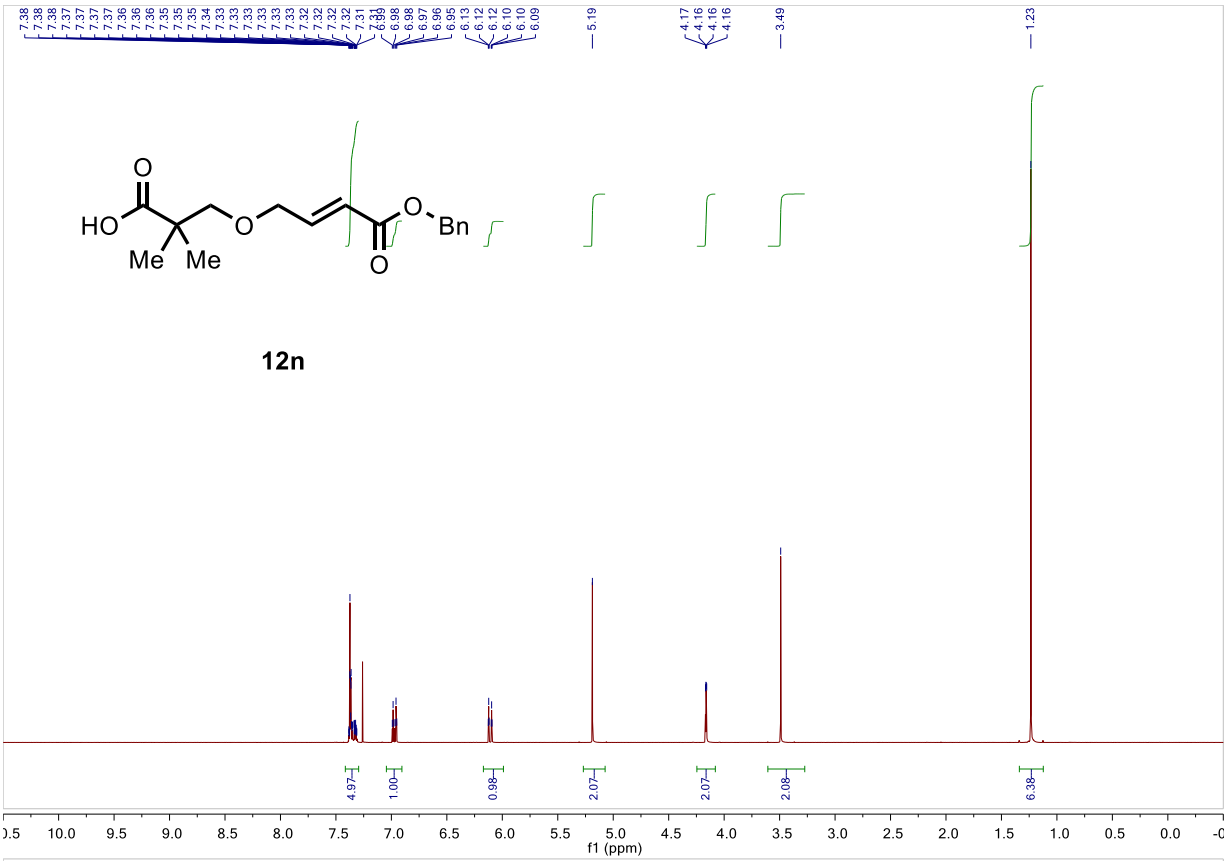

HO
O
Me
O
Bn
O
NC
12k
f1 (ppm)

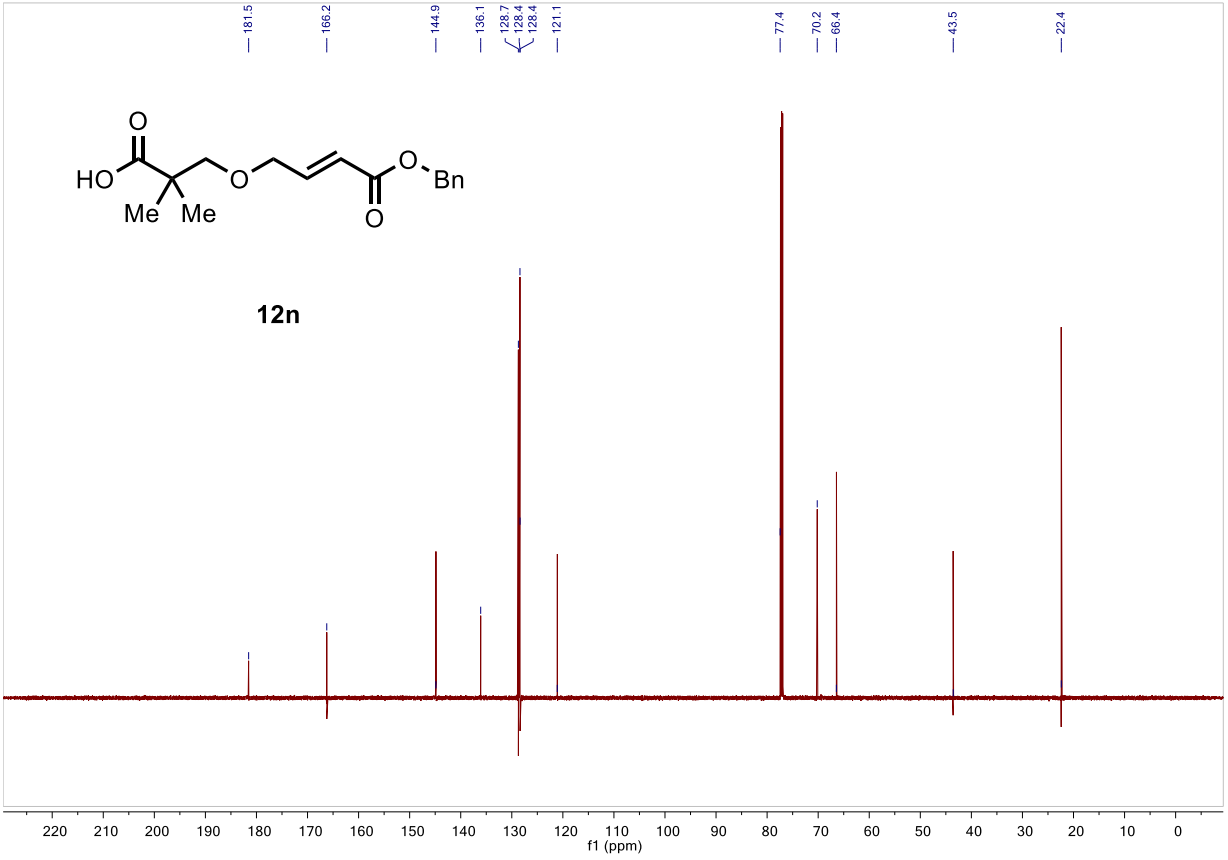

HO
O
Me
N
F3C
O
O
Bn
12l
f1 (ppm)

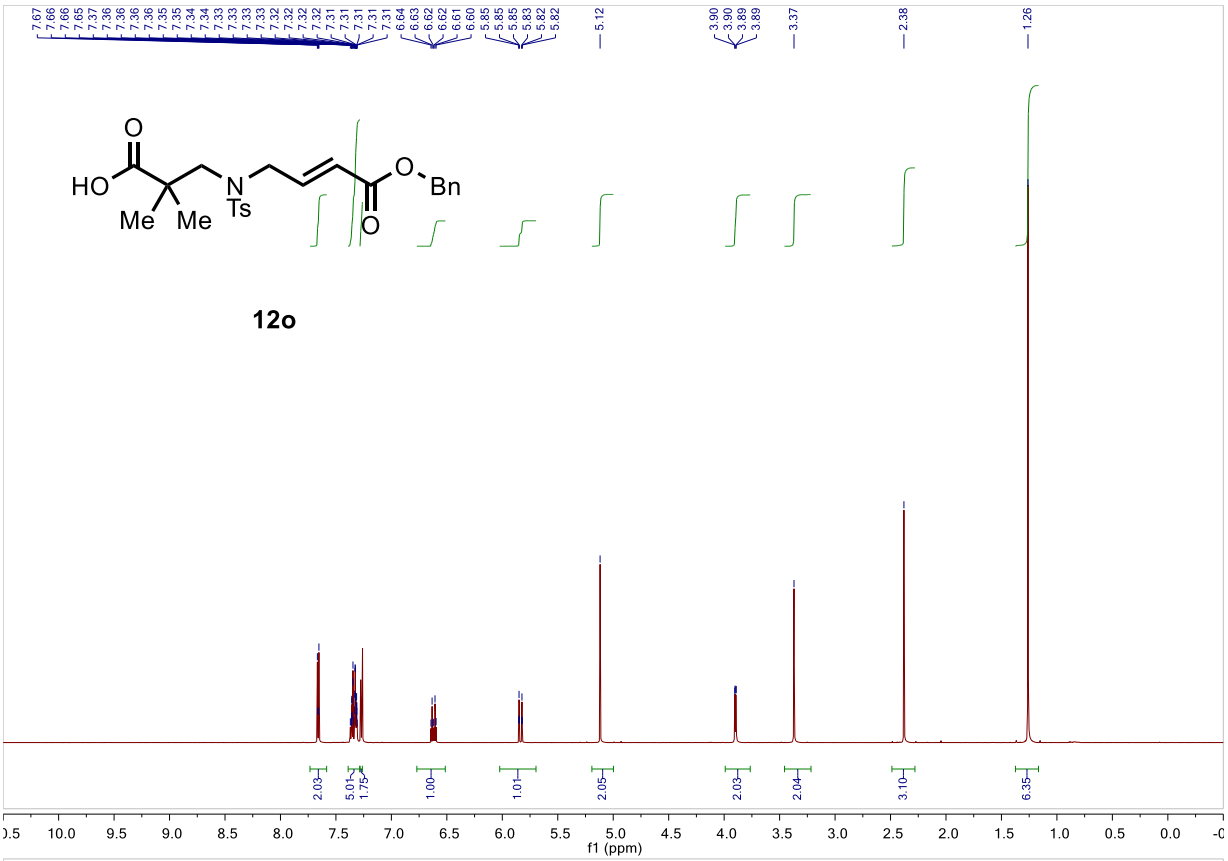

HO
O
Me
N
F3C
O
O
Bn
12l
f1 (ppm)


HO
O
Me
O
Bn
O
NTs
12m
f1 (ppm)

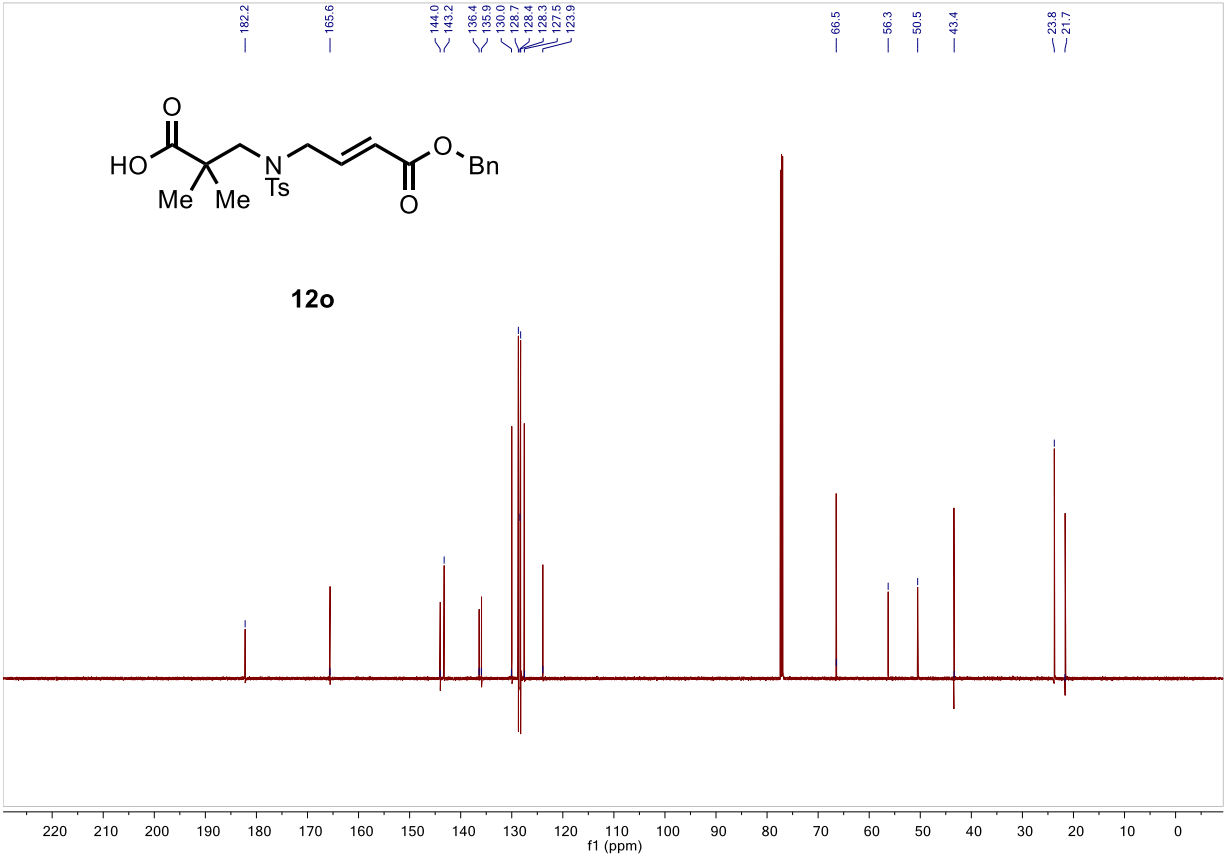

HO
O
Me
O
Bn
O
NTs
12m
f1 (ppm)


12n
f1 (ppm)

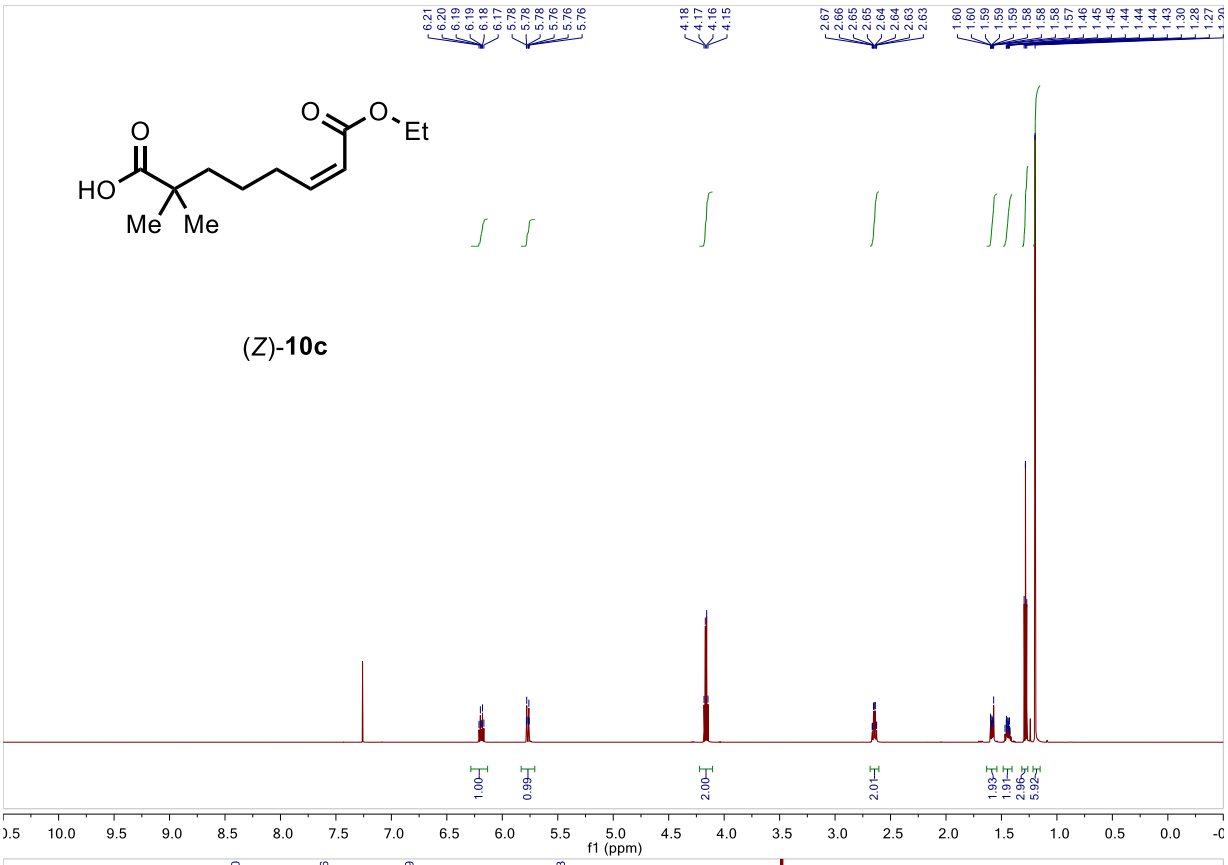

12n
f1 (ppm)

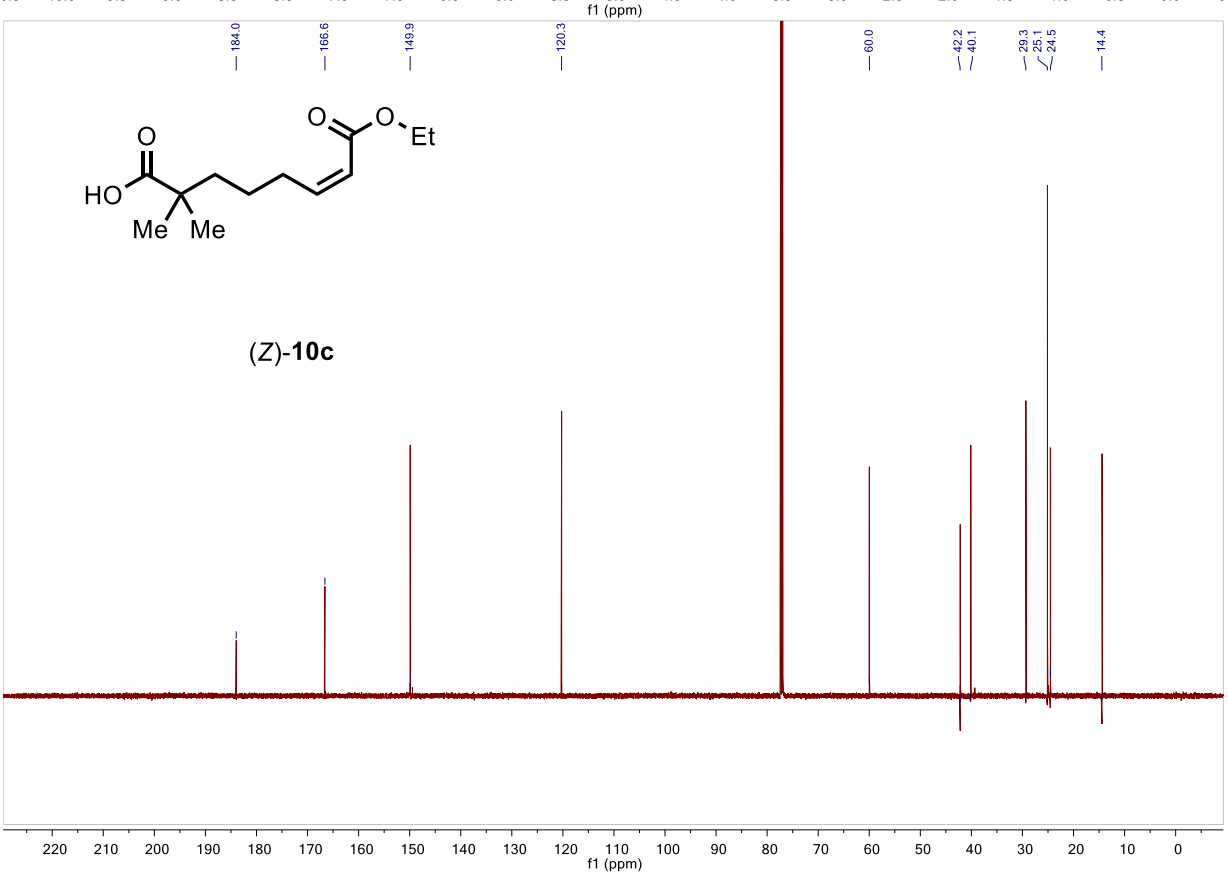

7.67 7.66 7.66 7.65 7.37 7.36 7.36 7.36 7.35 7.34 7.33 7.33 7.33 7.32 7.32 7.32 7.31 7.31 7.31 7.31 6.64 6.63 6.62 6.62 6.61 6.60 5.85 5.85 5.83 5.82 5.82 5.12 3.90 3.90 3.89 3.89 3.37 2.38 1.26
HO
O
Me Me
N
Ts
O
O
Bn
2.03 5.01 1.75 1.00 1.01 2.05 2.03 2.04 3.10 6.35
f1 (ppm)

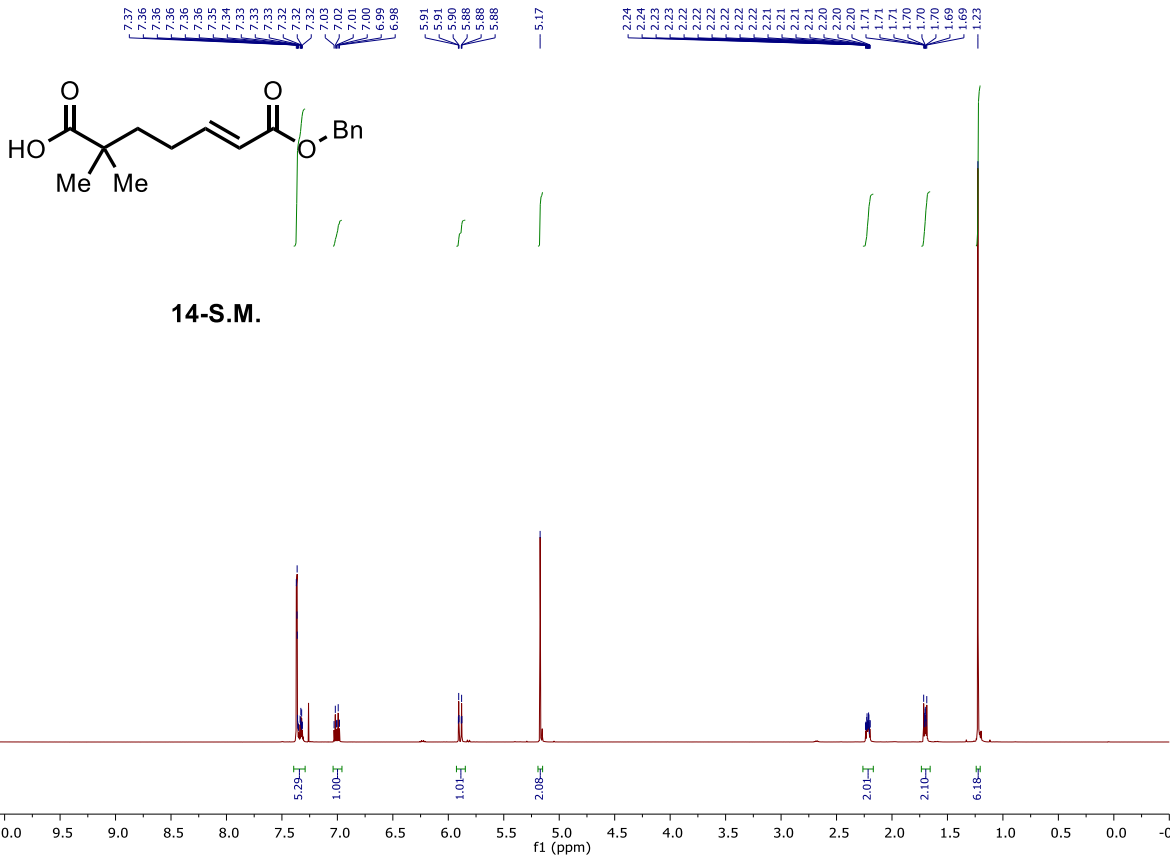
12o


182.2 165.6 144.0 143.2 136.4 135.9 130.0 128.7 128.4 128.3 127.5 123.9 66.5 56.3 50.5 43.4 23.8 21.7
HO
O
Me Me
N
Ts
O
O
Bn
f1 (ppm)

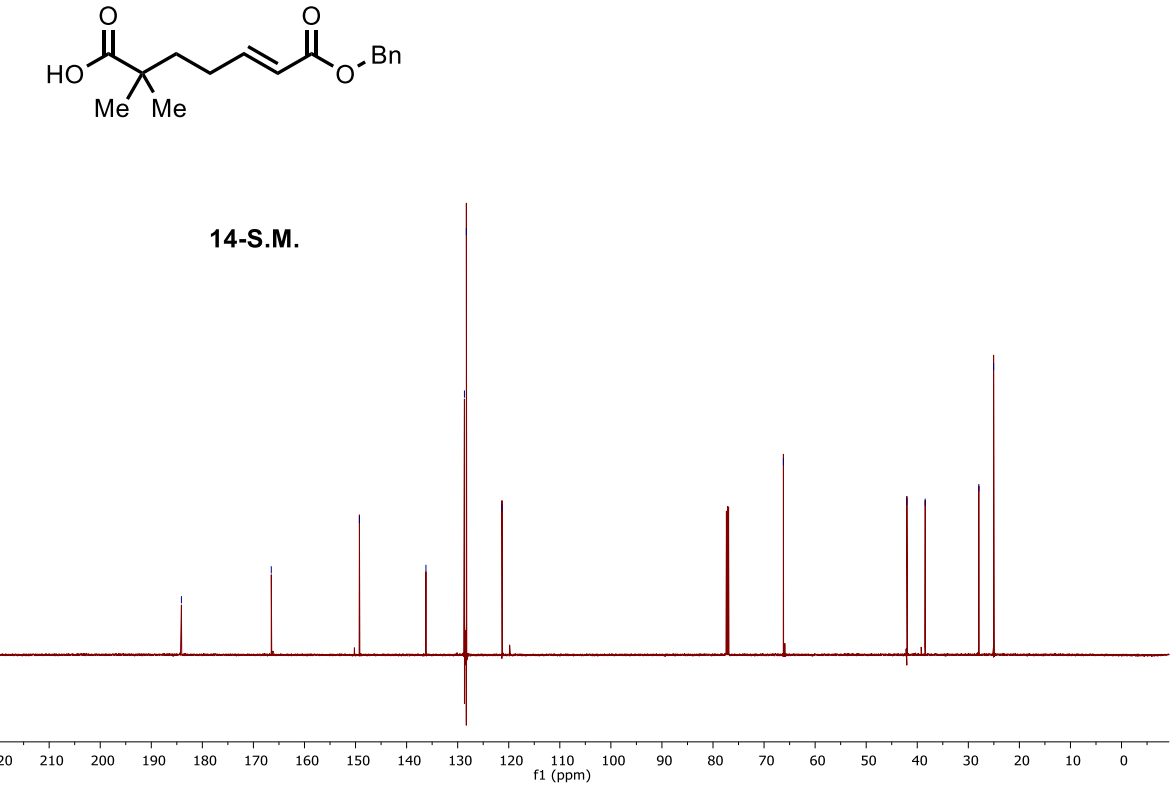
12o


HO
O
O
O
Et
Me
Me
(Z)-10c
f1 (ppm)

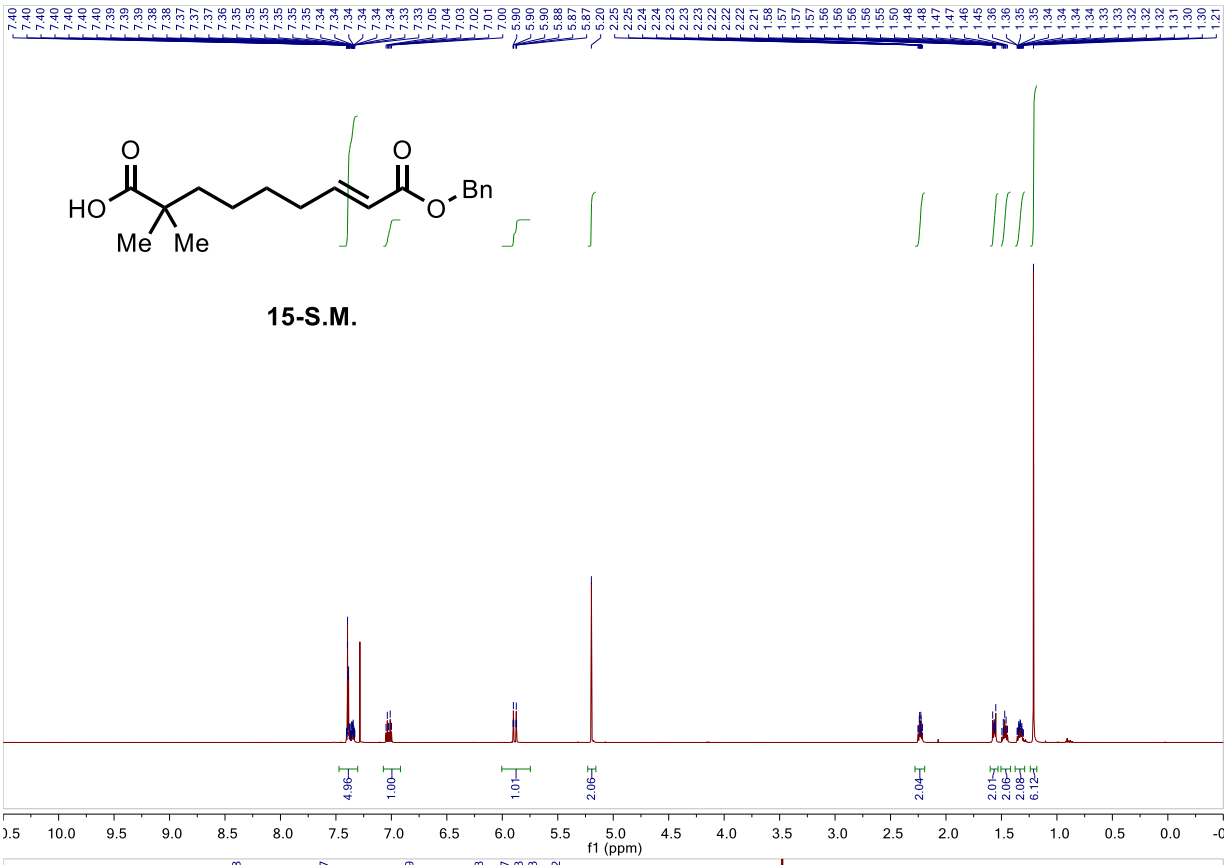

HO
O
O
O
Et
Me
Me
(Z)-10c
f1 (ppm)

