

# Regioswitchable Palladium-Catalyzed Decarboxylative Coupling of 1,3-Dicarbonyl Compounds

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## SUPPORTING INFORMATION

1. General Experimental Section	1
2. Ligand and Solvent Screen	2
3. Experimental Procedures	3
3.1. Synthesis of 1,3-Dicarbonyl Compounds	3
3.2. Propargyl Enol Carbonate Formation	6
3.3. Palladium-Catalysed Alkenylation Reactions	12
3.4. Mechanistic Studies	23
4. References	26
5. X-Ray Crystal Structure Data for 7a (CCDC 1411246)	27
6. <sup>1</sup> H and <sup>13</sup> C NMR Spectra	29
7. Deuterium-Labeling Studies: Mass Spectrometry Data	75

## 1. General Experimental Section.

All reactions were performed under an argon atmosphere in oven dry glassware. All solvents used were either purchased and kept over molecular sieves or passed through an activated alumina column. All other reagents and solvents were used as supplied and all aqueous reagents were saturated unless otherwise specified.

Thin layer chromatography (TLC) was carried out using pre-coated Fluka analytical silica gel on aluminium foils, with a fluorescent indicator (254 nm). Column chromatography was carried out using Fisher Silica 60 Å particle size. Petrol refers to the fraction of petroleum ether that boils between 40-60 °C. Visualisation of the TLC plates was done *via* staining with potassium permanganate or aqueous acidic ammonium molybdate (IV).

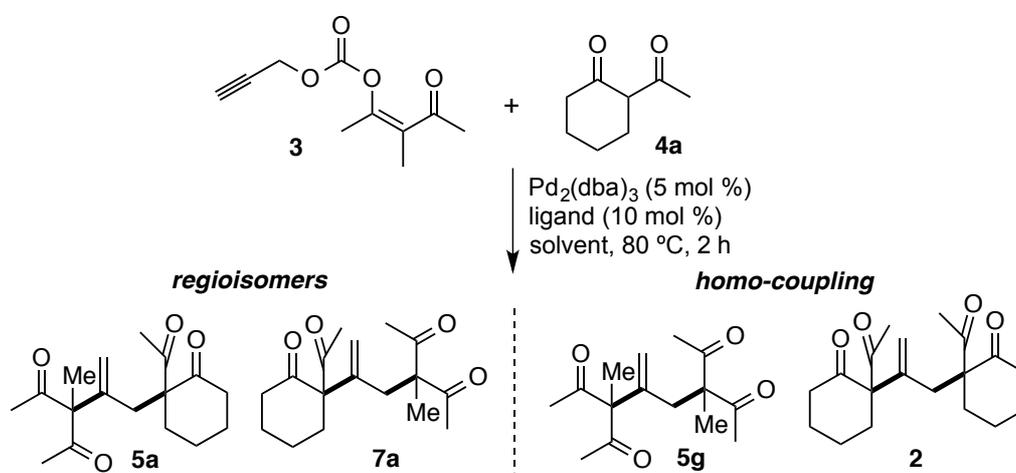
NMR spectra was recorded on a Bruker 400 MHz Ultra Shield Plus and was reported as follows: chemical shift  $\delta_{\text{H}}$  (in parts per million, ppm), multiplicity, coupling constant,  $J$ , and number of protons. Couplings are classed as singlet, s, doublet, d, triplet, t, quartet, q, quintet, quint, broad, br, multiplet, m, or a combination of these.  $^{13}\text{C}$  NMR spectra was recorded on the same instrument at 100 MHz. Residual solvent  $\text{CHCl}_3$  was referenced at 7.26 p.p.m for  $^1\text{H}$  NMR spectra and the central signal of  $\text{CDCl}_3$  was referenced to 77.0 p.p.m for  $^{13}\text{C}$  NMR spectra. A range of NMR techniques (DEPT-135, COSY, HMBC and HSQC) were used to aid the analysis of  $^1\text{H}$  and  $^{13}\text{C}$  spectra.

IR spectroscopy analysis was performed on an Agilent Technologies Cary 630 FTIR spectrometer. Accurate mass spectrometry was recorded using electron spray ionisation on Shimadzu HRMS LCMS-IT-TOF mass spectrometer at Lancaster University, Lancaster UK, as well as using the EPSRC Finnigan MAT 95 XP instrument at the UK EPSRC National Mass Spectrometry facility, Swansea UK. Melting points were measured on a Gallenkamp melting point apparatus and are uncorrected. X-ray crystallography data was recorded using a Beamline I19 diffractometer AT the UK EPSRC National Crystallography Service at the University of Southampton.

## 2. Ligand and Solvent Screen.

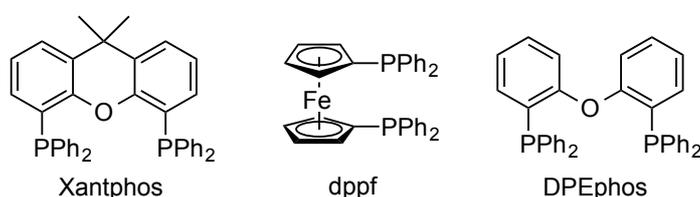
Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), phosphine ligand (0.024 mmol) and 2-acetylcyclohexanone (30 μL, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. Solvent (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5a**.

**Table S1.** Ligand and solvent screen.



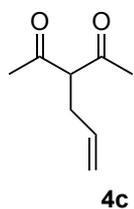
entry	ligand	solvent	selectivity <sup>a</sup>		yield ( <b>5a</b> ) (%) <sup>b</sup>
			regio ( <b>5a</b> : <b>7a</b> )	chemo ( <b>5a</b> : <b>5g</b> : <b>2</b> )	
1	Xantphos	1,4-dioxane	> 19 : 1	5.8 : 1 : 0	56
2	PPh <sub>3</sub> <sup>c</sup>	1,4-dioxane	> 19 : 1	5.9 : 1 : 0	59
3	dppf	1,4-dioxane	> 19 : 1	6.4 : 1 : 0	73
<b>4</b>	<b>DPEphos</b>	<b>1,4-dioxane</b>	<b>&gt; 19 : 1</b>	<b>6.1 : 1 : 0</b>	<b>85</b>
5	DPEphos	toluene	> 19 : 1	4.4 : 1 : 0	60
6	DPEphos	acetonitrile	> 19 : 1	1.4 : 1 : 1.4	31
7	DPEphos	DMF	> 19 : 1	1.6 : 1 : 1.6	26
8 <sup>d</sup>	DPEphos	CH <sub>2</sub> Cl <sub>2</sub>	> 19 : 1	1.7 : 1 : 2.2	16

<sup>a</sup>Ratio determined by <sup>1</sup>H NMR analysis of the crude product mixture. <sup>b</sup>Yield of isolated **5a**. <sup>c</sup>[Pd(PPh<sub>3</sub>)<sub>4</sub>] used in place of [Pd<sub>2</sub>(dba)<sub>3</sub>]. <sup>d</sup>Reaction was performed at 60 °C.

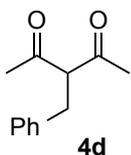


### 3. Experimental Procedures.

#### 3.1. Synthesis of 1,3-Dicarbonyl Compounds.

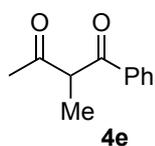


**3-Allylpentane-2,4-dione (4c):** According to a literature procedure,<sup>1</sup> to a solution of acetylacetone (1.50 ml, 15.0 mmol) in acetone (20 mL) was added potassium carbonate (2.40 g, 18.0 mmol) portionwise. The suspension was stirred at room temperature for 15 minutes. Allyl bromide (1.55 mL, 18.0 mmol) was added dropwise. The mixture was heated to reflux at 80 °C for 18 hours. The mixture was filtered under reduced pressure and the filtrate was concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 99:1] afforded **4c** (355 mg, 17%) as a pale liquid.  $R_F$  0.65 [Petrol:EtOAc 4:1];  $\nu_{\max}$  (film)/ $\text{cm}^{-1}$  2980, 1699, 1597, 1418;  $\delta_H$  (400 MHz,  $\text{CDCl}_3$ , 1.4:1 keto:enol tautomer, enol tautomer annotated by an asterisk) 16.68 (s, 1H\*), 5.86-5.75 (m, 1H\*), 5.72-5.61 (m, 1H), 5.09-4.93 (m, 2H and 2H\*), 3.70 (t,  $J = 7.5$  Hz, 1H), 2.95 (dt,  $J = 5.1, 1.9$  Hz, 2H\*), 2.55 (tt,  $J = 7.1, 1.3$  Hz, 2H), 2.15 (s, 6H), 2.06 (s, 6H\*);  $\delta_C$  (100 MHz,  $\text{CDCl}_3$ , 1.4:1 keto:enol tautomer, enol tautomer annotated by an asterisk) 203.6, 191.4\*, 135.6\*, 134.0, 117.4\*, 114.8, 107.0\*, 67.9, 32.1, 31.1\*, 29.2, 22.8\*. Synthesis of this compound has been reported in literature.<sup>1</sup>

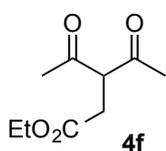


**3-Benzylpentane-2,4-dione (4d):** According to a literature procedure,<sup>2</sup> to a solution of acetylacetone (1.03 mL, 10.0 mmol) in acetone (8 mL) was added solid potassium carbonate (1.38 g, 10.0 mmol), followed by benzyl bromide (1.43 mL, 12.0 mmol). The mixture was heated to 65 °C for 18 hours. The solution was allowed to cool to room temperature and quenched with aq. HCl (1 N, 20 mL). The mixture was extracted with  $\text{Et}_2\text{O}$  (3 x 25 mL) and the combined organic fractions were washed with brine (30 mL), dried ( $\text{MgSO}_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol: $\text{Et}_2\text{O}$  9:1] afforded **4d** (645 mg, 34%) as a colourless oil.  $R_F$  0.50 [Petrol: $\text{Et}_2\text{O}$  4:1];  $\nu_{\max}$  (film)/ $\text{cm}^{-1}$  3062, 2048, 2924, 1723 1697, 1494;  $\delta_H$  (400 MHz, 1:0.97 enol:keto tautomer, keto tautomer annotated by an asterisk,  $\text{CDCl}_3$ ) 16.84 (s, 1H), 7.35-7.26 (m, 2H and 2H\*), 7.25-7.20 (m, 1H and 1H\*), 7.20-7.15 (m, 2H and 2H\*), 4.03 (t,  $J = 7.7$  Hz, 1H\*), 3.68 (s, 2H), 3.17 (d,  $J = 7.6$  Hz, 2H\*), 2.14 (s, 6H\*), 2.07 (s, 6H);  $\delta_C$  (100 MHz, 1:0.97 enol:keto tautomer, keto tautomer annotated by an asterisk,  $\text{CDCl}_3$ ) 203.5\*, 191.9, 139.6, 137.9\*, 128.7\*, 128.6, 128.5\*, 127.3, 126.7\*, 126.2, 108.2, 69.8\*, 34.2\*, 32.8, 29.7\*, 23.2;

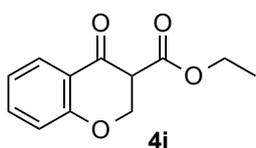
HRMS (ESI) Found:  $[M+H]^+$ , 191.1058.  $C_{12}H_{14}O_2$  requires  $[M+H]^+$ , 191.1067. Data matches literature values.<sup>2</sup>



**2-Methyl-1-phenylbutane-1,3-dione (4e):** According to a literature procedure,<sup>2</sup> to a stirred suspension of 1-phenyl-1,3-butadione (1.62 g, 10.0 mmol) and potassium carbonate (3.04 g, 22.0 mmol) in acetone (40 mL) was added methyl iodide (623  $\mu$ L, 10.0 mmol). The mixture was heated to reflux at 60 °C for 18 hours. After cooling to room temperature, the mixture was concentrated *in vacuo* to half the volume and quenched by addition of aq. HCl (1 N, 20 mL). The mixture was extracted with EtOAc (3 x 20 mL). The combined organic phases were washed with water (30 mL), brine (30 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded **4e** (1.00 g, 57%) as a yellow oil.  $R_F$  0.44 [Petrol:EtOAc 4:1];  $\nu_{max}$  (film)/ $cm^{-1}$  2927, 1718, 1675, 1597;  $\delta_H$  (400 MHz,  $CDCl_3$ ) 7.99-7.94 (m, 2H), 7.62-7.56 (m, 1H), 7.52-7.45 (m, 2H), 4.48 (t,  $J = 7.4$  Hz, 1H), 2.15 (s, 3H), 1.45 (dt,  $J = 7.0, 0.7$  Hz, 3H);  $\delta_C$  (100 MHz,  $CDCl_3$ ) 205.0, 197.3, 135.9, 133.7, 128.8, 128.6, 56.8, 27.8, 13.6; HRMS (ESI) Found:  $[M+H]^+$ , 177.0905.  $C_{11}H_{12}O_2$  requires  $[M+H]^+$ , 177.0910. Data matches literature values.<sup>2</sup>

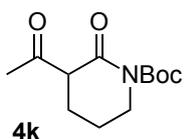


**Ethyl 3-acetyl-4-oxopentanoate (4f):** According to a literature procedure,<sup>2</sup> to a solution of acetylacetone (2.05 mL, 20.0 mmol) and ethyl bromoacetate (2.22 mL, 20.0 mmol) in dichloromethane (20 mL), was added solid potassium carbonate (2.76 g, 20.0 mmol). The mixture was stirred at room temperature for 24 hours. The reaction was quenched by addition of aq. HCl (1 N, 20 mL) and the aqueous layer was extracted with dichloromethane (3 x 20 mL). The combined organic phases were washed with brine (50 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 49:1-4:1] afforded **4f** (1.82g, 48%) as a yellow oil.  $R_F$  0.68 [Petrol:EtOAc 1:1];  $\nu_{max}$  (film)/ $cm^{-1}$  2983, 1723, 1701, 1602;  $\delta_H$  (400 MHz, 1.9:1 keto:enol tautomer, enol tautomer annotated by an asterisk,  $CDCl_3$ ) 16.76 (s, 1H)\*, 4.17-4.06 (m, 1H, 2H and 2H\*), 3.22 (s, 2H\*), 2.85 (d,  $J = 6.7$  Hz, 2H), 2.24 (s, 6H), 2.13 (s, 6H\*), 1.27-1.19 (m, 3H and 3H\*);  $\delta_C$  (100 MHz, 1.9:1 keto:enol tautomer, enol tautomer annotated by an asterisk,  $CDCl_3$ ) 202.4, 191.8\*, 171.4\*, 171.1, 104.3\*, 63.2, 61.1, 60.1\*, 33.3\*, 32.5, 29.5, 23.3\*, 14.1\*, 14.0; HRMS (ESI) Found:  $[M+H]^+$ , 187.0964.  $C_9H_{14}O_4$  requires  $[M+H]^+$ , 187.0965. Data matches literature values.<sup>2</sup>



**Ethyl 4-oxochroman-3-carboxylate (4i):** According to a literature procedure,<sup>3</sup> to a solution of 4-chromanone (1 g, 6.80 mmol) in THF (20 mL) stirred at  $-78\text{ }^{\circ}\text{C}$  was added a solution of LiHMDS (1 M in THF, 7.4 mL, 7.40 mmol) dropwise and the mixture was stirred for 30 minutes. Ethyl

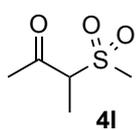
cyanofornate (0.8 mL, 8.0 mmol) in THF (6 mL) was added dropwise and the reaction was stirred at  $-78\text{ }^{\circ}\text{C}$  for 1 hour. The mixture was allowed to warm to room temperature and was quenched by the addition of aq.  $\text{NH}_4\text{Cl}$  (25 mL) and  $\text{H}_2\text{O}$  (25 mL). The mixture was extracted with  $\text{Et}_2\text{O}$  (3 x 25 mL). The combined organic phases were washed with brine (30 mL), dried ( $\text{MgSO}_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded **4i** (478 mg, 32%) as a white solid.  $R_F$  0.76 [Petrol:EtOAc 5:1]; m.p  $51\text{-}53\text{ }^{\circ}\text{C}$ ;  $\nu_{\text{max}}$  (film)/ $\text{cm}^{-1}$  2983, 2935, 1723, 1679, 1604, 1578, 1468;  $\delta_{\text{H}}$  (400 MHz, 2.1:1 keto:enol tautomer, enol tautomer shown by an asterisk,  $\text{CDCl}_3$ ) 11.97 (s, 1H\*), 7.82 (ddd,  $J = 7.8, 1.5, 0.3\text{ Hz}$ , 1H), 7.56 (dd,  $J = 7.87, 1.94\text{ Hz}$ , 1H\*), 7.39 (ddd,  $J = 7.3, 1.8, 0.6\text{ Hz}$ , 1H), 7.21 (ddd,  $J = 7.6, 1.8, 0.9\text{ Hz}$ , 1H\*), 6.98-6.92 (m, 1H), 6.91-6.85 (m, 1H and 1H\*), 6.77 (dd,  $J = 8.2, 0.9\text{ Hz}$ , 1H\*), 4.86 (s, 2H\*), 4.69 (dd,  $J = 11.6, 8.5\text{ Hz}$ , 1H), 4.54 (dd,  $J = 11.6, 4.8\text{ Hz}$ , 1H), 4.22-4.11 (m, 2H and 2H\*), 3.66 (dd,  $J = 8.6, 4.7\text{ Hz}$ , 1H), 1.25 (t,  $J = 7.5\text{ Hz}$ , 3H\*), 1.19 (t,  $J = 6.6\text{ Hz}$ , 3H);  $\delta_{\text{C}}$  (100 MHz, 2.08:1 keto:enol tautomer, enol tautomer shown by an asterisk,  $\text{CDCl}_3$ ) 186.7, 169.4\*, 166.9, 162.3\*, 161.0, 157.3\*, 136.0, 132.7\*, 127.2, 124.1\*, 121.4, 121.1\*, 120.2, 117.9\*, 117.5, 116.1\*, 91.6\*, 67.9, 63.4\*, 61.4, 60.4\*, 52.2, 13.9\*, 13.7; HRMS (ESI) Found:  $[\text{M}+\text{H}]^+$ , 221.0798.  $\text{C}_{12}\text{H}_{12}\text{O}_4$  requires  $[\text{M}+\text{H}]^+$ , 221.0808. Synthesis of this compound has been reported in the literature.<sup>3</sup>



**tert-Butyl-3-acetyl-2-oxopiperidine-1-carboxylate (4k):** According to a literature procedure,<sup>2</sup> to a stirred solution of *N*-Boc-2-piperidone (995 mg, 5.0 mmol) in THF (10 mL) at  $-78\text{ }^{\circ}\text{C}$  was added a solution of LiHMDS (1 M

in THF, 10.5 mL, 10.5 mmol) dropwise. The mixture was stirred at this temperature for 15 minutes. Acetic anhydride (471  $\mu\text{L}$ , 5.0 mmol) was added dropwise and the mixture was stirred at  $-78\text{ }^{\circ}\text{C}$  for a further 1 hour. The reaction was quenched by addition of aq.  $\text{NH}_4\text{Cl}$  (10 mL). The mixture was allowed to warm to room temperature and extracted with EtOAc (3 x 15 mL). The combined organic phases were washed with brine (30 mL), dried ( $\text{MgSO}_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded **4k** (222 mg, 18%) as a yellow oil.  $R_F$  0.36 [Petrol:EtOAc 1:1];  $\nu_{\text{max}}$  (film)/ $\text{cm}^{-1}$  2978, 2931, 1716, 1619;  $\delta_{\text{H}}$  (400 MHz, 2:1 enol:keto tautomer, keto tautomer annotated by an asterisk,  $\text{CDCl}_3$ ) 14.90 (s, 1H), 3.64-3.60 (m, 2H and 2H\*), 3.55 (t,  $J = 6.7\text{ Hz}$ , 1H\*),

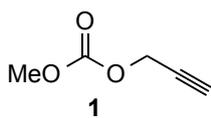
2.33 (t,  $J = 7.1$  Hz, 2H), 2.32 (s, 3H\*), 1.98 (s, 3H), 1.93-1.72 (m, 2H and 4H\*), 1.51 (s, 9H), 1.50 (s, 9H\*);  $\delta_C$  (100 MHz, 1.92:1 enol:keto tautomer annotated by an asterisk,  $CDCl_3$ ) 204.0\*, 175.2, 171.8, 168.4\*, 152.3\*, 152.1, 97.2, 83.3\*, 82.8, 57.8\*, 46.1, 45.9\*, 29.8\*, 28.0, 27.9\*, 23.8, 22.6\*, 22.4, 20.9\*, 19.5; HRMS (ESI) Found:  $[M+H]^+$ , 242.1391.  $C_{12}H_{19}NO_4$  requires  $[M+H]^+$ , 242.1387. Data matches literature values.<sup>2</sup>



**3-(Methylsulfonyl)butan-2-one (4I):** According to a procedure,<sup>4</sup> to a solution of methane sulfonylacetone (1.0 g, 7.85 mmol) in acetone (30 mL) was added potassium carbonate (1g, 7.85 mmol). Methyl iodide (458  $\mu$ L, 7.85 mmol) was

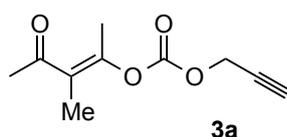
added dropwise and the mixture was stirred at room temperature for 2 hours. The reaction was quenched by addition of aq. HCl (1 N, 20 mL) and the mixture was extracted with EtOAc (3 x 20 mL). The combined organic phases were washed with brine (30 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 2:1] afforded **4I** (268 mg, 23%) as a colourless oil.  $R_F$  0.20 [Petrol:EtOAc 1:1];  $\nu_{max}$  (film)/ $cm^{-1}$  2935, 1716, 1699;  $\delta_H$  (400 MHz,  $CDCl_3$ ) 3.99 (q,  $J = 7.5$  Hz, 1H), 2.85 (d,  $J = 0.5$  Hz, 3H), 2.40 (s, 3H), 1.56 (d,  $J = 6.90$  Hz, 3H);  $\delta_C$  (100 MHz,  $CDCl_3$ ) 201.7, 69.1, 37.2, 30.8, 11.5. Synthesis of this compound has been reported in the literature.<sup>4</sup>

### 3.2. Propargyl Enol Carbonate Formation.

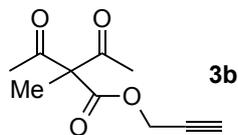


**Methyl prop-2-ynyl carbonate (1):** According to a literature procedure,<sup>5</sup> a solution of propargyl alcohol (5.19 mL, 89.0 mmol) and pyridine (14.4 mL, 178 mmol) in diethyl ether (90.0 mL) was cooled to 0 °C. Methyl

chloroformate (6.91 mL, 89.0 mmol) was added dropwise over 10 min. The mixture was stirred at room temperature for 15 hours, then quenched with aq. HCl (1 N, 30 mL) and extracted with diethyl ether (3 x 20 mL). The organic phases were combined and washed with brine (30 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 3:1] afforded **1** (5.27 g, 52 %) as a colourless liquid.  $\delta_H$  (400 MHz,  $CDCl_3$ ) 4.73 (d,  $J = 2.5$  Hz, 2H), 3.82 (s, 3H), 2.52 (t,  $J = 2.4$  Hz, 1H). Synthesis of this compound has been reported in the literature.<sup>5</sup>



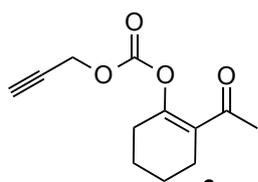
**3a**



**3b**

**3-Methyl-4-oxopent-2-en-2-yl prop-2-ynyl carbonate (3a)** and **prop-2-ynyl 2-acetyl-2-methyl-3-oxobutanoate (3b)**: According to a literature procedure,<sup>2</sup> a suspension of sodium hydride (60 wt%, 76 mg, 1.90 mmol) in THF (10 mL) was cooled to 0 °C. A solution of 3-methylpentane-2,4-dione (201  $\mu$ L, 1.73 mmol) in THF (5 mL) was added dropwise and the mixture was stirred at 0 °C for 10 minutes.