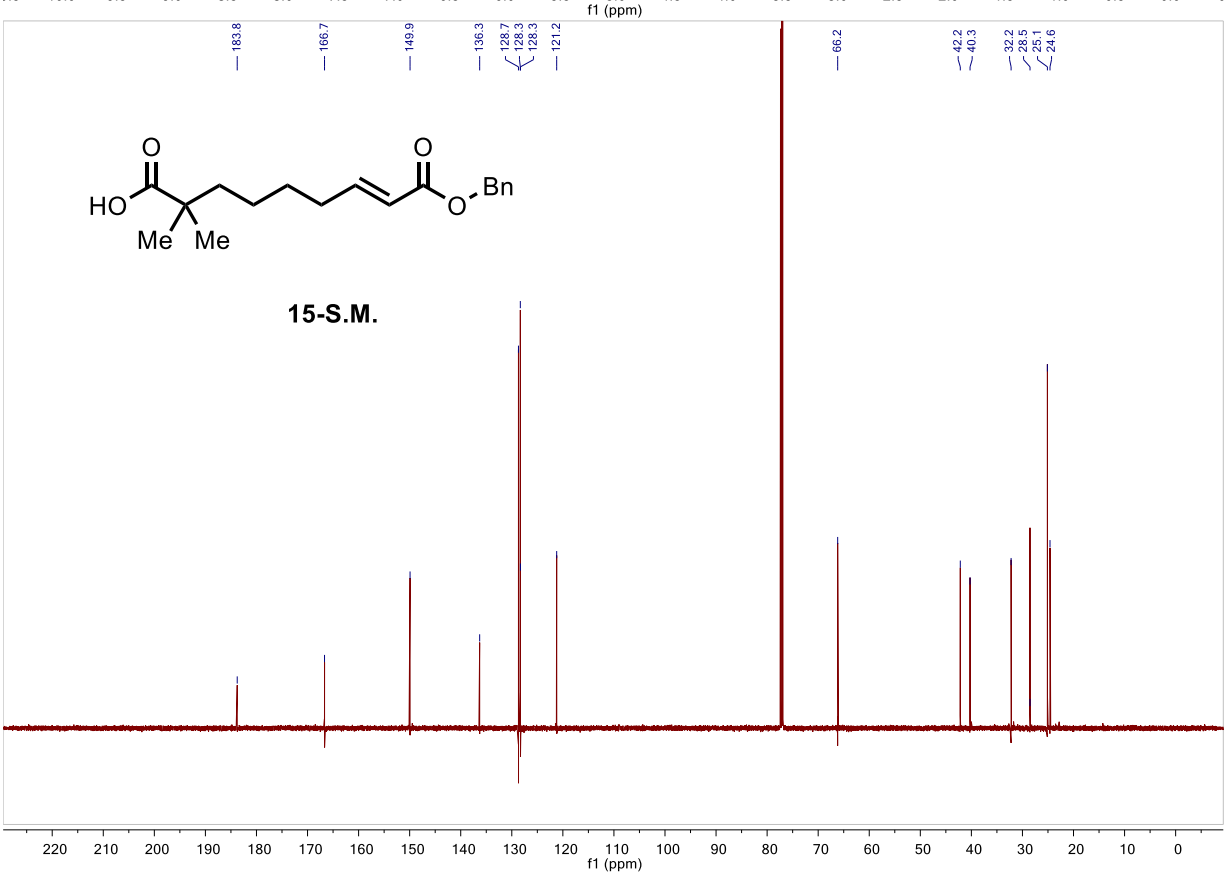

HO
O
O
O
Bn
Me
Me
5.29
1.00
1.01
2.08
2.01
2.10
6.18
f1 (ppm)

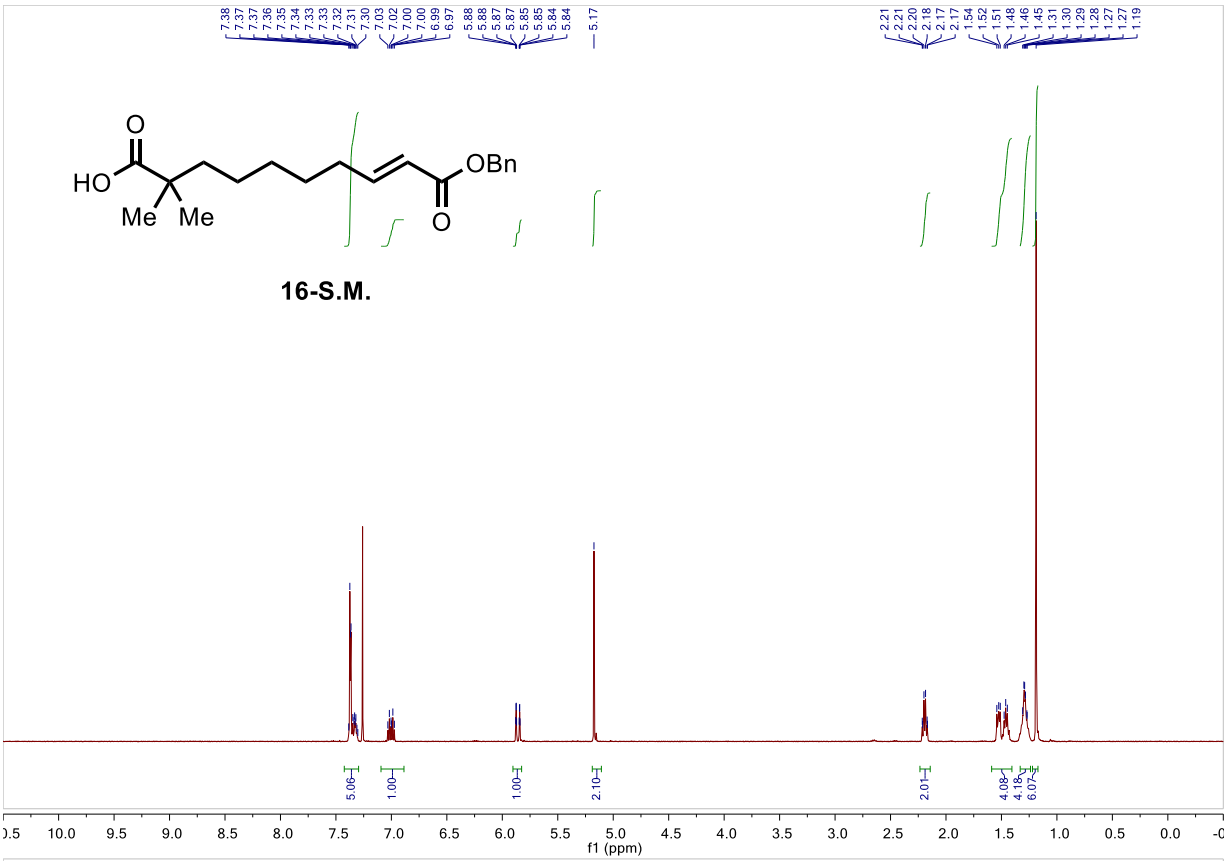
14-S.M.

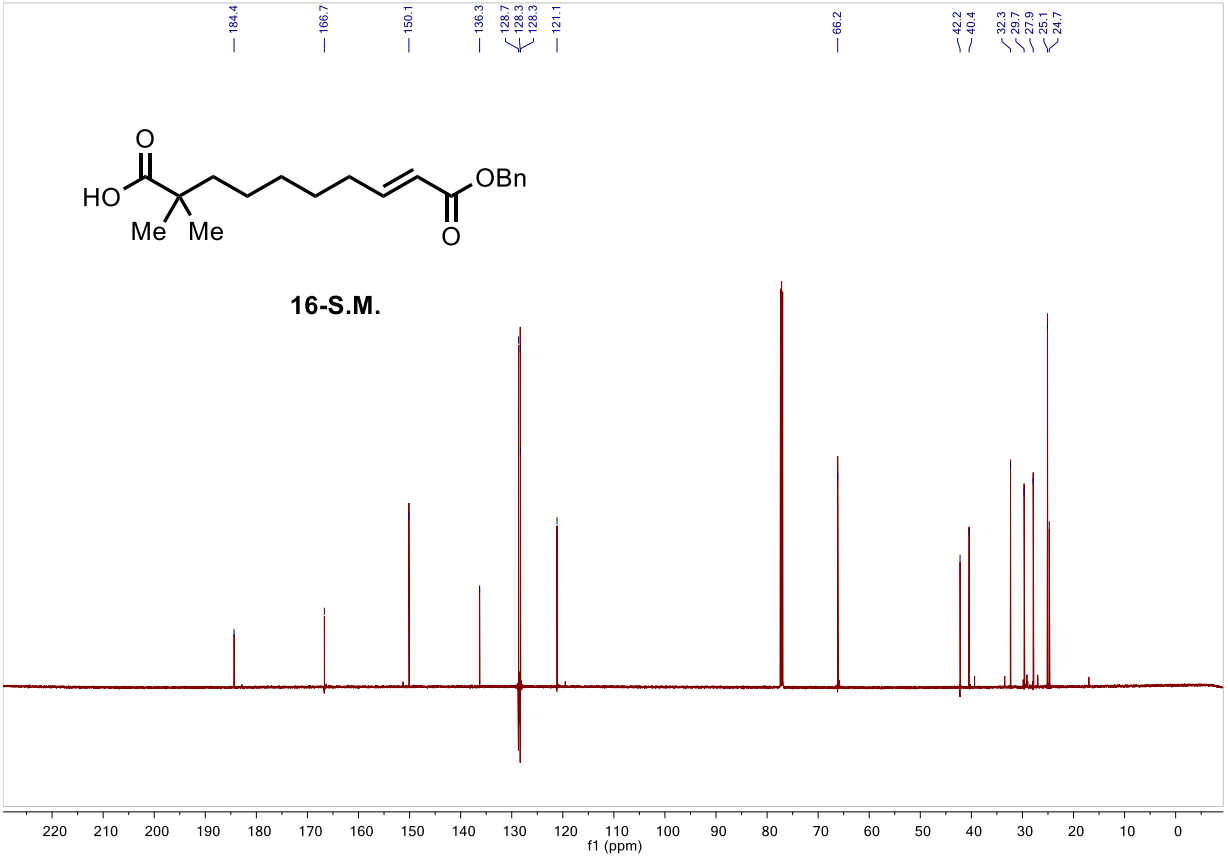

HO
O
O
O
Bn
Me
Me
184.1
166.5
149.2
136.2
128.7
128.3
121.3
66.2
42.0
38.4
27.9
25.0
f1 (ppm)

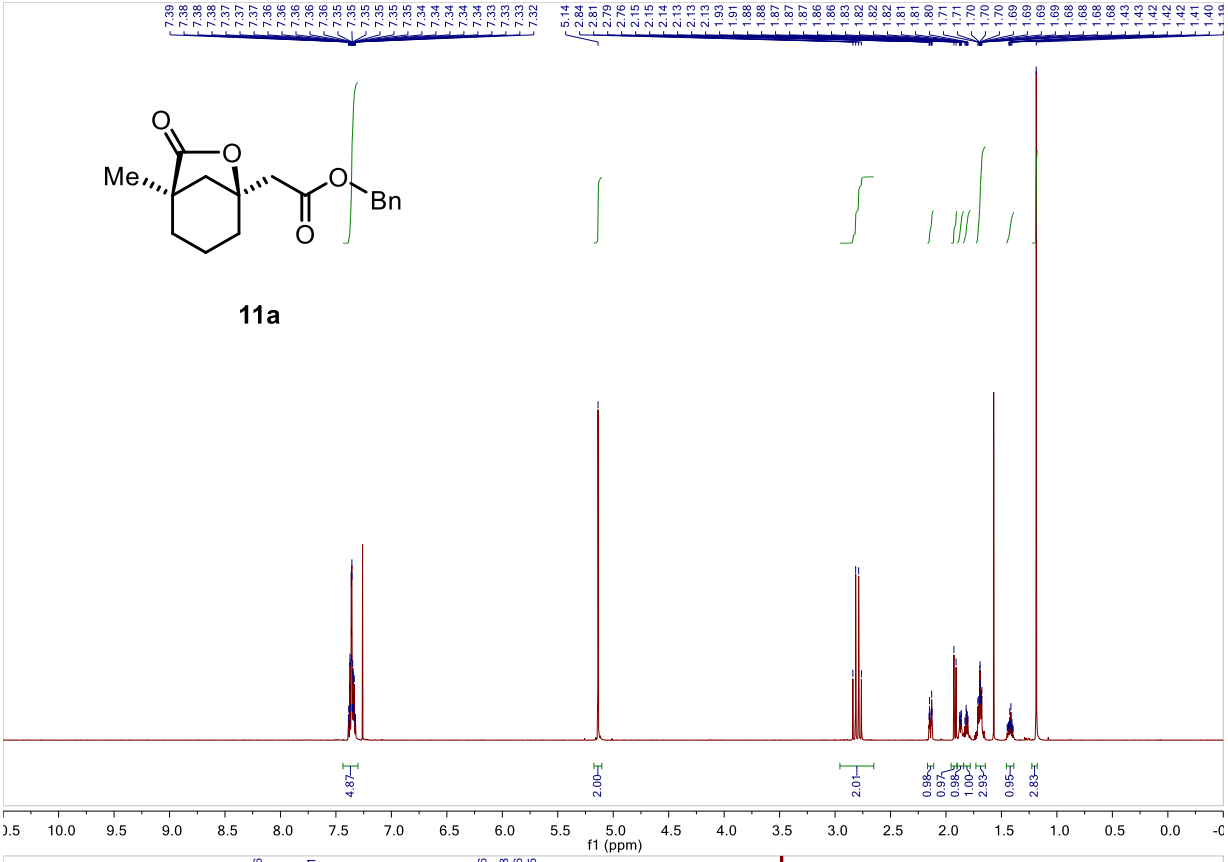
14-S.M.

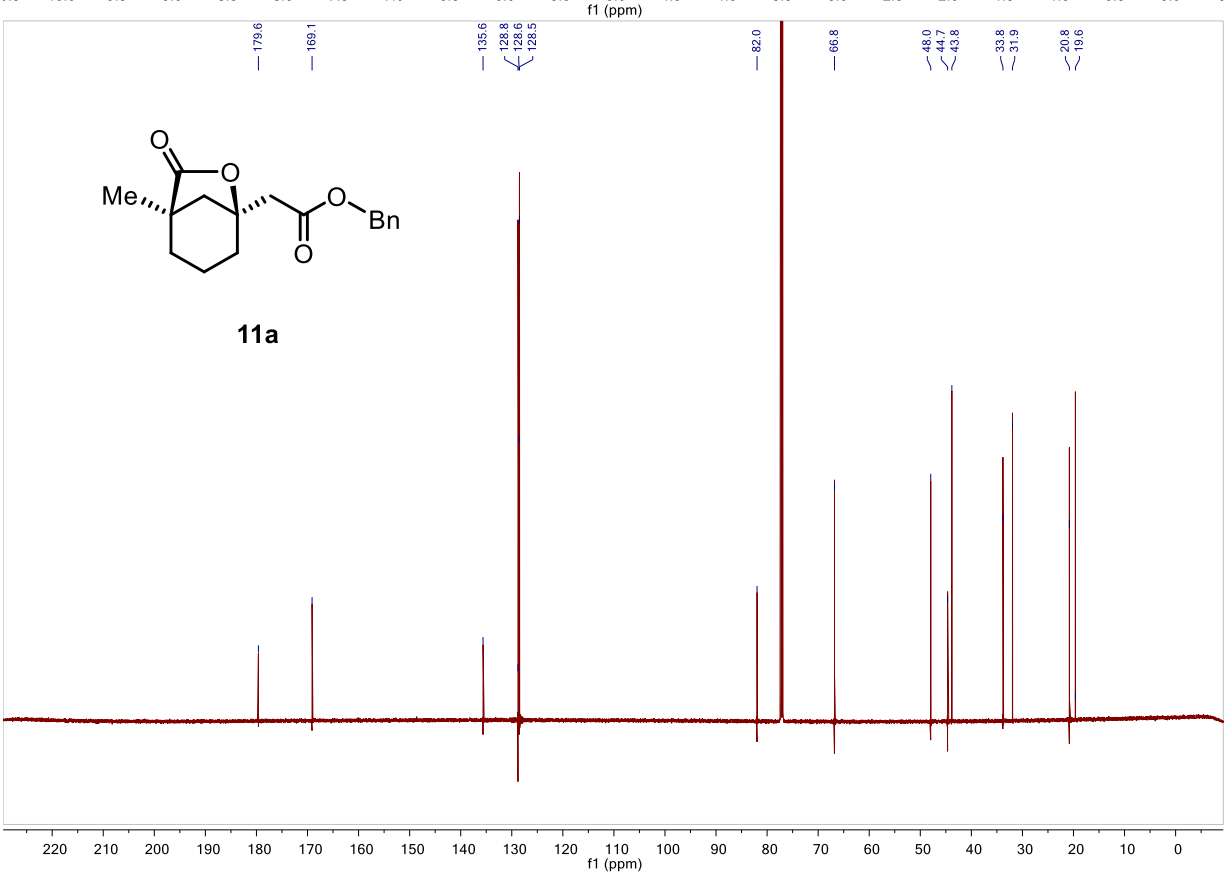

HO
O
O
O
Bn
Me
Me
15-S.M.
4.96
1.00
1.01
2.06
2.04
2.01
2.06
2.08
6.12
f1 (ppm)

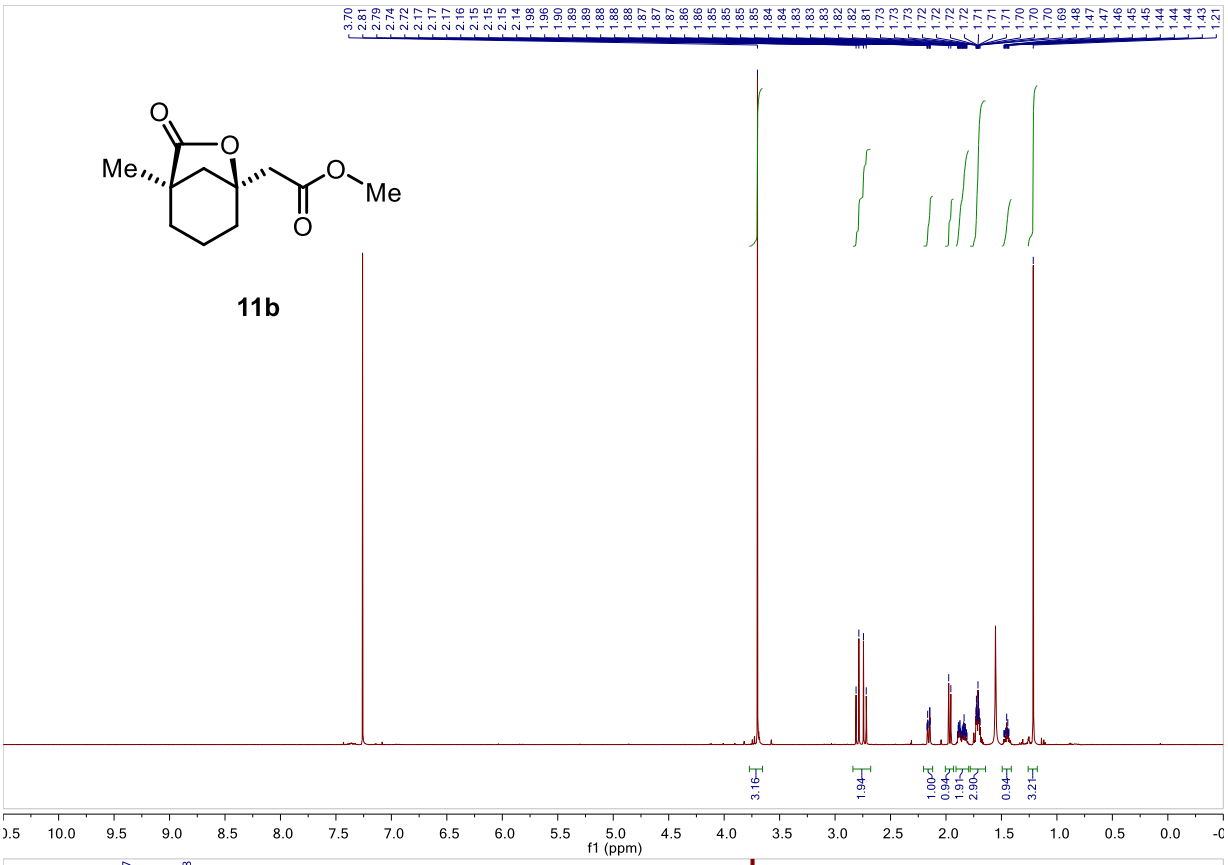

183.8
166.7
149.9
136.3
128.7
128.3
128.3
121.2
66.2
42.2
40.3
32.2
28.5
25.1
24.6
HO
O
O
O
Bn
Me
Me
15-S.M.
f1 (ppm)

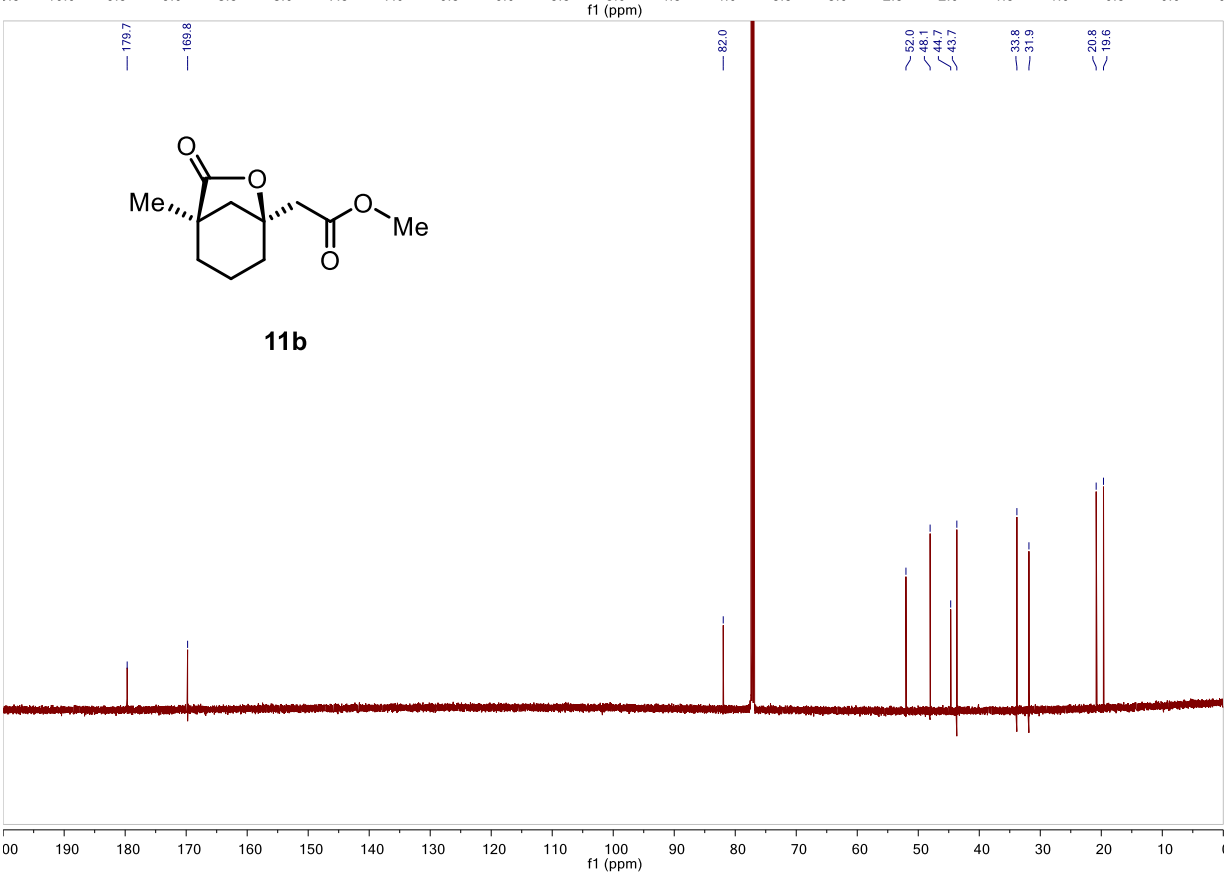

HO
O
Me Me
OBn
O
16-S.M.
f1 (ppm)

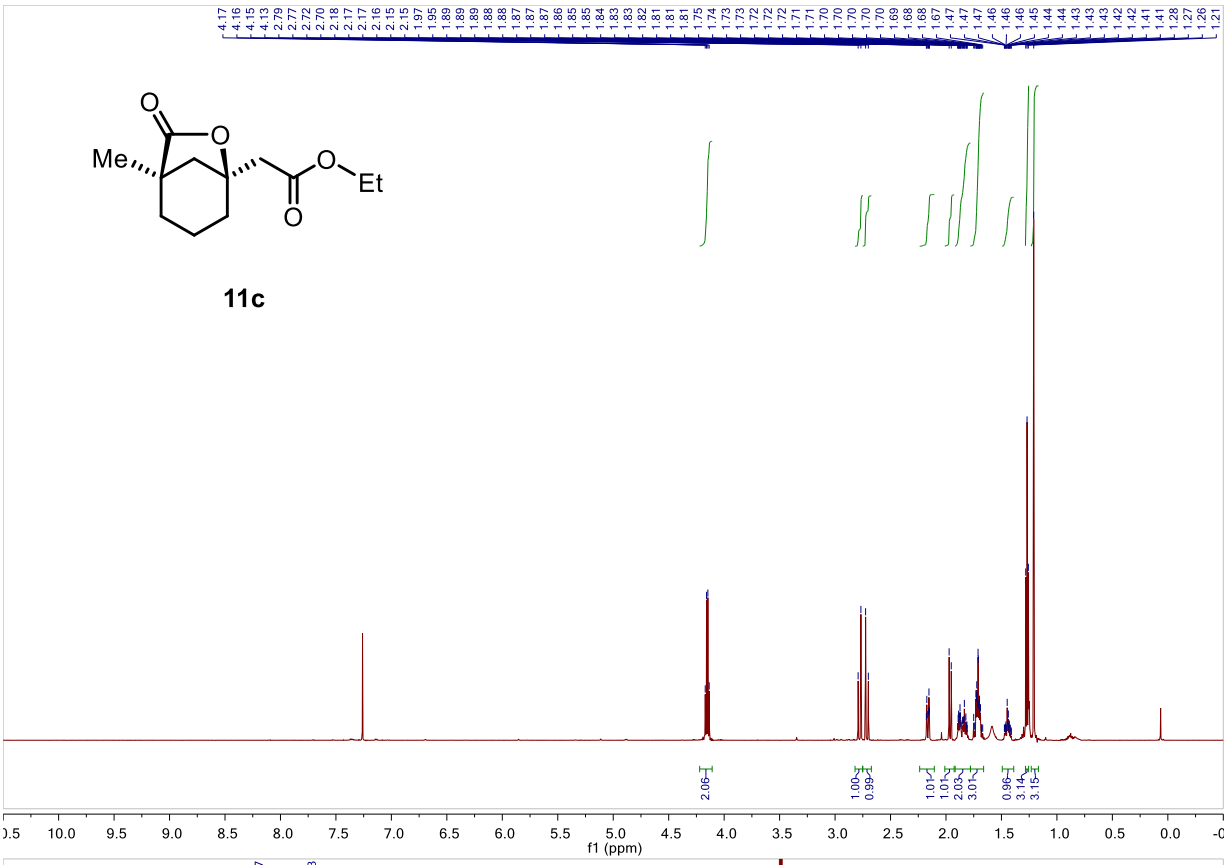

HO
O
Me Me
OBn
O
16-S.M.
f1 (ppm)

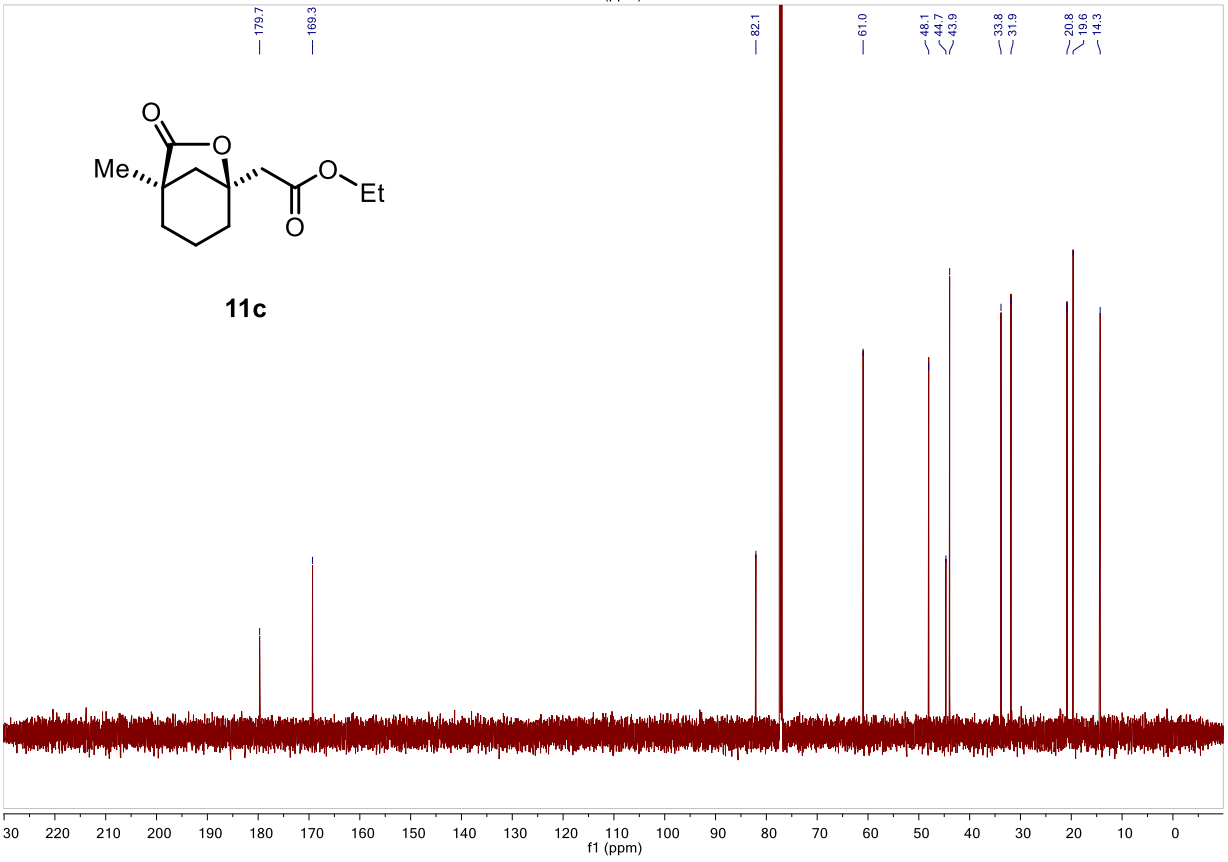

Me
O
O
O
O
Bn
11a
4.87
2.00
2.01
0.98
0.97
0.98
1.00
2.93
0.95
2.83
f1 (ppm)

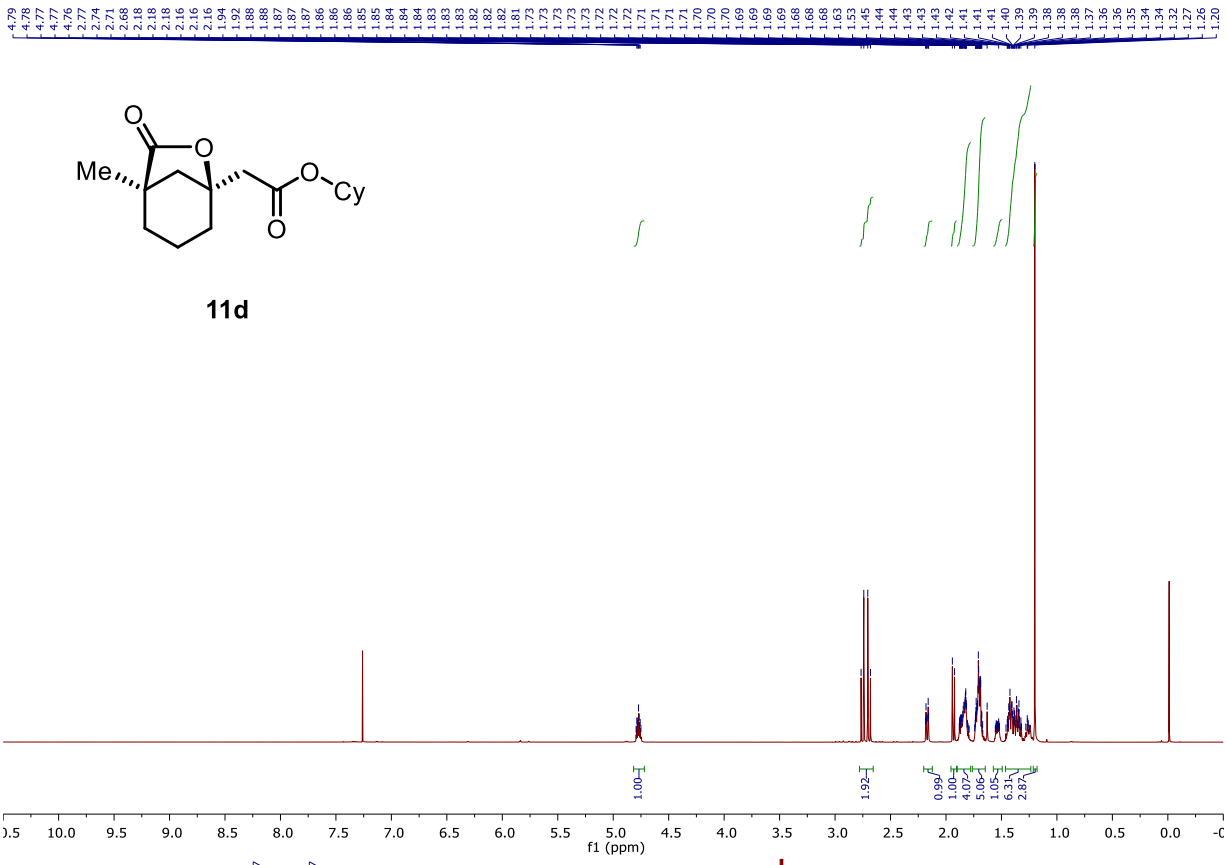

179.6
169.1
135.6
128.8
128.6
128.5
82.0
66.8
48.0
44.7
43.8
33.8
31.9
20.8
19.6
Me
O
O
O
O
Bn
11a
f1 (ppm)

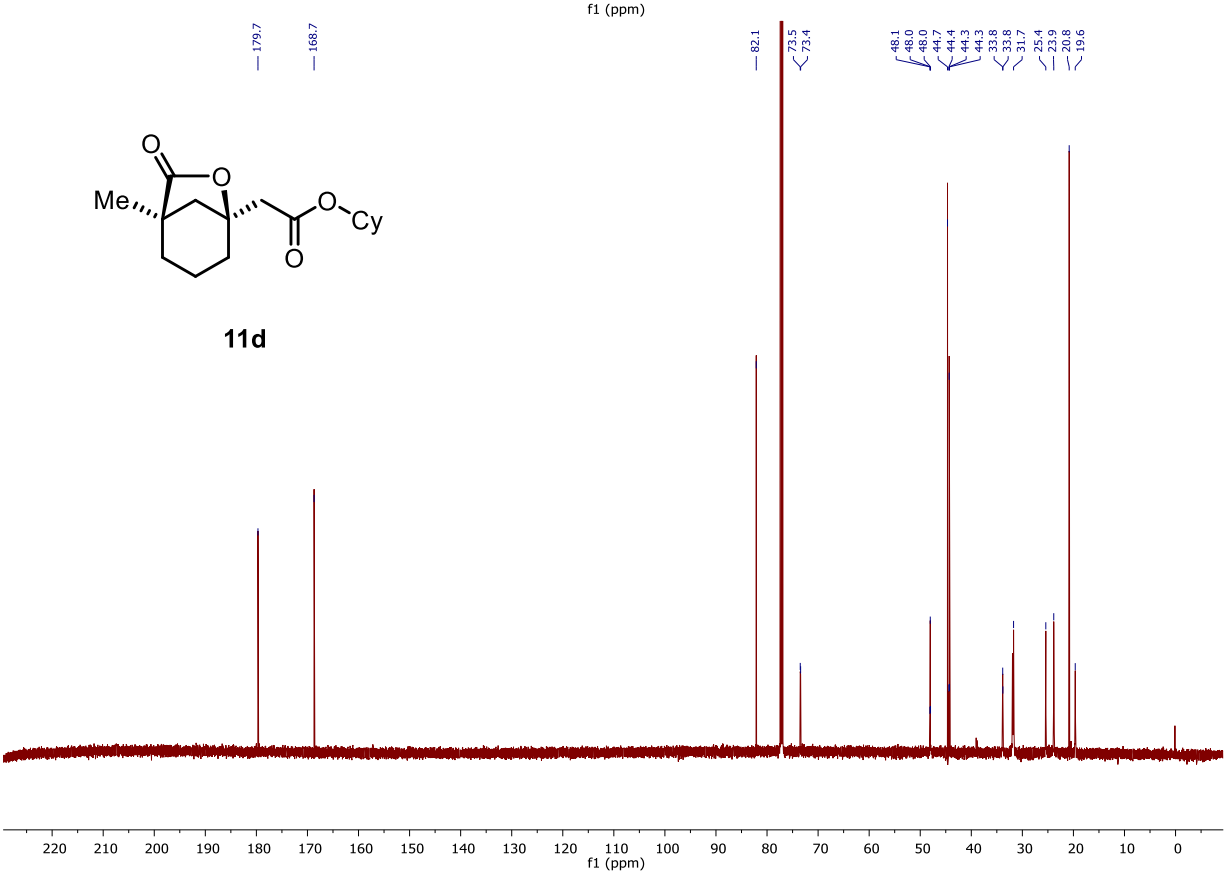

Me
O
O
O
O
Me
11b
3.16
1.94
1.00
0.94
1.91
2.90
0.94
3.21
f1 (ppm)

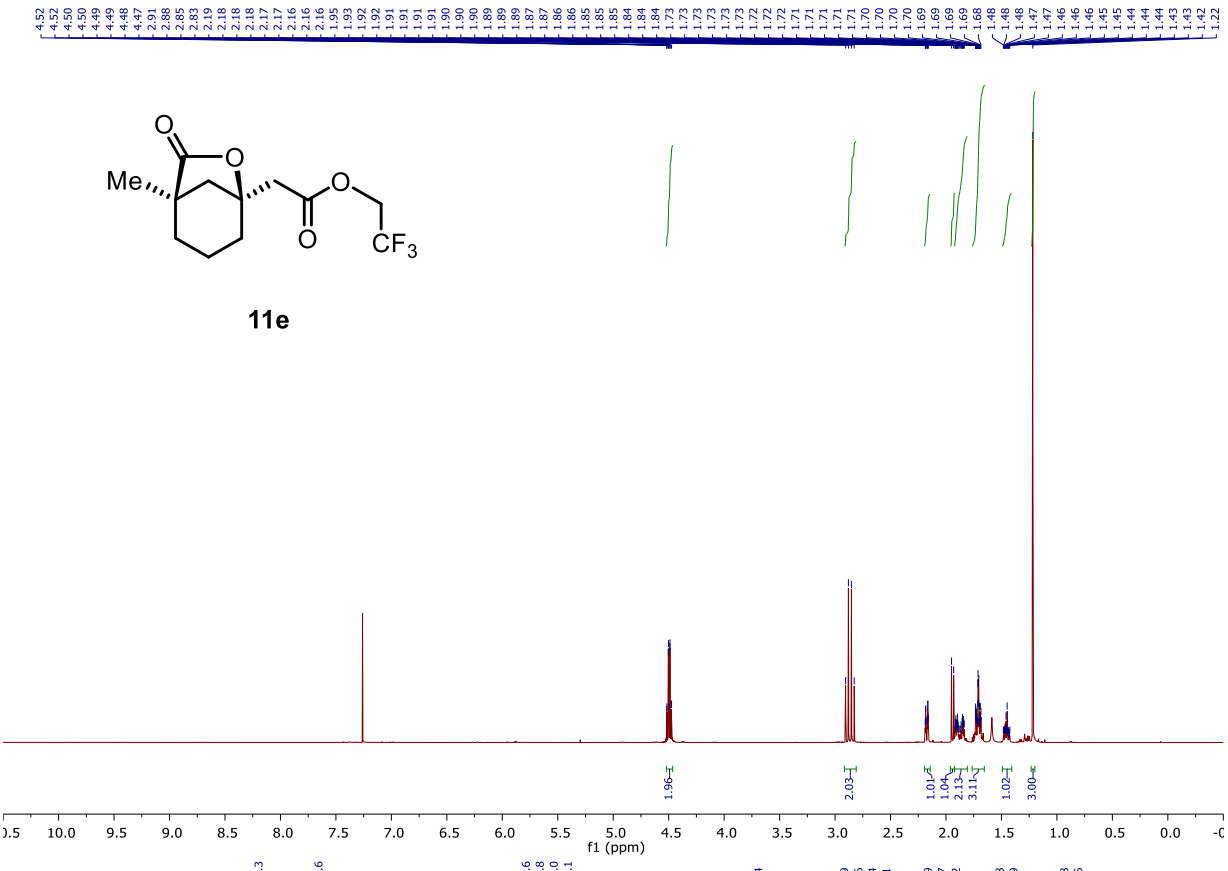

179.7
169.8
82.0
52.0
48.1
44.7
43.7
33.8
31.9
20.8
19.6
Me
O
O
O
O
Me
11b
f1 (ppm)

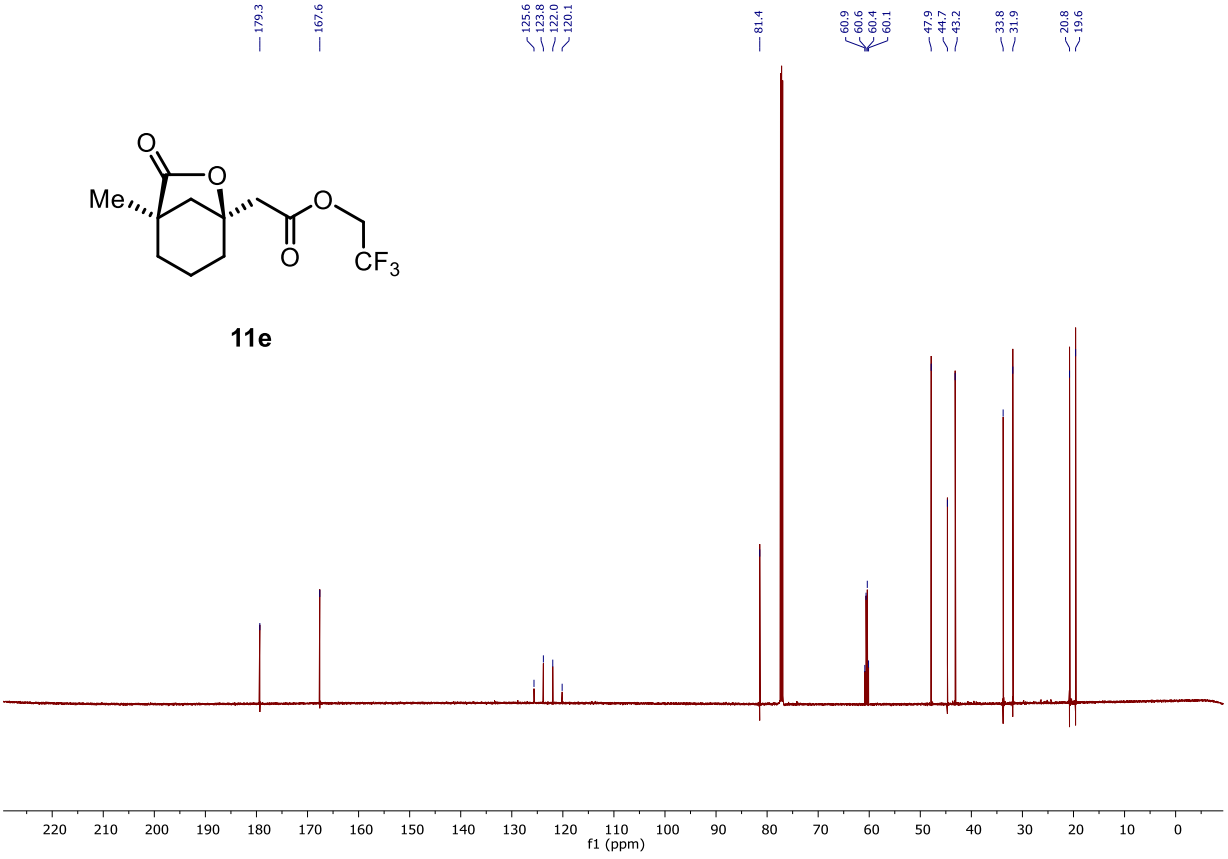

Me
O
O
O
O
Et
11c
f1 (ppm)

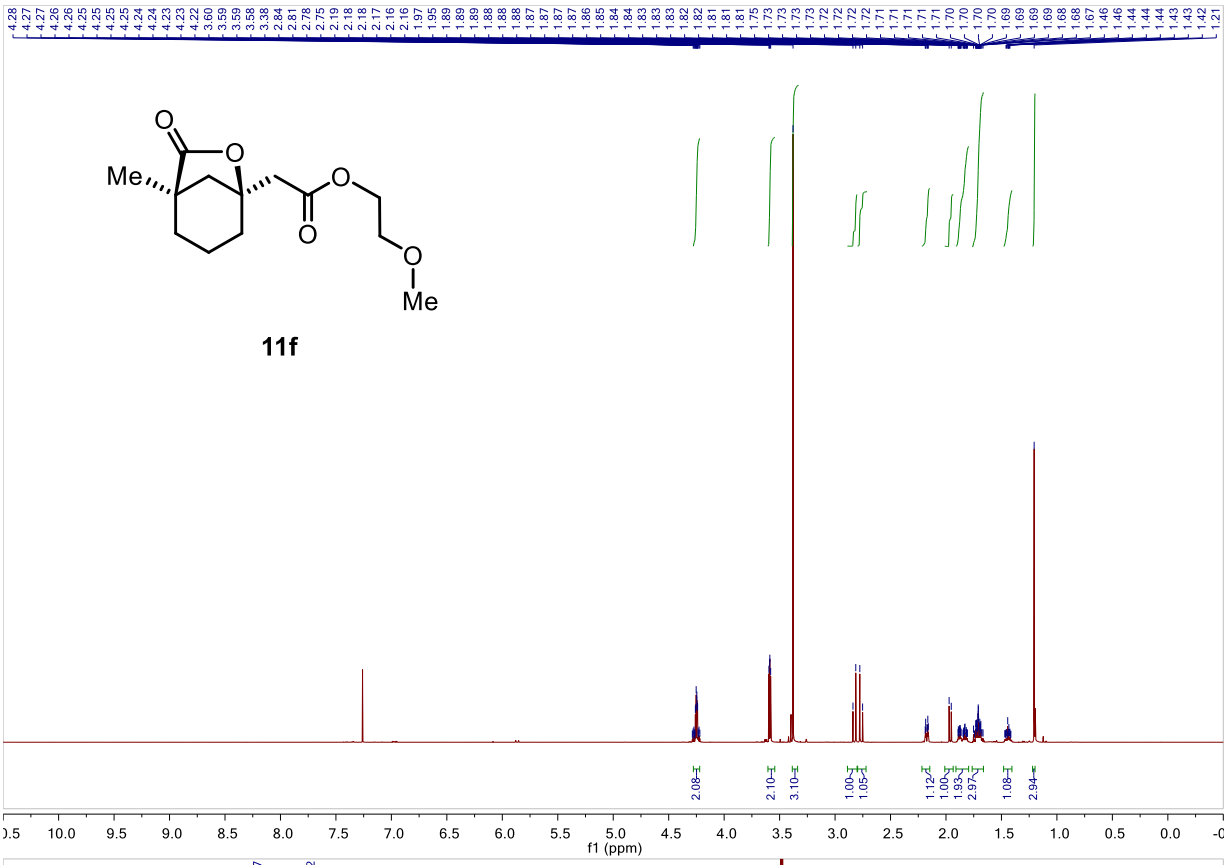

Me
O
O
O
O
Et
11c
f1 (ppm)

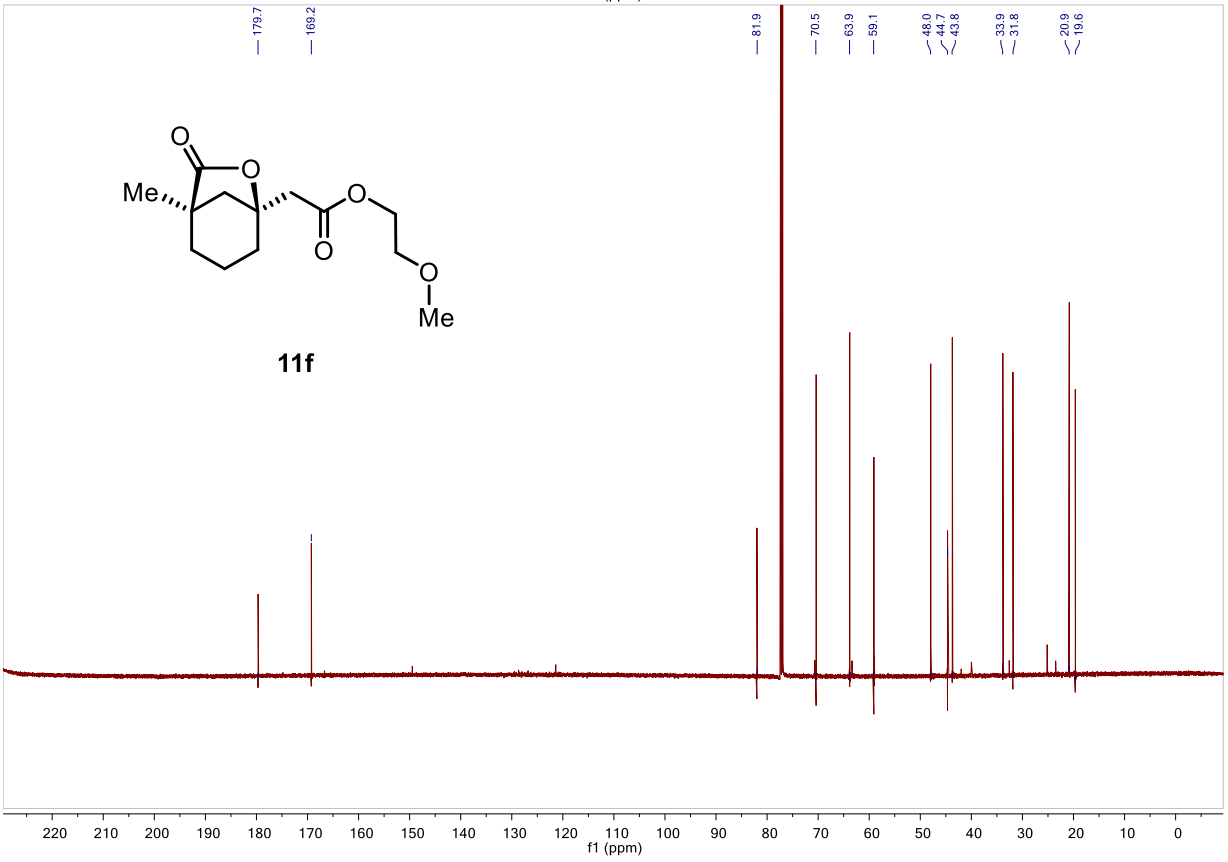

Me
O
O
O
O
Cy
11d
f1 (ppm)

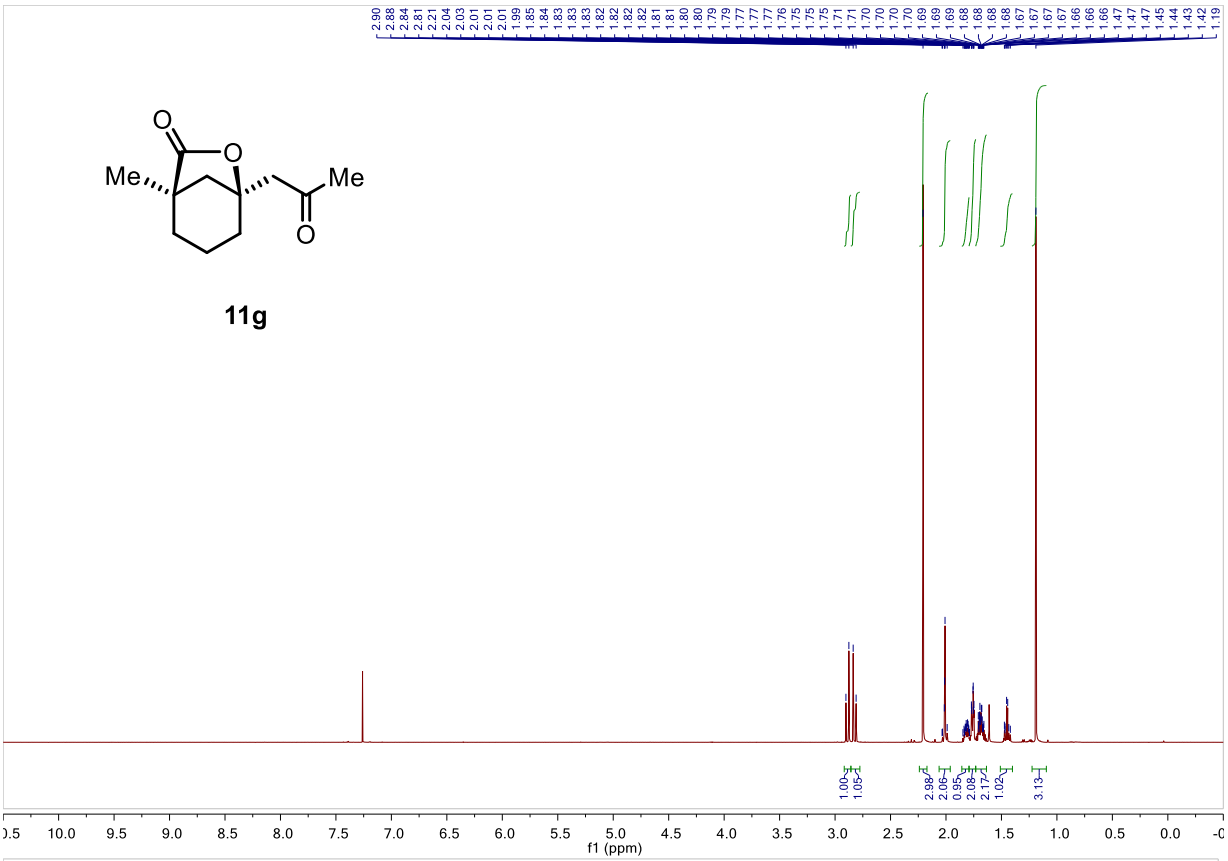

Me
O
O
O
O
Cy
11d
f1 (ppm)

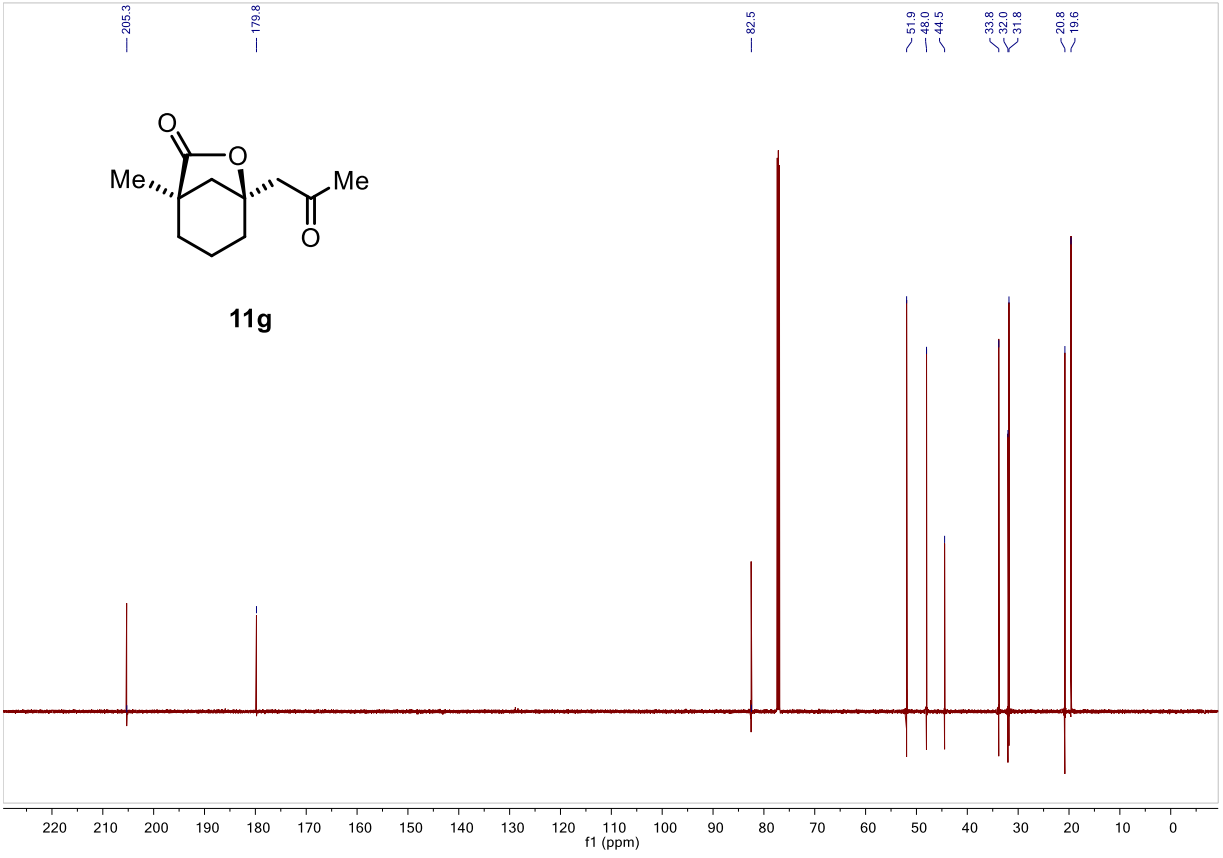

Me
O
O
O
O
CF3
11e
1.96
2.03
1.01
1.04
2.13
3.11
1.02
3.00
f1 (ppm)