Propargyl chloroformate (187  $\mu$ L, 1.90 mmol) was added dropwise and the mixture was stirred at this temperature for 1 hour. The reaction was quenched with aq. HCl (1 N, 50 mL) and extracted with EtOAc (3 x 30 mL). The combined organic fractions were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable 5.3:1 mixture of carbonate **3a** and ester **3b** (250 mg, 74%) as a clear oil.  $R_F$  0.21 [Petrol:EtOAc 4:1];  $\nu_{max}$  (film)/cm<sup>-1</sup> 3281, 2973, 2148, 1757, 1653, 1555;  $\delta_H$  (400 MHz, **3b** annotated by an asterisk, CDCl<sub>3</sub>) 4.80 (s, 2H\*), 4.79 (d,  $J$  = 2.5 Hz, 2H), 2.56 (t,  $J$  = 2.4 Hz, 1H), 2.52 (t,  $J$  = 2.6 Hz, 1H\*), 2.30 (s, 3H), 2.26 (s, 6H\*), 2.08 (d,  $J$  = 0.8 Hz, 3H), 1.83 (d,  $J$  = 1.0 Hz, 3H), 1.61 (s, 3H\*);  $\delta_C$  (100 MHz, 5:1 carbonate/ester, ester annotated by an asterisk, CDCl<sub>3</sub>) 201.5\*, 199.1, 168.2\*, 151.7, 150.5, 125.0, 76.3, 76.2, 75.8\*, 75.3\*, 72.7\*, 56.0, 53.2\*, 30.9, 27.6\*, 17.9, 17.3\*, 14.0; HRMS (ESI) Found: [M+H]<sup>+</sup>, 197.0804. C<sub>10</sub>H<sub>12</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 197.0808. Data matches literature values.<sup>2</sup>

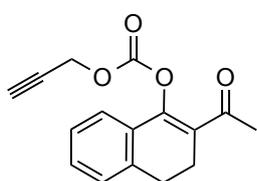


**6a**

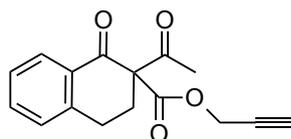
**2-Acetylcyclohex-1-enyl prop-2-ynyl carbonate (6a)**: According to a literature procedure,<sup>2</sup> a suspension of sodium hydride (60 wt%, 439 mg, 11.0 mmol) in THF (60 mL) was cooled to 0 °C. A solution of 2-acetylcyclohexanone (1.32 mL, 10.0 mmol) in THF (5 mL) was added

dropwise and the mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (1.07 mL, 11.0 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched with aq. HCl (1 N, 30 mL) and extracted with EtOAc (3 x 30 mL). The combined organic fractions were washed with brine (30mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded **6a** (1.57 g, 71%) as a colourless oil.  $R_F$  0.46 [Petrol:EtOAc 4:1];  $\nu_{max}$ (film)/cm<sup>-1</sup> 3283, 2940, 2864, 2128, 1757, 1695, 1649;  $\delta_H$  (400 MHz, CDCl<sub>3</sub>) 4.80 (d,  $J$  = 2.4 Hz, 2H), 2.56 (t,  $J$  = 2.4 Hz, 1H), 2.40-2.33 (m, 4H), 2.30 (s, 3H), 1.79-1.70 (m, 2H), 1.68-1.58 (m, 2H);  $\delta_C$  (100 MHz, CDCl<sub>3</sub>) 198.2, 154.2, 151.6, 126.3, 76.4, 76.2, 56.0, 30.8, 28.2, 24.8, 22.2, 21.5;

HRMS (ESI) Found:  $[M+H]^+$ , 223.0964.  $C_{12}H_{14}O_4$  requires  $[M+H]^+$ , 223.0965. Data matches literature values.<sup>2</sup>



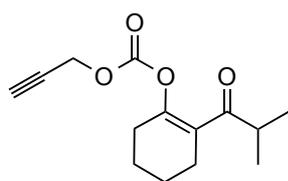
**6ba**



**6bb**

**2-Acetyl-3,4-dihydronaphthalen-1-yl prop-2-ynyl carbonate (6ba)** and **(1-oxo-3,4-dihydronaphthalen-2(1H)-ylidene)ethyl prop-2-ynyl carbonate (6bb)**: According to a literature procedure,<sup>2</sup>

a suspension of sodium hydride (60 wt%, 220 mg, 5.50 mmol) in THF (40 mL) was cooled to 0 °C. A solution of 2-acetyltetralone (940 mg, 5.0 mmol) in THF (2 mL) was added dropwise and the mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (540  $\mu$ L, 5.50 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 25 mL) and the mixture was extracted with EtOAc (3 x 25 mL). The combined organic phases were washed with brine (50 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded an inseparable 7.7:1 mixture of carbonate **6ba** and ester **6bb** (1.18 g, 87%) as a pale solid.  $R_F$  0.27 [Petrol:EtOAc 4:1]; m.p 53-55 °C;  $\nu_{max}$  (film)  $cm^{-1}$  3278, 2940, 2840, 2569, 2137, 1755, 1654, 1617, 1569;  $\delta_H$  (400 MHz, **6bb** annotated by an asterisk,  $CDCl_3$ ) 8.08 (dd,  $J = 7.9, 1.3$  Hz, 1H\*), 7.52 (td,  $J = 7.6, 1.5$  Hz, 1H\*), 7.39 (d,  $J = 8.3$  Hz, 1H), 7.37-7.20 (m, 3H and 2H\*), 4.87 (d,  $J = 2.8$  Hz, 2H), 4.80 (d,  $J = 2.6$  Hz, 2H\*), 2.99 (t,  $J = 6.4$  Hz, 2H\*), 2.89 (t,  $J = 6.8$  Hz, 2H), 2.76-2.69 (m, 2H and 2H\*), 2.62 (t,  $J = 2.5$  Hz, 1H), 2.51 (t,  $J = 2.5$  Hz, 1H\*), 2.45 (s, 3H), 2.37 (s, 3H\*);  $\delta_C$  (100 MHz, **6bb** annotated by an asterisk,  $CDCl_3$ ) 200.3\*, 197.2, 191.5\*, 167.7\*, 151.7, 149.9, 142.8\*, 138.5, 134.2\*, 131.3\*, 130.4, 129.5, 128.8\*, 128.0\*, 127.6, 127.0\*, 126.8, 124.9, 123.1, 77.2\*, 76.4, 76.2, 75.7\*, 71.4\*, 56.3, 53.2\*, 30.5, 28.9\*, 28.6\*, 27.1, 25.5\*, 23.4; HRMS (ESI) Found:  $[M+H]^+$ , 271.0961.  $C_{16}H_{14}O_4$  requires  $[M+H]^+$ , 271.0965. Synthesis of this compound has been reported in the literature.<sup>2</sup>

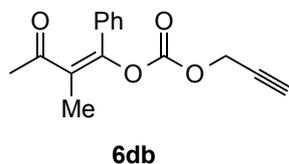
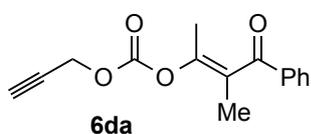


**6c**

**2-Isobutyrylcyclohex-1-enyl prop-2-ynyl carbonate (6c)**:

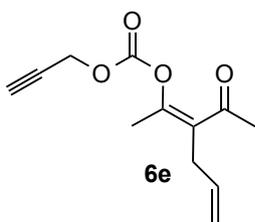
According to a literature procedure,<sup>2</sup> a suspension of sodium hydride (60 wt%, 110 mg, 2.75 mmol) in THF (20 mL) was cooled to 0 °C. A solution of 2-*iso*-butyrylcyclohexanone (410  $\mu$ L, 2.5 mmol) in THF (4 mL) was added dropwise and the mixture was stirred at 0 °C for 15 minutes. Propargyl chloroformate (268  $\mu$ L, 2.75 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was

quenched by addition of aq. HCl (1 N, 25 mL) and the mixture was extracted with EtOAc (3 x 25 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 49:1-19:1] afforded carbonate **6c** (384 mg, 61%) as a white oil. R<sub>F</sub> 0.56 [Petrol/EtOAc 4:1];  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3242, 2939, 2868, 2122, 1757, 1638;  $\delta_{\text{H}}$  (400 MHz, CDCl<sub>3</sub>) 4.66 (d, *J* = 2.6 Hz, 2H), 2.83 (quint, *J* = 6.8 Hz, 1H), 2.51 (t, *J* = 2.5 Hz, 1H), 2.26-2.20 (m, 4H), 1.68-1.51 (m, 4H), 0.94 (d, *J* = 6.8 Hz, 6H);  $\delta_{\text{C}}$  (100 MHz, CDCl<sub>3</sub>) 206.0, 151.4, 150.3, 125.7, 76.3, 75.9, 55.5, 38.8, 27.3, 25.4, 21.9, 21.3, 17.9; HRMS (ESI) Found: [M+H]<sup>+</sup>, 251.1273. C<sub>14</sub>H<sub>18</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 251.1278. Data matches literature values.<sup>2</sup>



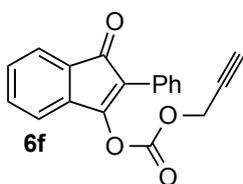
**2-Methyl-3-oxo-1-phenylbut-1-enyl prop-2-ynyl carbonate (6da)** and **3-methyl-4-oxo-4-phenylbut-2-en-2-yl prop-2-ynyl carbonate (6db)**: According to a literature procedure,<sup>2</sup> a suspension of sodium hydride (60 wt%, 240 mg, 6.0 mmol) in THF (40 mL) was cooled to 0 °C. A solution of diketone **4e** (880 mg, 5.0 mmol) in THF (3 mL) was added dropwise and the

mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (590  $\mu$ L, 6.0 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 20 mL) and the mixture was extracted with EtOAc (3 x 25 mL). The combined organic phases were washed with brine (50 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded an inseparable 4.9:1 mixture of carbonates **6da** and **6db** (1.16 g, 90%) as a colourless solid. R<sub>F</sub> 0.20 [Petrol:EtOAc 9:1]; m.p 54-56 °C;  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3255, 2126, 1759, 1690, 1595;  $\delta_{\text{H}}$  (400 MHz, CDCl<sub>3</sub>, resonances due to **6da** quoted, CDCl<sub>3</sub>) 7.85-7.80 (m, 2H), 7.54 (tt, *J* = 7.3, 2.0 Hz, 1H), 7.47-7.38 (m, 2H), 4.48 (d, *J* = 2.5 Hz, 2H), 2.43 (t, *J* = 2.4 Hz, 1H), 2.12 (q, *J* = 1.2 Hz, 3H), 1.96 (q, *J* = 1.3 Hz, 3H);  $\delta_{\text{C}}$  (100 MHz, resonances due to **6da** quoted, CDCl<sub>3</sub>) 196.9, 151.6, 145.6, 136.8, 133.1, 128.8, 128.5, 123.9, 76.3, 75.9, 55.5, 16.1, 15.2; HRMS (ESI) Found: [M+H]<sup>+</sup>, 259.0955. C<sub>15</sub>H<sub>14</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 259.0965. Synthesis of this compound has been reported in the literature.<sup>2</sup>



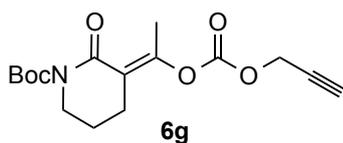
**3-Acetylhexa-2,5-dien-2-yl prop-2-ynyl carbonate (6e):** A suspension of sodium hydride (60 wt%, 48.4 mg, 1.21 mmol) in THF (7 mL) was cooled to 0 °C. A solution of diketone **4c** (154 mg, 1.10 mmol) in THF (3 mL) was added dropwise and the mixture was stirred at 0 °C for 15 minutes. Propargyl chloroformate (118 μL, 1.21 mmol)

was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 10 mL) and the mixture was extracted with EtOAc (3 x 15 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded **6e** (100 mg, 41 %) as a light green oil.  $R_F$  0.64 [Petrol:EtOAc 4:1];  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3285, 2926, 1757, 1649;  $\delta_H$  (400 MHz, CDCl<sub>3</sub>) 5.81-5.70 (m, 1H), 5.09-5.01 (m, 2H), 4.79 (d,  $J$  = 2.3 Hz, 2H), 3.01 (d,  $J$  = 5.9 Hz, 2H), 2.57 (t,  $J$  = 2.6 Hz, 1H), 2.29 (s, 3H), 2.07 (s, 3H);  $\delta_C$  (100 MHz, CDCl<sub>3</sub>) 198.5, 152.1, 151.6, 133.8, 127.0, 115.9, 76.3, 75.8, 56.0, 32.0, 31.0, 17.7; HRMS (ESI) Found: [M+H]<sup>+</sup>, 223.0967. C<sub>12</sub>H<sub>14</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 223.0965.



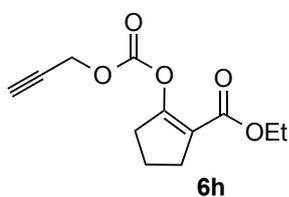
**3-Oxo-2-phenylcyclopent-1-enyl prop-2-ynyl carbonate (6f):** According to a literature procedure,<sup>2</sup> a suspension of NaH (60 wt%, 132 mg, 3.30 mmol) in THF (20 mL) was cooled to 0 °C. A solution of 2-phenyl-1,3-indandione (666 mg, 3.0 mmol) in THF (5 mL) was added

dropwise and the mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (323 μL, 3.30 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched with aq. HCl (1 N, 50 mL) and diluted with EtOAc (50 mL). The aqueous layer was separated and extracted further with EtOAc (2 x 50 mL). The combined organic fractions were washed with brine (50 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded **6f** (784 mg, 86%) as a bright orange solid.  $R_F$  0.28 [Petrol:EtOAc 4:1]; m.p 90-92 °C;  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3244, 1764, 1716;  $\delta_H$  (400 MHz, CDCl<sub>3</sub>) 7.60-7.52 (m, 2H), 7.41 (d,  $J$  = 7.2 Hz, 1H), 7.34-7.12 (m, 5H), 6.97 (d,  $J$  = 7.1 Hz, 1H), 4.68 (d,  $J$  = 2.5 Hz, 2H), 2.50 (t,  $J$  = 2.5 Hz, 1H);  $\delta_C$  (100 MHz, CDCl<sub>3</sub>) 192.7, 162.8, 149.7, 138.7, 133.4, 130.0, 129.7, 128.6, 128.4 (three signals), 122.6, 121.2, 119.0, 76.9, 75.7, 56.8. Data matches literature values.<sup>2</sup>



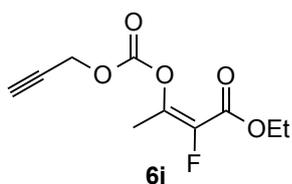
**tert-Butyl-2-oxo-3-(1((prop-2-ynyl)oxy)carbonyloxy)ethylidene) piperidine-1-carboxylate (6g):**

According to a literature procedure,<sup>2</sup> a suspension of sodium hydride (60 wt%, 26 mg, 0.65 mmol) in THF (7 mL) was cooled to 0 °C. A solution of **4k** (130 mg, 0.54 mmol) in THF (3 mL) was added dropwise and the mixture was stirred at 0 °C for 15 minutes. Propargyl chloroformate (59.0 μL, 0.60 mmol) was added dropwise and the mixture stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 10 mL) and the mixture was extracted with EtOAc (3 x 15 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded **6g** (121 mg, 69%) as a clear oil. R<sub>F</sub> 0.40 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3268, 2980, 1759, 1707, 1638; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.78 (d, *J* = 2.6 Hz, 2H), 3.69-3.63 (m, 2H), 2.57 (t, *J* = 2.4 Hz, 1H), 2.46 (td, *J* = 7.0, 2.0 Hz, 2H), 2.36 (t, *J* = 1.8 Hz, 3H), 1.85-1.77 (m, 2H), 1.53 (s, 9H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 165.2, 156.4, 152.4, 151.1, 120.7, 83.0, 76.3 (two signals), 56.0, 45.4, 28.0, 23.4, 21.7, 18.9; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 346.1258. C<sub>16</sub>H<sub>21</sub>NO<sub>6</sub> requires [M+Na]<sup>+</sup>, 346.1261. Data matches literature values.<sup>2</sup>



**1-(2-Oxocyclopentylidene) ethyl prop-2-ynyl carbonate (6h):**

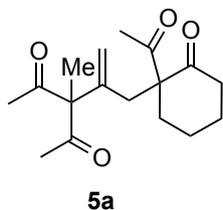
A suspension of sodium hydride (60 wt%, 660 mg, 16.50 mmol) in THF (40 mL) was cooled to 0 °C. A solution of 2-acetylcyclopentanone (2.20 mL, 15.0 mmol) in THF (2 mL) was added dropwise and the mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (1.61 mL, 16.50 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 30 mL) and the mixture was extracted with EtOAc (3 x 30 mL). The combined organic phases were washed with brine (40 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 9:1] afforded **6h** (2.60 g, 73%) as a pale solid. R<sub>F</sub> 0.30 [Petrol:EtOAc 4:1]; m.p 37-39 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3255, 2983, 2133, 1766, 1697, 1653; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.78 (d, *J* = 2.4 Hz, 2H), 4.15 (q, *J* = 7.2 Hz, 2H), 2.68-2.60 (m, 4H), 2.55 (t, *J* = 2.5 Hz, 1H), 1.94 (quint, *J* = 7.7 Hz, 2H), 1.24 (t, *J* = 6.9 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 163.3, 158.1, 150.8, 118.8, 76.3, 76.1, 60.2, 56.0, 32.9, 29.3, 18.8, 14.1; HRMS (ESI) Found: [M+H]<sup>+</sup>, 239.0915. C<sub>12</sub>H<sub>14</sub>O<sub>5</sub> requires [M+H]<sup>+</sup>, 239.0914.



### Ethyl 2-fluoro-3-((prop-2-ynoxy)carbonyloxy)but-2-enoate (**6i**):

A suspension of sodium hydride (60 wt%, 352 mg, 8.80 mmol) in THF (30 mL) was cooled to 0 °C. A solution of 2-ethyl fluoroacetate (1.00 mL, 8.0 mmol) in THF (5 mL) was added dropwise and the mixture was stirred at 0 °C for 10 minutes. Propargyl chloroformate (857  $\mu$ L, 8.80 mmol) was added dropwise and the mixture was stirred at room temperature for 1.5 hours. The reaction was quenched by addition of aq. HCl (1 N, 20 mL) and the mixture was extracted with EtOAc (3 x 25 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded **6i** (1.2 g, 65%) as a colourless oil.  $R_F$  0.70 [Petrol:EtOAc 4:1];  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3289, 2987, 2133, 1768, 1727, 1686;  $\delta_H$  (400 MHz, CDCl<sub>3</sub>) 4.79 (d,  $J$  = 2.4, 2H), 4.26 (q,  $J$  = 7.2 Hz, 2H), 2.57 (t,  $J$  = 2.2 Hz, 1H), 2.10 (d,  $J$  = 5.9 Hz, 3H), 1.29 (t,  $J$  = 7.3 Hz, 3H);  $\delta_C$  (100 MHz, CDCl<sub>3</sub>) 158.9 (d,  $J$  = 31.5 Hz), 151.4 (d,  $J$  = 3.9 Hz), 145.1 (d,  $J$  = 30.8 Hz), 143.7 (d,  $J$  = 235.1 Hz), 76.3, 76.1, 61.7, 56.2, 15.3, 13.9; HRMS (ESI) Found:  $[M+Na]^+$ , 253.0471. C<sub>10</sub>H<sub>11</sub>FO<sub>5</sub> requires  $[M+Na]^+$ , 253.0483.

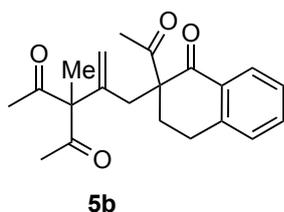
### 3.3. Palladium-Catalysed Alkenylation Reactions.



### 3-(3-(1-Acetyl-2-oxocyclohexyl)prop-1-en-2-yl)-3-methylpentane-2,4-

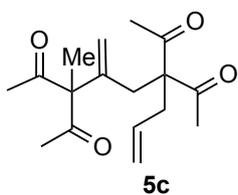
**dione (5a):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 2-acetyl cyclohexanone (31  $\mu$ L, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL)

was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5a** and **5g** in an 8.8:1 ratio (66 mg, corresponding to 60 mg of **5a**, 85%, *r.r.* > 19:1) as a red solid.  $R_F$  0.40 [Petrol:EtOAc 4:1]; m.p 68-71 °C;  $\nu_{\max}$  (film)/cm<sup>-1</sup> 3419, 2911, 2870, 1693, 1644, 1421;  $\delta_H$  (400 MHz, CDCl<sub>3</sub>) 5.02 (q,  $J$  = 1.4 Hz, 1H), 4.91 (q,  $J$  = 1.4 Hz, 1H), 2.59-2.37 (m, 6H), 2.18 (s, 9H), 1.75-1.62 (m, 4H), 1.55 (s, 3H);  $\delta_C$  (100 MHz, CDCl<sub>3</sub>) 209.7, 208.3, 207.5 (two signals), 141.1, 116.8, 71.9, 67.1, 41.2, 36.2, 35.7, 27.2 (two signals), 27.0, 26.3, 21.9, 18.8; HRMS (ESI) Found:  $[M+H]^+$ , 293.1736. C<sub>17</sub>H<sub>24</sub>O<sub>4</sub> requires  $[M+H]^+$ , 293.1747.



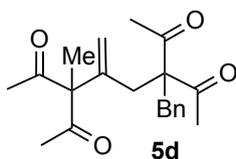
**3-(3-(2-Acetyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)prop-1-en-2-yl)-3-methylpentane-2,4-dione (5b):**

Carbonate **3** (23.5 mg, 0.12 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (5.5 mg, 0.006 mmol), DPEphos (6.5 mg, 0.012 mmol) and 2-acetyl-1-tetralone (26.7 mg, 0.12 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5b** and **5g** in a 14:1 ratio (34.8 mg, corresponding to 32.3 mg of **5b**, 79%, *r.r.* > 19:1) as a red solid. R<sub>F</sub> 0.33 [Petrol:EtOAc 4:1]; m.p 82-84 °C;  $\nu_{\max}$  (film)/cm<sup>-1</sup> 2976, 2931, 1702, 1674;  $\delta_{\text{H}}$  (400 MHz, CDCl<sub>3</sub>) 8.01 (dd, *J* = 7.9, 1.1 Hz, 1H), 7.47 (td, *J* = 7.5, 1.4 Hz, 1H), 7.30 (t, *J* = 8.2 Hz, 1H), 7.20 (d, *J* = 7.8 Hz, 1H), 5.04 (q, *J* = 1.2 Hz, 1H), 4.98 (q, *J* = 1.2 Hz, 1H), 3.12-3.01 (m, 1H), 2.92 (dt, *J* = 17.4, 5.0 Hz, 1H), 2.75 (dt, *J* = 17.1, 1.4 Hz, 1H), 2.56 (dt, *J* = 14.0, 5.0 Hz, 1H), 2.47 (dt, *J* = 17.2, 1.2 Hz, 1H), 2.38-2.26 (m, 1H) 2.20 (s, 3H), 2.16 (s, 3H), 2.16 (s, 3H), 1.54 (s, 3H);  $\delta_{\text{C}}$  (100 MHz, CDCl<sub>3</sub>) 207.2, 207.1, 206.8, 197.1, 143.3, 141.3, 134.0, 131.9, 128.8, 127.9, 126.8, 117.5, 72.0, 63.5, 36.0, 28.9, 27.2 (two signals), 27.1, 25.7, 18.7; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 363.1551. C<sub>21</sub>H<sub>24</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 363.1554.



**3,6-Diacetyl-6-allyl-3-methyl-4-methyleneoctane-2,7-dione (5c):**

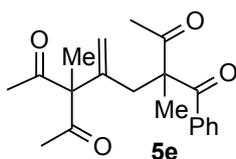
Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4c** (33.6 mg, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5c** and **5g** in a 9.3:1 ratio (55 mg, corresponding to 49.4 mg of **5c**, 70%, *r.r.* > 19:1) as a pale yellow solid. R<sub>F</sub> 0.33 [Petrol:EtOAc 4:1]; m.p. 64-66 °C;  $\nu_{\max}$  (film)/cm<sup>-1</sup> 2981, 2926, 1694, 1638;  $\delta_{\text{H}}$  (400 MHz, CDCl<sub>3</sub>) 5.50-5.38 (m, 1H), 5.11-5.04 (m, 2H), 4.97 (q, *J* = 1.6 Hz, 1H), 4.87 (q, *J* = 1.8 Hz, 1H), 2.82 (dt, *J* = 7.3, 1.3 Hz, 2H), 2.57 (t, *J* = 1.8 Hz, 2H), 2.16 (s, 6H), 2.14 (s, 6H), 1.56 (s, 3H);  $\delta_{\text{C}}$  (100 MHz, CDCl<sub>3</sub>) 207.0, 206.2, 141.9, 132.0, 119.4, 115.3, 71.9, 69.6, 35.5, 32.5, 27.1, 26.8, 18.9; HRMS (ESI) Found: [M+H]<sup>+</sup>, 293.1736. C<sub>17</sub>H<sub>24</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 293.1747.



**3,6-Diacetyl-6-benzyl-3-methyl-4-methyleneoctane-2,7-dione (5d):**

Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4d** (44.6 mg, 0.24 mmol) were

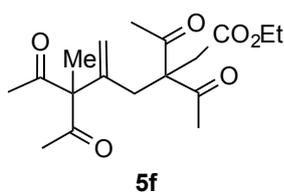
added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5d** (60 mg, 73%, *r.r.* > 19:1) as a yellow oil. R<sub>F</sub> 0.38 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3386, 2924, 2338, 1695, 1638; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 7.25-7.19 (m, 3H), 6.97-6.91 (m, 2H), 5.02 (q, *J* = 1.8 Hz, 1H), 4.98 (q, *J* = 1.5 Hz, 1H), 3.40 (s, 2H), 2.44 (t, *J* = 1.7 Hz, 2H), 2.20 (s, 6H), 2.10 (s, 6H), 1.40 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.9, 206.4, 142.1, 135.9, 129.5, 128.4, 127.2, 115.4, 71.8, 70.3, 37.4, 32.7, 27.3, 27.0, 18.6; HRMS (ESI) Found: [M+H]<sup>+</sup>, 343.1888. C<sub>21</sub>H<sub>26</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 343.1904.



**3-Acetyl-6-benzoyl-3,6-dimethyl-4-methyleneoctane-2,7-dione (5e):**

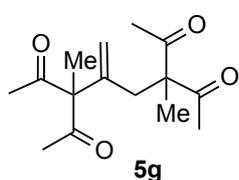
Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4e** (42.3 mg, 0.24 mmol) were

added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5e** and **5g** in a 13:1 ratio (46 mg, corresponding to 42.7 mg of **5e**, 54%, *r.r.* > 19:1) as a red oil. R<sub>F</sub> 0.31 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2987, 2928, 1762, 1674; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 7.68-7.64 (m, 2H), 7.50 (tt, *J* = 7.4, 2.0 Hz, 1H), 7.41-7.35 (m, 2H), 5.02 (q, *J* = 1.3 Hz, 1H), 4.93 (q, *J* = 1.2 Hz, 1H), 2.80 (dt, *J* = 18.3, 1.6 Hz, 1H), 2.70 (dt *J* = 18.3, 1.1 Hz, 1H), 2.13 (s, 3H), 2.04 (s, 3H), 1.88 (s, 3H), 1.58 (s, 3H), 1.40 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.1, 206.9 (two signals), 200.1, 141.6, 136.4, 132.9, 128.6, 128.5, 116.7, 72.2, 64.6, 36.8, 26.8, 26.4, 19.7, 18.5; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 351.1556. C<sub>20</sub>H<sub>24</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 351.1567.



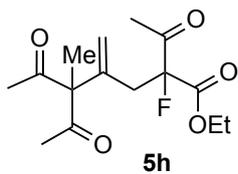
**Ethyl 3,3,6-triacetyl-6-methyl-5-methylene-7-oxooctanoate (5f):**

Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4f** (44.6 mg, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4 Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5f**, homocoupled **4f** and **5g** in a 11:1.2:1 ratio (59 mg, corresponding to 48.4 mg of **5f**, 60%, *r.r.* > 19:1) as an orange oil. R<sub>F</sub> 0.38 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2992, 2967, 1700, 1678; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.97 (q, *J* = 1.5 Hz, 1H), 4.77 (q, *J* = 1.7 Hz, 1H), 4.11 (q, *J* = 6.9 Hz, 2H), 3.26 (s, 2H), 2.82 (t, *J* = 1.7 Hz, 2H), 2.16 (s, 6H), 2.15 (s, 6H), 1.57 (s, 3H), 1.23 (t, *J* = 7.2 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.7, 204.9, 171.2, 142.4, 115.3, 71.9, 68.5, 61.0, 35.6, 33.2, 27.0, 26.0, 18.8, 14.0; HRMS (ESI) Found: [M+H]<sup>+</sup>, 339.1789. C<sub>18</sub>H<sub>26</sub>O<sub>6</sub> requires [M+H]<sup>+</sup>, 339.1802.



**3,6-Diacetyl-3,6-dimethyl-4-methyleneoctane-2,7-dione (5g):**

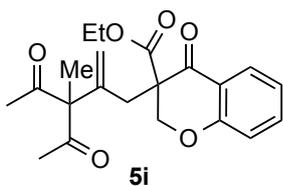
Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11.0 mg, 0.012 mmol), DPEphos (13.1 mg, 0.020 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5g** (47 mg, 74%) as a yellow solid. R<sub>F</sub> 0.42 [Petrol:EtOAc 4:1]; m.p. 72-74 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3386, 2909, 1698, 1652, 1426; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.99 (q, *J* = 1.4 Hz, 1H), 4.83 (q, *J* = 1.3 Hz, 1H), 2.56 (t, *J* = 2.5 Hz, 2H), 2.15 (s, 6H), 2.13 (s, 6H), 1.55 (s, 3H), 1.42 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.0 (two signals), 141.9, 115.7, 72.0, 66.0, 36.0, 27.1, 26.3, 18.8, 18.2; HRMS (ESI) Found: [M+H]<sup>+</sup>, 267.1578. C<sub>15</sub>H<sub>22</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 267.1591.



**Ethyl 2,5-diacetyl-2-fluoro-5-methyl-4-methylene-6-oxoheptanoate**

**(5h):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and ethyl-2-fluoroacetoacetate (30 μL, 0.24 mmol) were added to a dried tube under argon. The tube

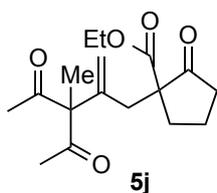
was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5h** (40 mg, 55%, *r.r.* > 19:1) as a yellow oil. R<sub>F</sub> 0.39 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2987, 2933, 2341, 1736, 1762, 1717; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 5.37 (s, 1H), 5.07 (s, 1H), 4.29-4.20 (m, 2H), 2.84 (quint, *J* = 28.2 Hz, 2H), 2.30 (d, *J* = 5.0 Hz, 3H), 2.15 (s, 6H), 1.52 (s, 3H), 1.28 (t, *J* = 7.0 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.6, 201.0 (d, *J* = 27.5 Hz), 165.6 (d, *J* = 25.4 Hz), 139.8, 118.8, 99.8 (d, *J* = 197.1 Hz), 71.7, 62.9, 35.1 (d, *J* = 20.0 Hz), 27.0, 26.9, 25.5, 18.7, 13.9; HRMS (ESI) Found: [M+H]<sup>+</sup>, 301.1451. C<sub>15</sub>H<sub>21</sub>FO<sub>5</sub> requires [M+H]<sup>+</sup>, 301.1446.