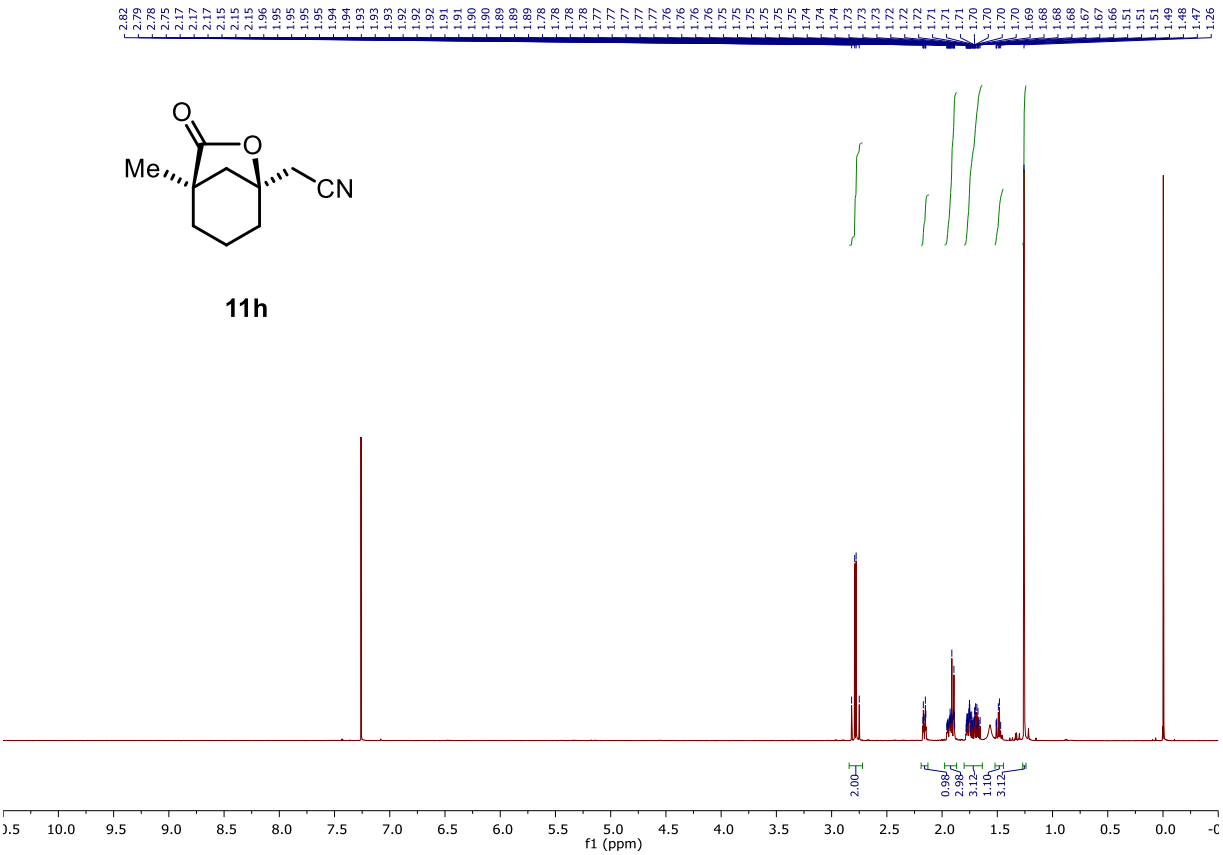

179.3
167.6
125.6
123.8
122.0
120.1
81.4
60.9
60.6
60.4
60.1
47.9
44.7
43.2
33.8
31.9
20.8
19.6
Me
O
O
O
O
CF3
11e
f1 (ppm)

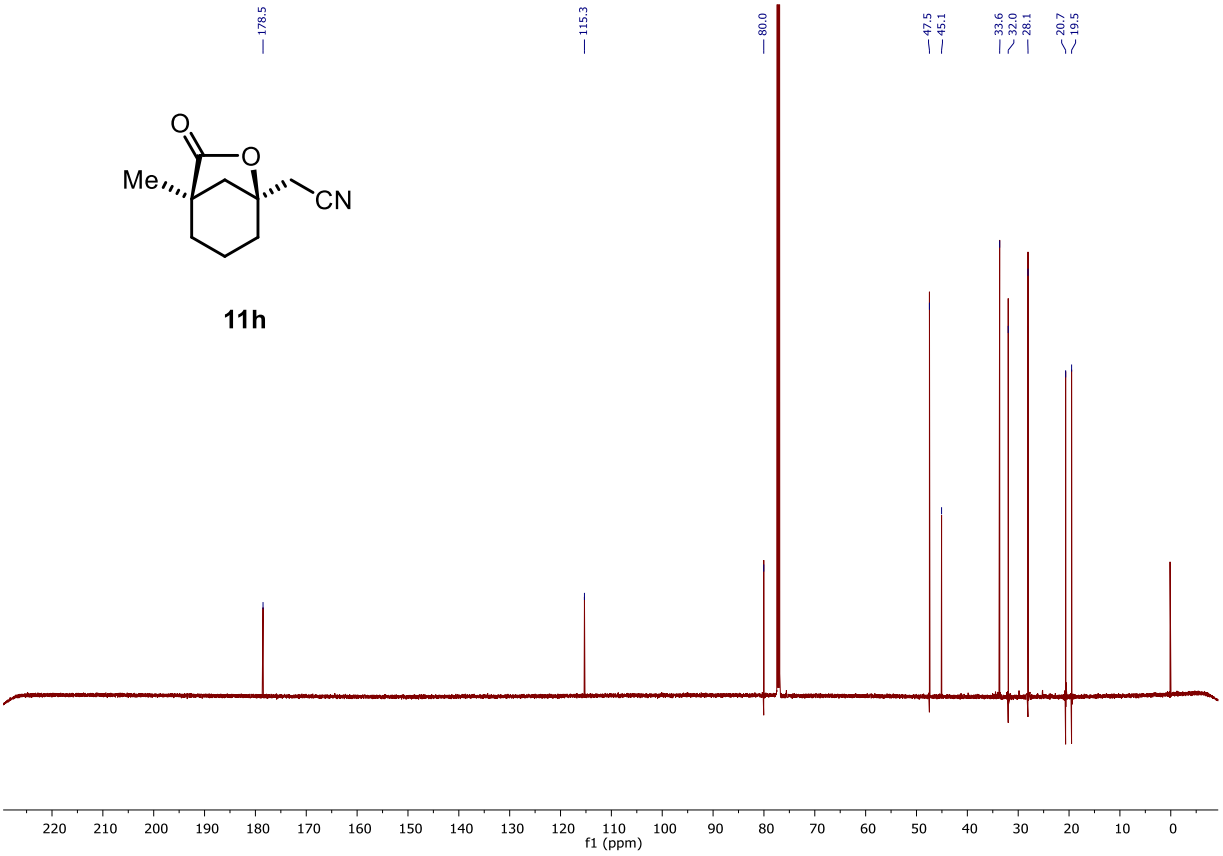

Me
O
O
O
O
O
Me
11f
2.08
2.10
3.10
1.00
1.05
1.12
1.00
1.93
2.97
1.08
2.94
f1 (ppm)

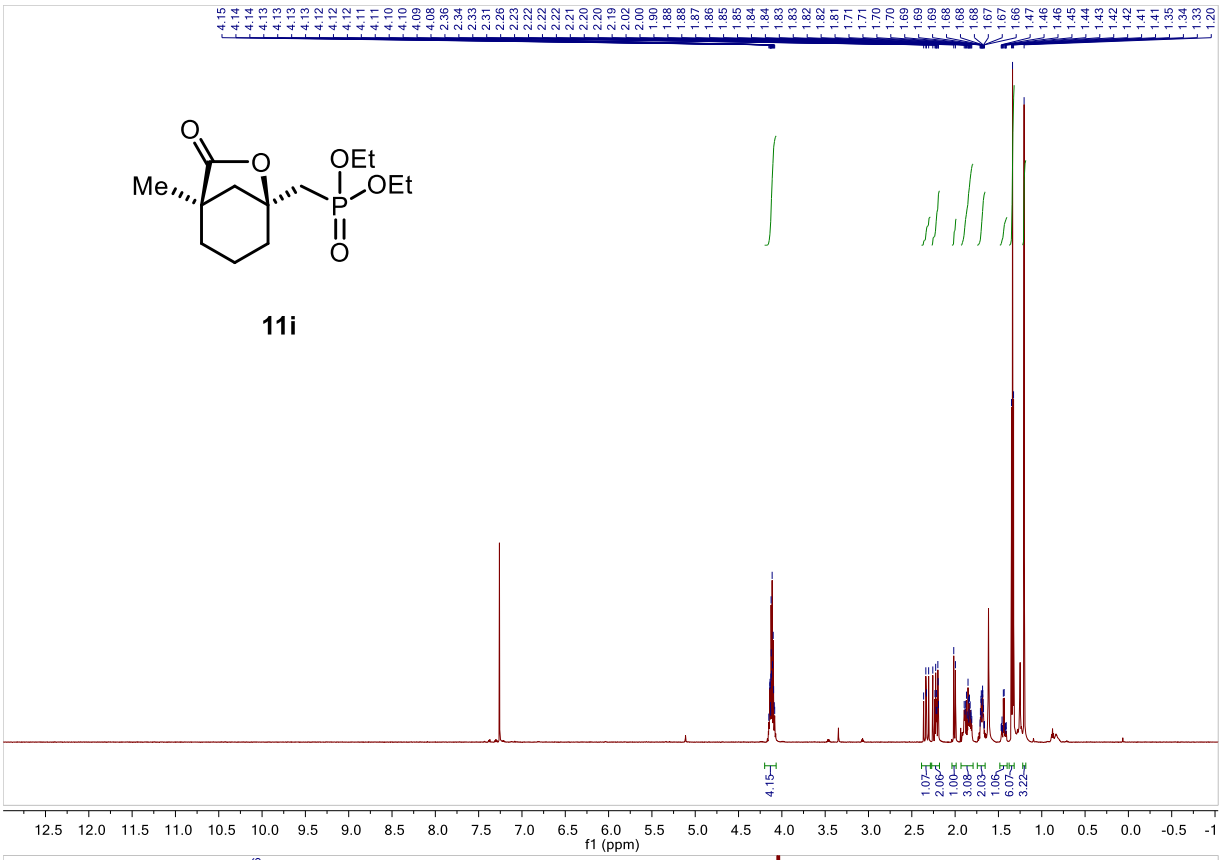

179.7
169.2
81.9
70.5
63.9
59.1
48.0
44.7
43.8
33.9
31.8
20.9
19.6
Me
O
O
O
O
O
Me
11f
f1 (ppm)

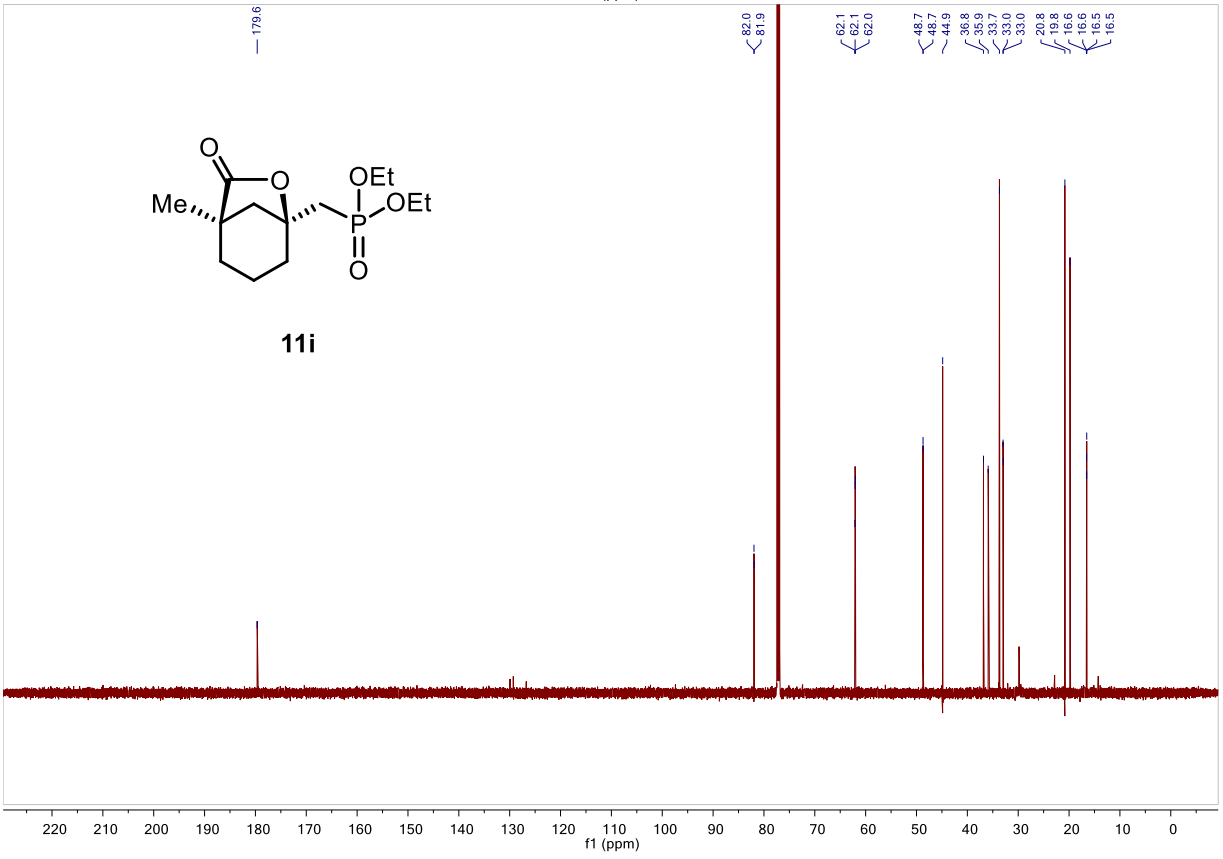

Me
O
O
Me
O
11g
f1 (ppm)

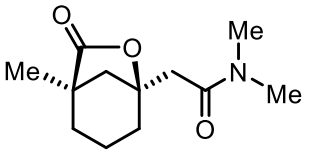

205.3
179.8
82.5
51.9
48.0
44.5
33.8
32.0
31.8
20.8
19.6
Me
O
O
Me
O
11g
f1 (ppm)


Me
CN
11h
f1 (ppm)


178.5
115.3
80.0
47.5
45.1
33.6
32.0
28.1
20.7
19.5
Me
CN
11h
f1 (ppm)

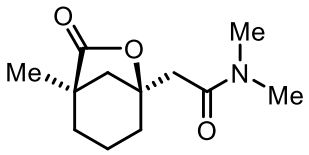

Me
O
OEt
OEt
P
O
11i
f1 (ppm)


Me
O
OEt
OEt
P
O
11i
f1 (ppm)


O
O
Me
Me
N
Me
O

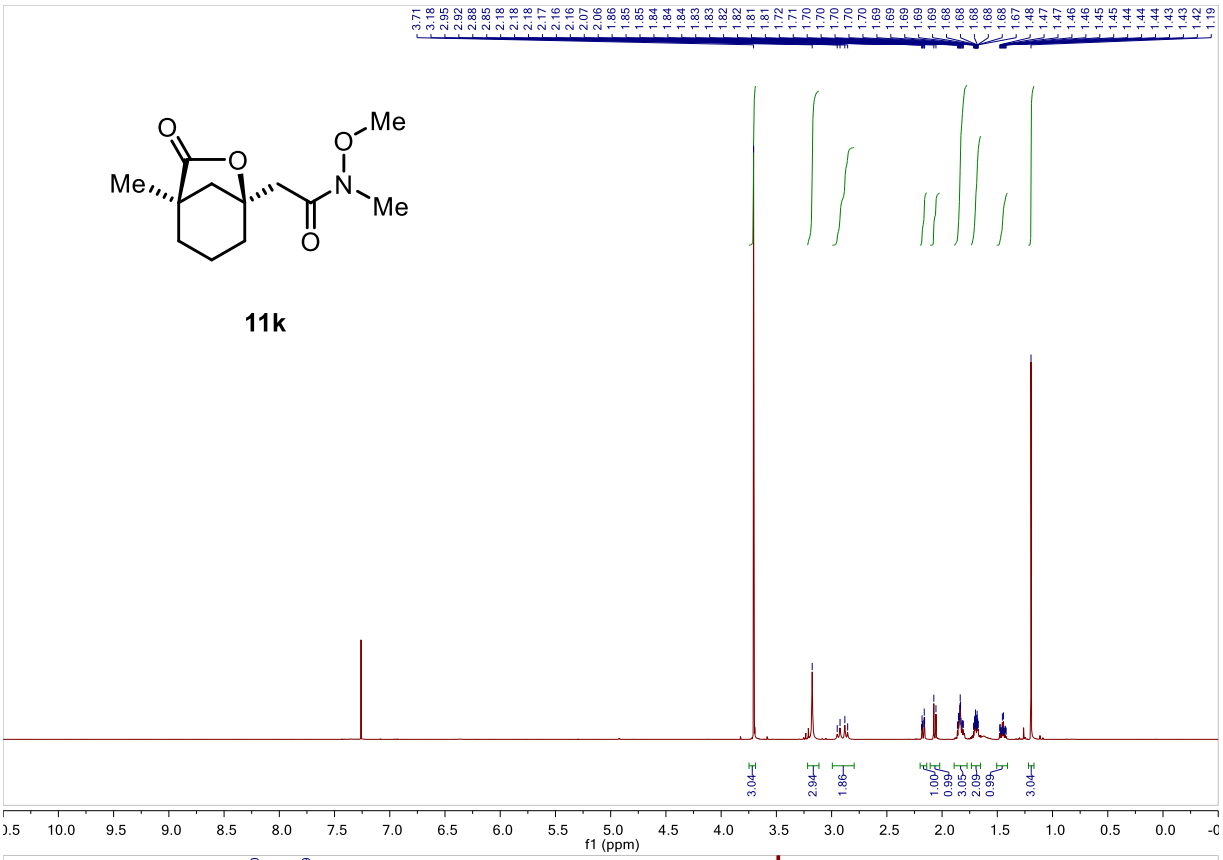
11j

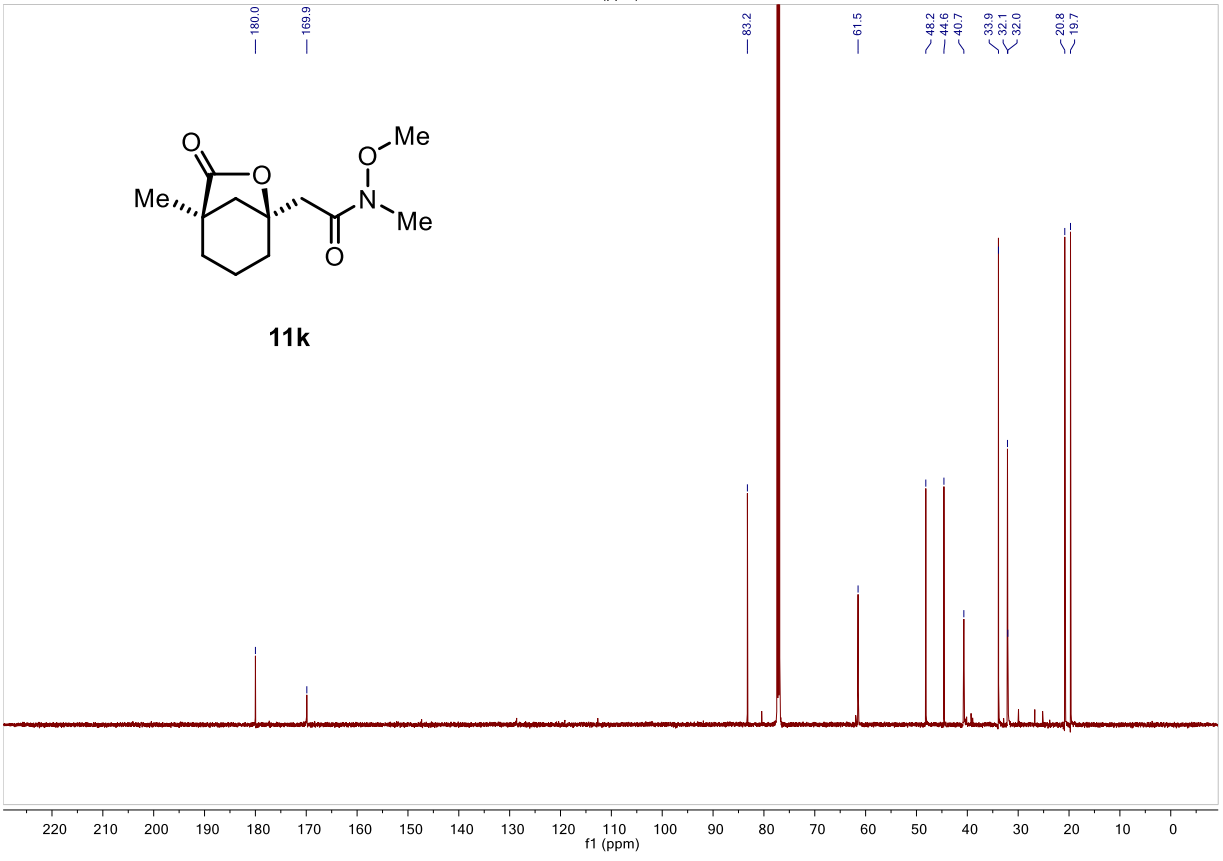
3.11
2.92
2.00
2.07
3.33
2.19
1.02
3.08
f1 (ppm)

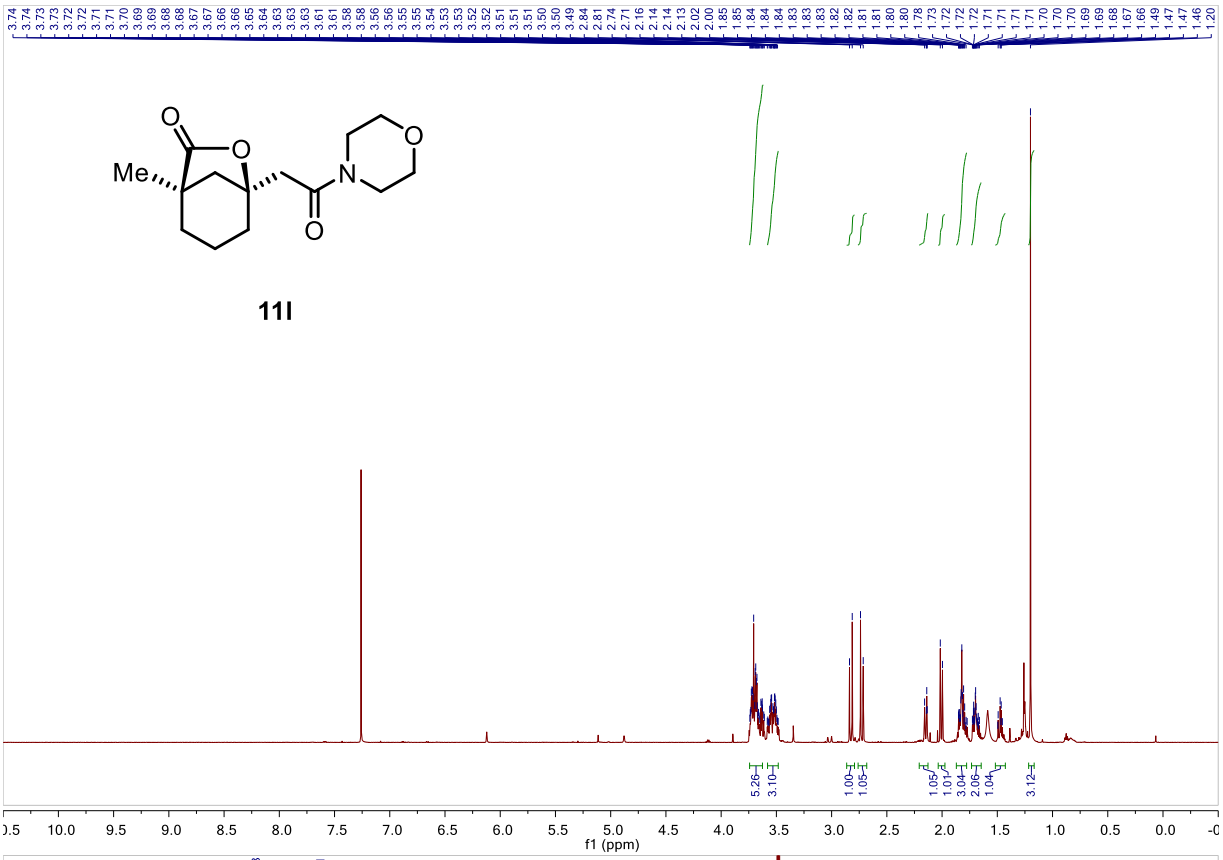

O
O
Me
Me
N
Me
O

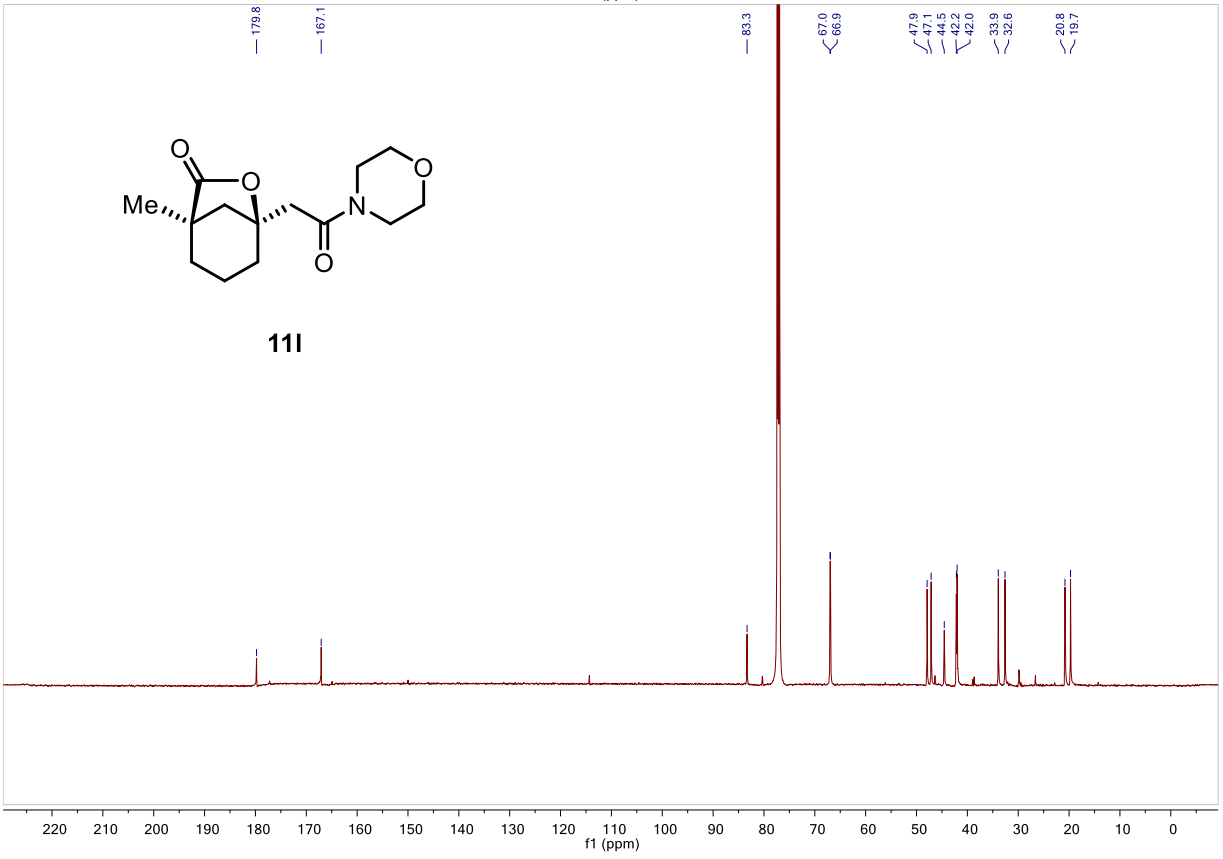
11j

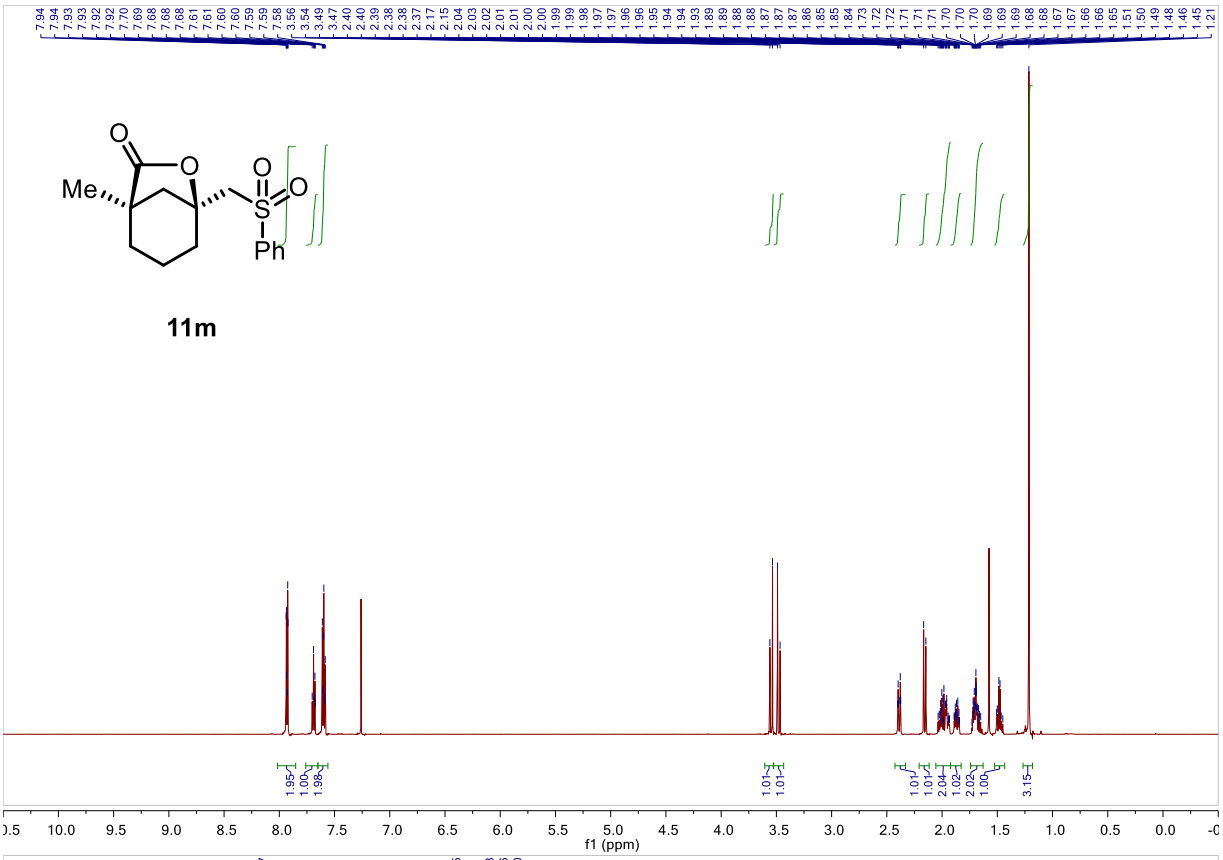
180.1
168.6
83.8
48.1
44.5
42.4
38.2
35.6
33.9
32.3
20.8
19.7
f1 (ppm)