**Ethyl 3-(3-acetyl-3-methyl-2-methylene-4-oxopentyl)-4-**

**oxochroman-3-carboxylate (5i):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4i** (53 mg, 0.24 mmol) were added to a dried tube under

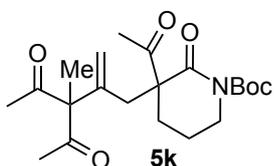
argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5i** (55 mg, 62%) as a brown oil. R<sub>F</sub> 0.42 [Petrol:EtOAc 5:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2982, 2117, 1695, 1607, 1480; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 7.88 (ddd, *J* = 7.9, 1.8, 0.4 Hz, 1H), 7.47 (ddd, *J* = 8.4, 1.8, 0.5 Hz, 1H), 7.05-7.00 (m, 1H), 6.95 (dd, *J* = 8.4, 0.6 Hz, 1H), 5.21 (q, *J* = 1.2 Hz, 1H), 5.09 (q, *J* = 0.5 Hz, 1H), 4.78 (d, *J* = 11.7 Hz, 1H), 4.67 (d, *J* = 12.1 Hz, 1H), 4.17 (qd, *J* = 7.2, 1.2 Hz, 2H), 2.69 (d, *J* = 17.0 Hz, 1H), 2.49 (d, *J* = 16.8 Hz, 1H), 2.16 (s, 3H), 2.15 (s, 3H), 1.57 (s, 3H), 1.18 (t, *J* = 6.9 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.2, 207.1, 189.6, 169.3, 160.8, 140.8, 136.2, 127.9, 121.8, 119.8, 118.5, 117.7, 71.9, 70.9, 62.0, 56.7, 31.8, 27.1, 27.0, 18.6, 13.8; HRMS (ESI) Found: [M+H]<sup>+</sup>, 373.1629. C<sub>21</sub>H<sub>24</sub>O<sub>6</sub> requires [M+H]<sup>+</sup>, 373.1646.



**Ethyl 1-(3-acetyl-3-methyl-2-methylene-4-oxopentyl)-2-**

**oxocyclopentanecarboxylate (5j):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.0120 mmol), DPEphos (13.1 mg, 0.024 mmol) and ethyl-2-oxocyclopentane carboxylate (35 μL, 0.24 mmol) were added to a

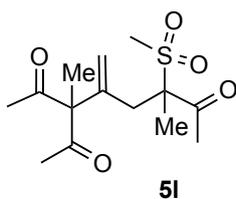
dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5j** (43 mg, 58%, *r.r.* > 19:1) as a yellow oil. R<sub>F</sub> 0.35 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2982, 2110, 1752, 1702; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.99 (q, *J* = 1.3 Hz, 1H), 4.98 (q, *J* = 1.4 Hz, 1H), 4.14 (dq, *J* = 7.2, 1.3 Hz, 2H), 2.78-2.69 (m, 2H), 2.44-2.24 (m, 2H), 2.16 (s, 3H), 2.14 (s, 3H), 2.10-1.88 (m, 4H), 1.51 (s, 3H), 1.21 (t, *J* = 7.0 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 213.5, 207.2 (two signals), 170.0, 142.6, 115.5, 71.5, 61.7, 59.6, 37.4, 36.3, 32.3, 27.3, 26.9, 19.6, 18.6, 13.9; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 331.1502. C<sub>17</sub>H<sub>24</sub>O<sub>5</sub> requires [M+Na]<sup>+</sup>, 331.1516.



**tert-Butyl-3-acetyl-3-(3-acetyl-3-methyl-2-methylene-4-**

**oxopiperidine-1-carboxylate (5k):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4k** (58 mg, 0.24 mmol) were added to a dried tube

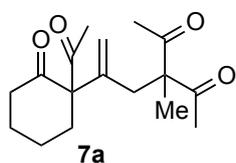
under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **5k** and homocoupled product of **4k** in a 17:1 ratio (81 mg, corresponding to 76 mg of **5k**, 81%, *r.r.* > 19:1); as a red oil. R<sub>F</sub> 0.30 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2980, 2933, 1768, 1714; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.98 (d, *J* = 0.7 Hz, 1H), 4.95 (q, *J* = 1.0 Hz, 1H), 3.65-3.53 (m, 2H), 2.78 (dt, *J* = 16.8, 1.6 Hz, 1H), 2.39-2.30 (m, 1H), 2.28-2.22 (m, 2H), 2.24 (s, 3H), 2.13 (s, 3H), 2.11 (s, 3H), 2.00-1.91 (m, 1H), 1.80-1.70 (m, 1H), 1.56 (s, 3H), 1.47 (s, 9H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.3, 207.1, 206.1, 171.6, 152.6, 141.3, 117.9, 83.1, 71.8, 62.5, 46.5, 37.4, 27.8, 27.3, 27.1, 26.9, 26.7, 20.6, 18.7; Found: [M+Na]<sup>+</sup>, 416.2029. C<sub>21</sub>H<sub>31</sub>NO<sub>6</sub> requires [M+Na]<sup>+</sup>, 416.2044.



### 3-Acetyl-3,6-dimethyl-4-methylene-6-(methylsulfonyl)octane-2,7-

**dione (5I):** Carbonate **3** (47.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and **4I** (36.0 mg, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a

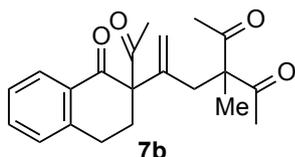
septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **5I** (39 mg, 54%, *r.r.* > 19:1) as a dark yellow solid. R<sub>F</sub> 0.15 [Petrol:EtOAc 4:1]; m.p. 89-92 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3006, 2931, 1701, 1641; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 5.05 (t, *J* = 1.2 Hz, 1H), 4.83 (q, *J* = 1.6 Hz, 1H), 3.20 (d, *J* = 15.8 Hz, 1H), 2.80 (s, 3H), 2.45 (s, 3H), 2.45 (dd, *J* = 16.4, 1.1 Hz, 1H), 2.17 (s, 3H), 2.13 (s, 3H), 1.75 (s, 3H), 1.60 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.6, 206.5, 206.0, 140.5, 118.0, 74.8, 71.8, 35.4, 33.6, 28.8, 27.1, 27.0, 18.9, 14.5; HRMS (ESI) Found: [M+H]<sup>+</sup>, 303.1250. C<sub>14</sub>H<sub>22</sub>O<sub>5</sub>S requires [M+H]<sup>+</sup>, 303.1261.



### 3-(2-(1-Acetyl-2-oxocyclohexyl)allyl)-3-methylpentane-2,4-dione

**(7a):** Carbonate **6a** (53.3 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under

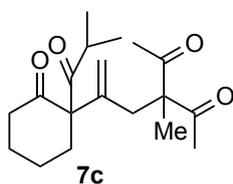
argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **7a** (49 mg, 70%, *r.r.* >19:1) as a yellow solid. R<sub>F</sub> 0.38 [Petrol:EtOAc 4:1]; m.p. 55-58 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3389, 2933, 1699; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.97 (q, *J* = 1.3 Hz, 1H), 4.84 (q, *J* = 1.4 Hz, 1H), 2.54 (t, *J* = 1.5 Hz, 2H), 2.49 (t, *J* = 7.0 Hz, 2H), 2.31-2.21 (m, 1H), 2.14 (s, 6H), 2.13 (s, 3H), 1.93-1.52 (m, 5H), 1.43 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 209.3, 207.3 (two signals), 207.1, 141.2, 116.4, 73.9, 65.8, 41.0, 36.5, 32.9, 27.1, 26.7, 26.3 (two signals), 21.8, 18.3; HRMS (ESI) Found: [M+H]<sup>+</sup>, 293.1749. C<sub>17</sub>H<sub>24</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 293.1782.



### 3-(2-(2-Acetyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)allyl)-3-

**methylpentane-2,4-dione (7b):** Carbonate **6b** (64.8 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were

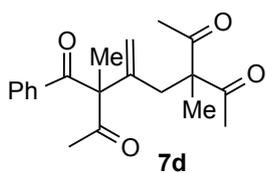
added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **7b** (58 mg, 71% yield, *r.r.* > 19:1) as a yellow oil. R<sub>F</sub> 0.34 (4:1 Petrol:EtOAc); ν<sub>max</sub> (film)/cm<sup>-1</sup> 2929, 1695, 1599; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 8.03 (dd, *J* = 8.0, 1.2 Hz, 1H), 7.47 (td, *J* = 7.4, 1.5 Hz, 1H), 7.31 (tt, *J* = 8.0, 0.5 Hz, 1H), 7.20 (d, *J* = 7.9 Hz, 1H), 4.88 (q, *J* = 1.2 Hz, 1H), 4.79 (q, *J* = 1.7 Hz, 1H), 3.01-2.88 (m, 2H), 2.81 (dt, *J* = 18.4, 2.0 Hz, 1H), 2.63-2.44 (m, 3H), 2.28 (s, 3H), 2.15 (s, 3H), 2.14 (s, 3H), 1.47 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.9, 206.8, 206.0, 196.4, 142.9, 140.5, 133.8, 132.1, 128.6, 127.8, 127.0, 116.9, 70.4, 66.1, 36.5, 29.3, 28.3, 26.3, 25.8, 18.1; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 363.1568. C<sub>21</sub>H<sub>24</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 363.1567.



### 3-(2-(1-Isobutyryl-2-oxocyclohexyl)allyl)-3-methylpentane-2,4-

**dione (7c):** Carbonate **6c** (60.1 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under

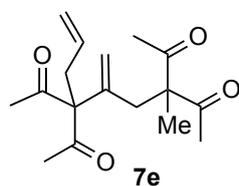
argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded product **7c** (47 mg, 61%, *r.r.* > 19:1) as a yellow solid. R<sub>F</sub> 0.35 [4:1 Pet:EtOAc]; m.p. 82-84 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2968, 2935, 1694, 1636; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.93 (q, *J* = 1.5 Hz, 1H), 4.87 (q, *J* = 1.5 Hz, 1H), 2.92 (quint, *J* = 7.0 Hz, 1H), 2.64 (dt, *J* = 18.5, 1.6 Hz, 1H), 2.56-2.43 (m, 3H), 2.33-2.22 (m, 2H), 2.17 (s, 3H), 2.17 (s, 3H), 1.92-1.81 (m, 2H), 1.77-1.67 (m, 2H), 1.48 (s, 3H), 1.10 (d, *J* = 6.6 Hz, 3H), 1.06 (d, *J* = 6.7 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 213.7, 209.9, 207.4, 207.3, 140.6, 116.2, 74.5, 66.0, 41.1, 37.2, 36.5, 32.4, 26.9, 26.4 (two signals), 21.8, 20.9, 20.5, 18.3; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 343.1872. C<sub>19</sub>H<sub>28</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 343.1880.



### 6-Acetyl-3-benzoyl-3,6-dimethyl-4-methyleneoctane-2,7-dione

**(7d):** Carbonate **6d** (61.9 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under

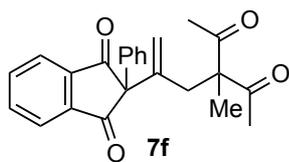
argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **7d** and homocoupled **4e** in a 5.1:1 ratio (60 mg, corresponding to 49.5 mg of **7d**, 63%, *r.r.* > 19:1) as a red solid. R<sub>F</sub> 0.26 [Petrol:EtOAc 4:1]; m.p. 73-76 °C; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2976, 2928, 1717, 1698, 1667; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 7.83-7.79 (m, 2H), 7.50 (tt, *J* = 7.3, 1.9 Hz, 1H), 7.41-7.35 (m, 2H), 5.13 (q, *J* = 1.3 Hz, 1H), 4.87 (q, *J* = 1.6 Hz, 1H), 2.80 (dt, *J* = 18.3, 1.9 Hz, 1H), 2.61 (dt, *J* = 18.3, 1.6 Hz, 1H), 2.18 (s, 3H), 2.14 (s, 3H), 2.12 (s, 3H), 1.68 (s, 3H), 1.43 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.2 (two signals), 206.2, 200.7, 143.0, 135.7, 132.9, 129.3, 128.3, 115.8, 70.3, 65.9, 36.7, 27.6, 26.3, 26.2, 20.9, 18.2; HRMS (ESI) Found: [M+H]<sup>+</sup>, 329.1759. C<sub>20</sub>H<sub>24</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 329.1747.



### 3,6-Diacetyl-3-allyl-6-methyl-4-methyleneoctane-2,7-dione (7e):

Carbonate **6e** (53.2 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under argon. The tube was

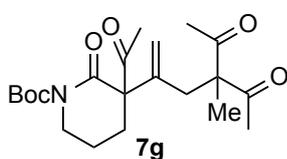
fitted with a septum and purged further with argon. 1,4 Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded product **7e** (32 mg, 46%, *r.r.* 10:1) as a brown oil. R<sub>F</sub> 0.34 [Pet:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3386, 2924, 2835, 1694; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 5.67-5.55 (m, 1H), 5.16-5.04 (m, 3H), 4.90 (q, *J* = 1.8 Hz, 1H), 2.80 (dt, *J* = 7.0, 1.5 Hz, 2H), 2.57 (t, *J* = 1.5 Hz, 2H), 2.17 (s, 6H), 2.13 (s, 6H), 1.42 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.8, 205.8, 140.6, 132.9, 118.8, 117.2, 76.8, 65.9, 36.0, 35.7, 27.8, 26.2, 18.2; HRMS (ESI) Found: [M+H]<sup>+</sup> 293.1741, C<sub>17</sub>H<sub>24</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 293.1747.



**2-(4-Acetyl-4-methyl-5-oxohex-1-en-2-yl)-2-phenyl-1H-indene-**

**1,3(2H)-dione (7f):** Carbonate **6f** (73.0 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.240 mmol) were added to a

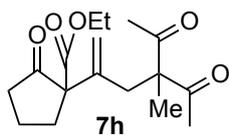
dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded **7f** (66 mg, 74%) as an orange oil. R<sub>F</sub> 0.33 [Pet:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2102, 1740, 1699, 1591; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 8.08-8.02 (m, 2H), 7.91-7.84 (m, 2H), 7.45-7.39 (m, 2H), 7.36-7.27 (m, 3H), 4.96 (q, *J* = 1.4 Hz, 1H), 4.92 (q, *J* = 1.2 Hz, 1H), 2.74 (t, *J* = 1.5 Hz, 2H), 2.08 (s, 6H), 1.42 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.0, 199.0, 141.6, 141.2, 136.1, 134.6, 128.8, 128.4, 128.1, 123.9, 118.7, 69.8, 66.3, 36.3, 26.1, 17.8; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 397.1397. C<sub>24</sub>H<sub>22</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 397.1410.



**tert-Butyl 3-acetyl-3-(4-acetyl-4-methyl-5-oxohex-1-en-2-yl)-2-**

**oxopiperidine-1-carboxylate (7g):** Carbonate **6g** (77.6 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were

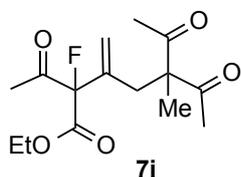
added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded product **7g** (50 mg, 53%, *r.r.* > 19:1) as a red oil. R<sub>F</sub> 0.31 (4:1 Pet:EtOAc); ν<sub>max</sub> (film)/cm<sup>-1</sup> 2978, 2933, 1764, 1714, 1695, 1457; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.98 (q, *J* = 1.2 Hz, 1H), 4.78 (q, *J* = 1.7 Hz, 1H), 3.67-3.53 (m, 2H), 2.82 (dt, *J* = 1.82, 1.8 Hz, 1H), 2.49 (dt, *J* = 18.4, 1.9 Hz, 1H), 2.39-2.29 (m, 1H), 2.27 (s, 3H), 2.15 (s, 3H), 2.13 (s, 3H), 2.07-1.99 (m, 1H), 1.83-1.74 (m, 2H), 1.49 (s, 9H), 1.46 (s, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 207.1, 206.8, 204.4, 170.6, 153.0, 142.0, 116.2, 83.3, 69.5, 66.2, 46.5, 36.1, 28.1 (two signals), 27.9, 26.4, 26.1, 19.6, 18.1; HRMS (ESI) Found: [M+Na]<sup>+</sup>, 416.2049. C<sub>21</sub>H<sub>31</sub>NO<sub>6</sub> requires [M+Na]<sup>+</sup>, 416.2044.



### Ethyl 1-(4-acetyl-4-methyl-5-oxohex-1-en-2-yl)-2-

**oxocyclopentanecarboxylate (7h):** Carbonate **6h** (57.2 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024

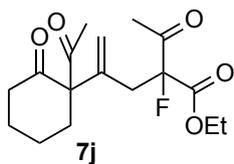
mmol) and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of **7h** and **5g** in a 17:1 ratio (45 mg, corresponding to 43 mg of **7h**, 58%, *r.r.* > 19:1) as a red oil. R<sub>F</sub> 0.36 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3015, 2935, 1716; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 4.99 (q, *J* = 1.2 Hz, 1H), 4.72 (q, *J* = 1.5 Hz, 1H), 4.17 (dq, *J* = 7.2, 0.8 Hz, 2H), 2.81 (dt, *J* = 18.2, 1.4 Hz, 1H), 2.66 (dt, *J* = 17.9, 1.6 Hz, 1H), 2.57-2.49 (m, 1H), 2.37-2.24 (m, 3H), 2.11 (s, 3H), 2.10 (s, 3H), 1.98-1.80 (m, 2H), 1.41 (s, 3H), 1.23 (t, *J* = 6.2 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 212.0, 207.1, 207.0, 170.2, 139.3, 114.8, 67.4, 66.2, 61.8, 37.7, 35.9, 33.2, 26.3, 26.1, 19.2, 17.8, 14.0; HRMS (ESI) Found: [M+H]<sup>+</sup>, 309.1699. C<sub>17</sub>H<sub>24</sub>O<sub>5</sub> requires [M+H]<sup>+</sup>, 309.1697.



### Ethyl 2,5-diacetyl-2-fluoro-5-methyl-3-methylene-6-oxoheptanoate

**(7i):** Carbonate **6i** (55.2 mg, 0.240 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol), and 3-methyl-2,4-pentanedione (28 μL, 0.24 mmol) were added to a dried tube under

argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded product **7i** (25 mg, 35%, *r.r.* > 19:1) as a colourless oil. R<sub>F</sub> 0.35 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2987, 2937, 1753, 1727, 1697; δ<sub>H</sub> (400 MHz, CDCl<sub>3</sub>) 5.33 (q, *J* = 0.7 Hz, 1H), 5.09 (sextet, *J* = 1.6 Hz, 1H), 4.30 (q, *J* = 7.1 Hz, 2H), 2.78 (s, 2H), 2.30 (d, *J* = 4.7 Hz, 3H), 2.12 (s, 6H), 1.38 (s, 3H), 1.31 (t, *J* = 6.9 Hz, 3H); δ<sub>C</sub> (100 MHz, CDCl<sub>3</sub>) 206.6, 206.5, 199.9 (d, *J* = 29.5 Hz), 165.1 (d, *J* = 26.0 Hz), 136.7 (d, *J* = 21.5 Hz), 119.1 (d, *J* = 8.4 Hz), 100.0 (d, *J* = 197.1 Hz), 66.2, 62.9, 34.4 (d, *J* = 4.1 Hz), 26.4 (two signals), 25.7, 17.9, 13.9; HRMS (ESI) Found: [M+H]<sup>+</sup>, 301.1448. C<sub>15</sub>H<sub>21</sub>FO<sub>5</sub> requires [M+H]<sup>+</sup>, 301.1446.

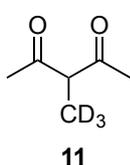


### Ethyl 2-acetyl-4-(1-acetyl-2-oxocyclohexyl)-2-fluoropent-4-enoate

**(7j)**: Carbonate **6a** (53.3 mg, 0.24 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and ethyl 2-fluoroacetoacetate (30 μL, 0.24 mmol) were added to a dried tube under argon. The tube

was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of diastereoisomers of **7j** in a 1:1 ratio (49 mg, 63%, *r.r.* > 19:1) as a yellow oil. R<sub>F</sub> 0.37 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2944, 2870, 1751, 1699, 1640; δ<sub>H</sub> (400 MHz, diastereoisomer **7jb** annotated by an asterisk, CDCl<sub>3</sub>) 5.37 (s, 1H and 1H\*), 5.02 (d, *J* = 6.3 Hz, 1H and 1H\*), 4.23 (q, *J* = 7.0 Hz, 2H and 2H\*), 2.96-2.68 (m, 2H and 2H\*), 2.58-2.35 (m, 2H and 2H\*), 2.30 (dd, *J* = 8.9, 1.4 Hz, 3H), 2.27-2.21 (m, 1H and 1H\*), 2.13 (s, 3H and 3H\*), 2.11-2.01 (m, 1H and 1H\*), 1.85-1.52 (m, 4H and 4H\*), 1.26 (t, *J* = 7.2, Hz, 3H), 1.25 (t, *J* = 7.2 Hz, 3H\*); δ<sub>C</sub> (100 MHz, diastereoisomer **7jb** annotated by an asterisk, CDCl<sub>3</sub>) 208.9, 208.7\*, 206.7, 206.5\*, 201.2 (d, *J* = 28.8 Hz), 200.9\* (d, *J* = 28.8 Hz), 165.7 (d, *J* = 25.3 Hz), 165.7\* (d, *J* = 25.5 Hz), 139.2 (d, *J* = 22.4 Hz), 139.2\* (d, *J* = 22.3 Hz), 119.5 (d *J* = 3.4 Hz), 118.8\* (d, *J* = 3.8 Hz), 99.8 (d, *J* = 201.5 Hz), 99.7\* (d, *J* = 201.1 Hz), 73.8\*, 73.4, 62.8, 62.8\*, 40.8\*, 40.8, 35.4 (d, *J* = 20.0 Hz), 35.3\* (d, *J* = 20.0 Hz), 33.2, 33.2\*, 27.0, 26.9, 26.9\*, 26.7\*, 25.6, 25.4\*, 21.7, 21.7\*, 13.9, 13.8\*; HRMS (ESI) Found: [M+H]<sup>+</sup>, 327.1604. C<sub>17</sub>H<sub>23</sub>FO<sub>5</sub> requires [M+H]<sup>+</sup>, 327.1602.

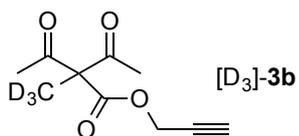
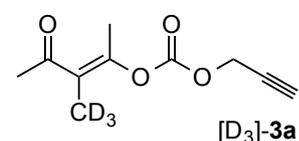
### 3.4. Mechanistic Studies.



**d<sub>3</sub>-3-Methyl 2,4-pentanedione (11)**: To a solution of acetylacetone (1.02 mL, 10.0 mmol) in acetone (30 mL) was added potassium carbonate (1.38 g, 10.0 mmol). The mixture was stirred at room temperature for 15 minutes then d<sub>3</sub>-iodomethane (0.747 mL, 12.0 mmol) was added dropwise and the reaction

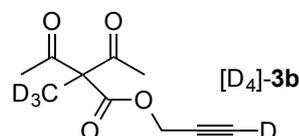
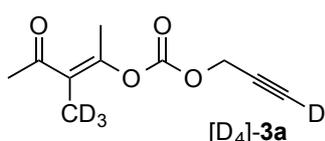
was refluxed at 65 °C for 18 hours. The reaction was quenched with aq. HCl (1N, 30 mL). The mixture was extracted with EtOAc (3 x 30 mL). The combined organic phases were washed with brine (30 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 19:1] afforded **11** (200 mg, 17%) as a green liquid. Analysis by <sup>1</sup>H NMR spectroscopy indicated 98% deuterium incorporation. R<sub>F</sub> 0.55 [Petrol:EtOAc 4:1]; ν<sub>max</sub>(film)/cm<sup>-1</sup> 2240, 1721, 1700, 1611; δ<sub>H</sub> (400 MHz, 1.4:1 keto:enol tautomer, enol

tautomer is shown by an asterisk, CDCl<sub>3</sub>) 16.39\* (s, 1H), 3.62 (s, 1H), 2.16 (s, 6H), 2.08 (s, 6H\*); δ<sub>C</sub> (100 MHz, 1.4:1 keto:enol tautomer, enol shown by an asterisk, CDCl<sub>3</sub>) 205.1, 190.4\*, 104.6\*, 61.8, 28.6, 23.3\*, 12.7-11.5 (m).



***d*<sub>3</sub>-3-Methyl-4-oxopent-2-en-2-yl prop-2-ynyl carbonate ([D<sub>3</sub>]-3a)** and ***d*<sub>3</sub>-prop-2-ynyl 2-acetyl-2-methyl-3-oxobutanoate ([D<sub>3</sub>]-3b):**

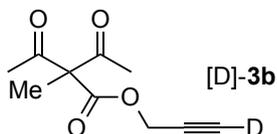
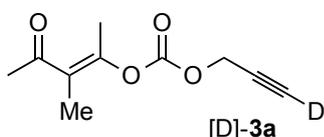
A suspension of sodium hydride (60 wt%, 56 mg, 1.40 mmol) in THF (15 mL) was cooled to 0 °C. A solution of **11** (150 mg, 1.28 mmol) in THF (3 mL) was added dropwise and was stirred at 0 °C for 10 minutes. Propargyl chloroformate (136 μL, 1.40 mmol) was added dropwise and the mixture was stirred at room temperature for 1 hour. The reaction was quenched by addition of aq. HCl (1 N, 10 mL) and the mixture was extracted with EtOAc (3 x 15 mL). The combined organic phases were washed with brine (15 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of carbonate [D<sub>3</sub>]-3a and ester [D<sub>3</sub>]-3b in a 5:1 ratio (120 mg, 47 %) as a colourless oil. R<sub>F</sub> 0.21 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3285, 2130, 1757, 1668, 1647; δ<sub>H</sub> (400 MHz, resonances due to [D<sub>3</sub>]-3a quoted, CDCl<sub>3</sub>) 4.80 (d, *J* = 2.4 Hz, 2H), 2.57 (t, *J* = 2.4 Hz, 1H), 2.31 (s, 3H), 2.09 (s, 3H); δ<sub>C</sub> (100 MHz, resonances due to [D<sub>3</sub>]-3a quoted, CDCl<sub>3</sub>) 199.1, 151.7, 150.6, 124.9, 76.4, 76.2, 56.0, 30.9, 18.0; HRMS (ESI) Found: [M+H]<sup>+</sup>, 200.1004. C<sub>10</sub>H<sub>9</sub>D<sub>3</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 200.0997.



***d*<sub>4</sub>-3-Methyl-4-oxopent-2-en-2-yl prop-2-ynyl carbonate ([D<sub>4</sub>]-3a)** and ***d*<sub>4</sub>-prop-2-ynyl 2-acetyl-2-methyl-3-oxobutanoate ([D<sub>4</sub>]-3b):** According to a literature procedure,<sup>6</sup> to a solution of [D<sub>3</sub>]-3 (45.7 mg, 0.23 mmol) in acetonitrile (4 mL) was added potassium carbonate (95.5 mg, 0.69 mmol) at room temperature and the suspension was stirred for 30 minutes. Deuterium oxide

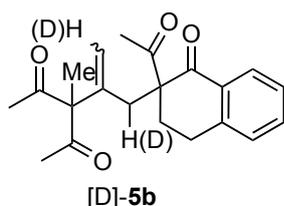
(0.61 mL) was added and the mixture was stirred at room temperature for 18 hours. The mixture was extracted with CH<sub>2</sub>Cl<sub>2</sub> (10 mL), dried (MgSO<sub>4</sub>) and concentrated *in vacuo* to afford an inseparable mixture of carbonate [D<sub>4</sub>]-3a and ester [D<sub>4</sub>]-3b in a 5:1 ratio (44.5 mg, 97%) as a colourless oil. Analysis by <sup>1</sup>H NMR spectroscopy indicated 96% deuterium incorporation. R<sub>F</sub> 0.21 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 3285, 2924, 2585, 1991, 1760, 1648; δ<sub>H</sub> (400 MHz, resonances due to [D<sub>4</sub>]-3a quoted, CDCl<sub>3</sub>); 4.79 (s, 2H), 2.30 (s, 3H), 2.08 (s, 3H); δ<sub>C</sub> (100 MHz, resonances due to [D<sub>4</sub>]-3a quoted, CDCl<sub>3</sub>) 199.0, 151.7, 150.5,

124.9, 76.3 (t,  $J = 12.6$  Hz), 75.9 (t,  $J = 8.3$  Hz), 56.0, 30.9, 17.9; HRMS (ESI) Found:  $[M+H]^+$  201.1064.  $C_{10}H_8D_4O_4$  requires  $[M+H]^+$ , 201.1059.



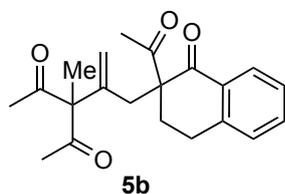
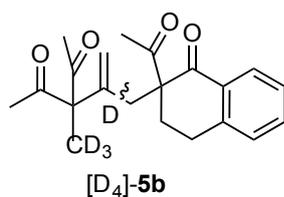
**$d_1$ -3-Methyl-4-oxopent-2-en-2-yl prop-2-ynyl carbonate ([D]-3a)** and  **$d_4$ -prop-2-ynyl 2-acetyl-2-methyl-3-oxobutanoate ([D<sub>4</sub>]-3b)**: According to a literature procedure,<sup>6</sup> to a solution of propargyl carbonate **3** (144 mg, 0.730 mmol) in MeCN (8 mL) was added solid potassium carbonate (311 mg, 2.25 mmol). The suspension was stirred at room temperature for 30 min.

Deuterium oxide (2 mL) was added via syringe and the solution was stirred at room temperature for 1 hour. The mixture was extracted with  $CH_2Cl_2$  (10 mL), dried ( $MgSO_4$ ) and concentrated *in vacuo* to afford an inseparable mixture of deuterated alkyne [D]-3a and ester [D]-3b in a 5.3:1 ratio (140 mg, 97%) as a pale yellow oil. Analysis by  $^1H$  NMR spectroscopy indicated 97% deuterium incorporation.  $R_F$  0.21 [Petrol:EtOAc 4:1];  $\nu_{max}$  (film)/ $cm^{-1}$  2950, 2584, 1990, 1757, 1709, 1653;  $\delta_H$  (400 MHz, resonances due to [D]-3a quoted,  $CDCl_3$ ) 4.74 (s, 2H), 2.24 (s, 3H), 2.03 (s, 3H), 1.77 (s, 3H);  $\delta_C$  (100 MHz, resonances due to [D]-3a quoted,  $CDCl_3$ ) 199.1, 151.7, 150.5, 125.0, 76.4 (t,  $J = 6.9$  Hz), 75.9 (t,  $J = 8.3$  Hz), 56.0, 30.9, 17.9, 14.0; HRMS (ESI) Found:  $[M+Na]^+$  220.0685.  $C_{10}H_{11}DO_4$  requires  $[M+Na]^+$ , 220.0691.



**$d_1$ -3-(3-(2-Acetyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)prop-1-en-2-yl)-3-methylpentane-2,4-dione ([D]-5b)**: [D]-3 (47.3 mg, 0.24),  $Pd_2(dba)_3$  (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 2-acetyl-1-tetralone (53.2 mg, 0.24 mmol) were added to

a dried tube under argon. The tube was fitted with a septum and purged further with argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded an inseparable mixture of [D]-5b and the homocoupled product of 2-acetyl-1-tetralone (**4b**) in a 10:1 ratio (60 mg, corresponding to 54 mg of [D]-5b, 66%, *r.r.* > 19:1) as a red oil.  $^1H$  NMR analysis indicated 35% deuterium incorporation at the vinylic position and 29% deuterium incorporation at the allylic position.  $R_F$  0.41 [Petrol:EtOAc 4:1];  $\nu_{max}$  (film)/ $cm^{-1}$  2935, 1699, 1671, 1599; HRMS (ESI) Found:  $[M+H]^+$ , 342.1805.  $C_{21}H_{23}DO_4$  requires  $[M+H]^+$ , 342.1810.



***d*<sub>4</sub>-3-(3-(2-Acetyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)prop-1-en-2-yl)-3-methylpentane-2,4-dione ([D<sub>4</sub>]-**5b**) and 3-(3-(2-Acetyl-1-oxo-1,2,3,4-tetrahydronaphthalen-2-yl)prop-1-en-2-yl)-**

**3-methylpentane-2,4-dione (**5b**):** Carbonate **3** (23.5mg, 0.12 mmol), carbonate [D<sub>4</sub>]-**3** (24.0 mg, 0.12 mmol), Pd<sub>2</sub>(dba)<sub>3</sub> (11 mg, 0.012 mmol), DPEphos (13.1 mg, 0.024 mmol) and 2-acetyl-1-tetralone (53.2 mg, 0.24 mmol) were added to a dried tube under argon. The tube was fitted with a septum and purged further with

argon. 1,4-Dioxane (1.5 mL) was added and the sealed tube was added to an oil bath preheated to 80 °C. The mixture was stirred at 80 °C for 2 hours, then cooled to room temperature and concentrated *in vacuo*. Flash column chromatography [Petrol:EtOAc 4:1] afforded a mixture of **5b** and [D<sub>4</sub>]-**5b** (57 mg, 69 %, *r.r.* >19:1) as a red oil. R<sub>F</sub> 0.41 [Petrol:EtOAc 4:1]; ν<sub>max</sub> (film)/cm<sup>-1</sup> 2927, 1699, 1671, 1599; HRMS analysis indicated the presence **5b** and [D<sub>4</sub>]-**5b** only. HRMS (ESI) **5b**: Found: [M+Na]<sup>+</sup> 363.1559. C<sub>21</sub>H<sub>24</sub>O<sub>4</sub> requires [M+H]<sup>+</sup>, 363.1567; [D<sub>4</sub>]-**5b**: Found: [M+Na]<sup>+</sup>, 367.1813. C<sub>21</sub>H<sub>20</sub>D<sub>4</sub>O<sub>4</sub> requires [M+Na]<sup>+</sup>, 367.1818.

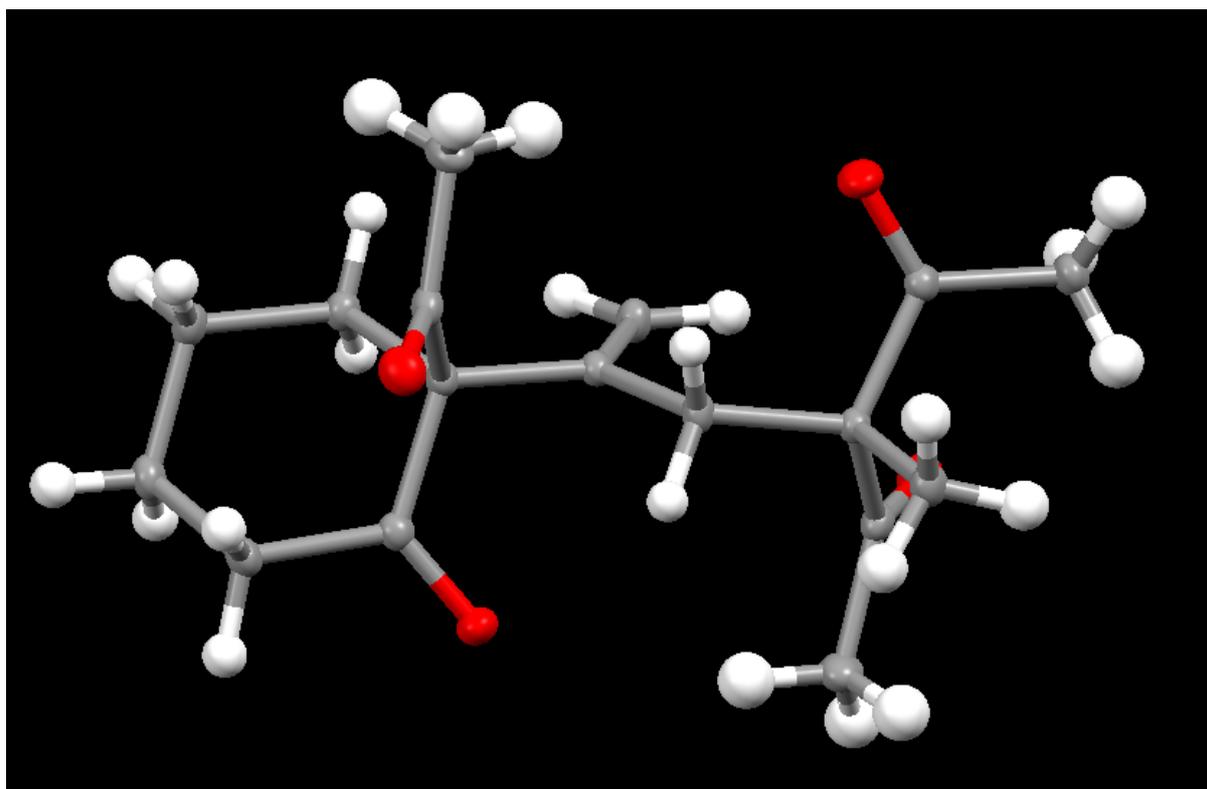
#### 4. References.

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- 2) Schröder, S. P.; Taylor, N. J.; Jackson, P.; Franckevičius, V. *Org. Lett.* **2013**, *15*, 3778.
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- 5) Ding, X.; Nguyen, T.; Williams, J. D.; Norton, P. P. *Tetrahedron. Lett.* **2014**, *55*, 7002.
- 6) Bew, S. P.; Hiatt-Gipson, G. D.; Lovell, J. A. Poullain, C. *Org. Lett.* **2012**, *14*, 456.

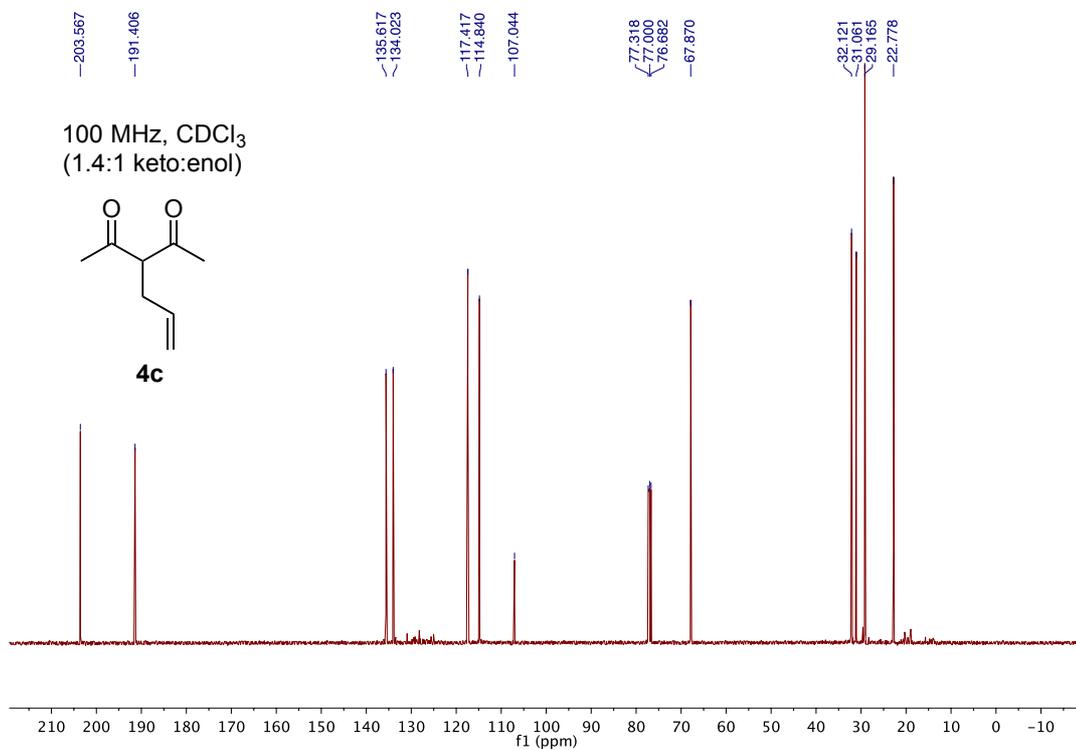
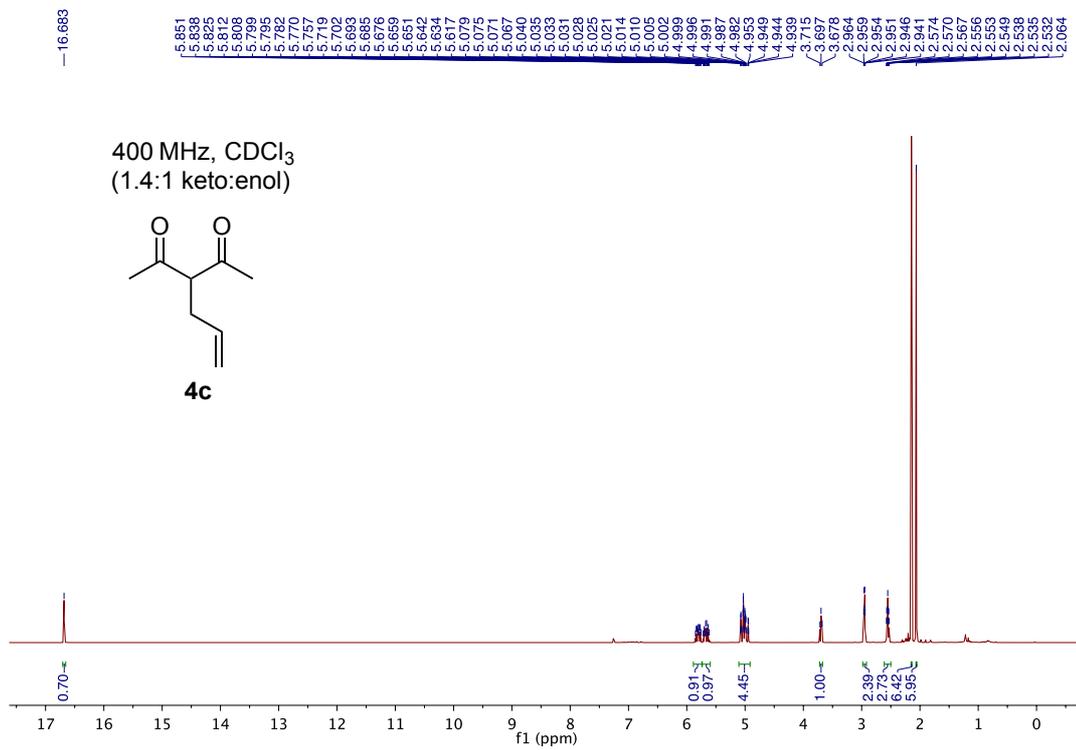
## 5. X-Ray Crystal Structure Data for 7a (CCDC 1411246).

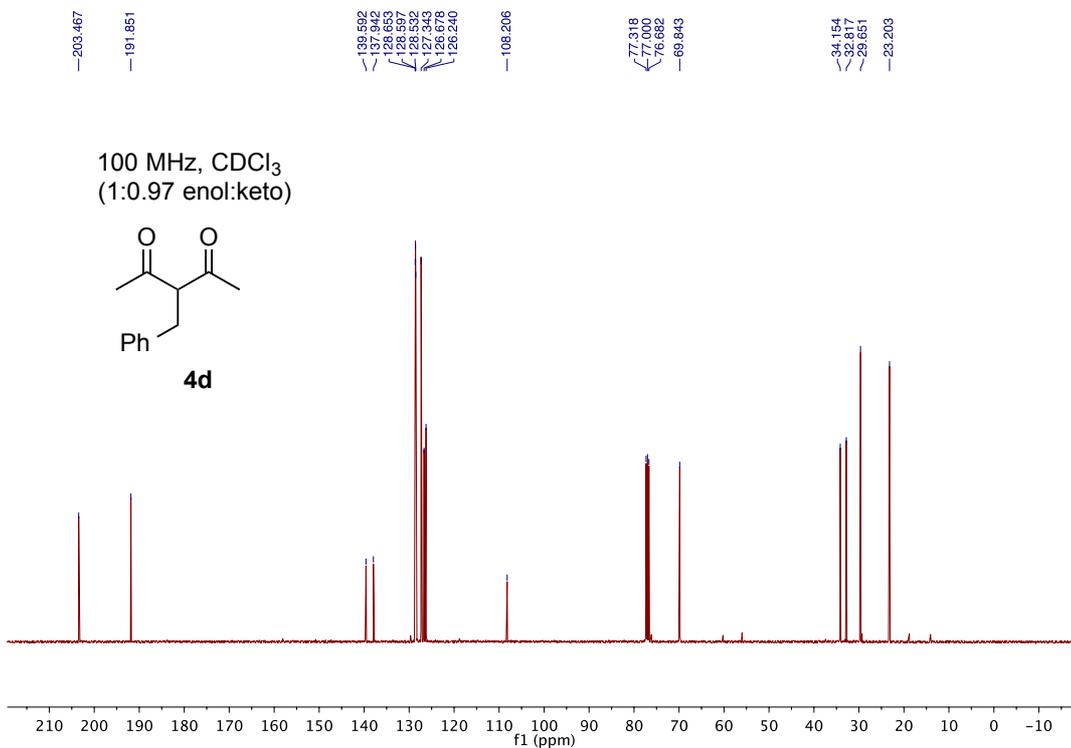
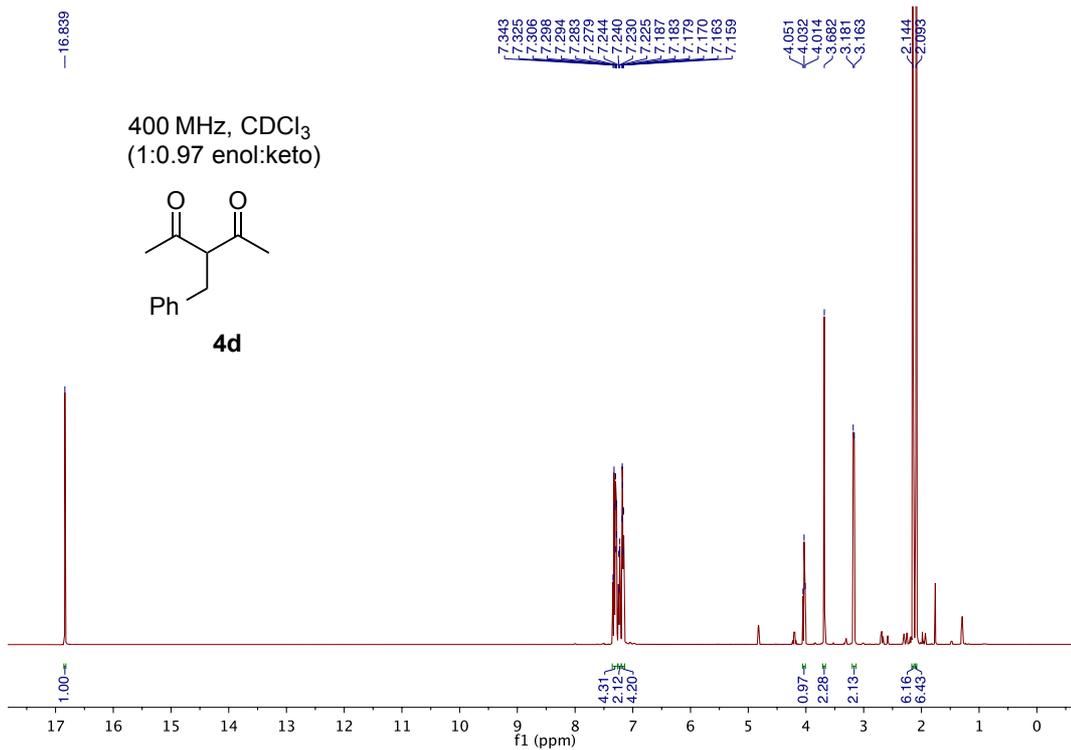
Identification code	<b>2015ncs0412a</b>	
Empirical formula	C <sub>17</sub> H <sub>24</sub> O <sub>4</sub>	
Formula weight	292.36	
Temperature	100(2) K	
Wavelength	0.6889 Å	
Crystal system	Monoclinic	
Space group	<i>P</i> 21/ <i>n</i>	
Unit cell dimensions	<i>a</i> = 6.0924(2) Å	$\alpha = 90^\circ$
	<i>b</i> = 27.0824(6) Å	$\beta = 97.770(2)^\circ$
	<i>c</i> = 9.3335(2) Å	$\gamma = 90^\circ$
Volume	1525.86(7) Å <sup>3</sup>	
<i>Z</i>	4	
Density (calculated)	1.273 Mg / m <sup>3</sup>	
Absorption coefficient	0.083 mm <sup>-1</sup>	
<i>F</i> (000)	632.0	
Crystal	Chip; colourless	
Crystal size	0.03 × 0.03 × 0.01 mm <sup>3</sup>	
$\theta$ range for data collection	2.256 – 31.788°	
Index ranges	-9 ≤ <i>h</i> ≤ 9, -40 ≤ <i>k</i> ≤ 41, -14 ≤ <i>l</i> ≤ 13	
Reflections collected	30947	
Independent reflections	5401 [ <i>R</i> <sub>int</sub> = 0.0605]	
Completeness to $\theta = 24.415^\circ$	99.7 %	
Absorption correction	Semi-empirical from equivalents	
Max. and min. transmission	1.00000 and 0.81133	
Refinement method	Full-matrix least-squares on <i>F</i> <sup>2</sup>	
Data / restraints / parameters	5401 / 0 / 194	
Goodness-of-fit on <i>F</i> <sup>2</sup>	1.035	
Final <i>R</i> indices [ <i>F</i> <sup>2</sup> > 2 $\sigma$ ( <i>F</i> <sup>2</sup> )]	<i>R</i> 1 = 0.0486, <i>wR</i> 2 = 0.1144	
<i>R</i> indices (all data)	<i>R</i> 1 = 0.0674, <i>wR</i> 2 = 0.1282	
Extinction coefficient	n/a	
Largest diff. peak and hole	0.464 and -0.347 e Å <sup>-3</sup>	

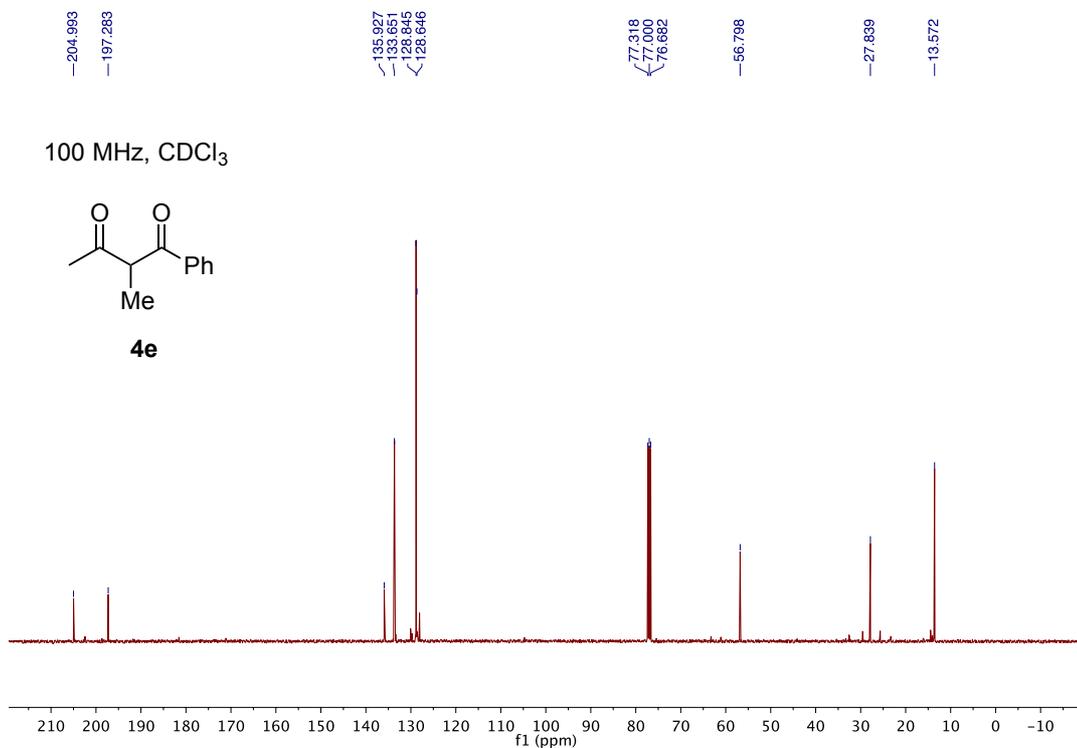
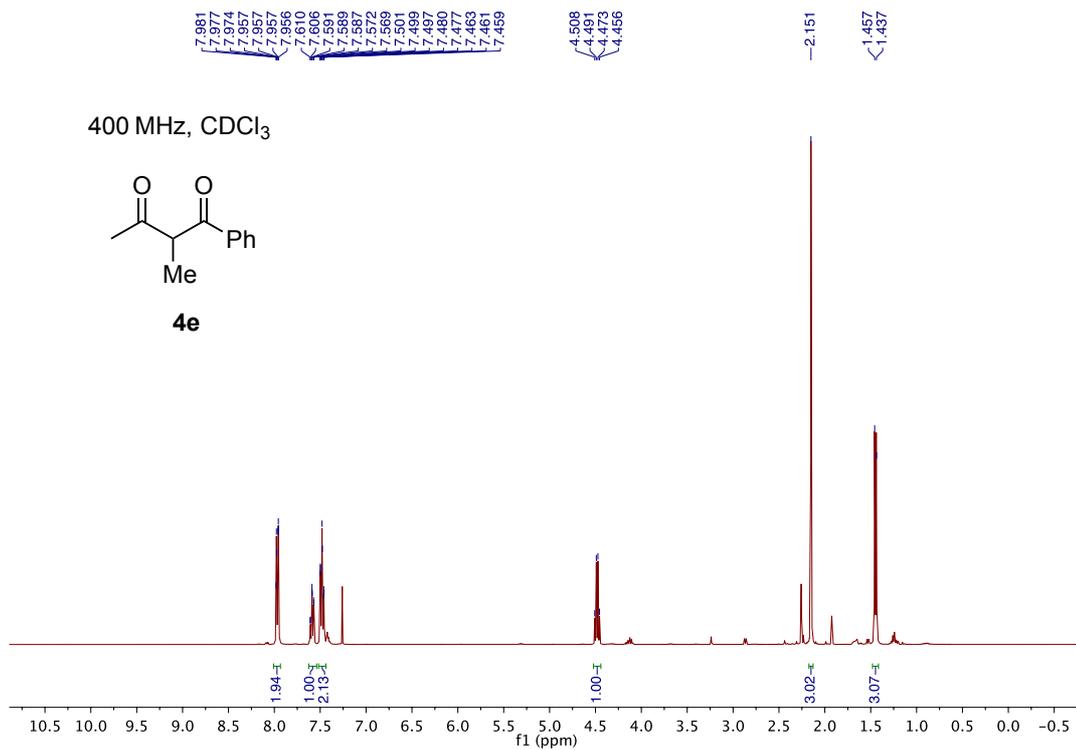
**Diffraction:** Beamline I19 situated on an undulator insertion device with a combination of double crystal monochromator, vertical and horizontal focussing mirrors and a series of beam slits (primary white beam and either side of the focussing mirrors). The experimental hutch (EH1) is equipped with a Crystal Logic 4-circle kappa geometry goniometer with a Rigaku Saturn 724 CCD detector and an Oxford Cryosystems Cryostream plus cryostat (80-500K). For conventional service crystallography the beamline operates at a typical energy of 18 keV (Zr K absorption edge) and a Rigaku ACTOR robotic sample changing system is available. **Cell determination and data collection:** *CrystalClear-SM Expert 2.0 r5* (Rigaku, 2010) **Data reduction and cell refinement & Absorption correction:** CrysAlisPRO 171.37.35 (Rigaku Oxford Diffraction 2015). **Structure solution:** SHELXST (G. M. Sheldrick, *Acta Cryst.* (2008) **A64** 112–122). **Structure refinement:** SHELXL97 (G. M. Sheldrick (1997), University of Göttingen, Germany). **Graphics:** Mercury 3.5.1 (CCDC 2014). **Publication material:** WinGX: Farrugia, L. J. *J. Appl. Cryst.* 2012, **45**, 849-854.