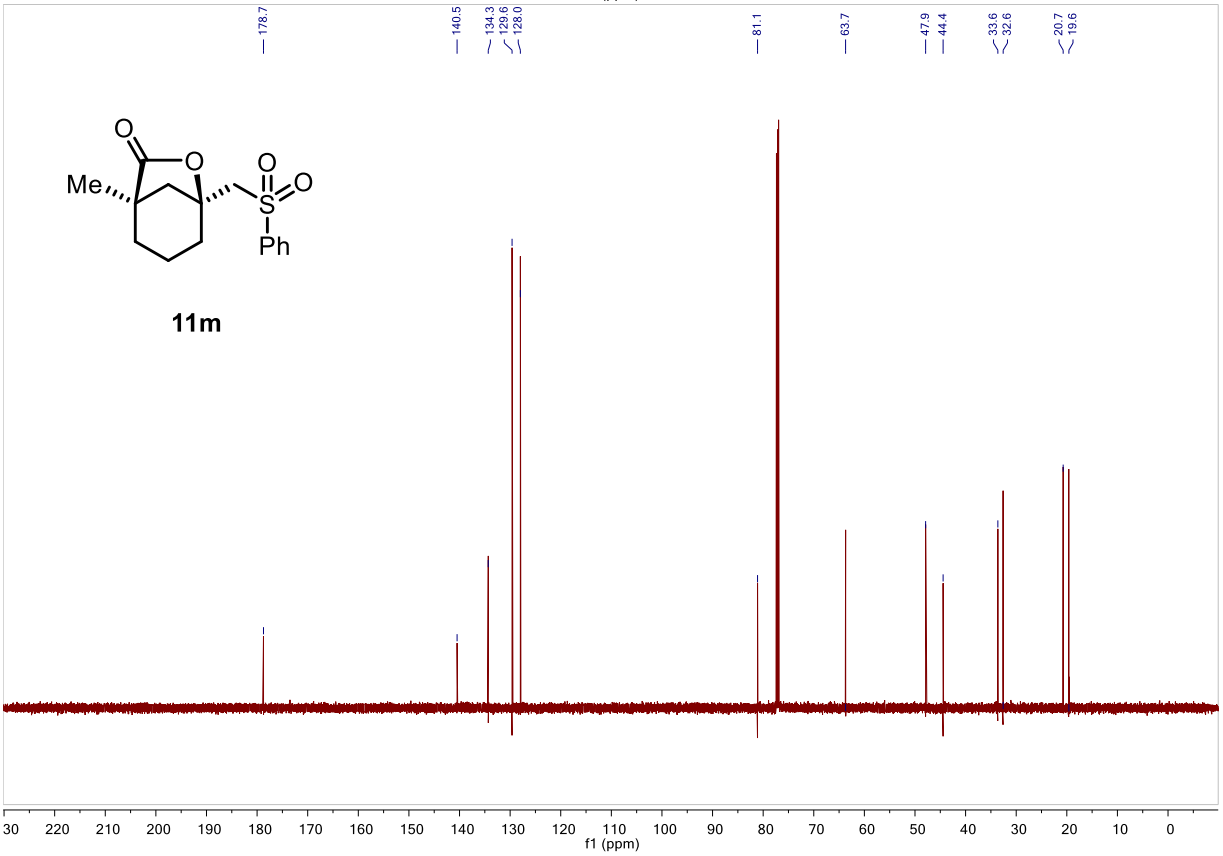

Me
O
O
O
N
Me
Me
O
11k
f1 (ppm)

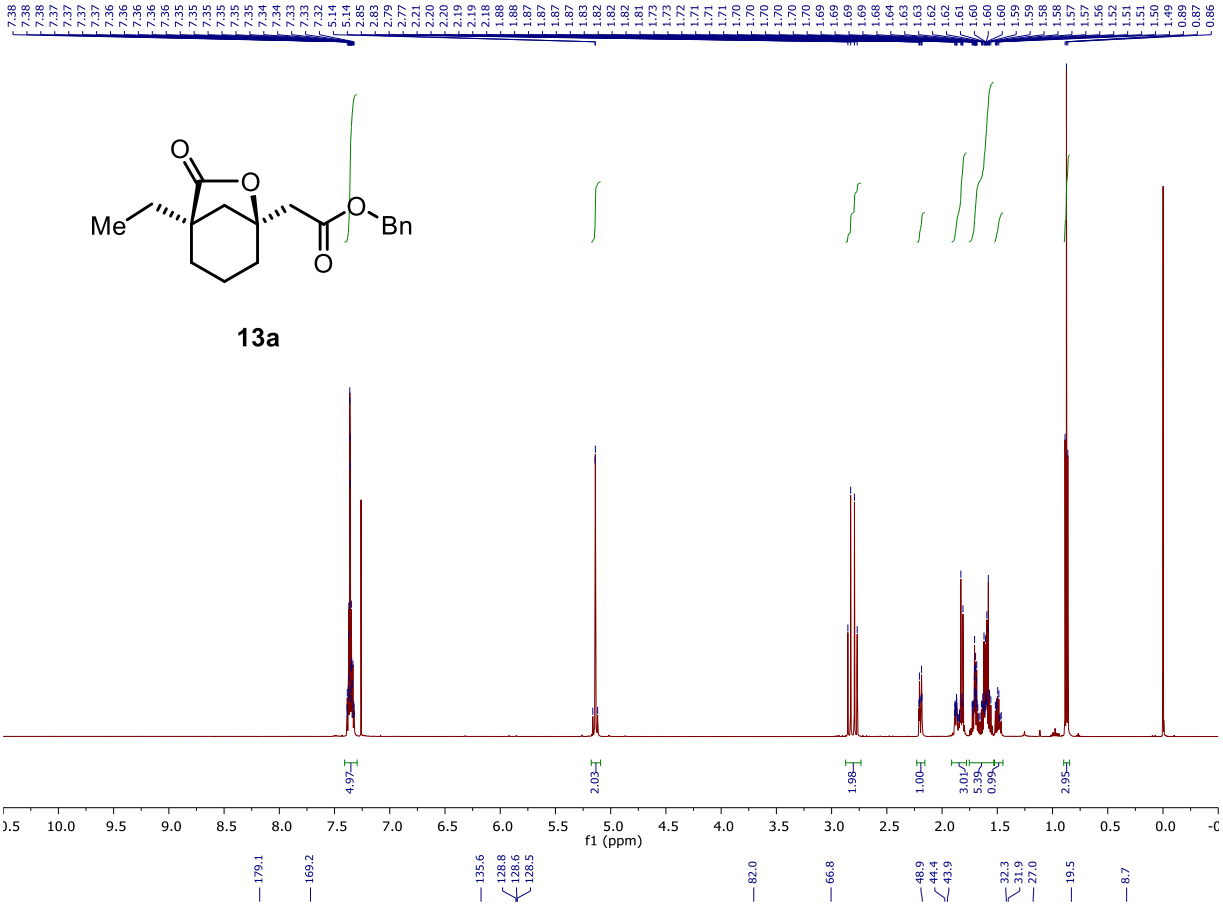

180.0
169.9
83.2
61.5
48.2
44.6
40.7
33.9
32.1
32.0
20.8
19.7
Me
O
O
O
N
Me
Me
O
11k
f1 (ppm)

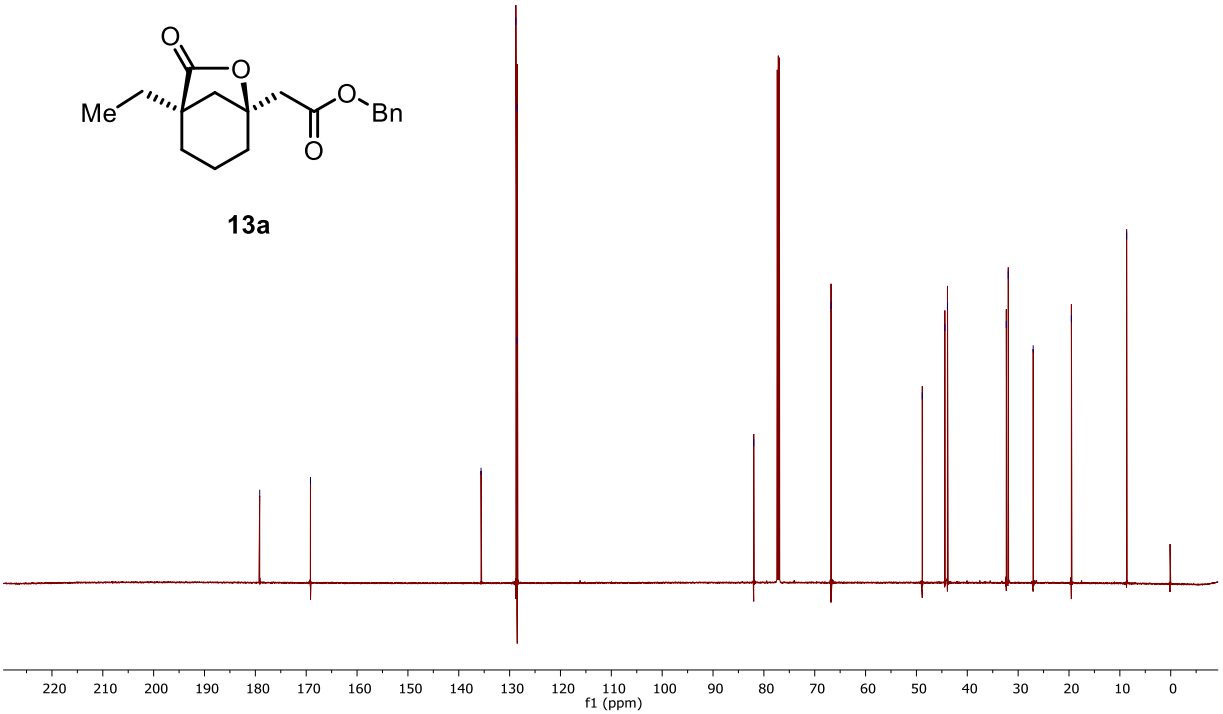

Me
O
O
O
N
O
11l
f1 (ppm)

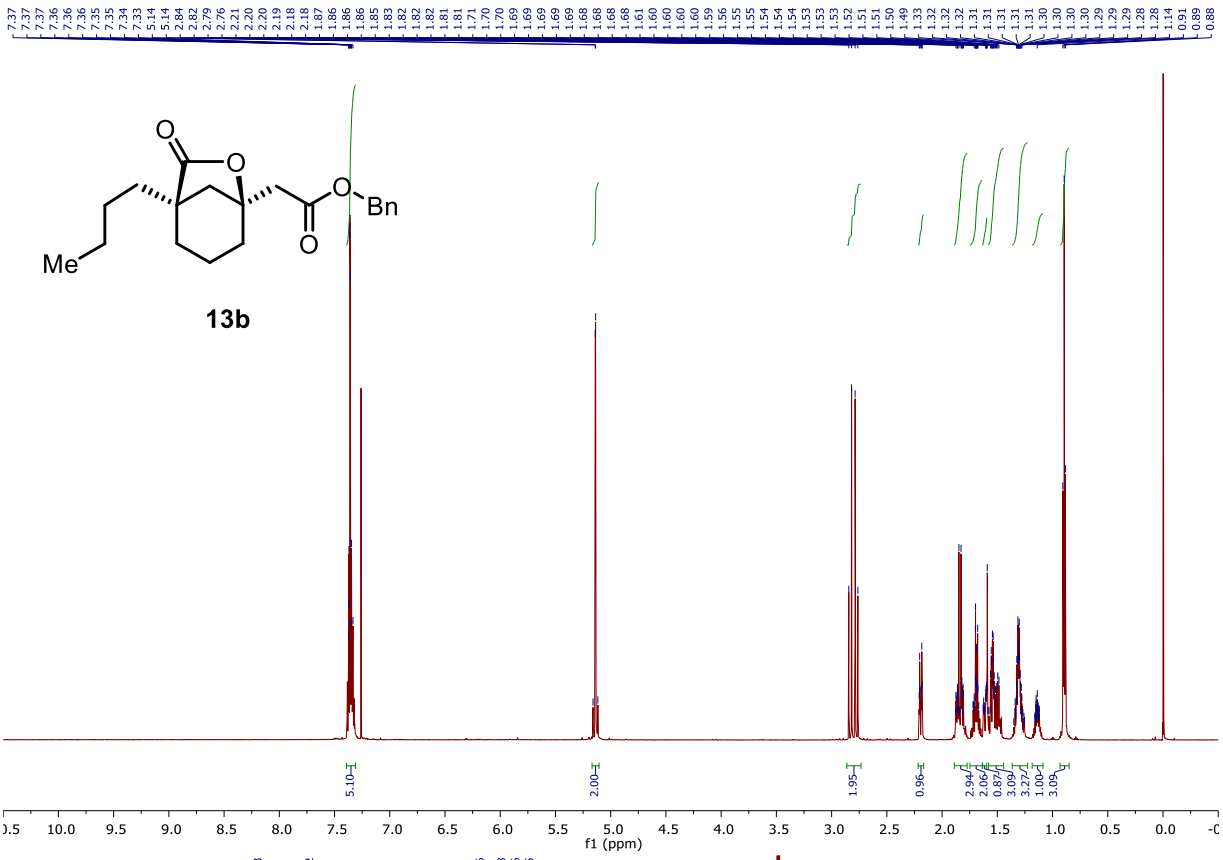

179.8
167.1
83.3
67.0
66.9
47.9
47.1
44.5
42.2
42.0
33.9
32.6
20.8
19.7
Me
O
O
O
N
O
11l
f1 (ppm)

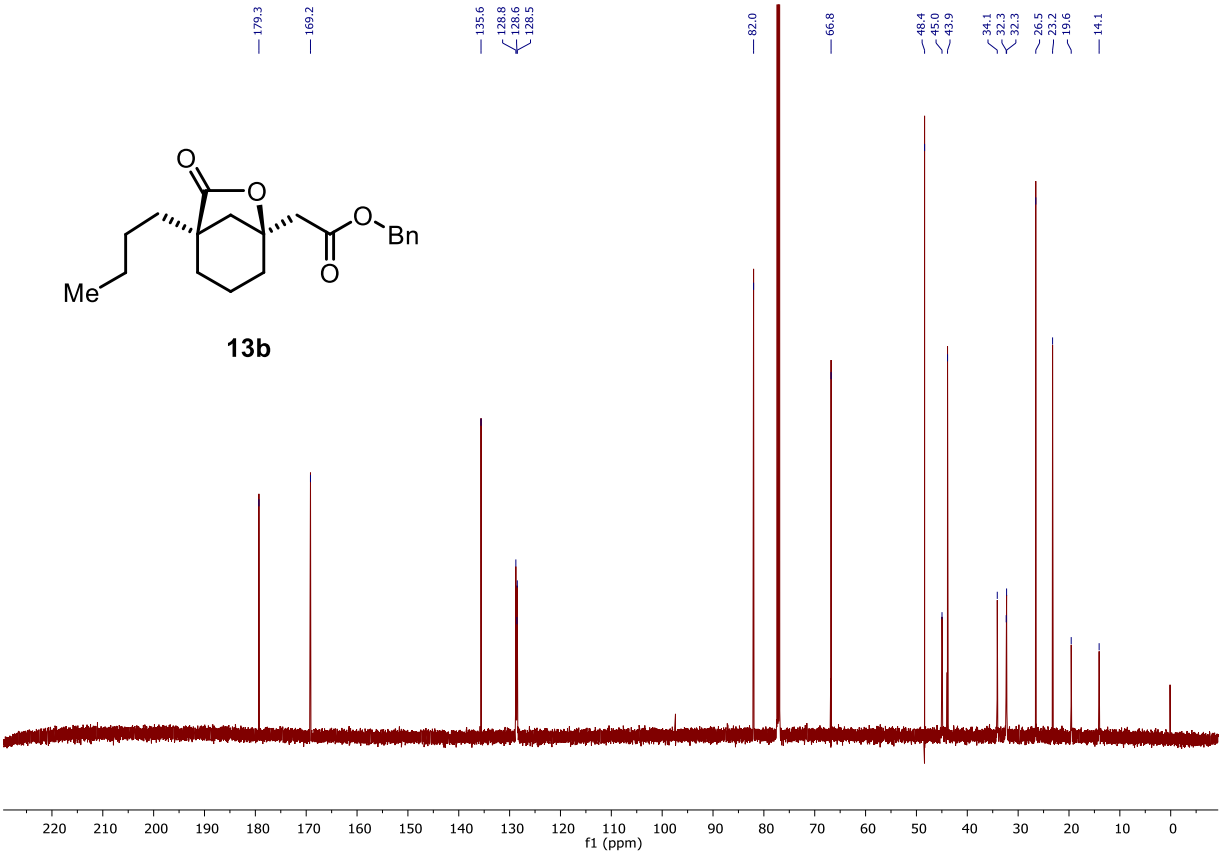

Me
O
O
O
S
O
Ph
11m
f1 (ppm)

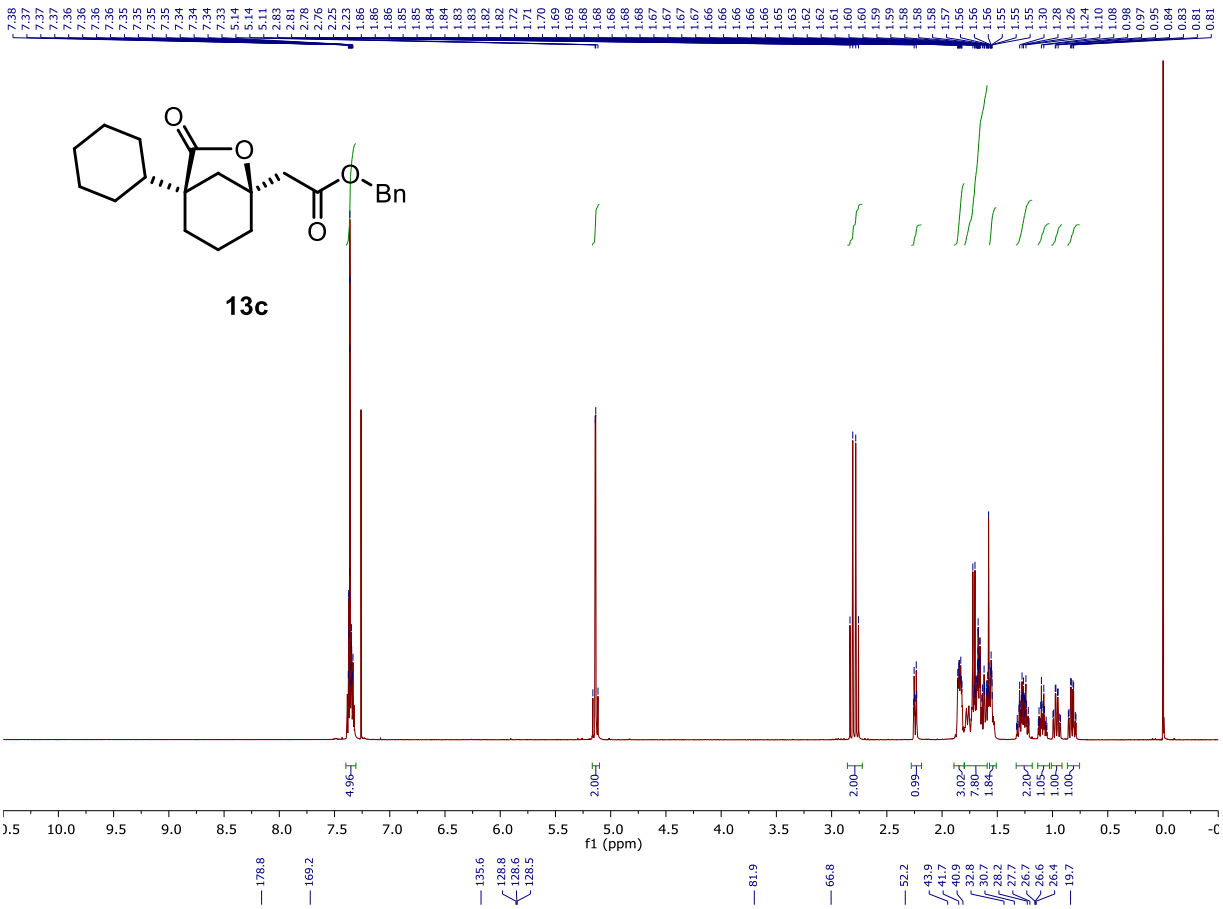

Me
O
O
O
S
O
Ph
11m
178.7
140.5
134.3
129.6
128.0
81.1
63.7
47.9
44.4
33.6
32.6
20.7
19.6
f1 (ppm)

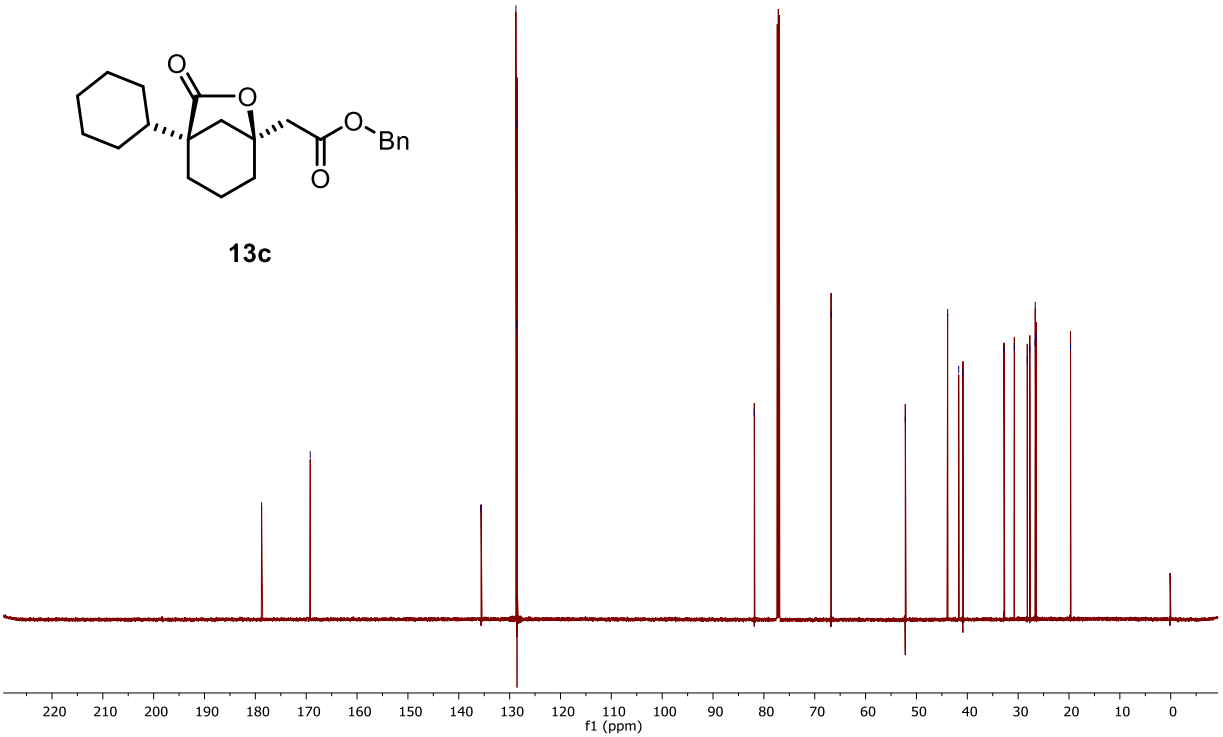

Me
O
O
O
O
Bn
13a
f1 (ppm)

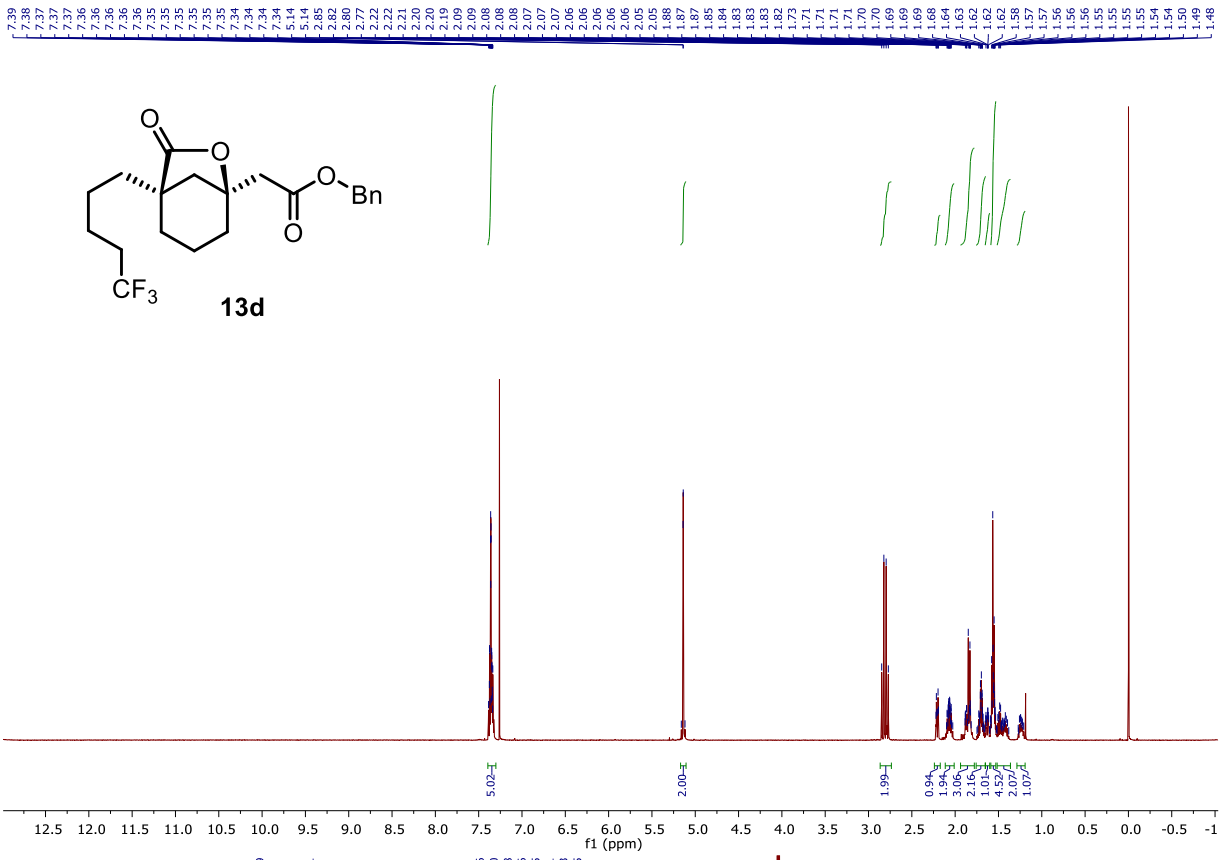

Me
O
O
O
O
Bn
13a
f1 (ppm)