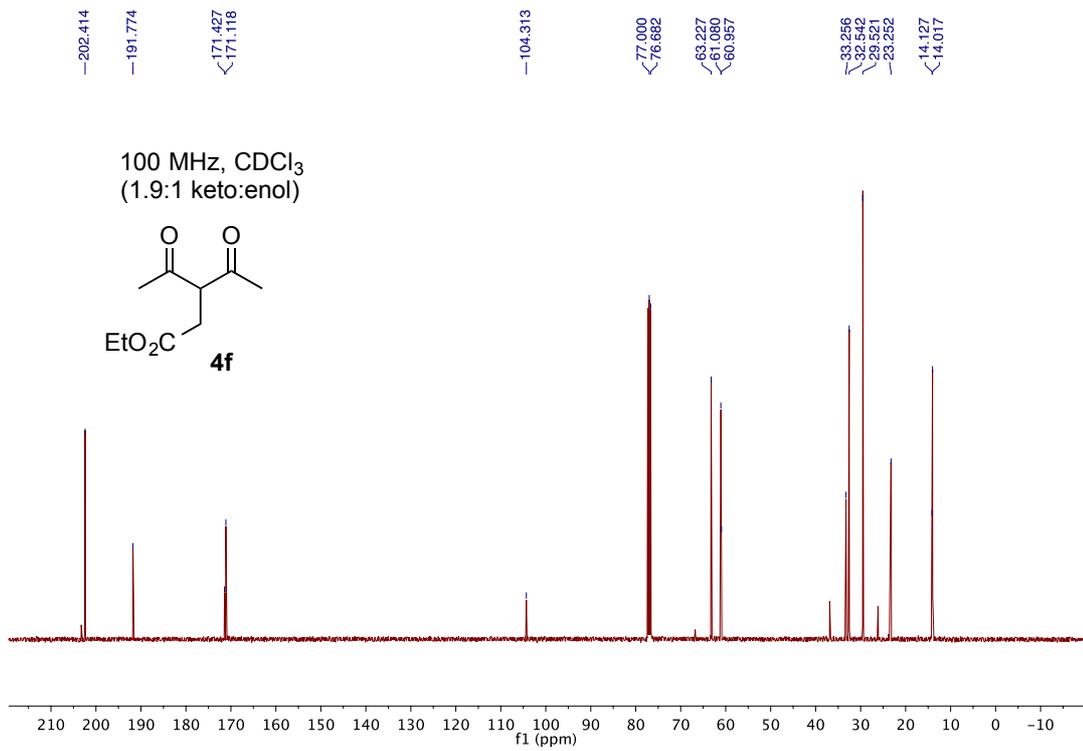
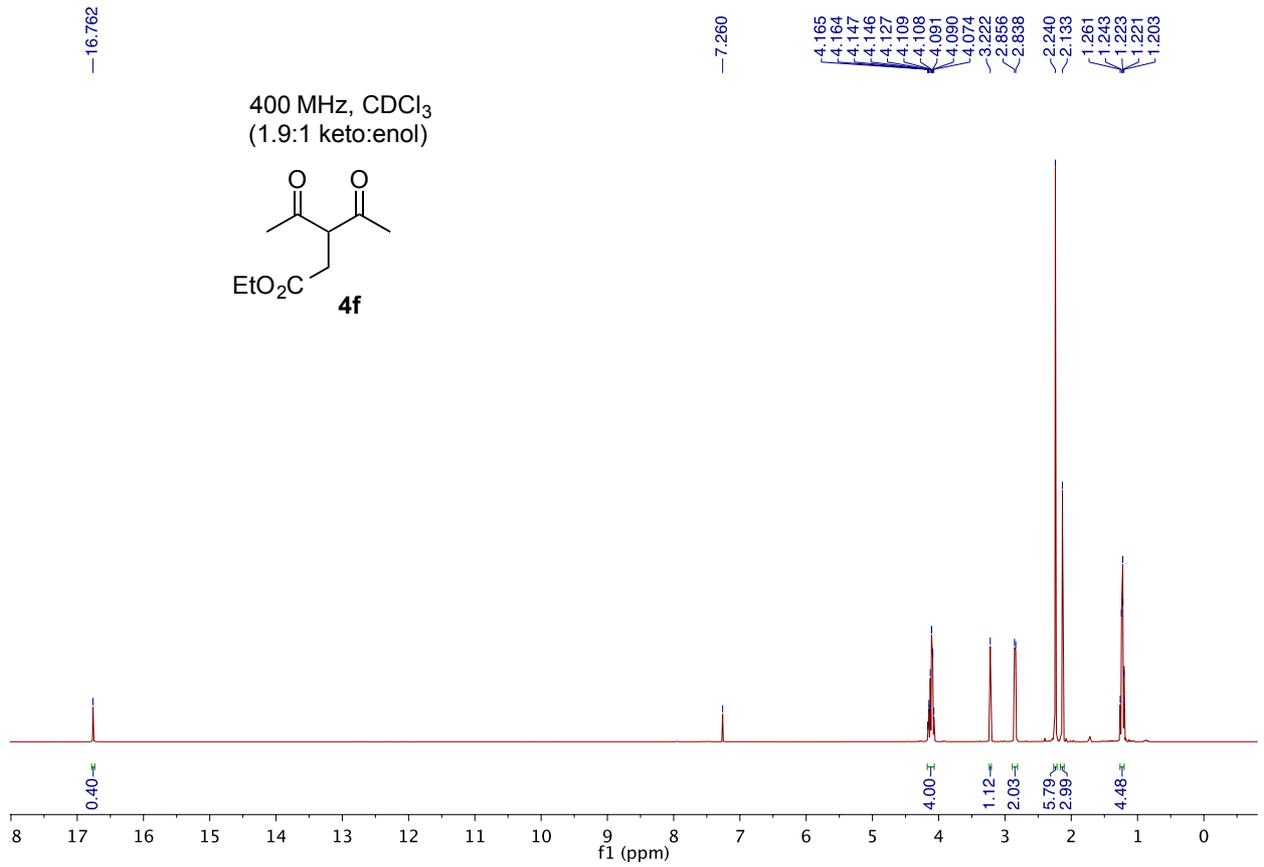


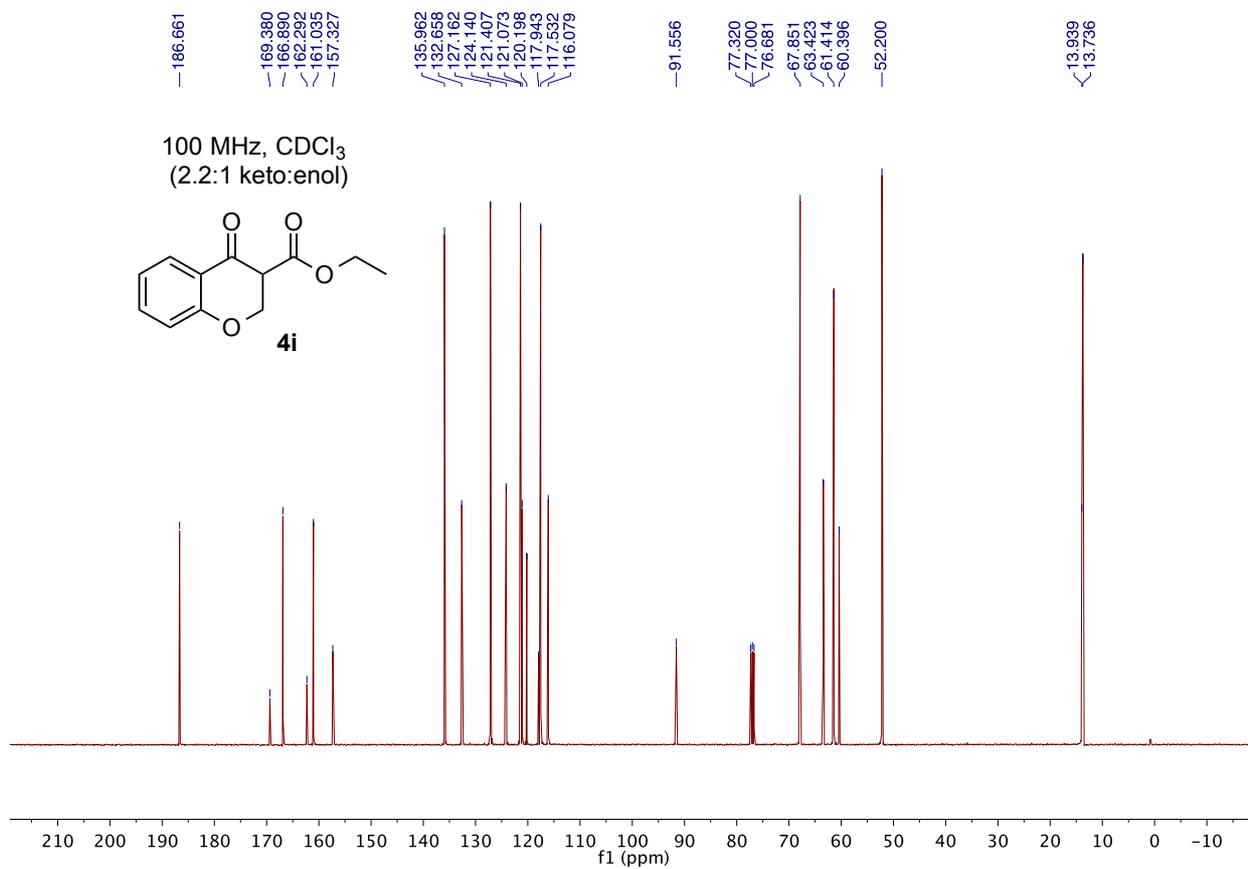
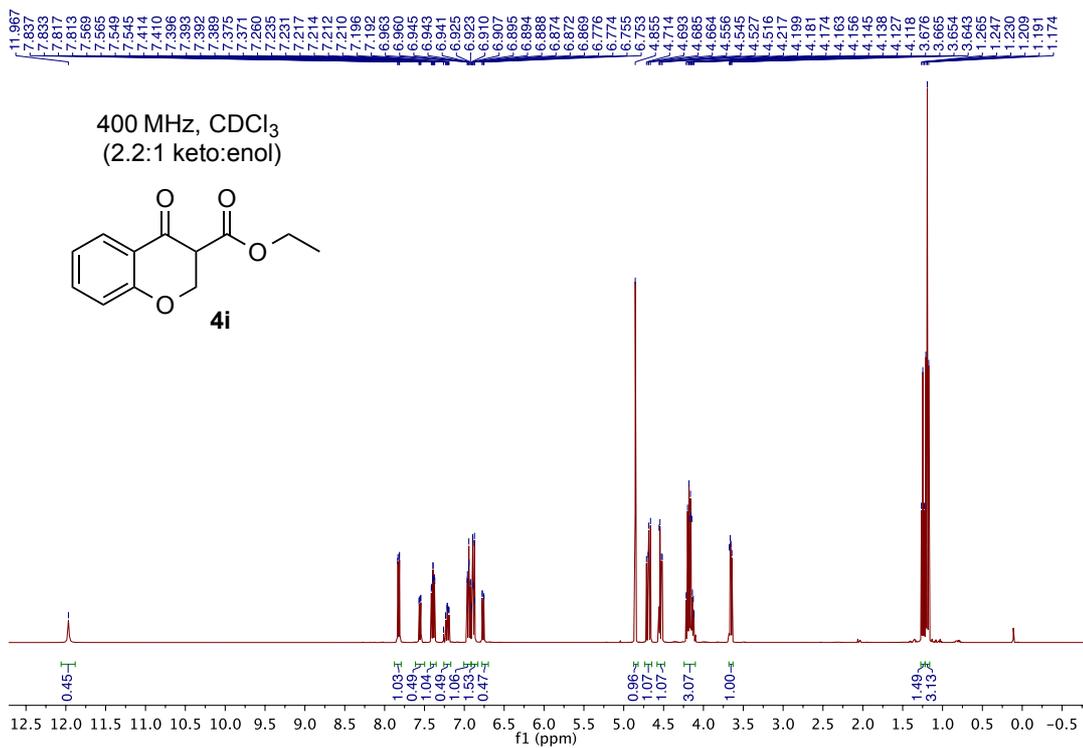
## 6. $^1\text{H}$ and $^{13}\text{C}$ NMR Spectra.

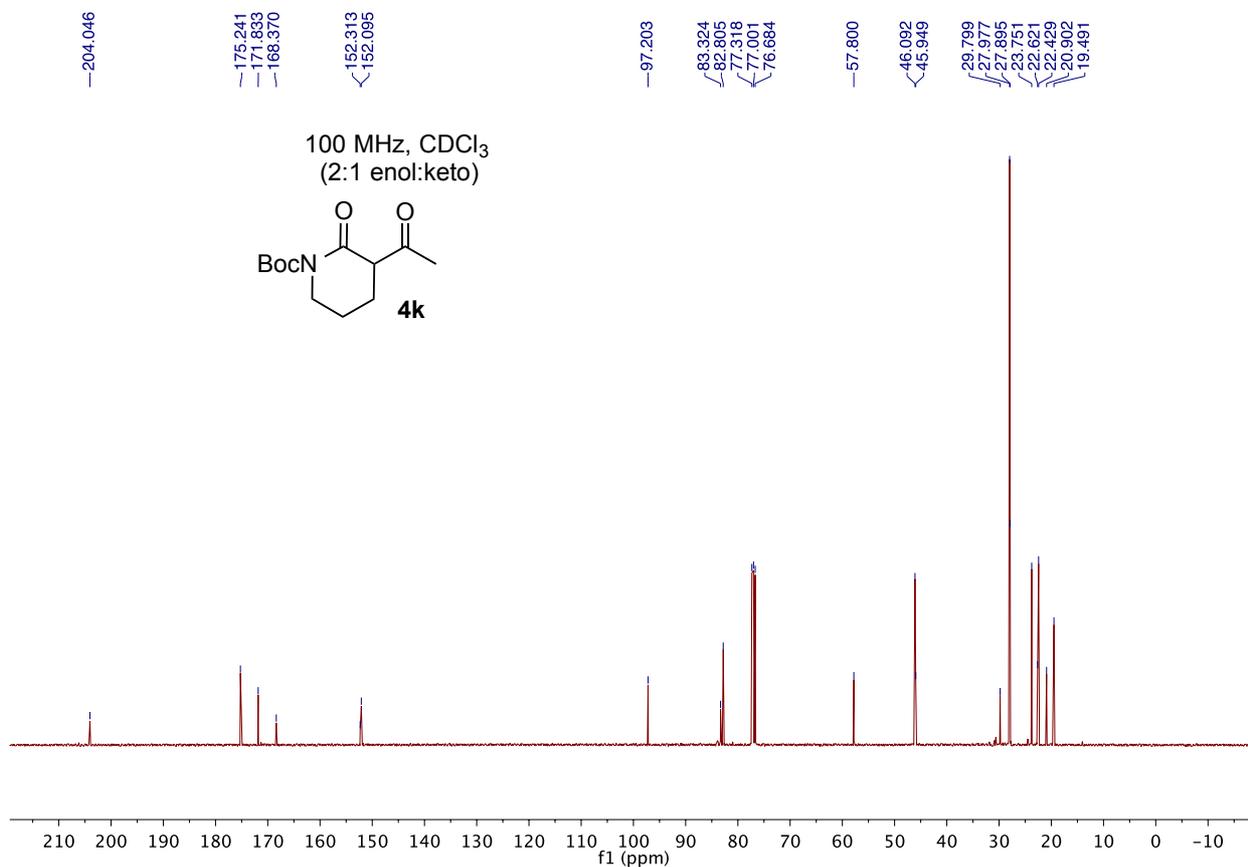
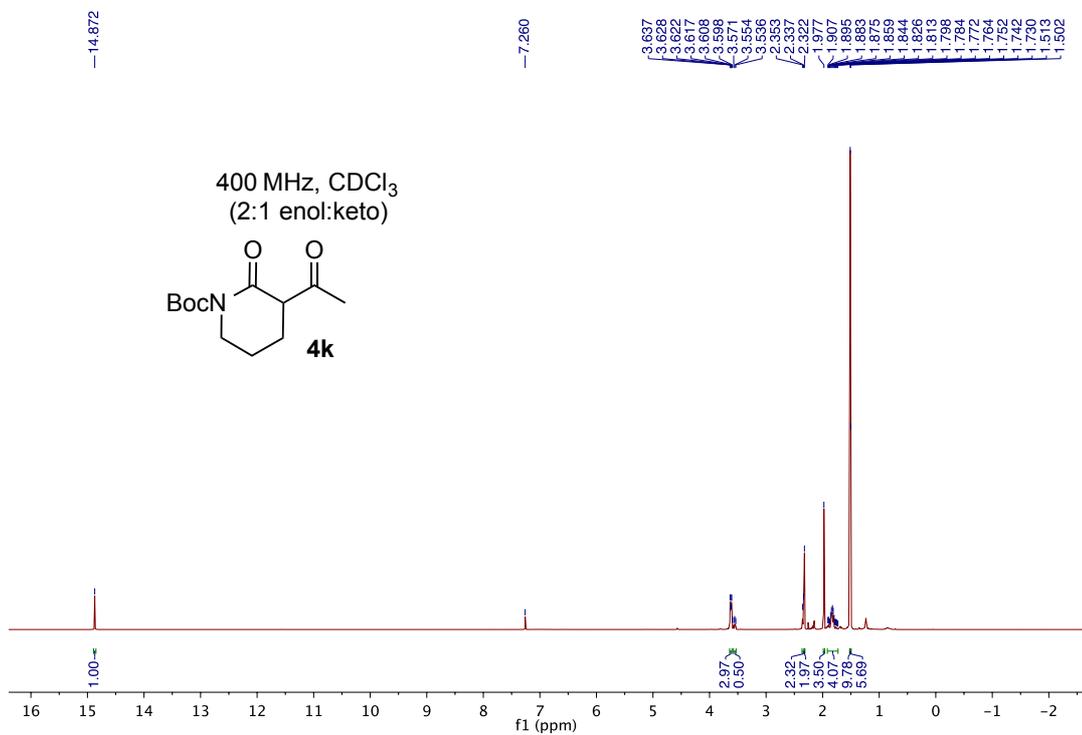


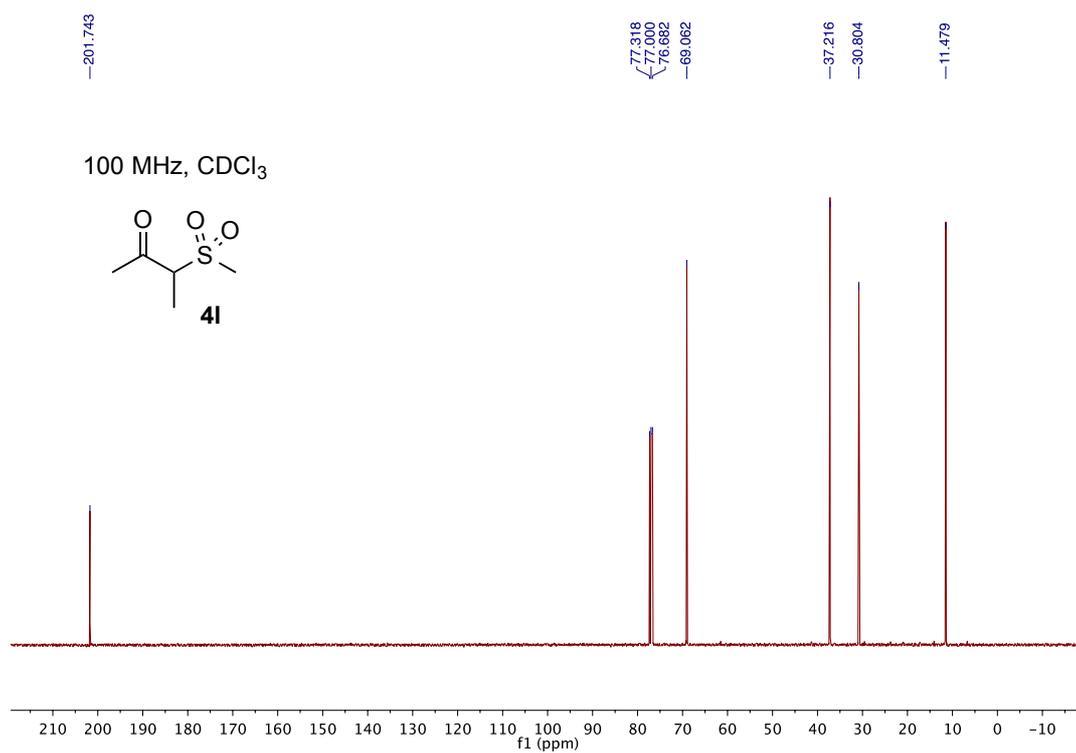
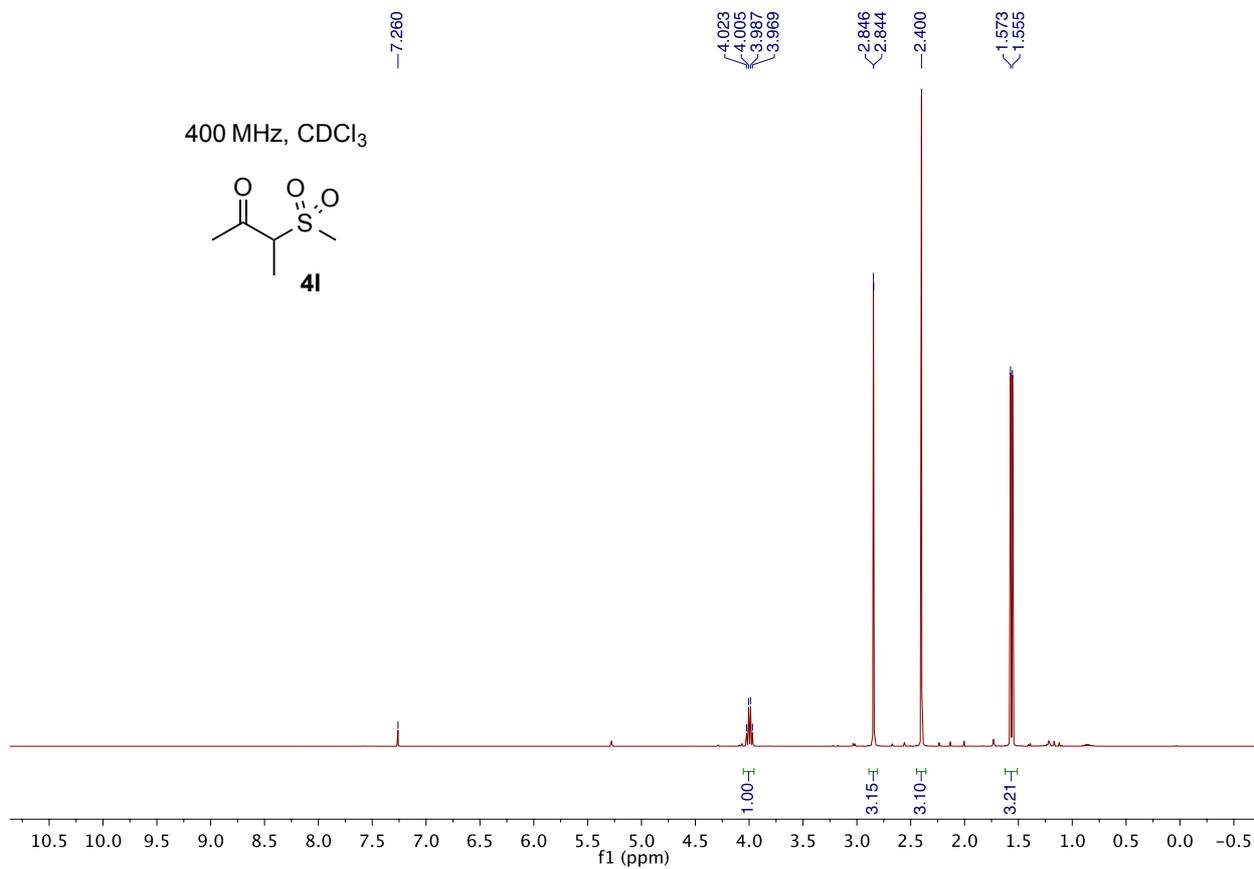


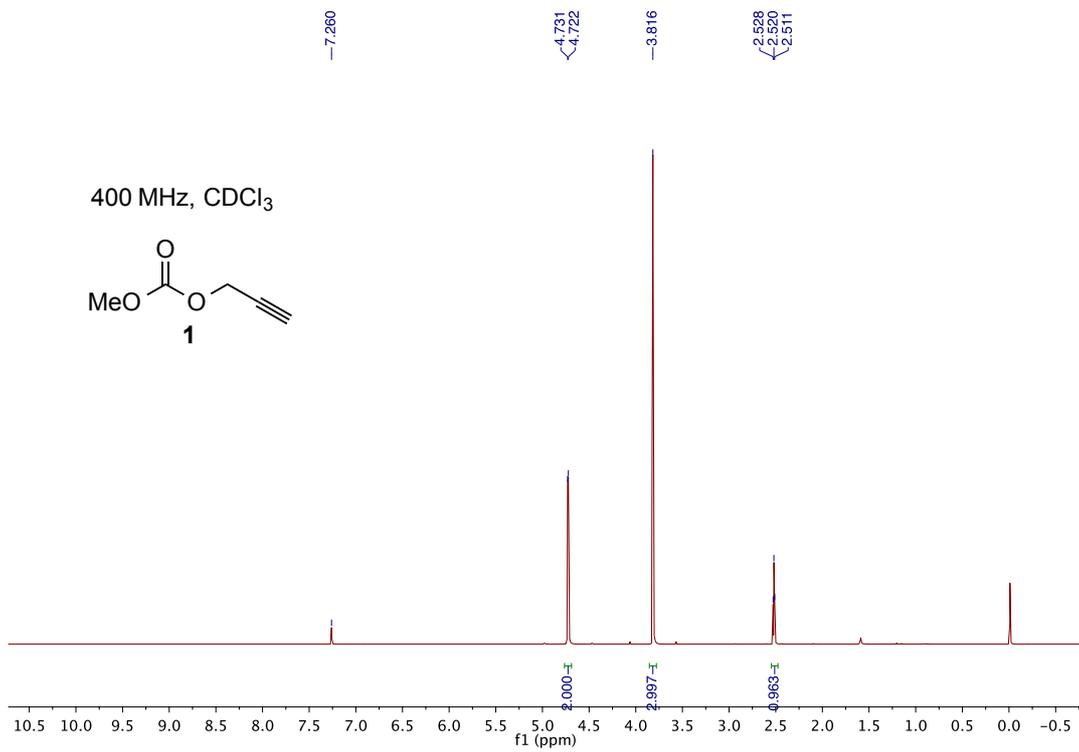


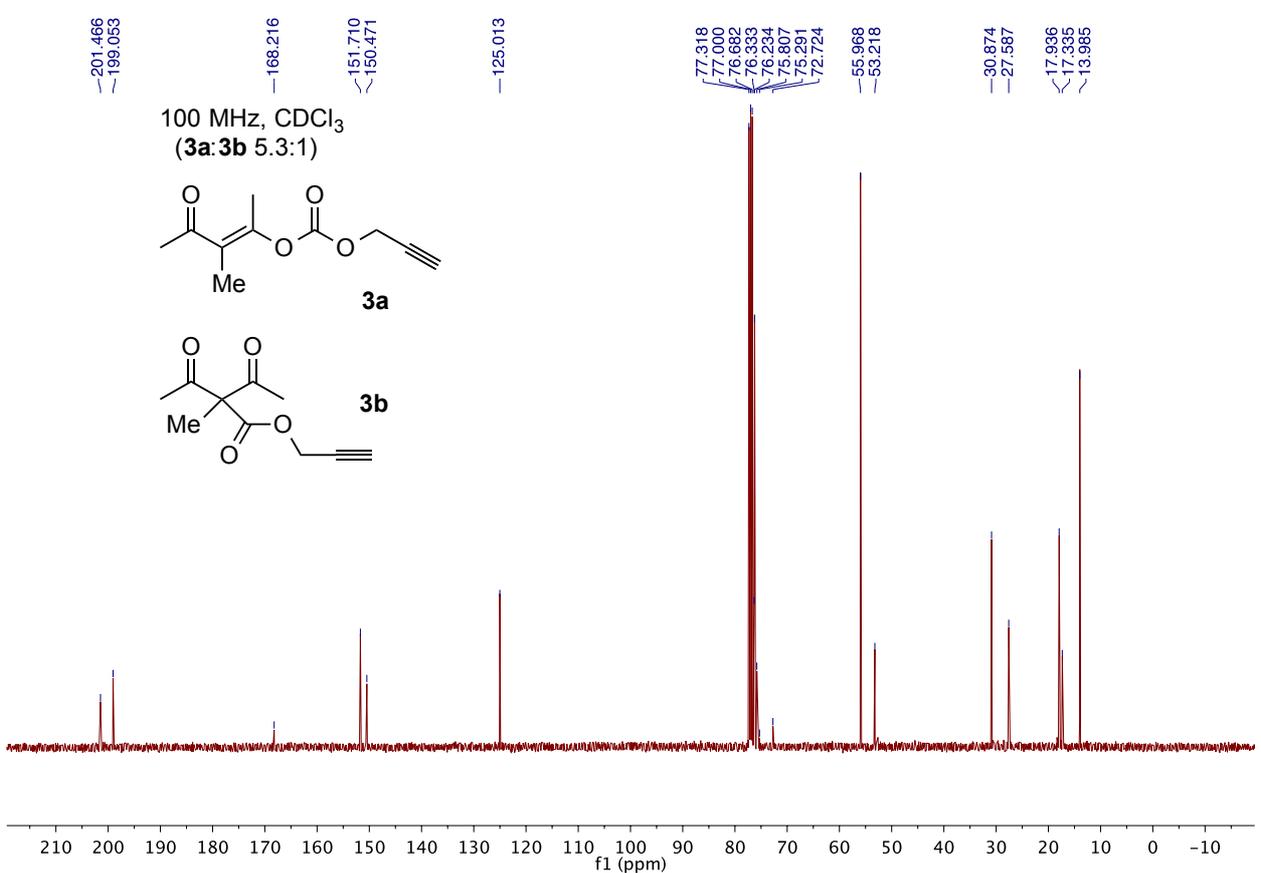
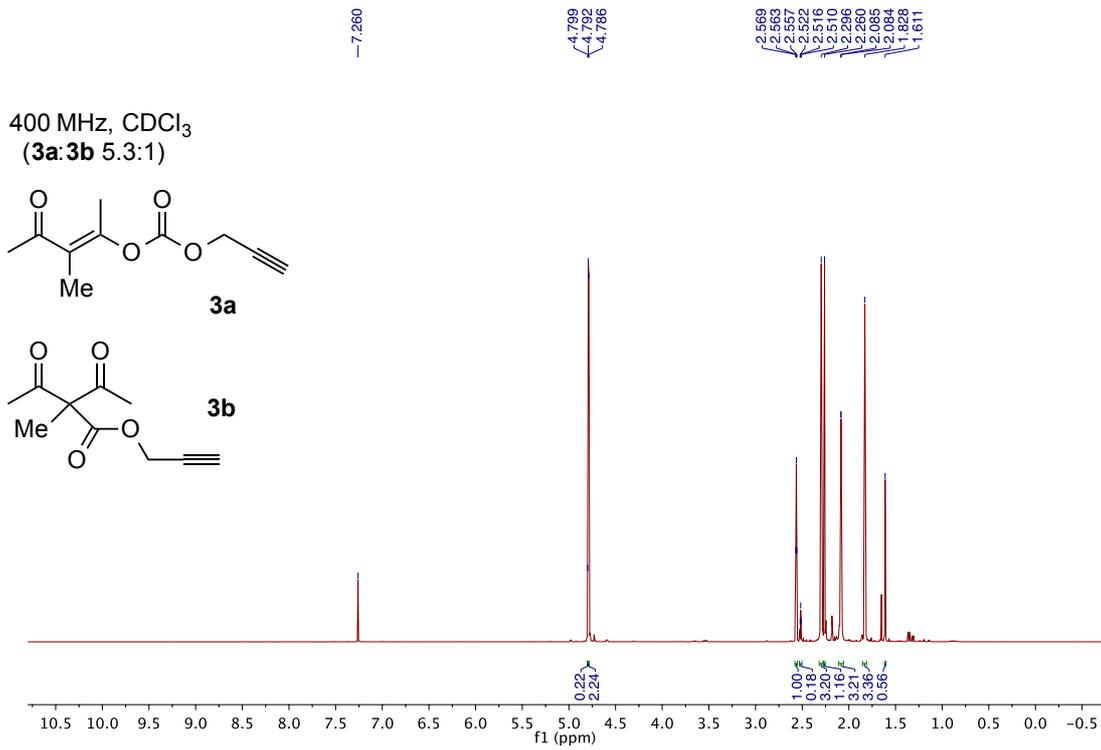


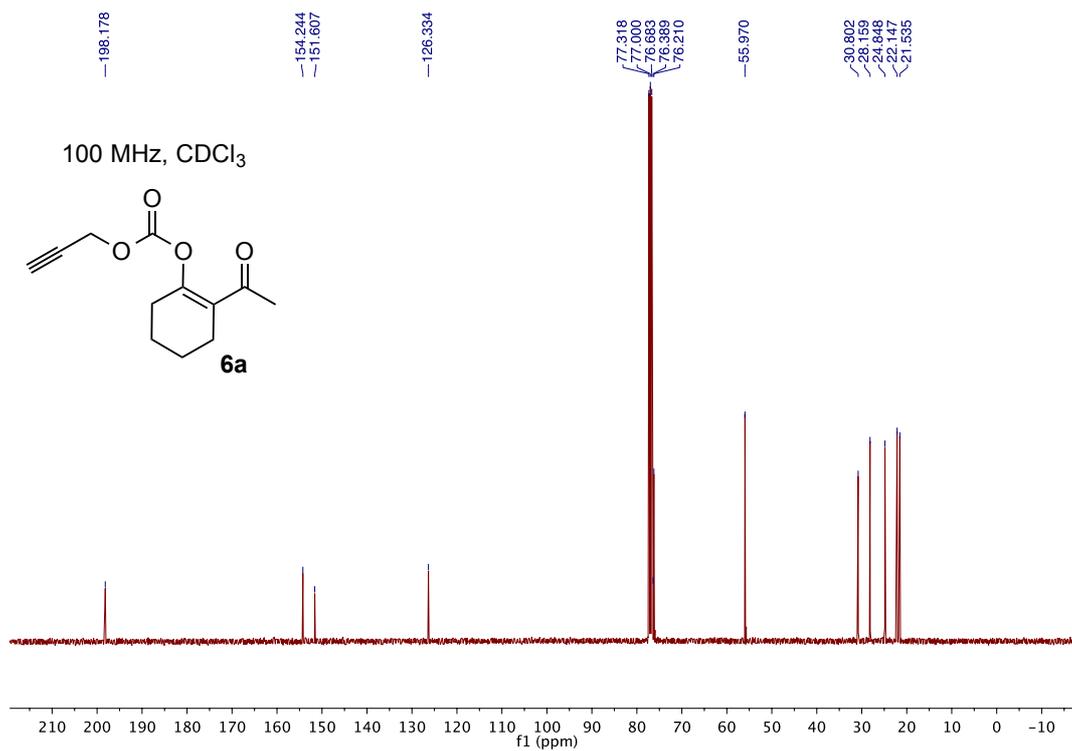
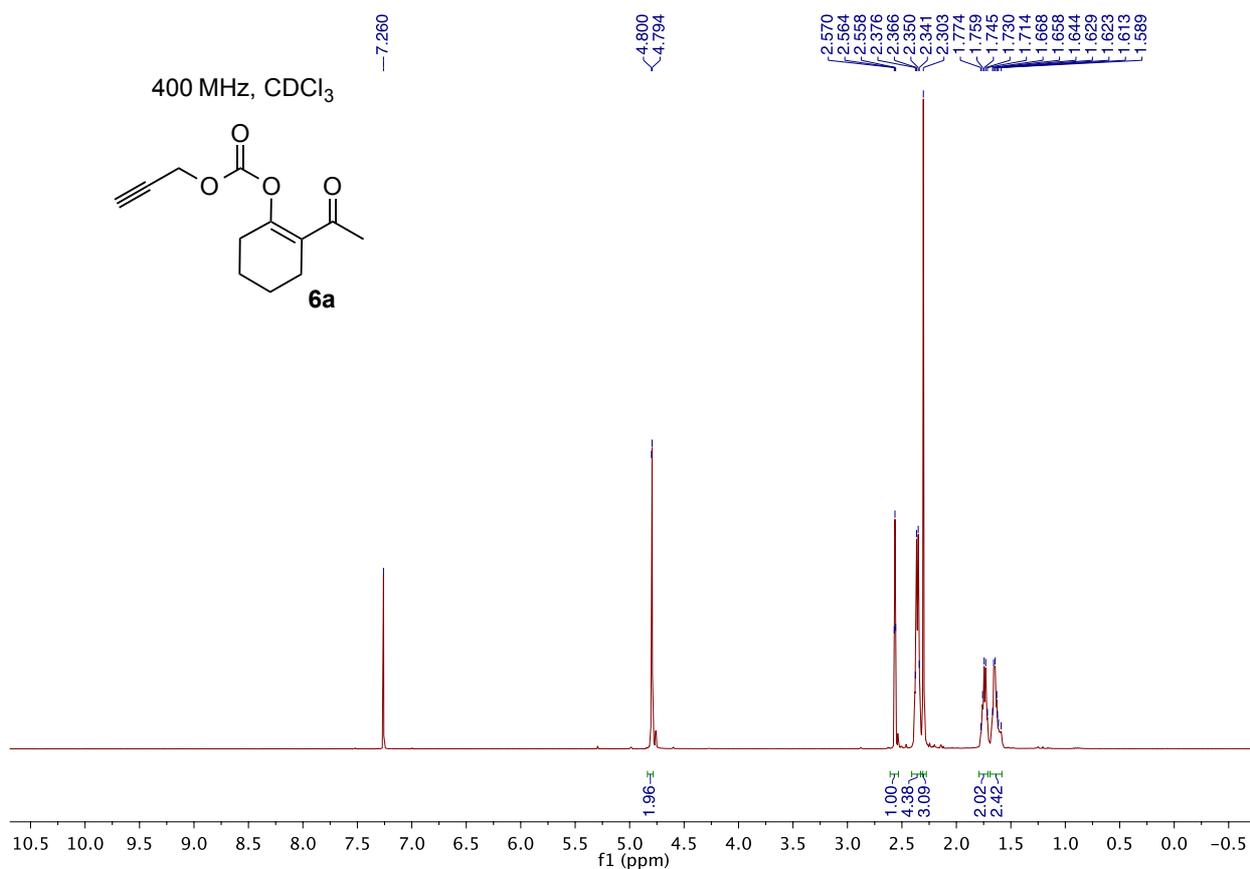


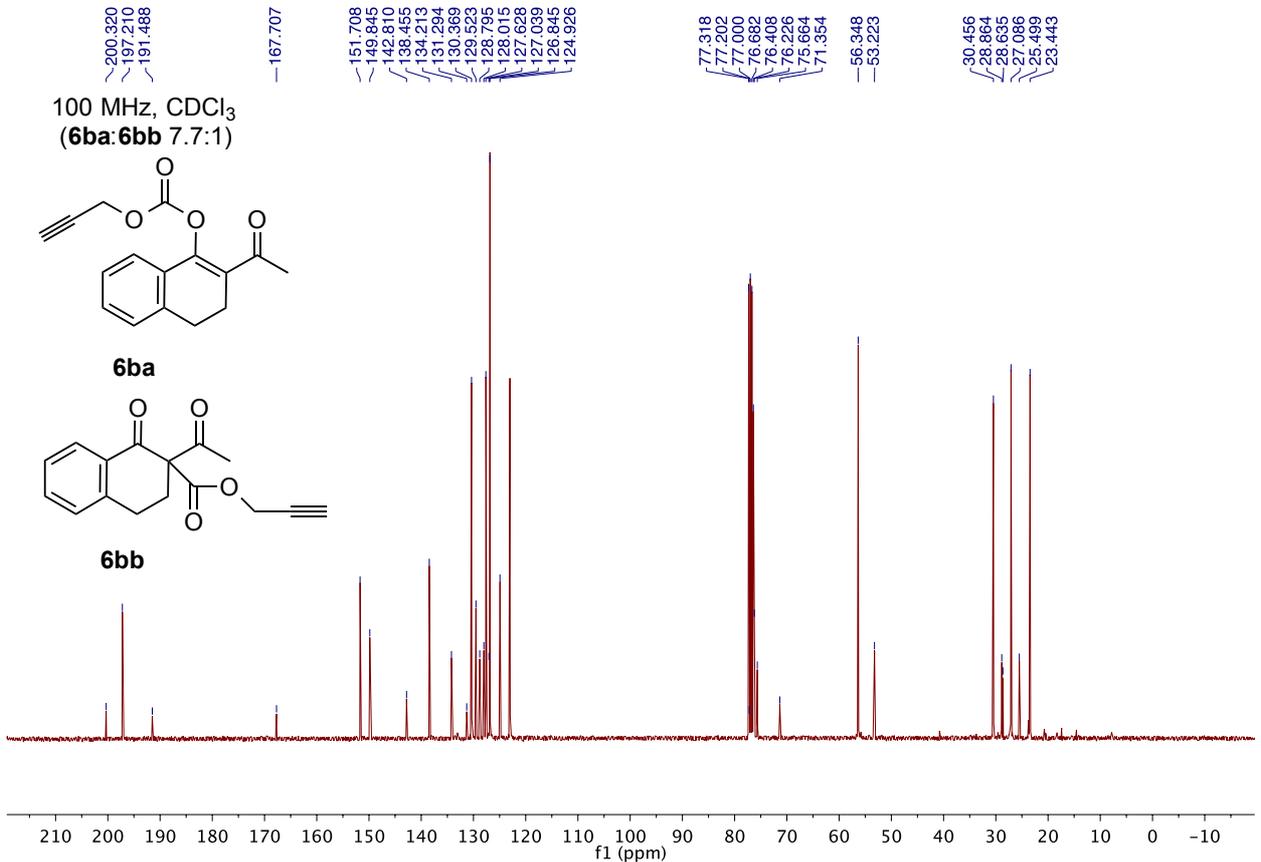
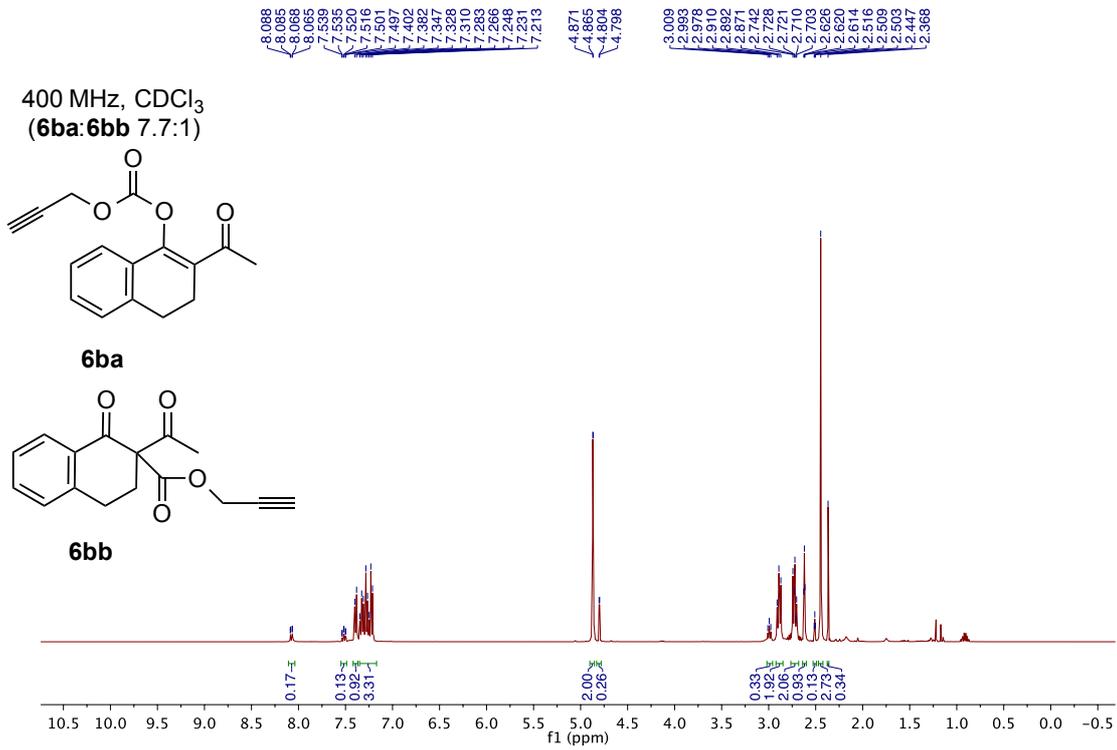


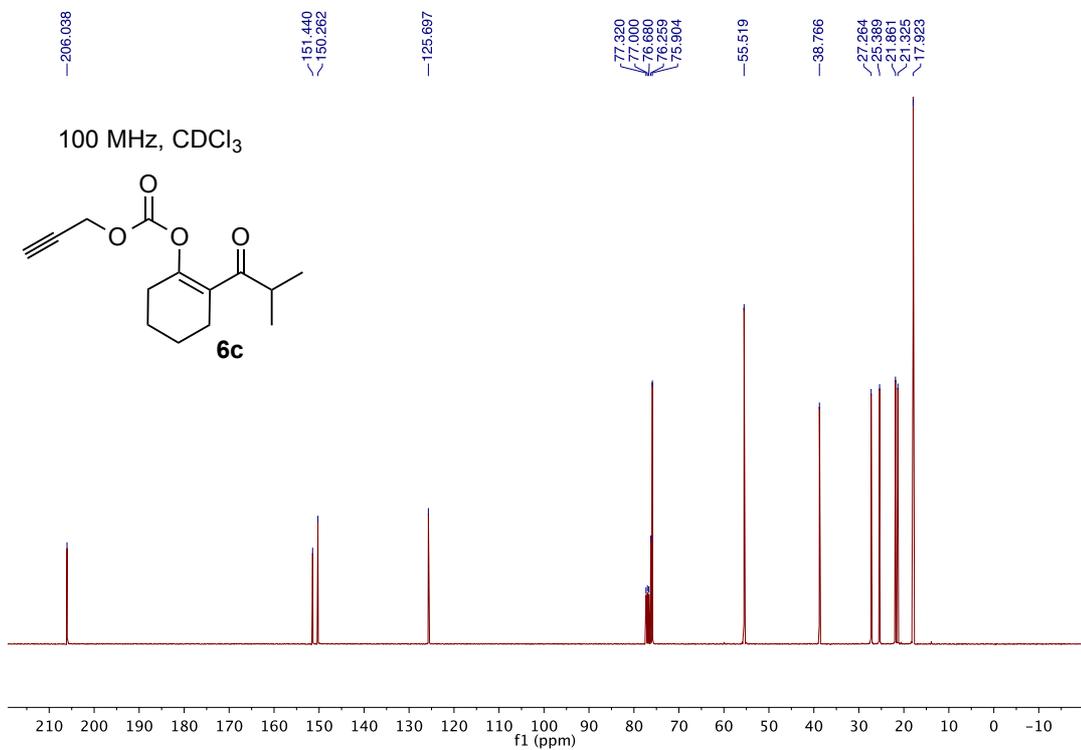
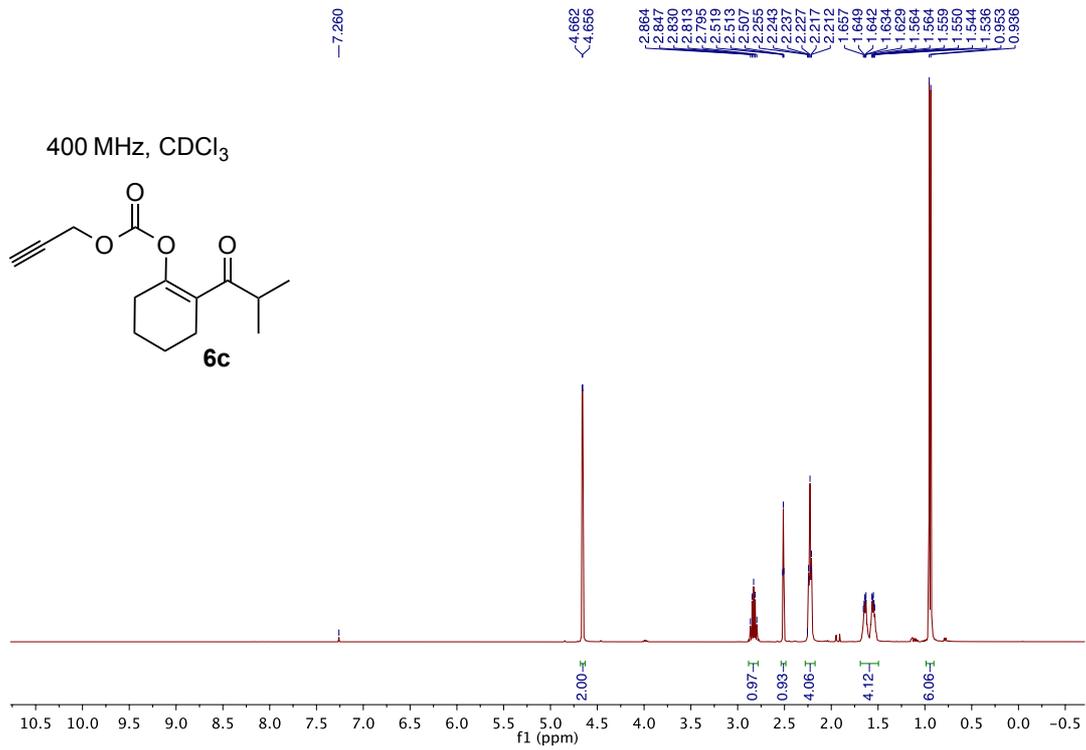


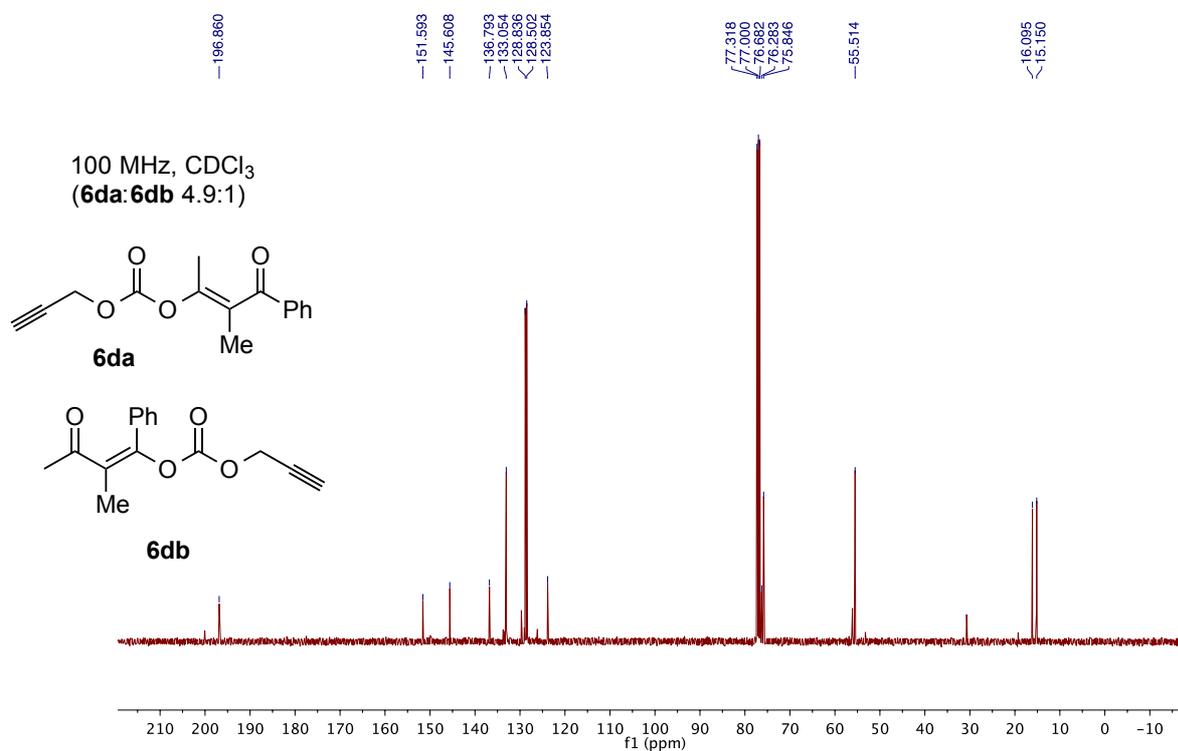
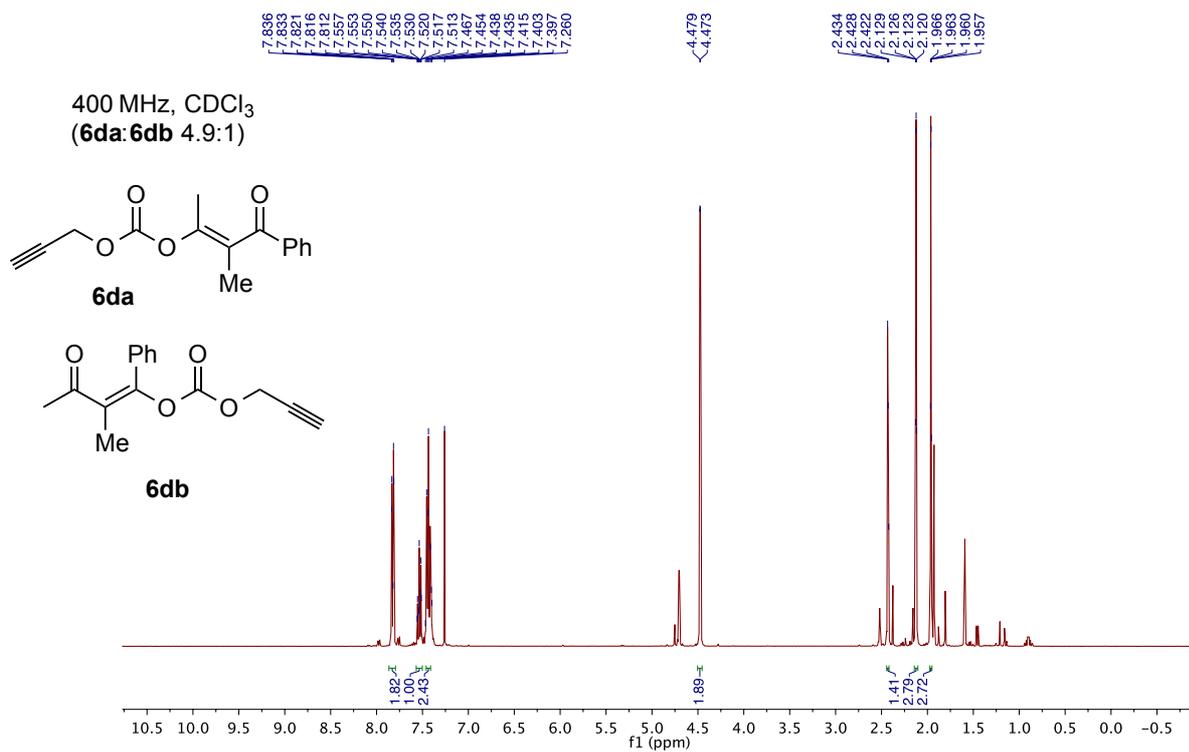