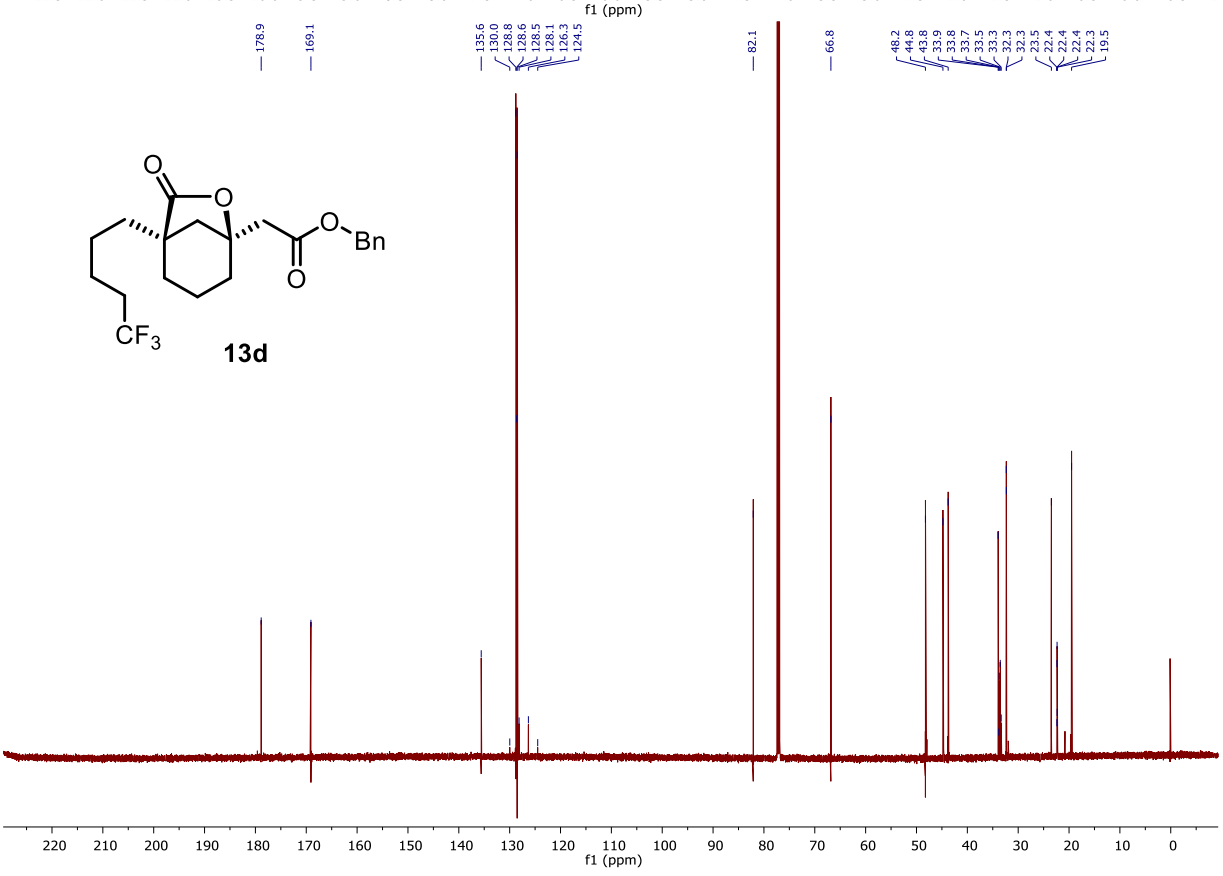

Me
O
O
O
O
Bn
13b
f1 (ppm)

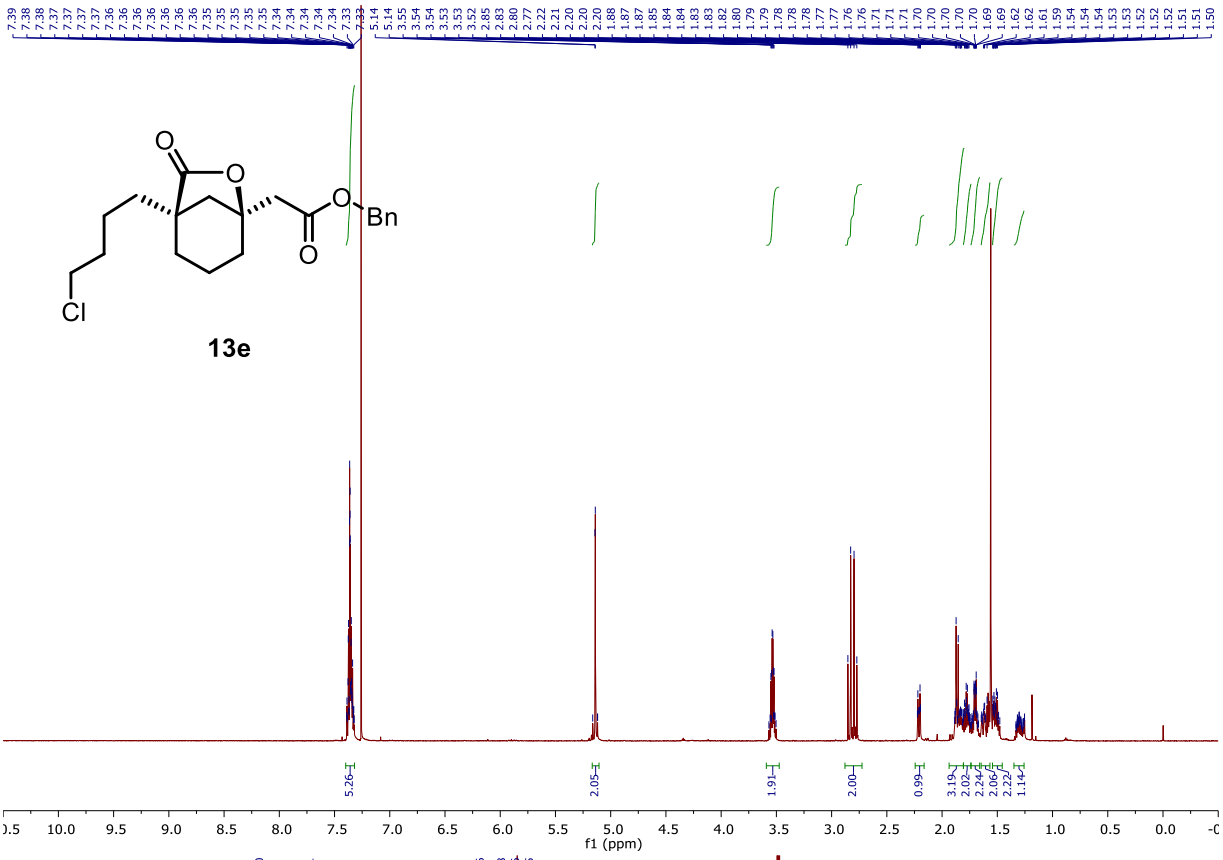

Me
O
O
O
O
Bn
13b
f1 (ppm)

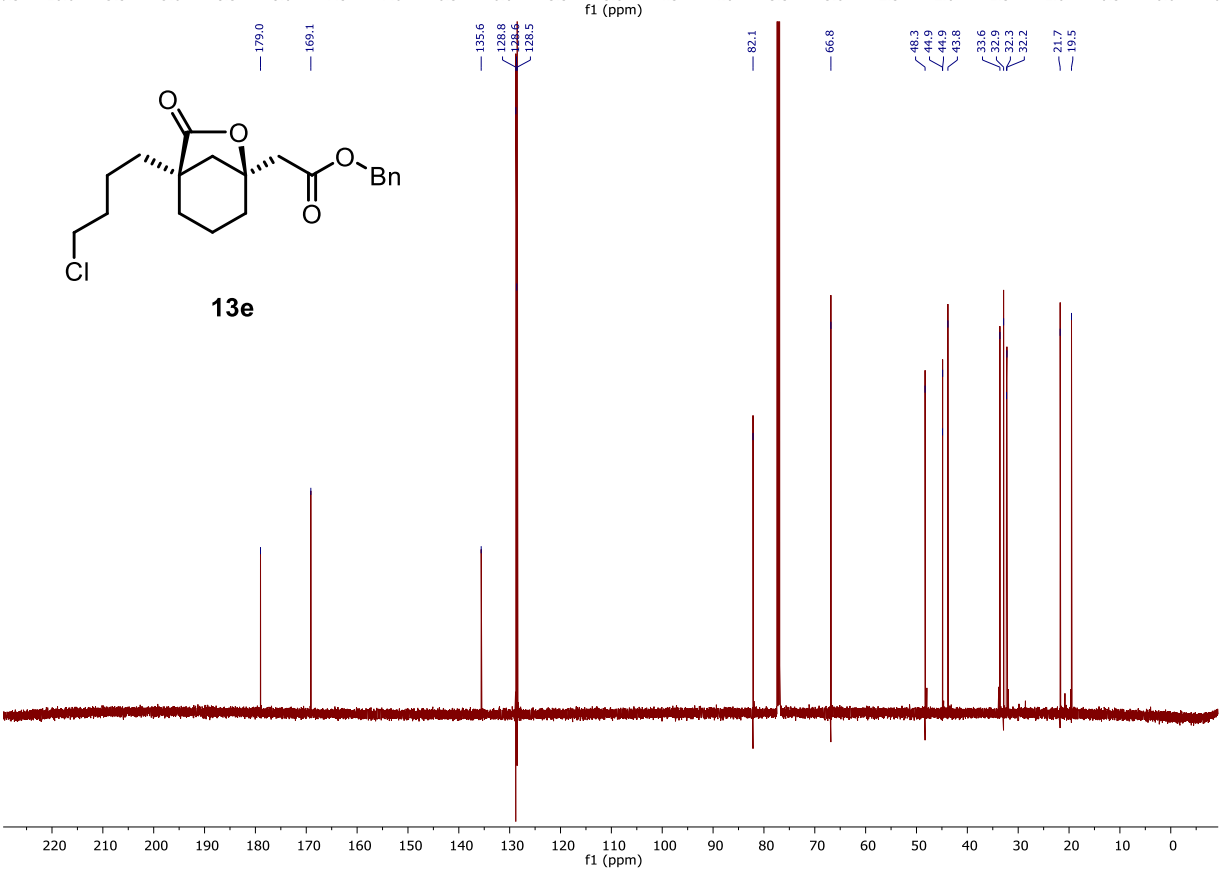

O
O
O
O
Bn
13c
f1 (ppm)

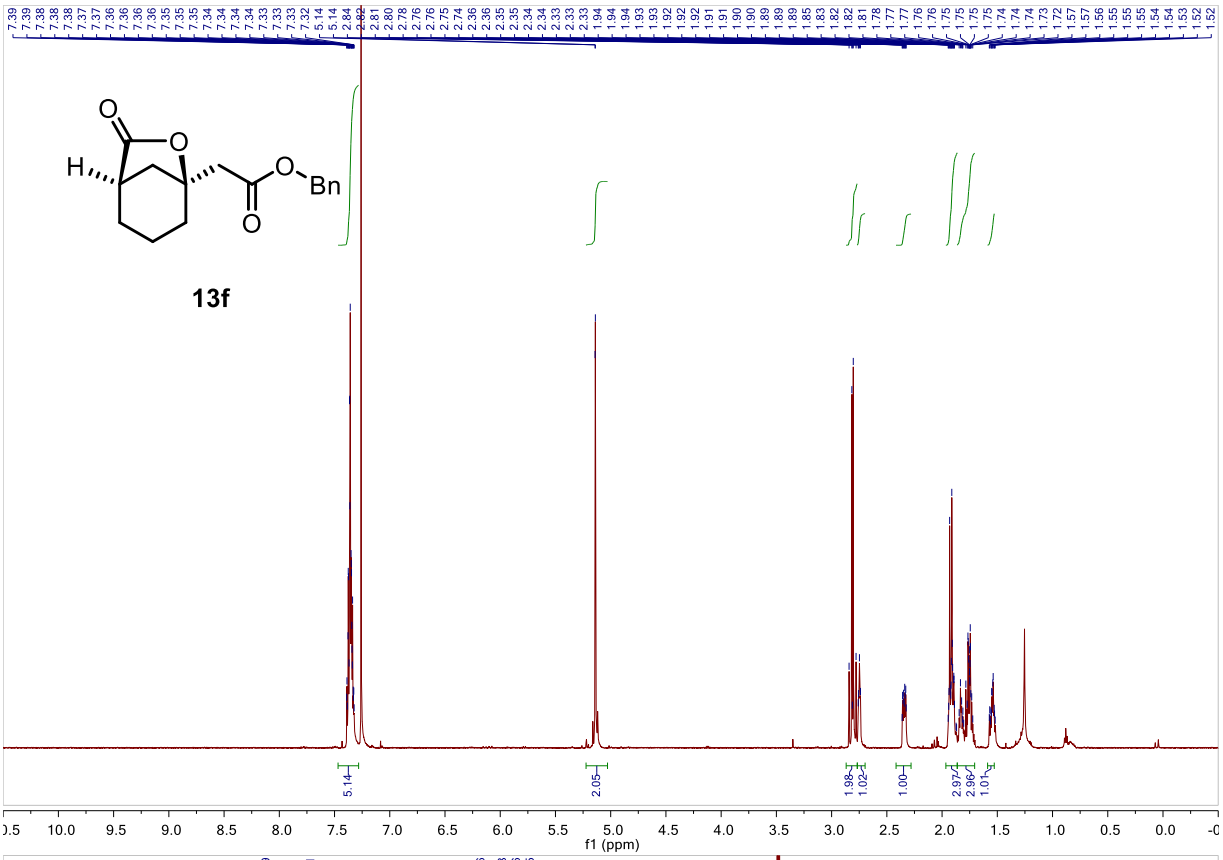

O
O
O
O
Bn
13c
f1 (ppm)

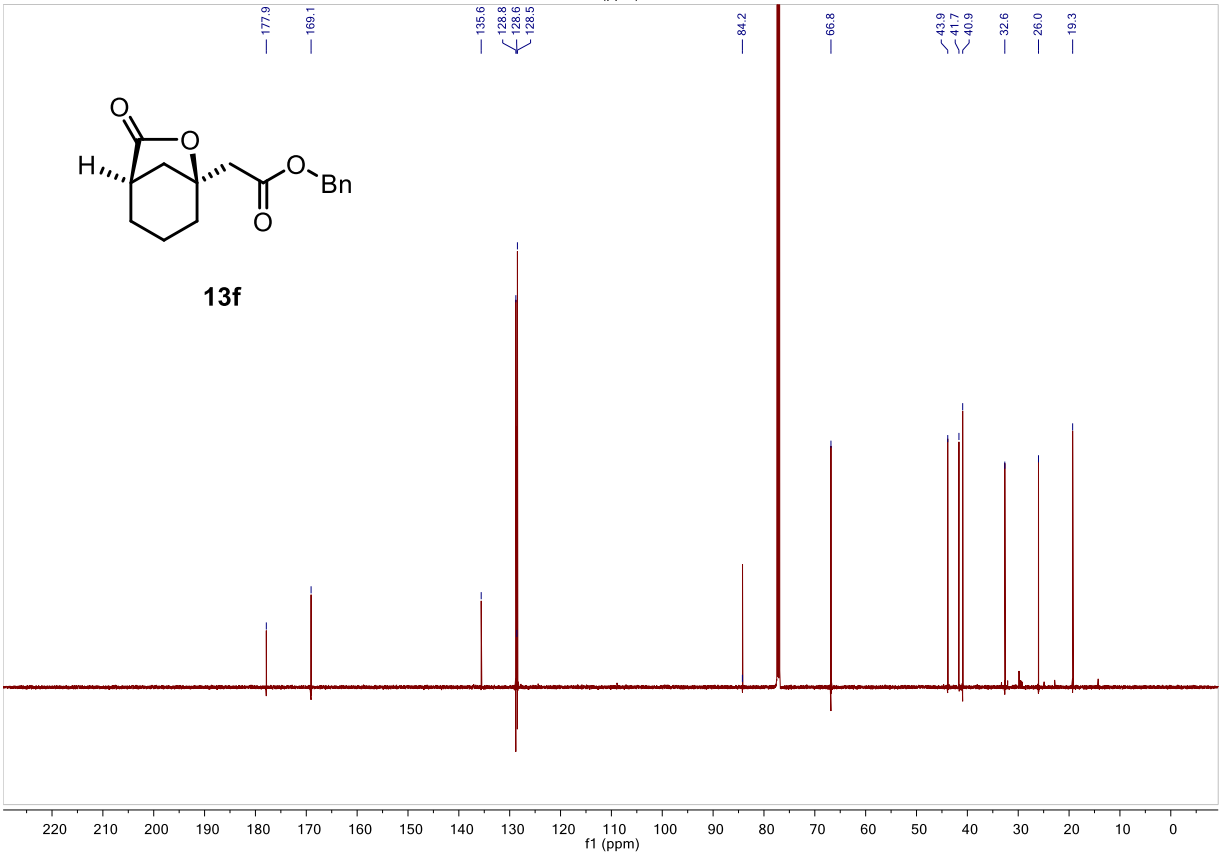

O
O
O
O
Bn
CF3
13d
f1 (ppm)

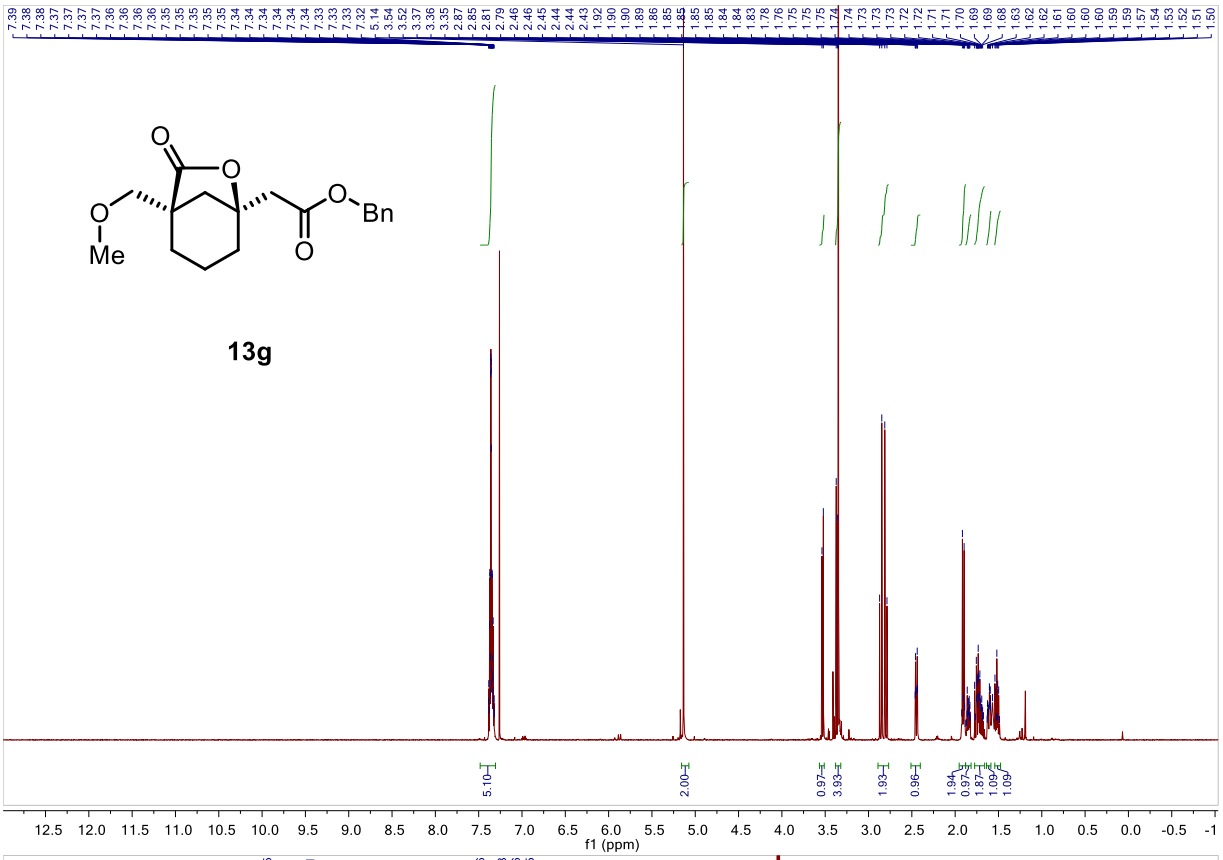

O
O
O
O
Bn
CF3
13d
f1 (ppm)

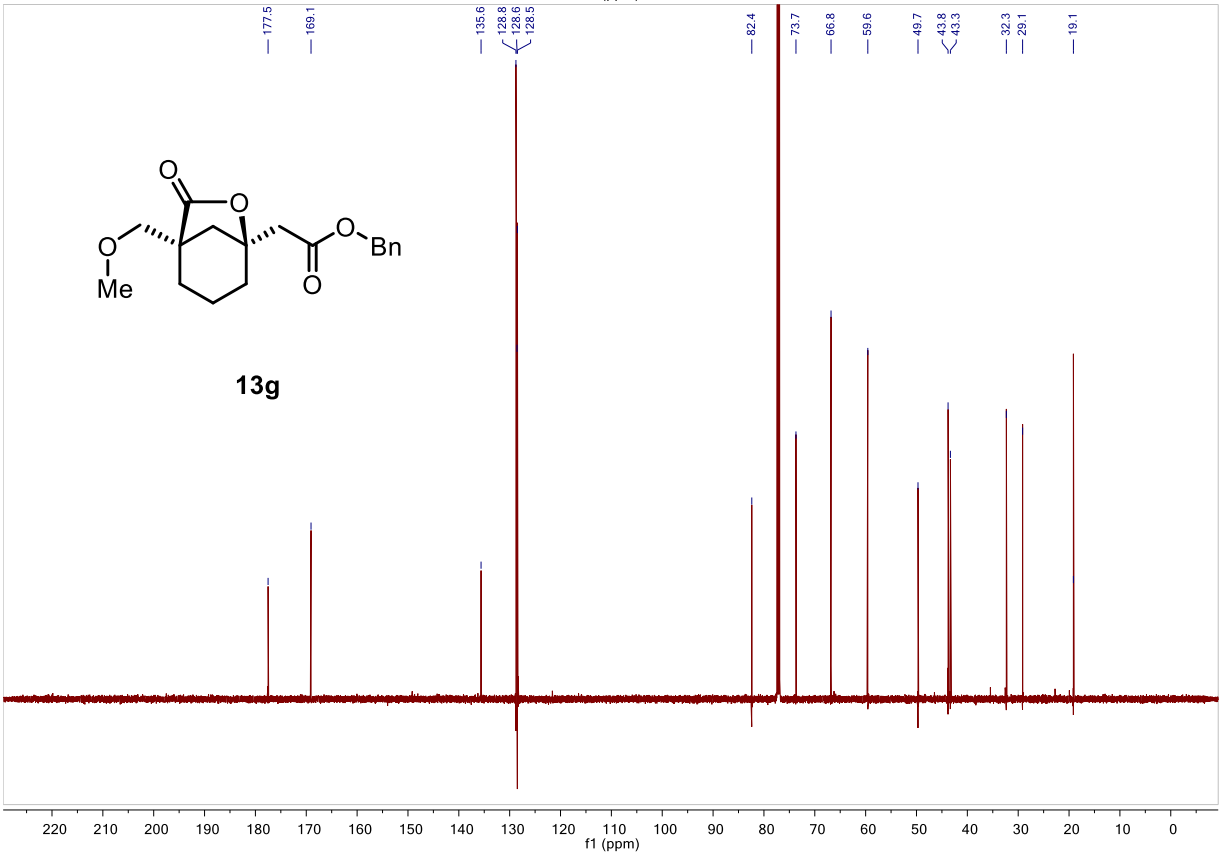

O
O
O
Bn
O
Cl
13e
5.26
2.05
1.91
2.00
0.99
3.19
2.02
2.24
2.06
2.22
1.14
f1 (ppm)

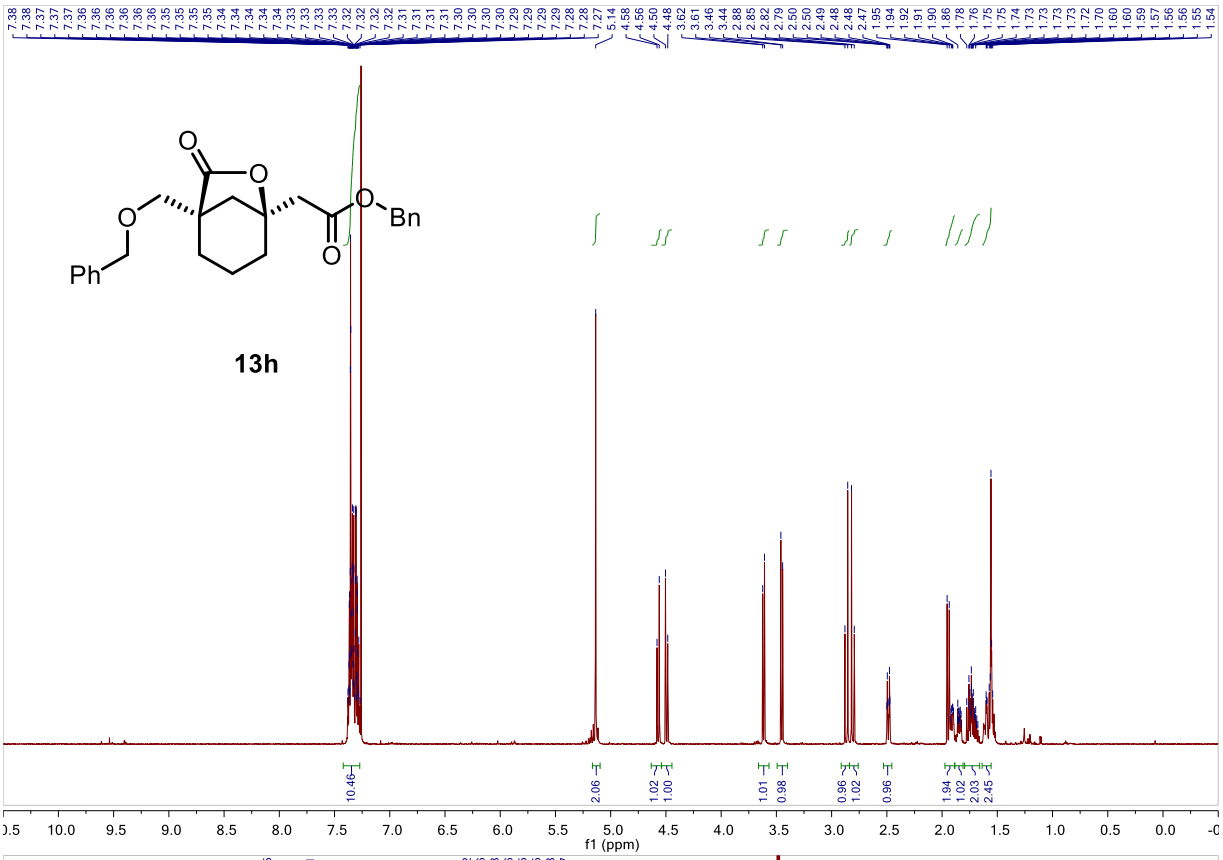

179.0
169.1
135.6
128.8
128.6
128.5
82.1
66.8
48.3
44.9
44.9
43.8
33.6
32.9
32.3
32.2
21.7
19.5
O
O
O
Bn
O
Cl
13e
f1 (ppm)

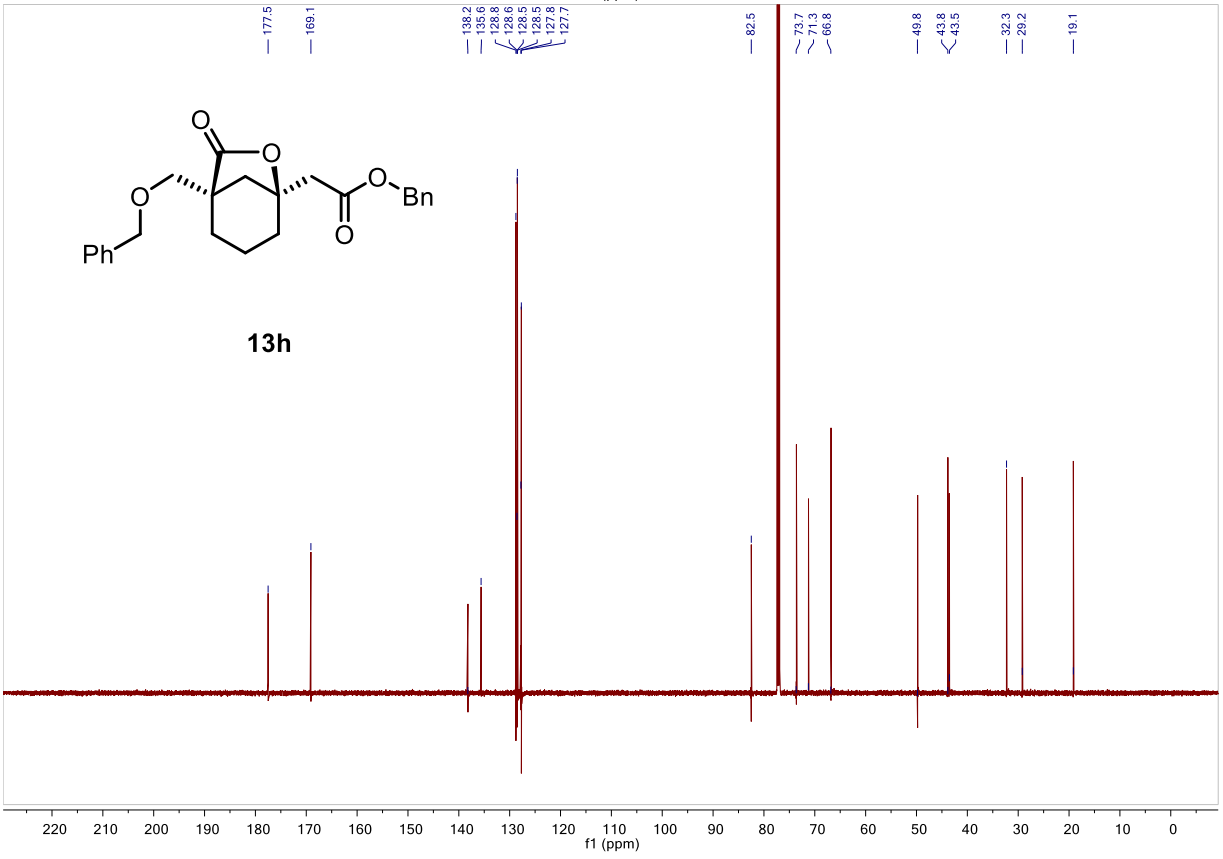

13f
5.14
2.05
1.98
1.02
1.00
2.97
2.96
1.01
f1 (ppm)