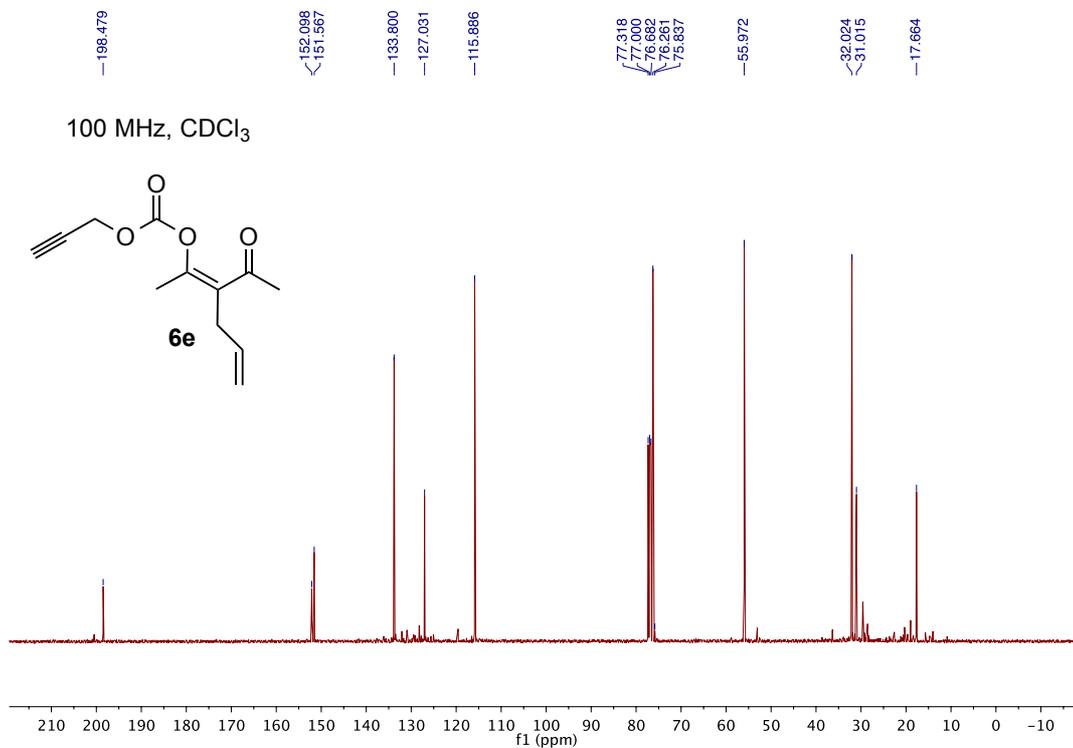
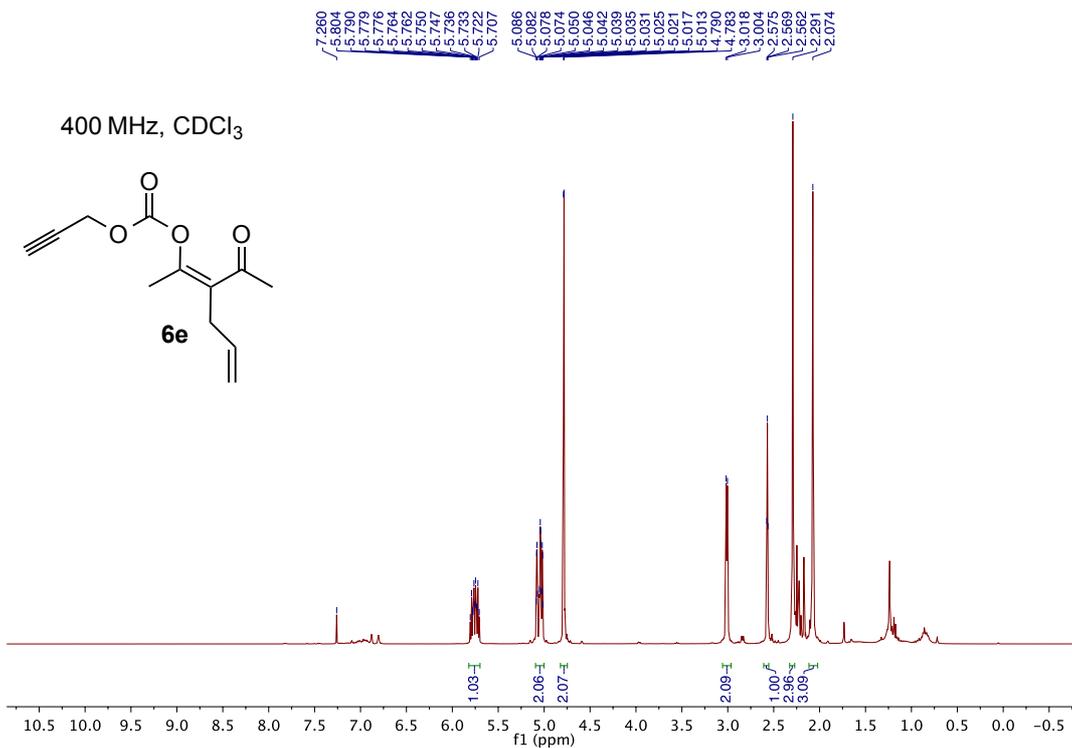


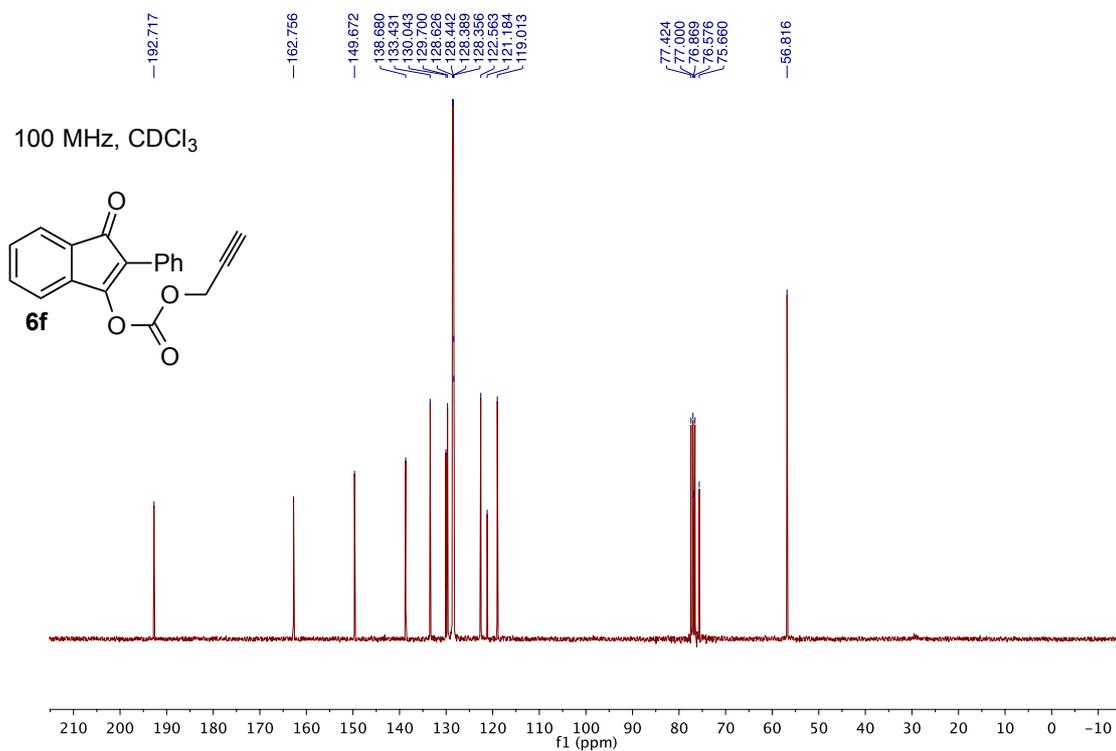
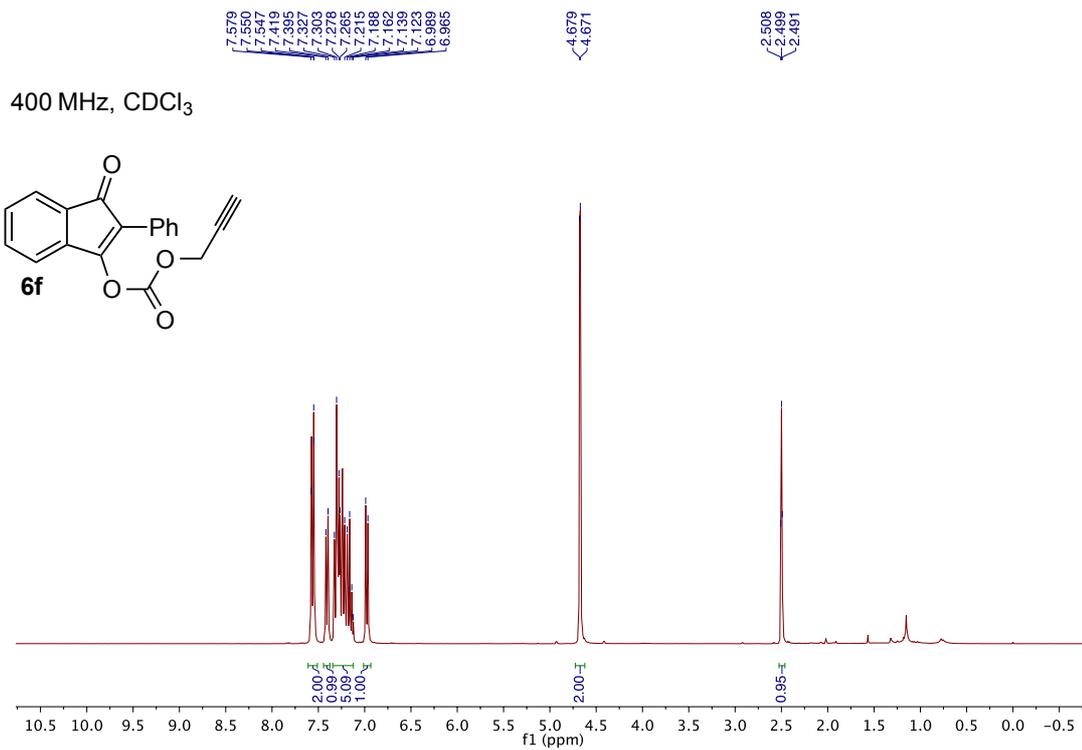


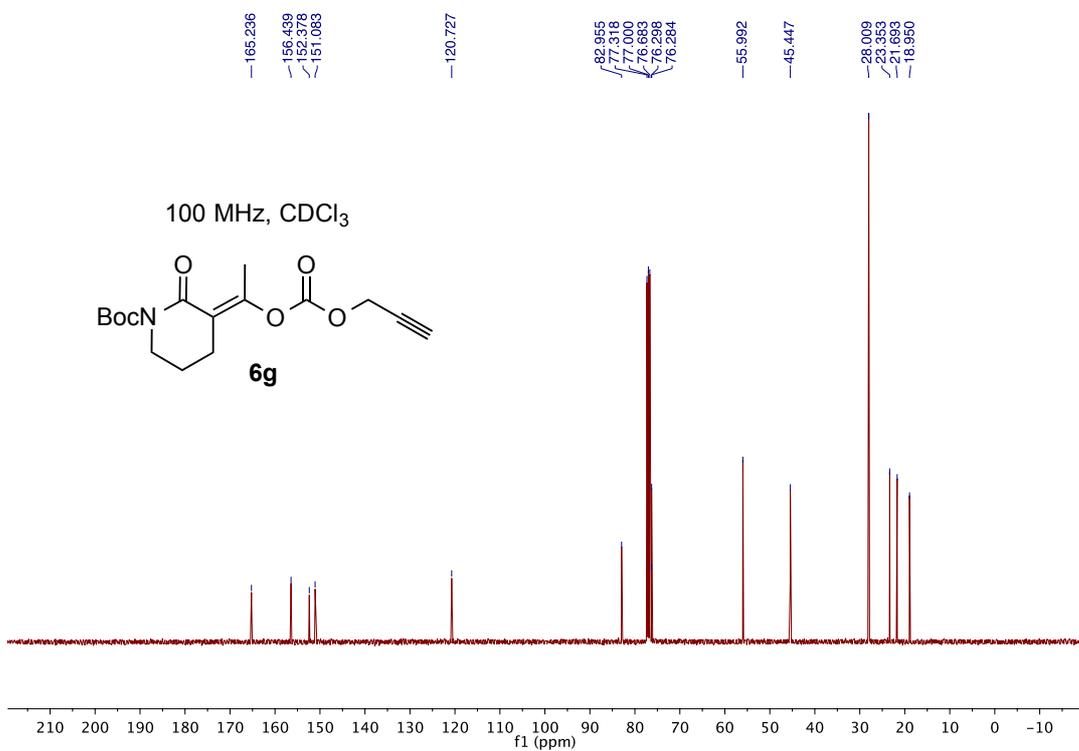
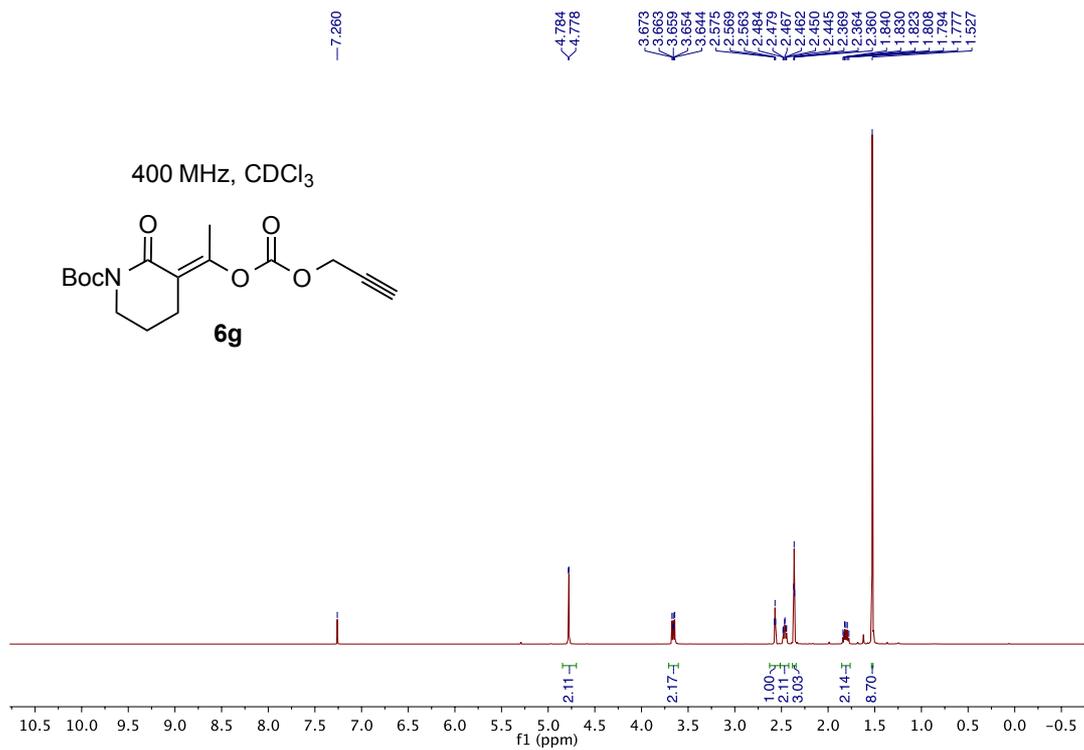


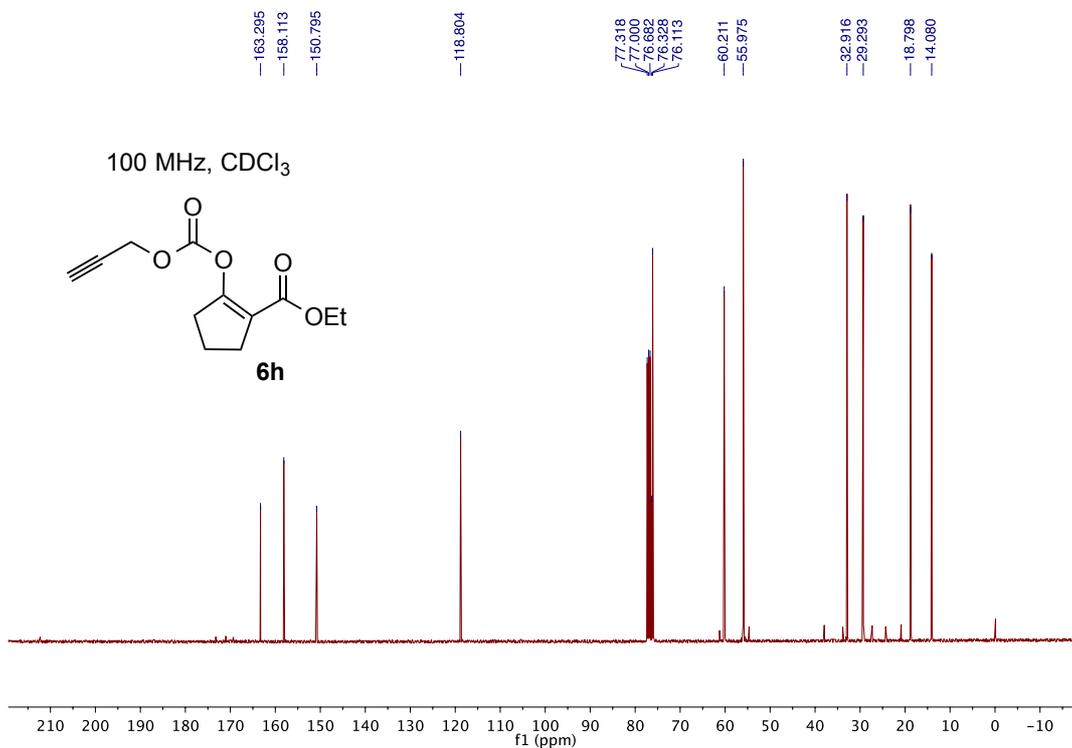
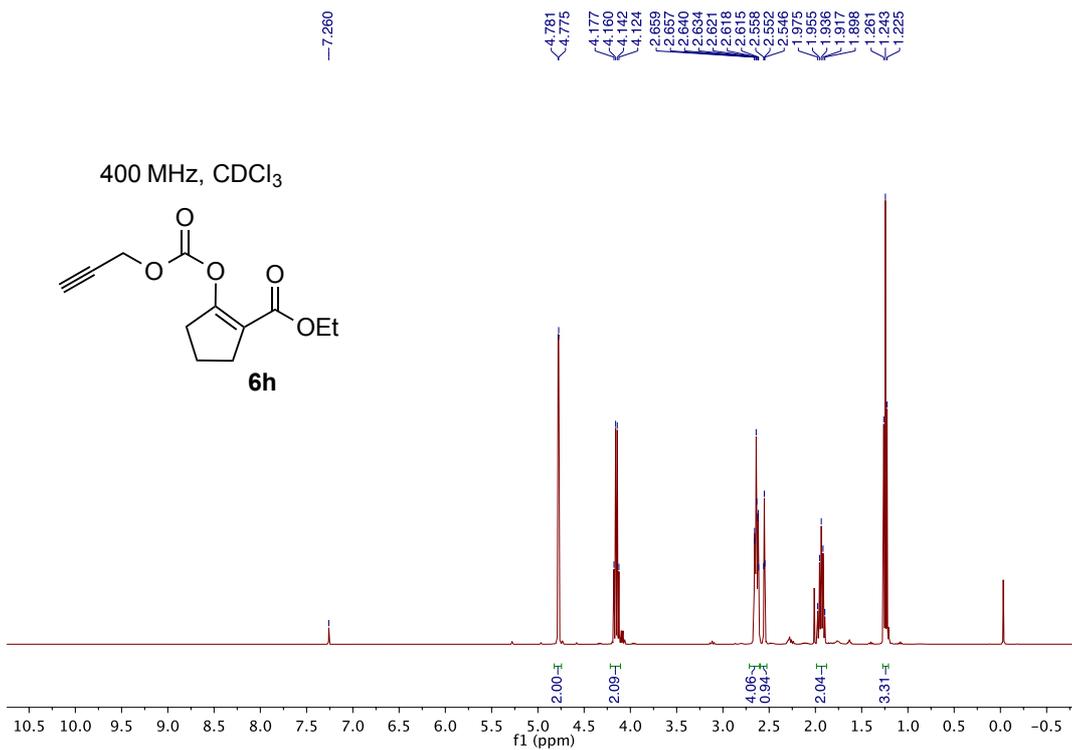


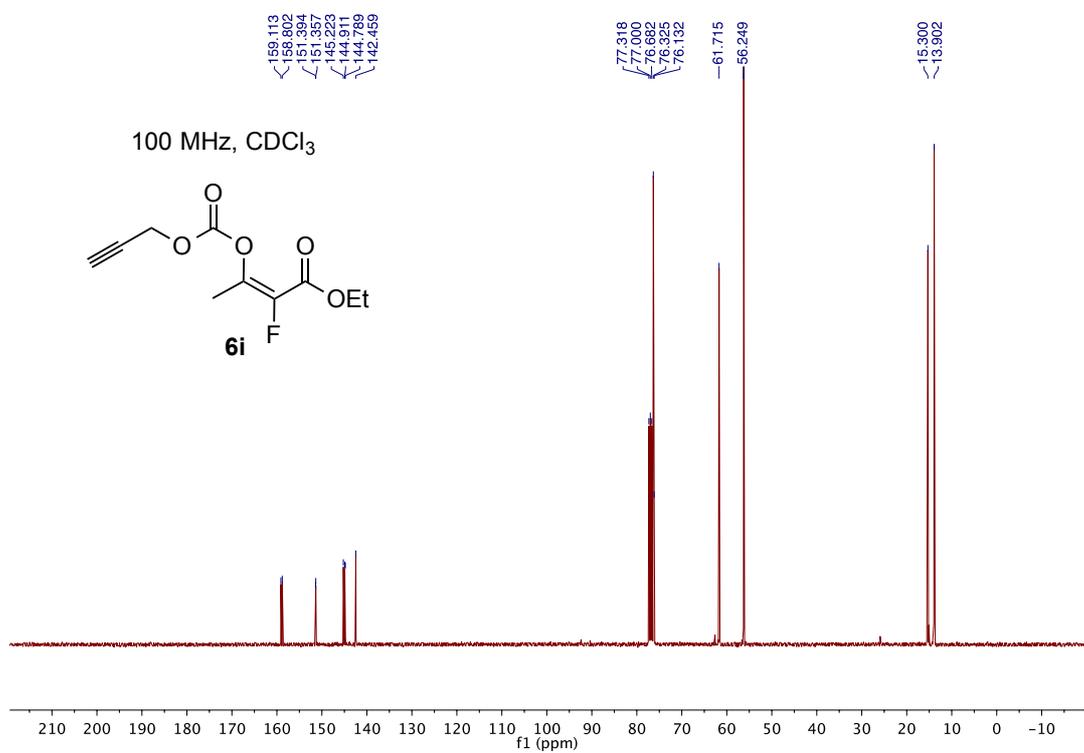
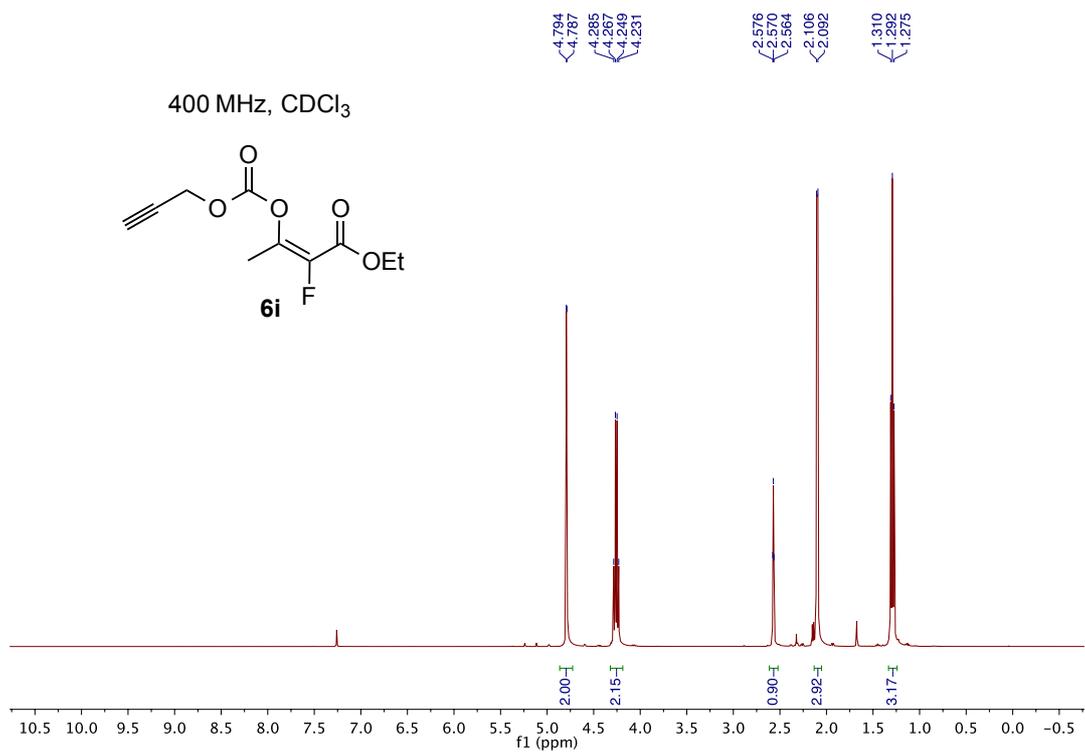