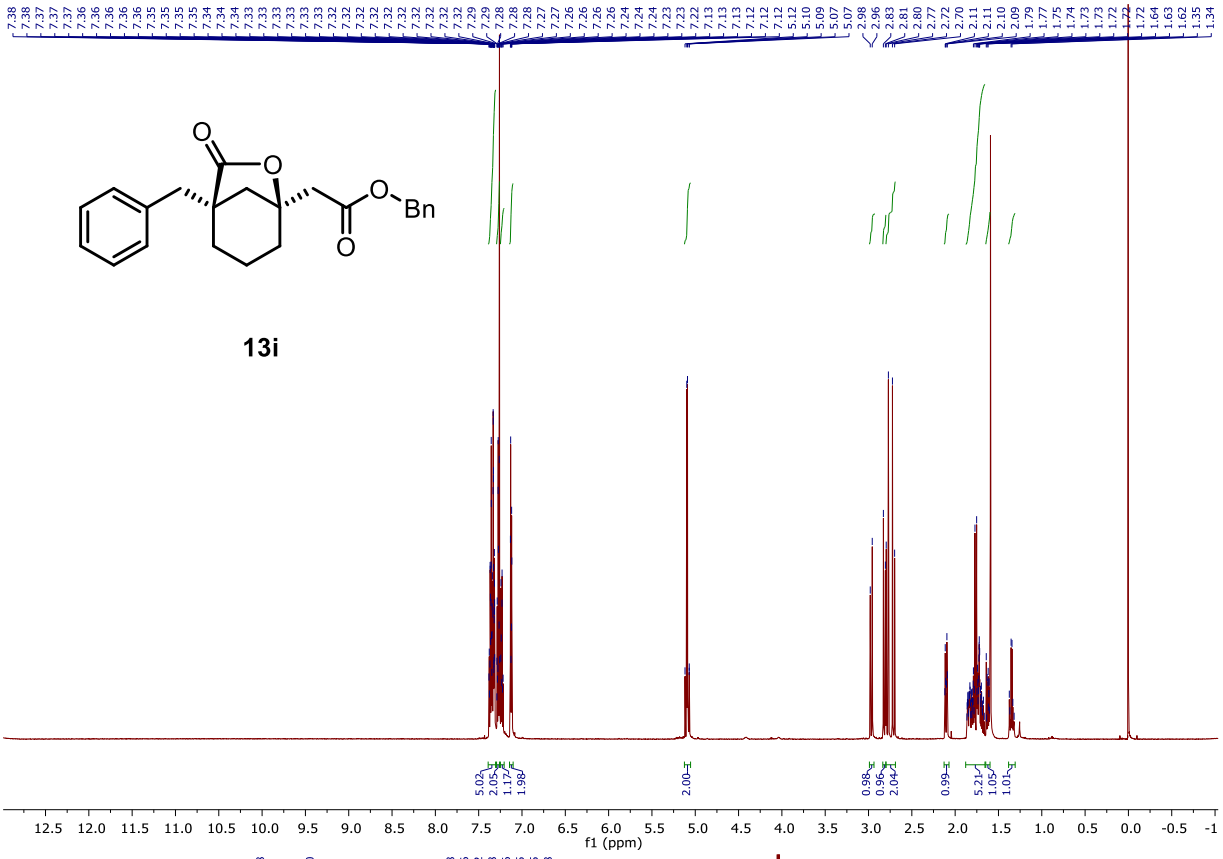

177.9
169.1
135.6
128.8
128.6
128.5
84.2
66.8
43.9
41.7
40.9
32.6
26.0
19.3
13f
f1 (ppm)

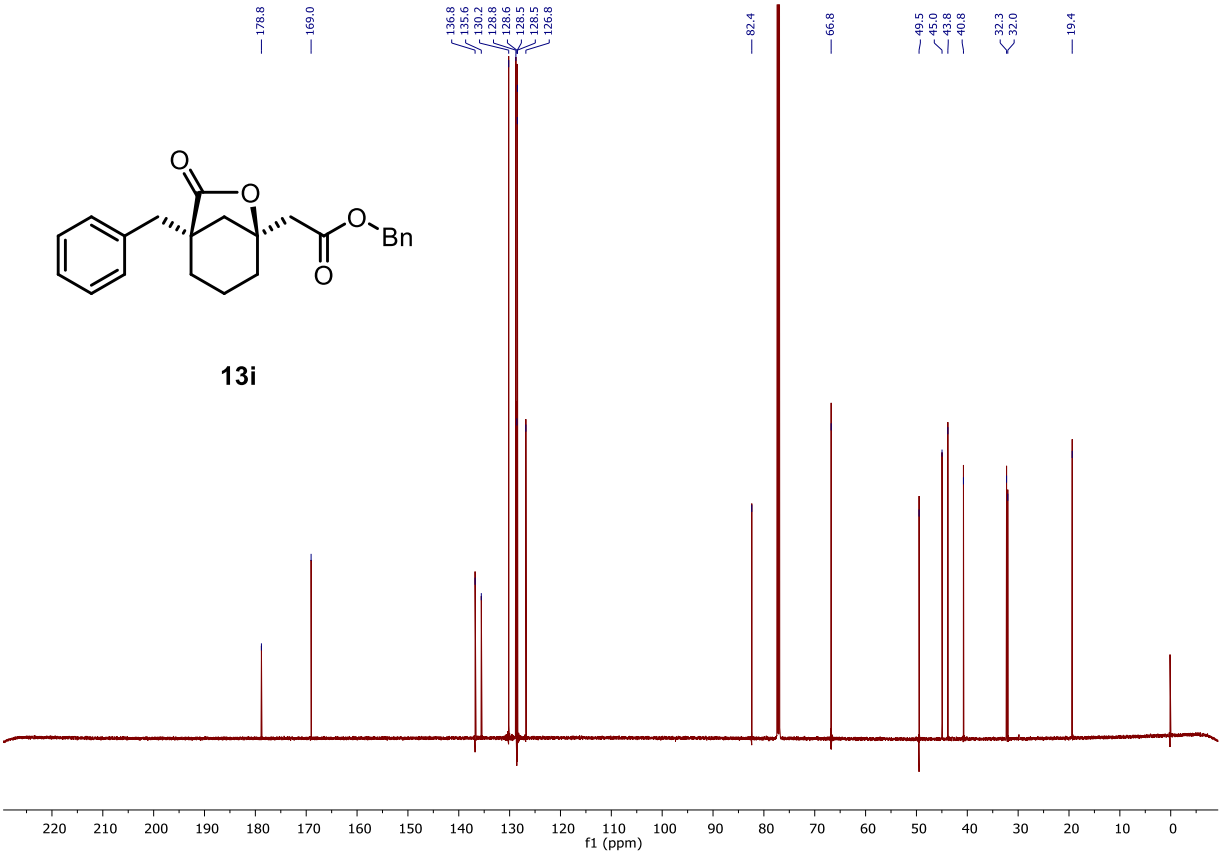

O
O
O
O
Bn
O
Me
13g
5.10
2.00
0.97
3.93
1.93
0.96
1.94
0.97
1.87
1.09
1.09
f1 (ppm)

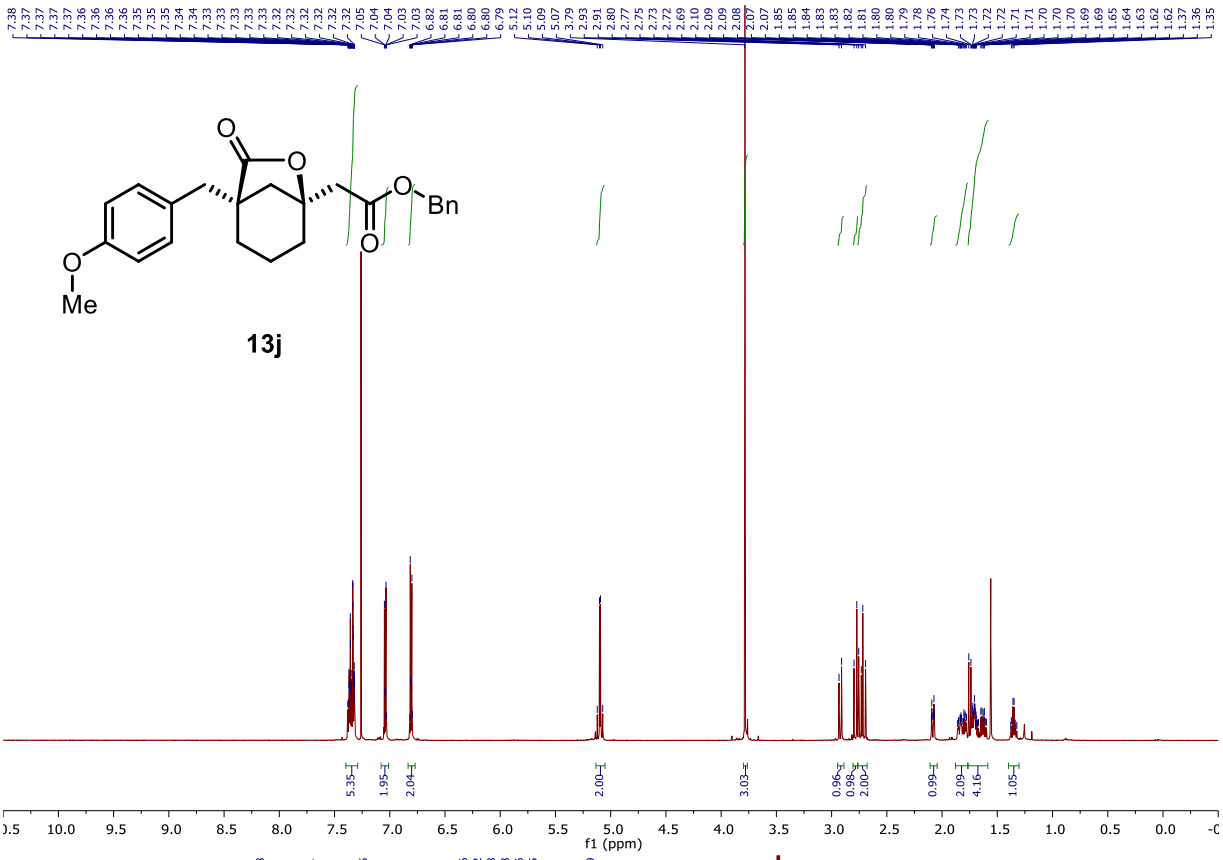

177.5
169.1
135.6
128.8
128.6
128.5
82.4
73.7
66.8
59.6
49.7
43.8
43.3
32.3
29.1
19.1
O
O
O
O
Bn
O
Me
13g
f1 (ppm)

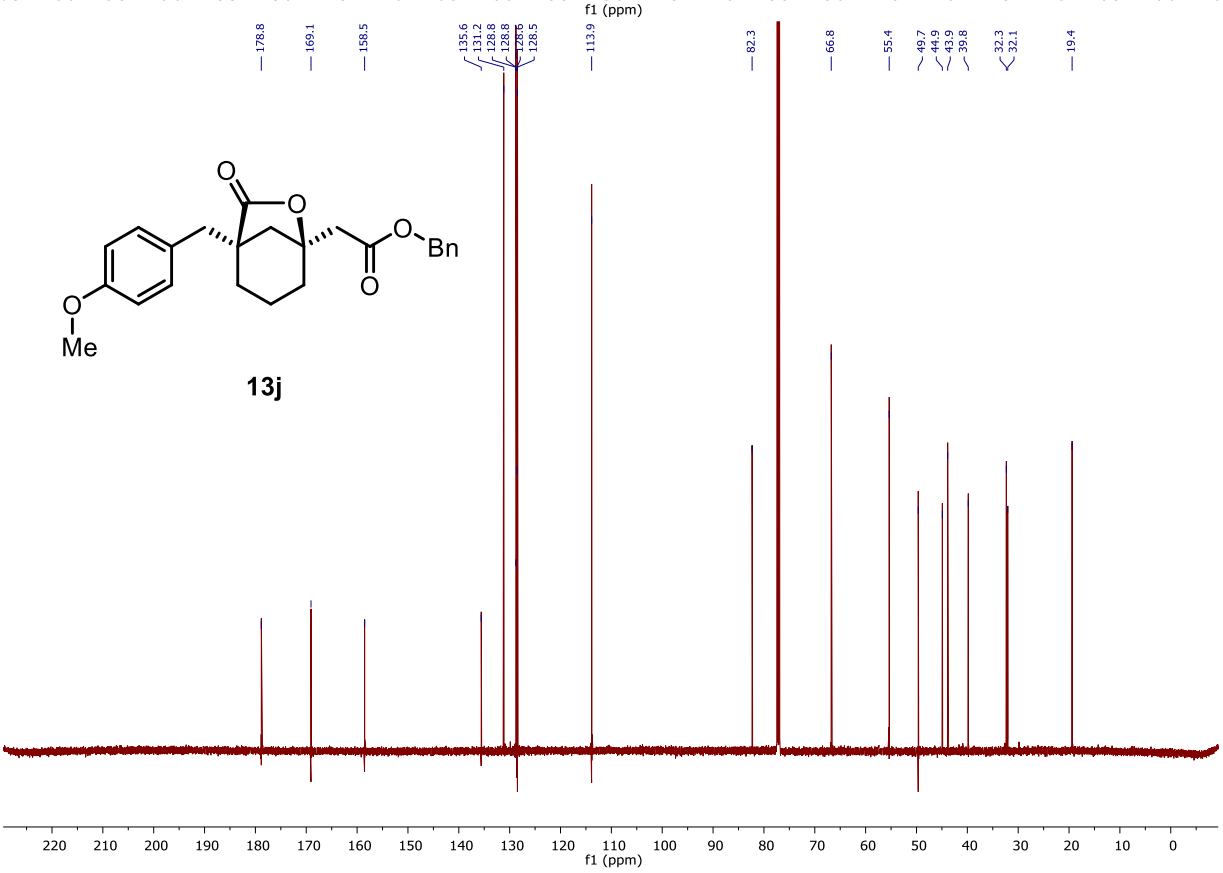

13h
f1 (ppm)

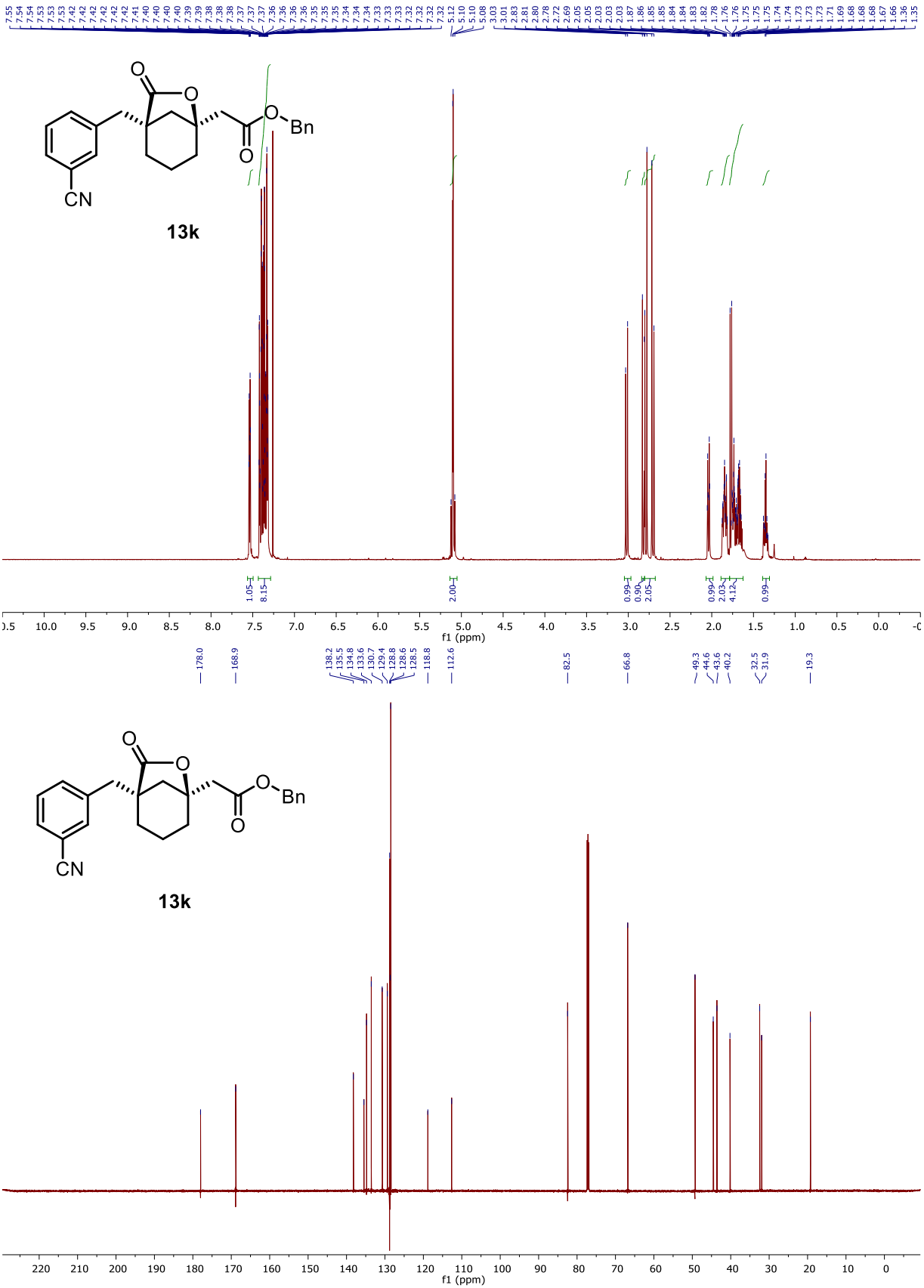

13h
f1 (ppm)

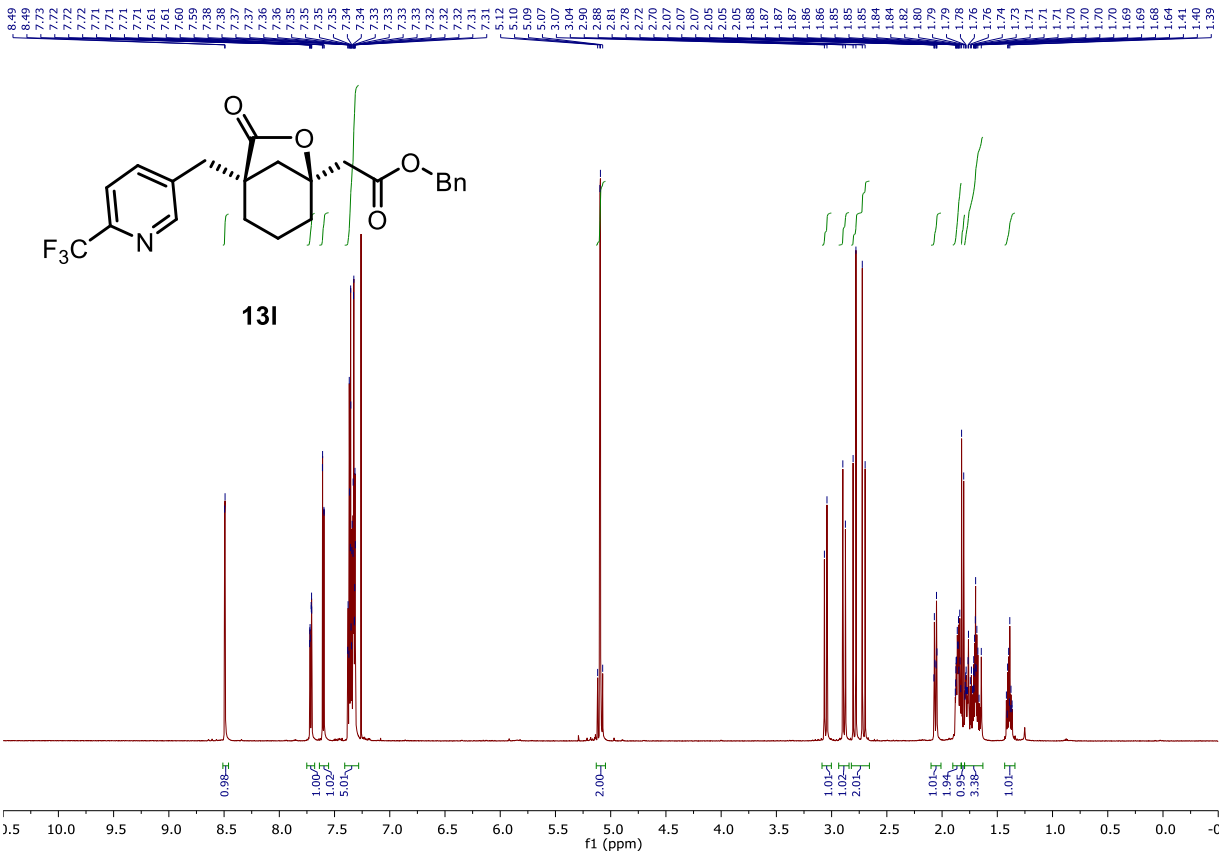

O
O
O
O
Bn
13i
f1 (ppm)

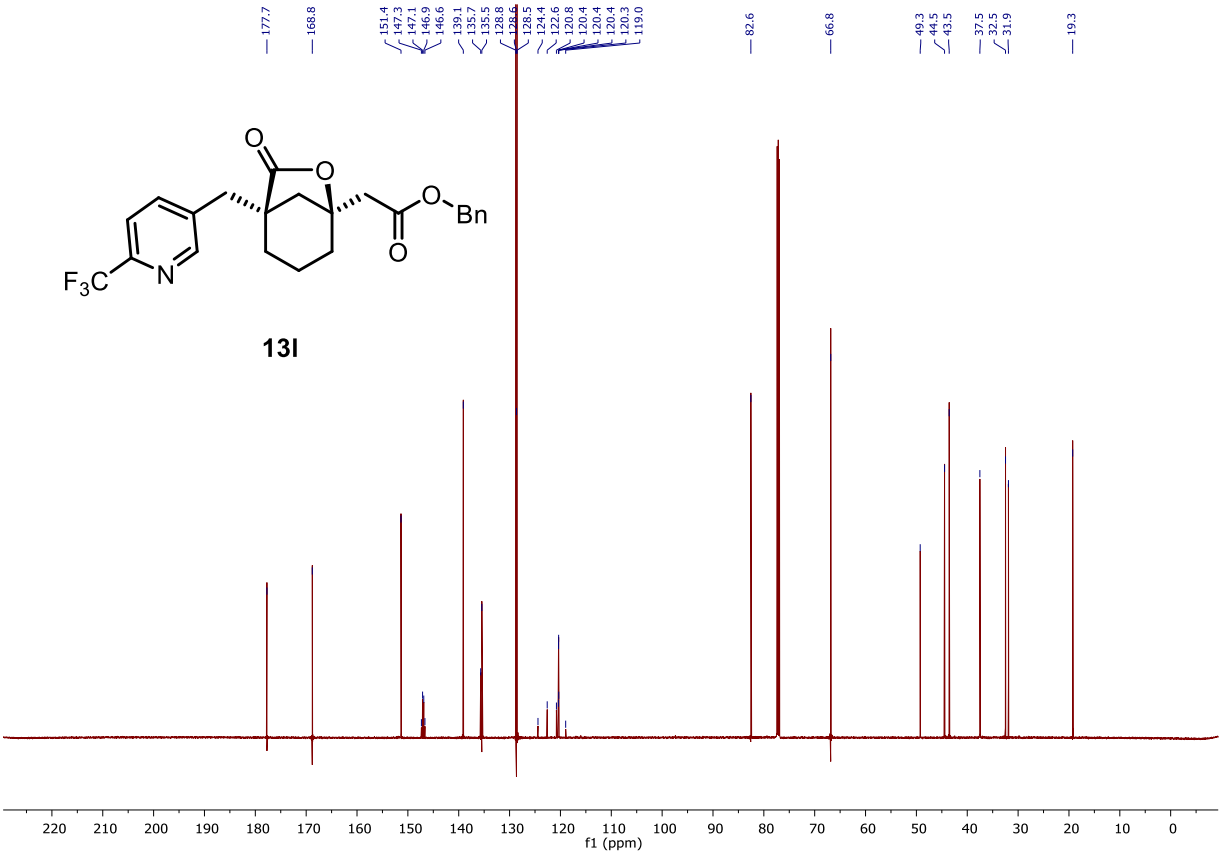

O
O
O
O
Bn
13i
f1 (ppm)

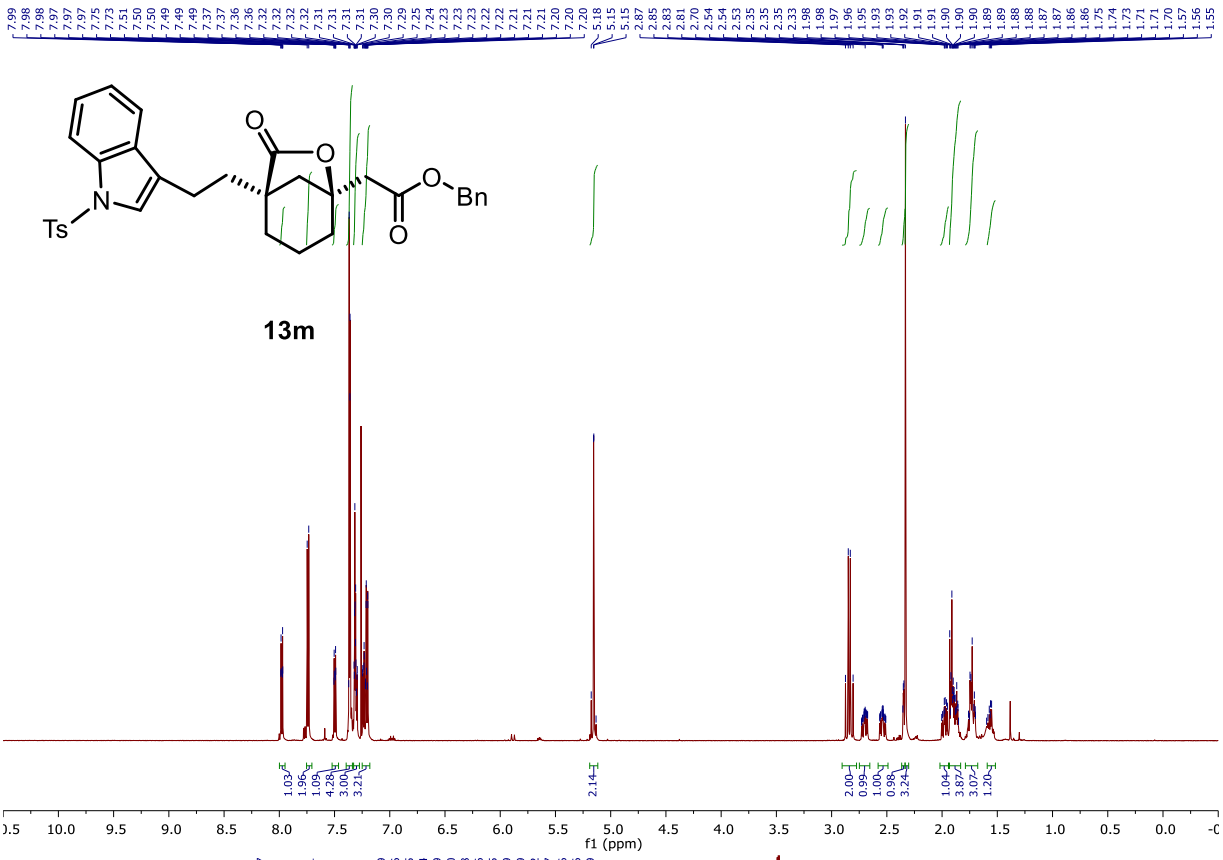

O
O
O
O
Bn
O
Me
13j
5.35
1.95
2.04
2.00
3.03
0.96
0.98
2.00
0.99
2.09
4.16
1.05
f1 (ppm)

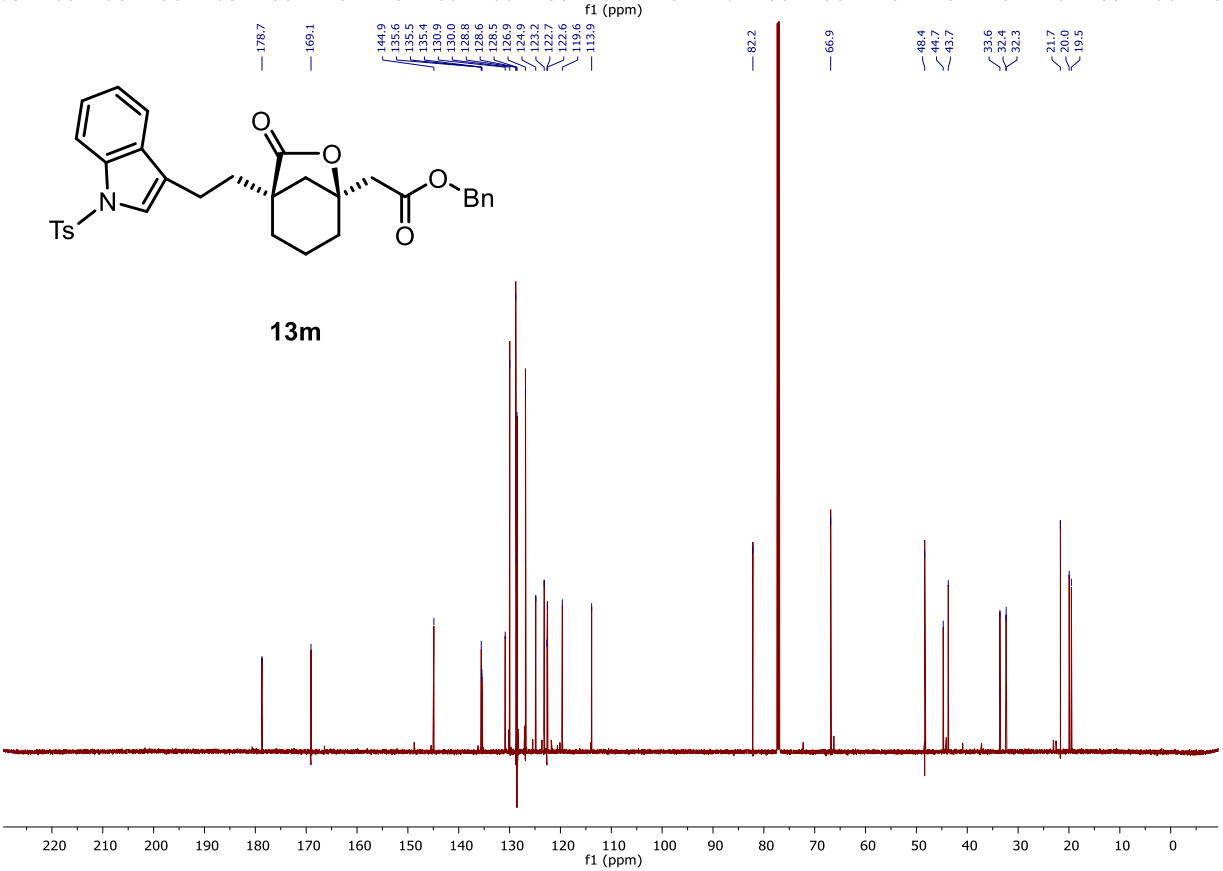

178.8
169.1
158.5
135.6
131.2
128.8
128.8
128.6
128.5
113.9
82.3
66.8
55.4
49.7
44.9
43.9
39.8
32.3
32.1
19.4
O
O
O
O
Bn
O
Me
13j
f1 (ppm)

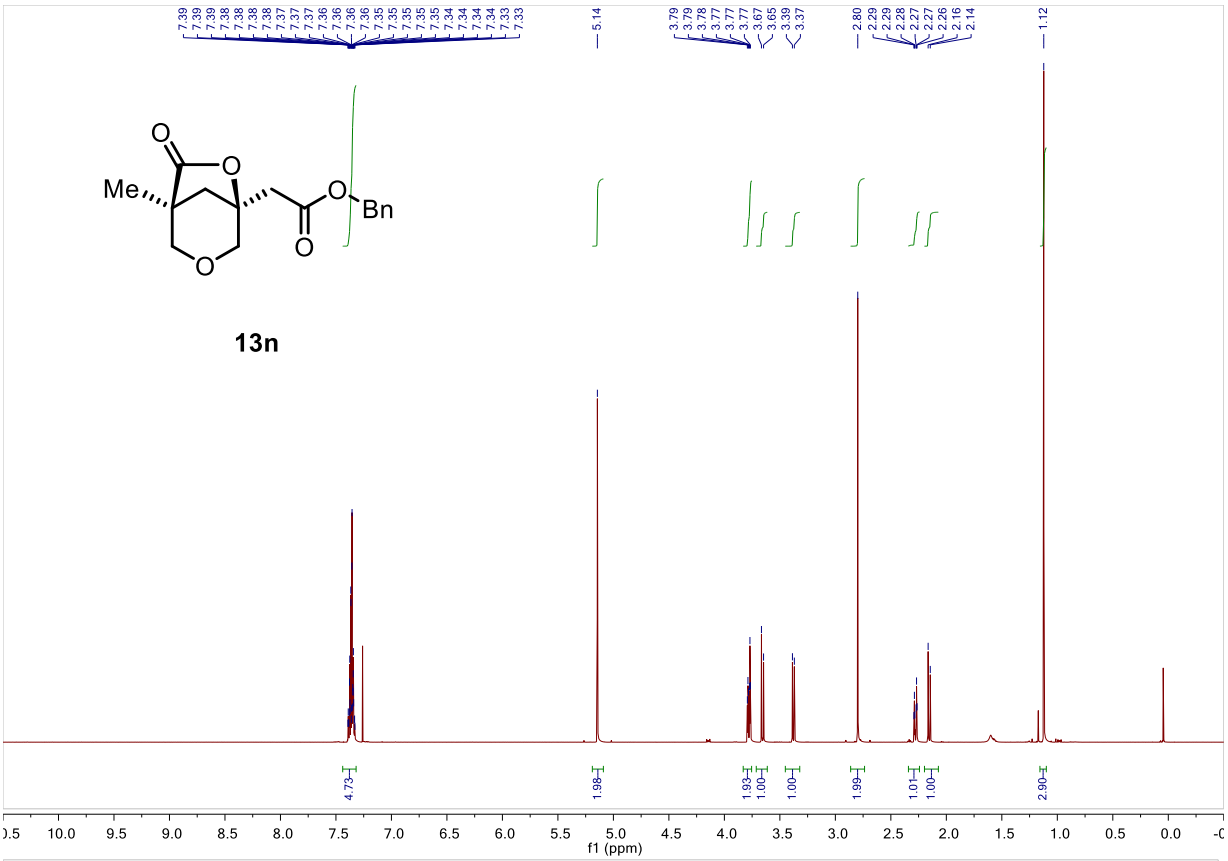

13k
f1 (ppm)
13k
f1 (ppm)

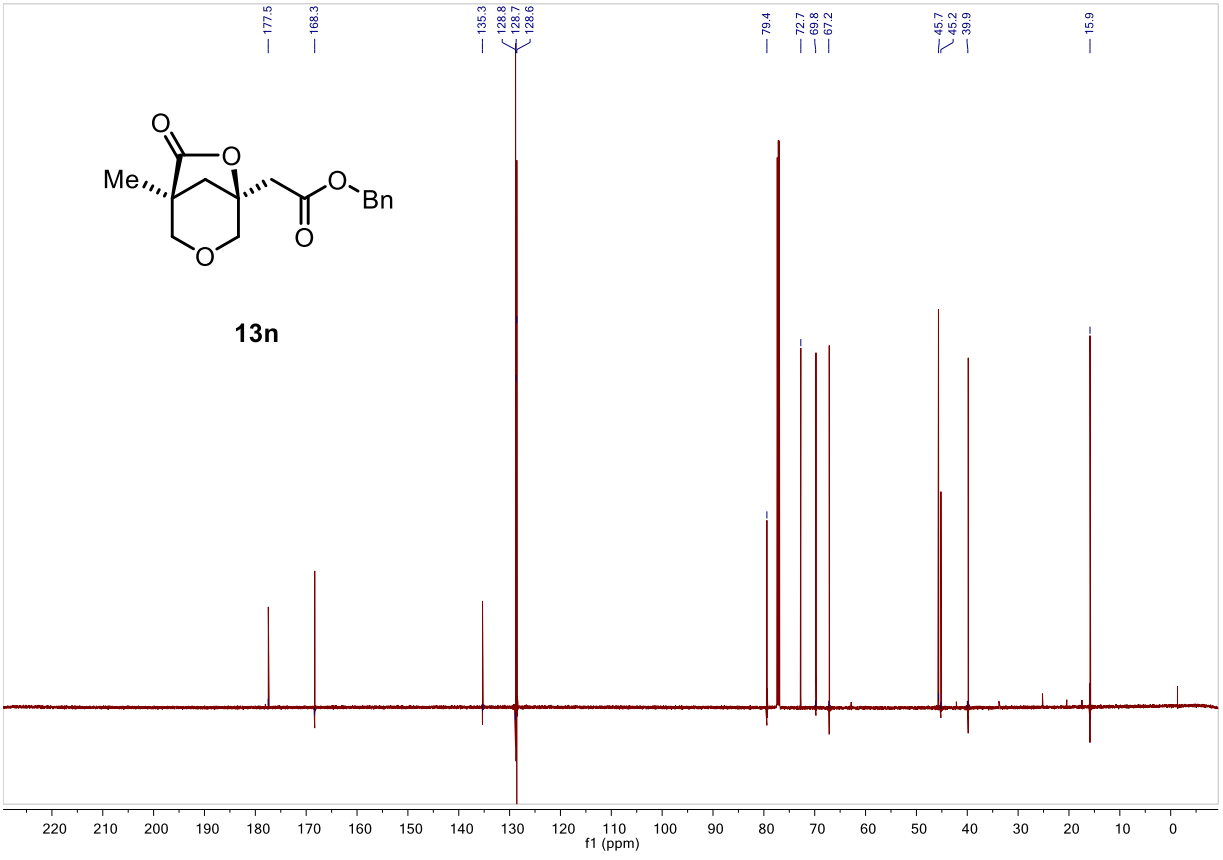

13l
f1 (ppm)

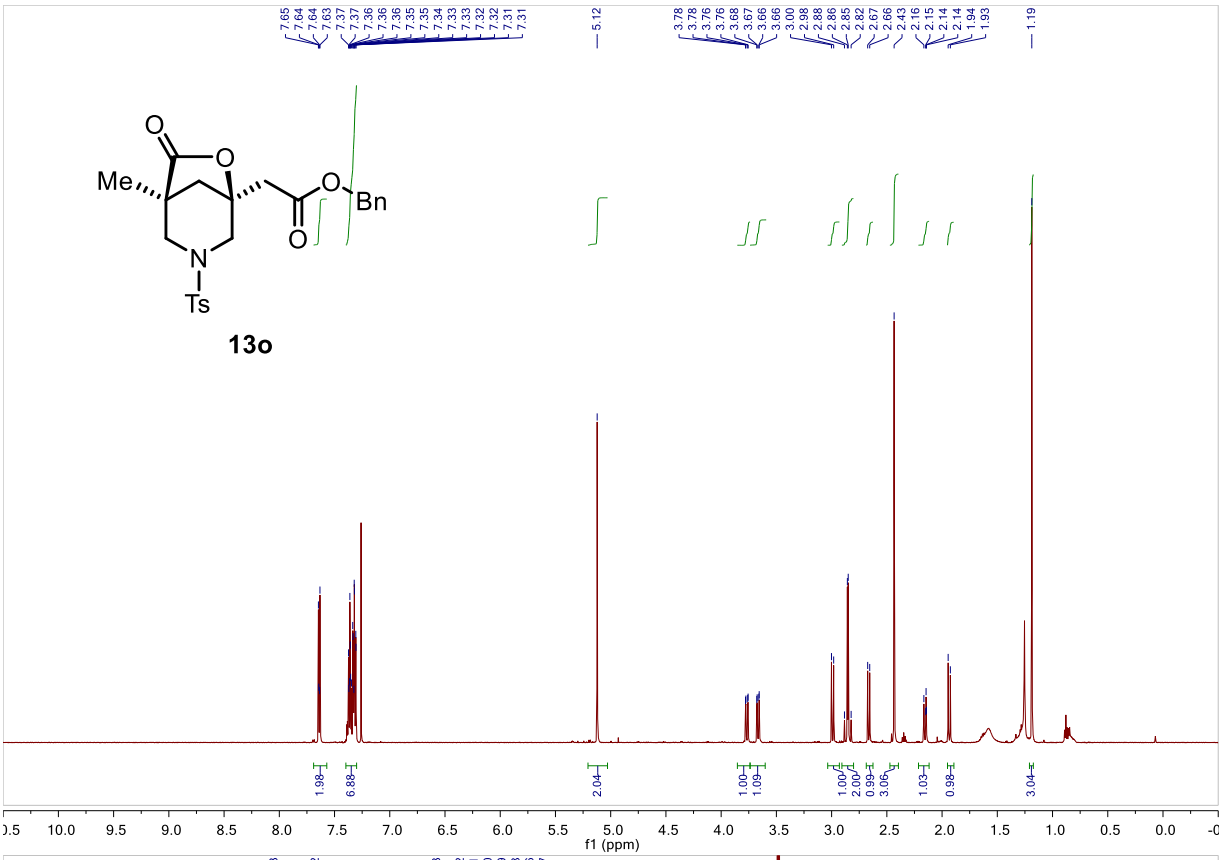

13l
f1 (ppm)

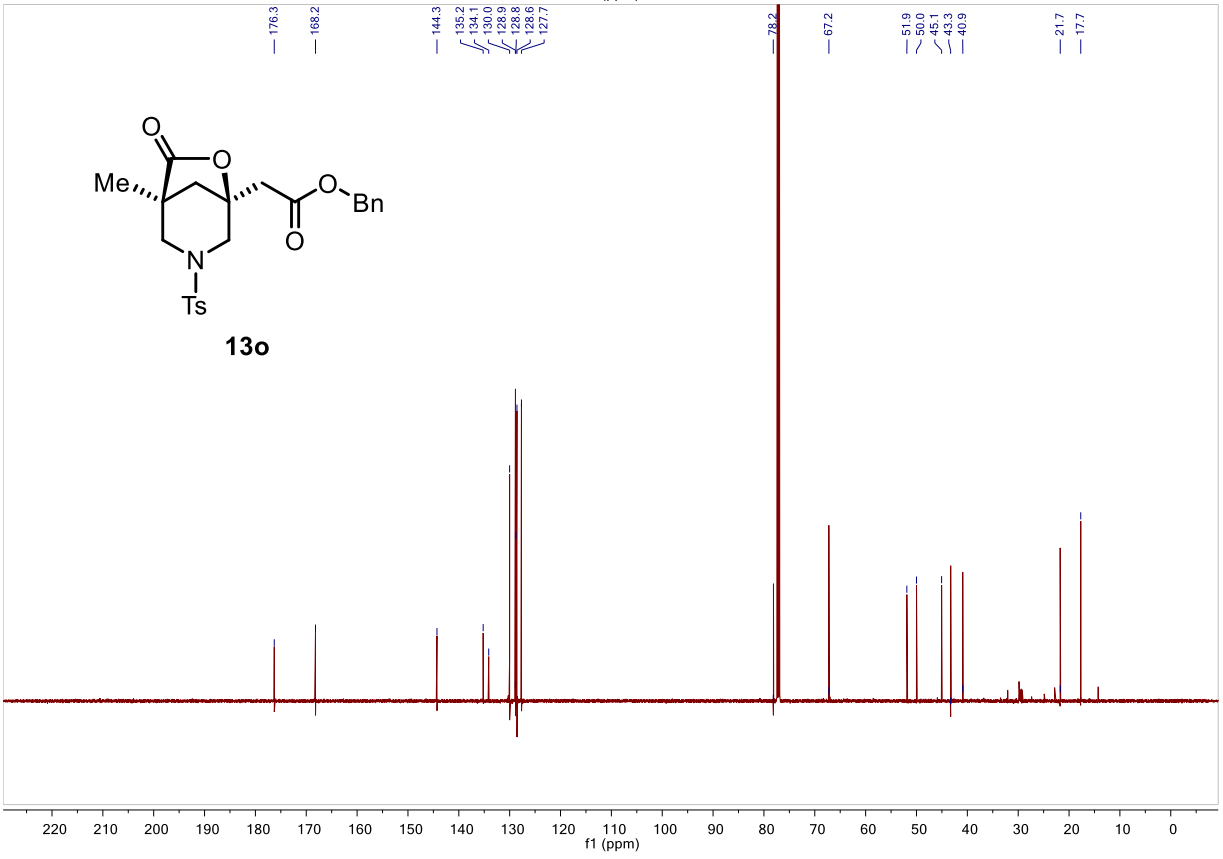

13m
f1 (ppm)

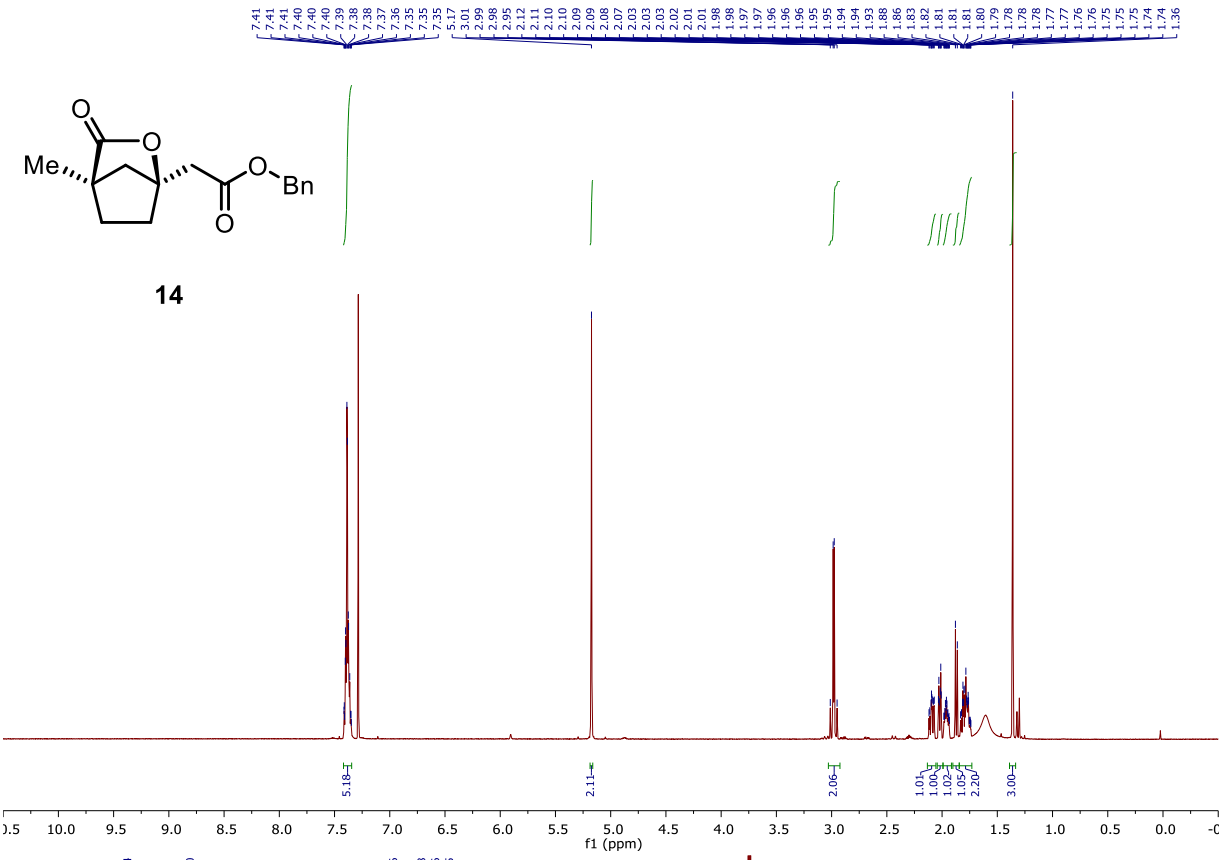

13m
f1 (ppm)

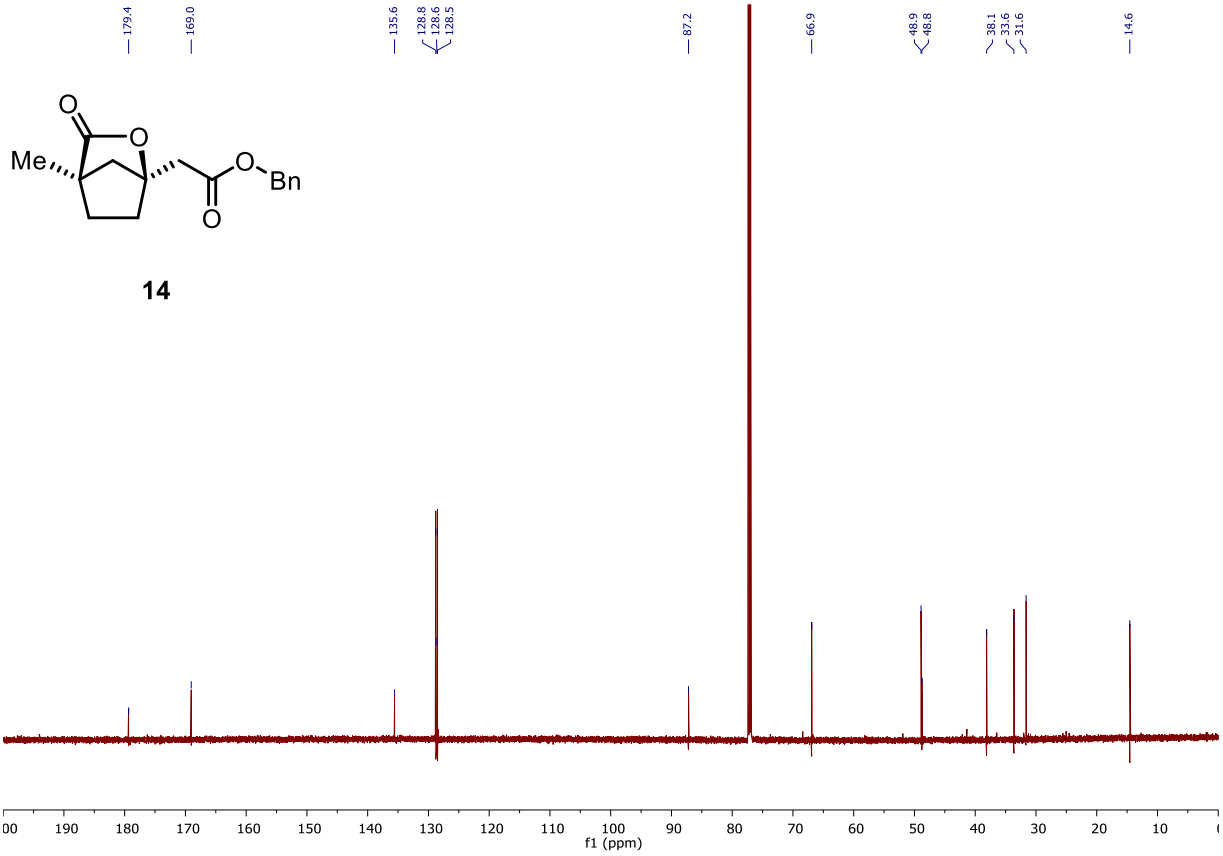

Me
O
O
O
O
Bn
O
13n
f1 (ppm)

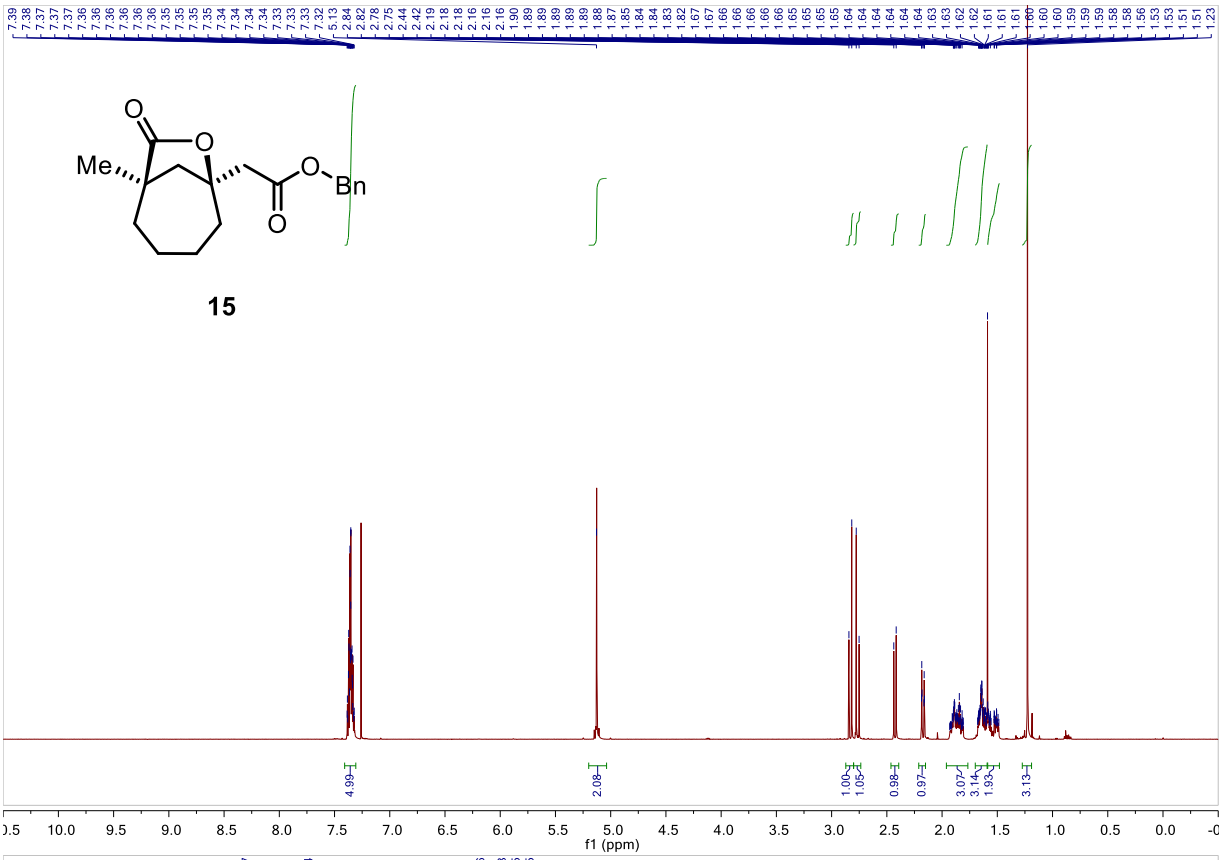

Me
O
O
O
O
Bn
O
13n
f1 (ppm)

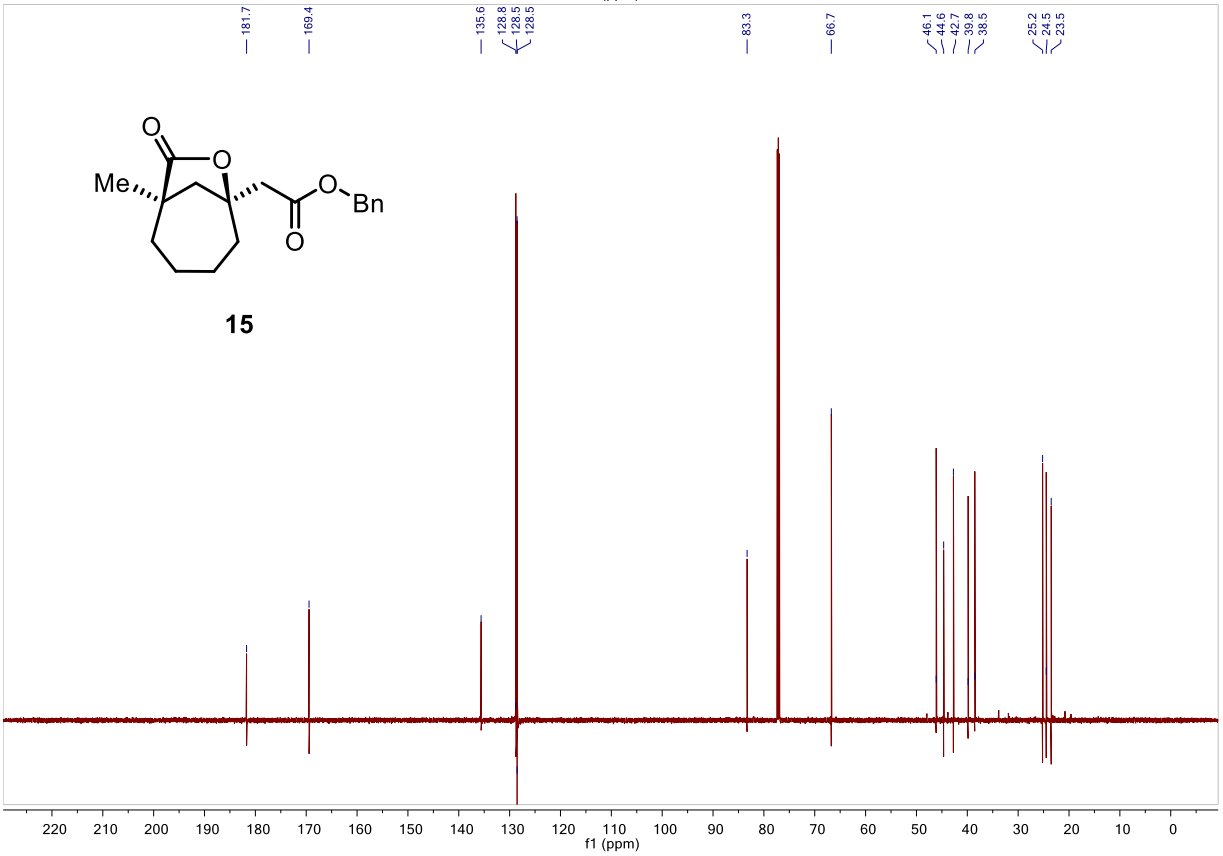

Me
O
O
O
O
Bn
N
Ts
13o
f1 (ppm)


Me
O
O
O
O
Bn
N
Ts
13o
f1 (ppm)


Me
O
O
O
O
Bn
14
f1 (ppm)


Me
O
O
O
O
Bn
14
f1 (ppm)


Me
O
O
O
O
Bn
15
4.99
2.08
1.00
1.05
0.98
0.97
3.07
3.14
1.93
3.13
f1 (ppm)


181.7
169.4
135.6
128.8
128.5
128.5
83.3
66.7
46.1
44.6
42.7
39.8
38.5
25.2
24.5
23.5
Me
O
O
O
O
Bn
15
f1 (ppm)