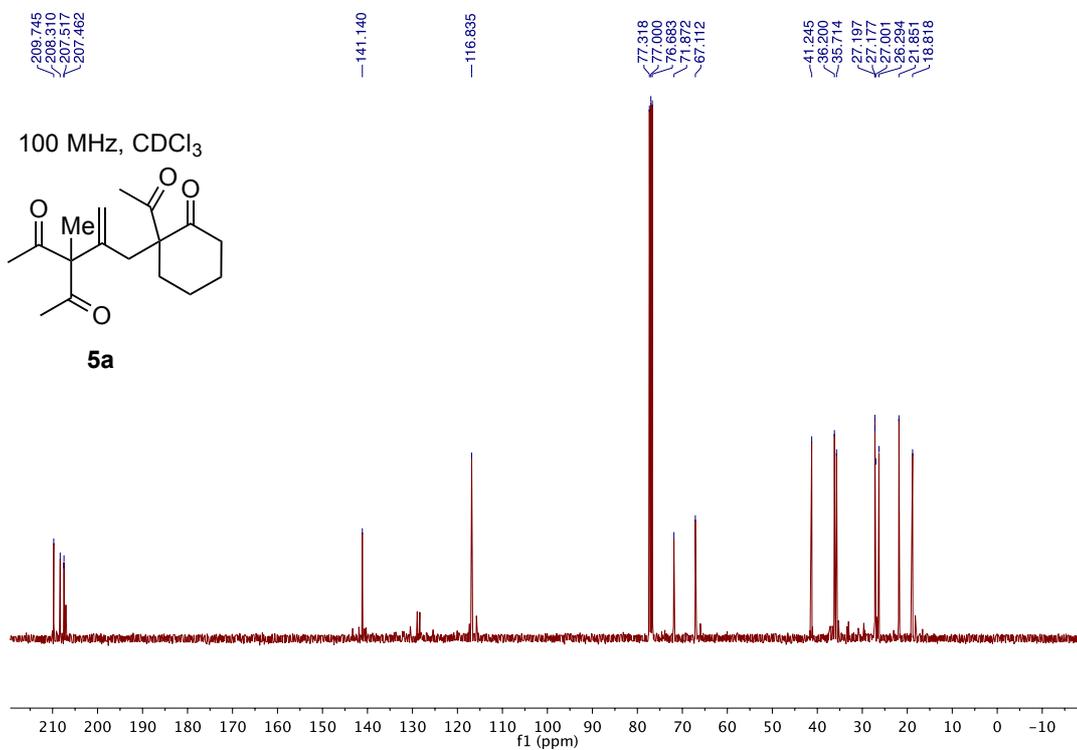
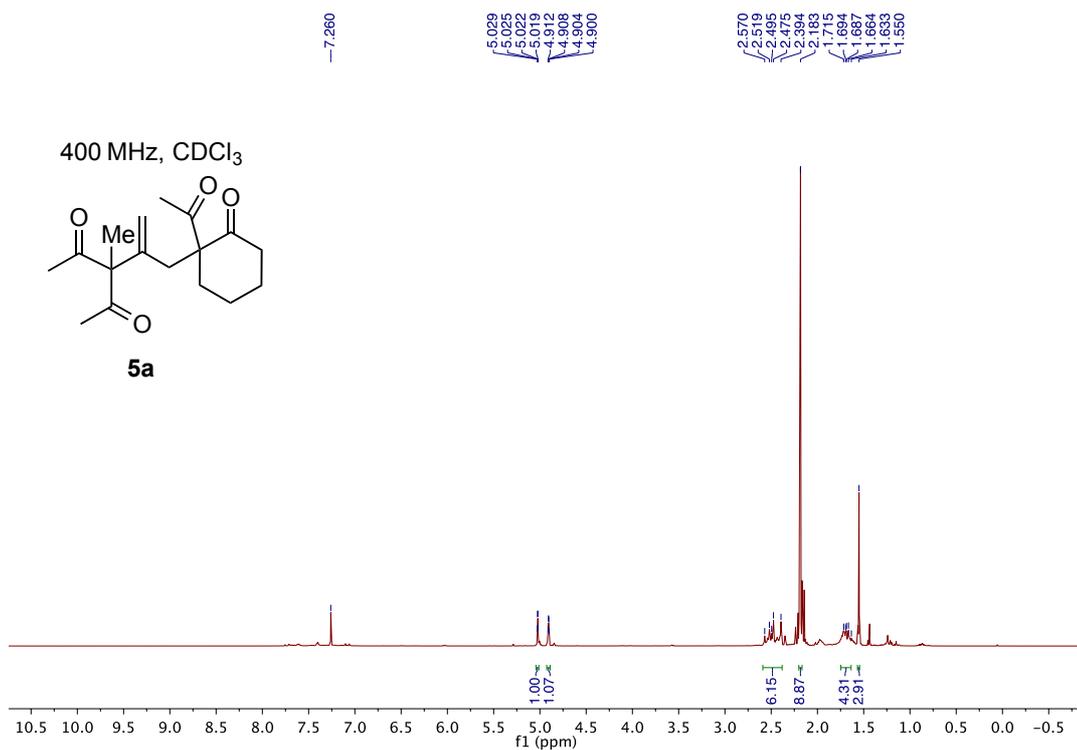


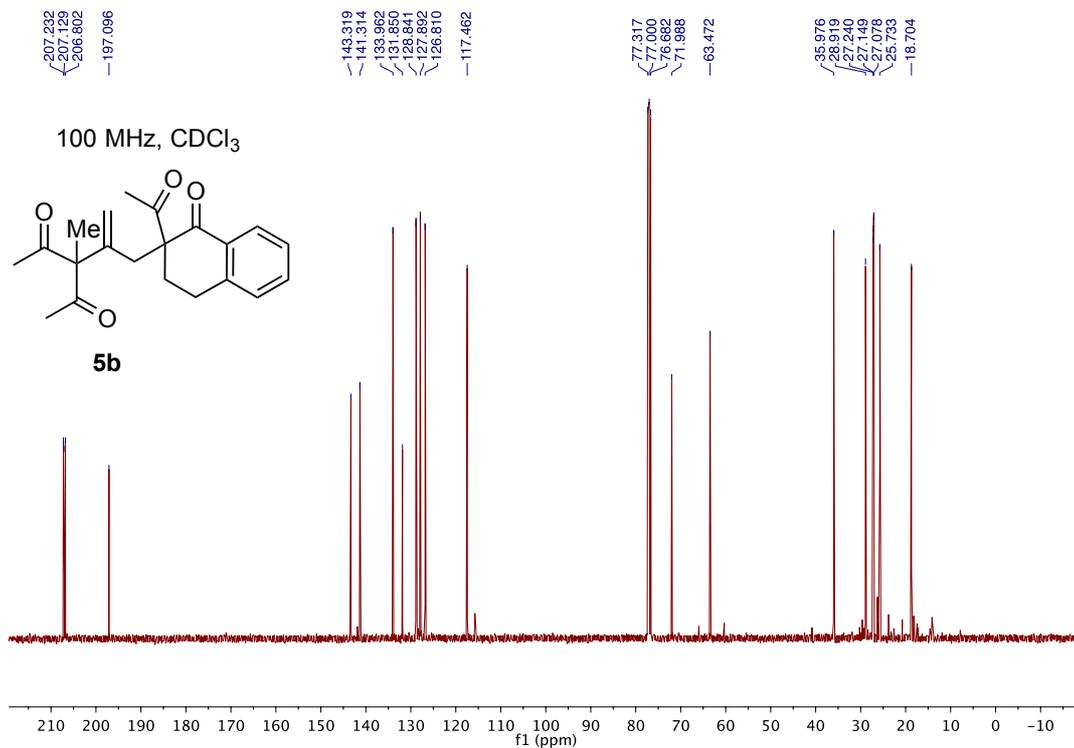
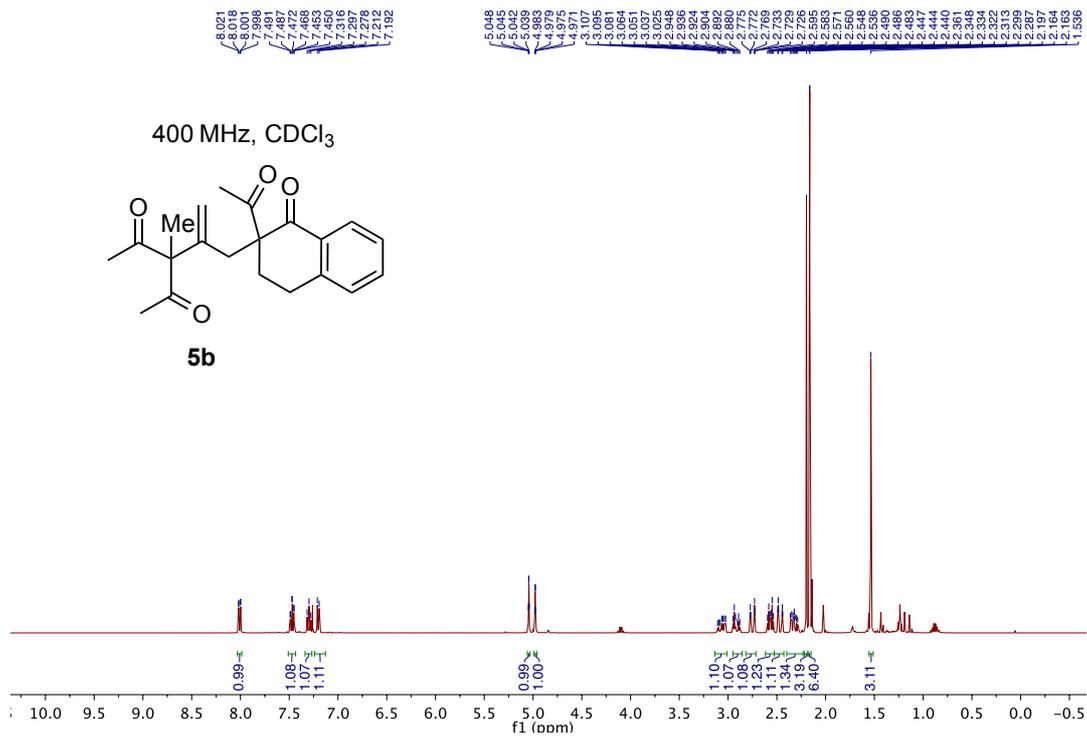


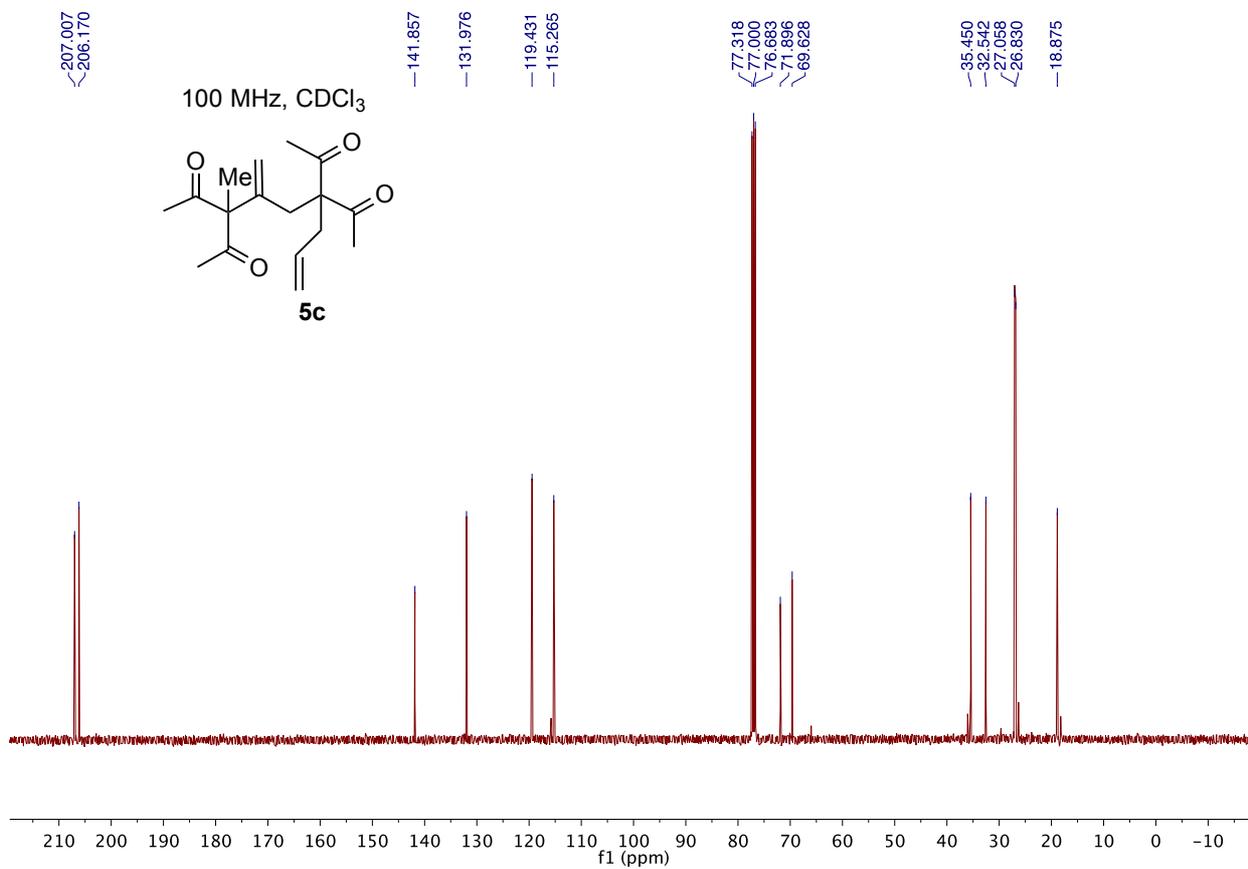
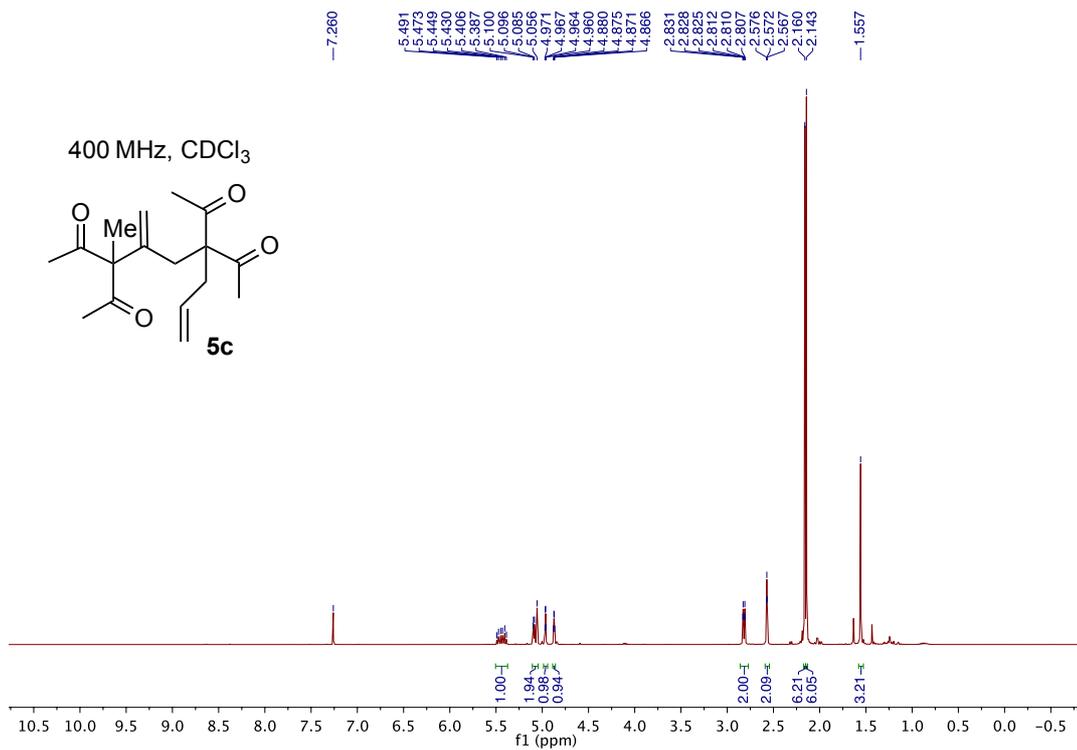


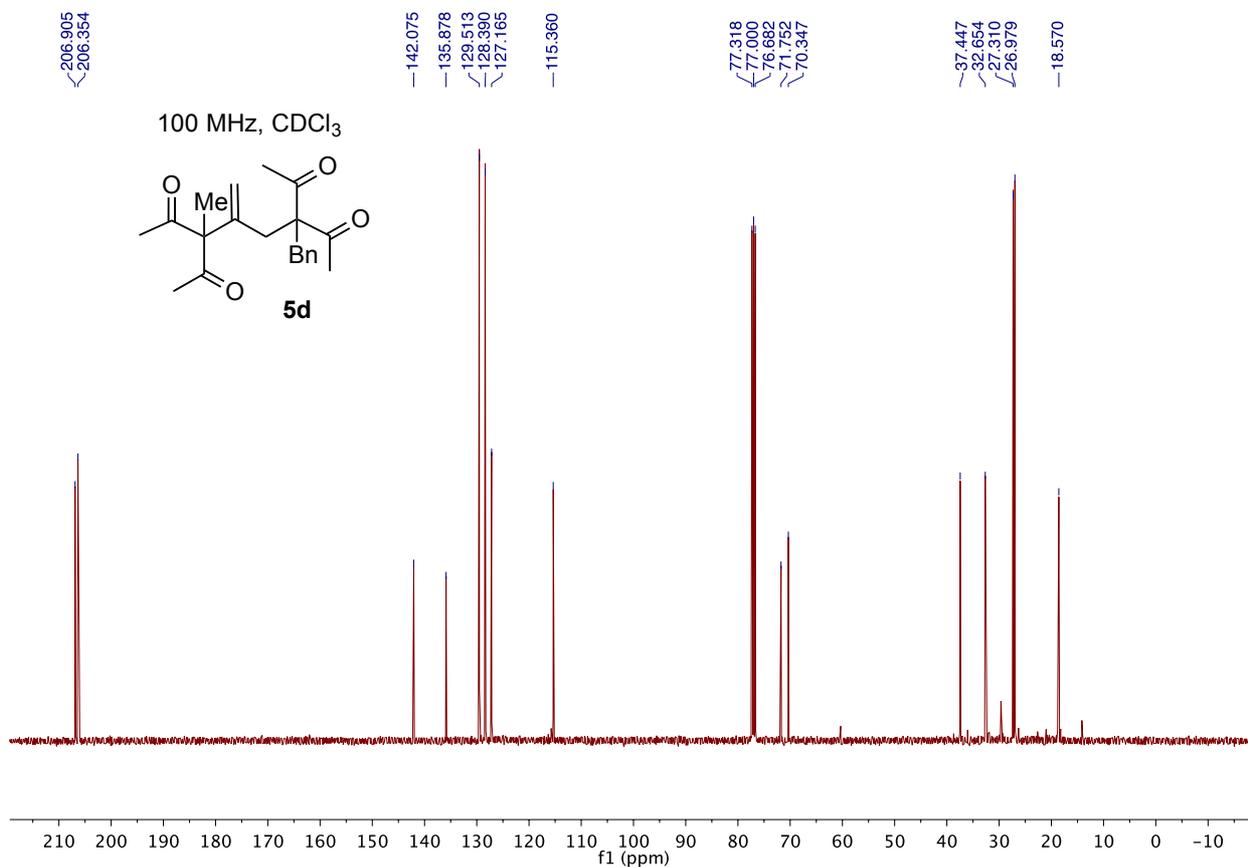
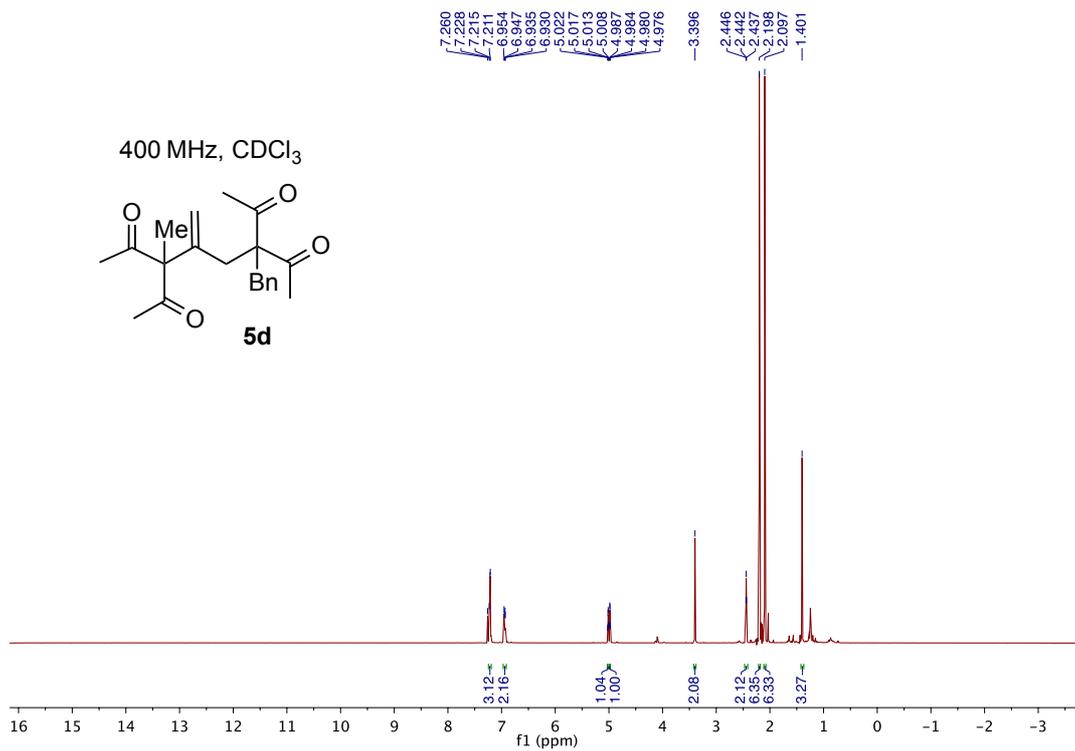


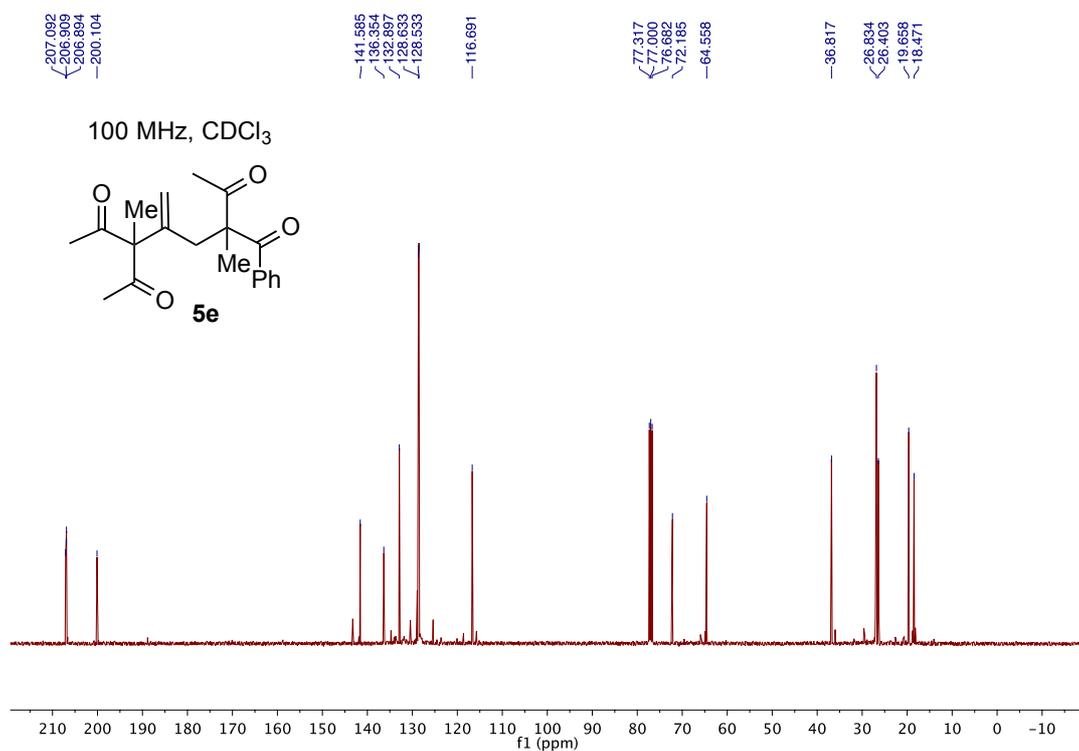
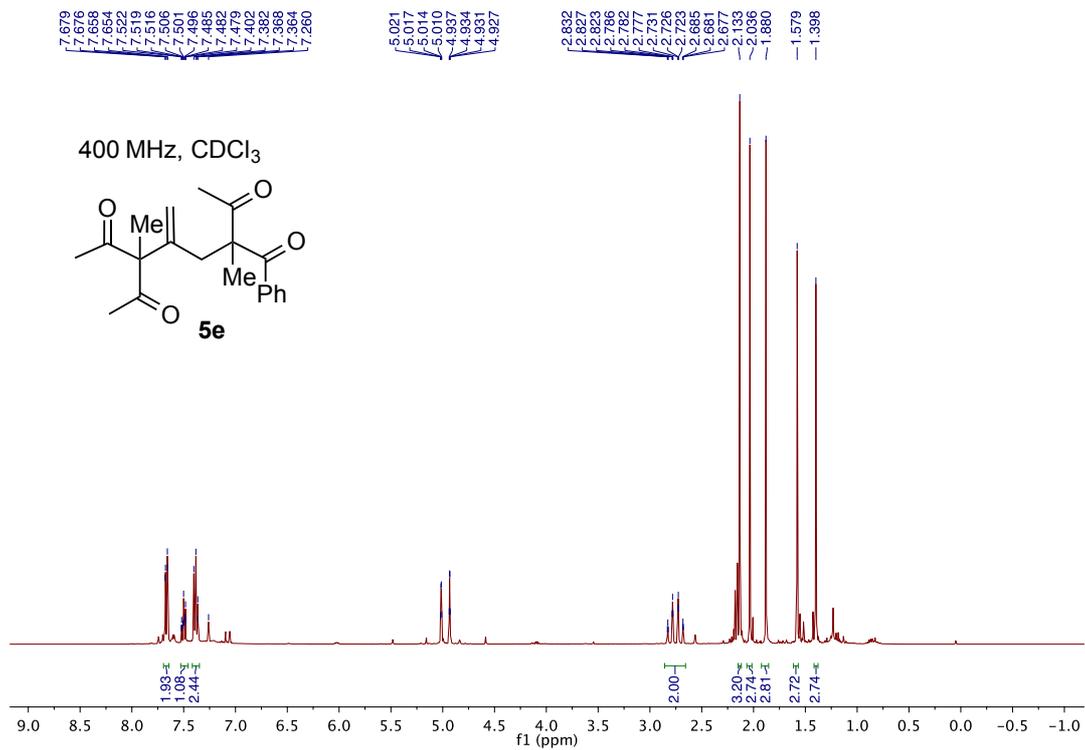


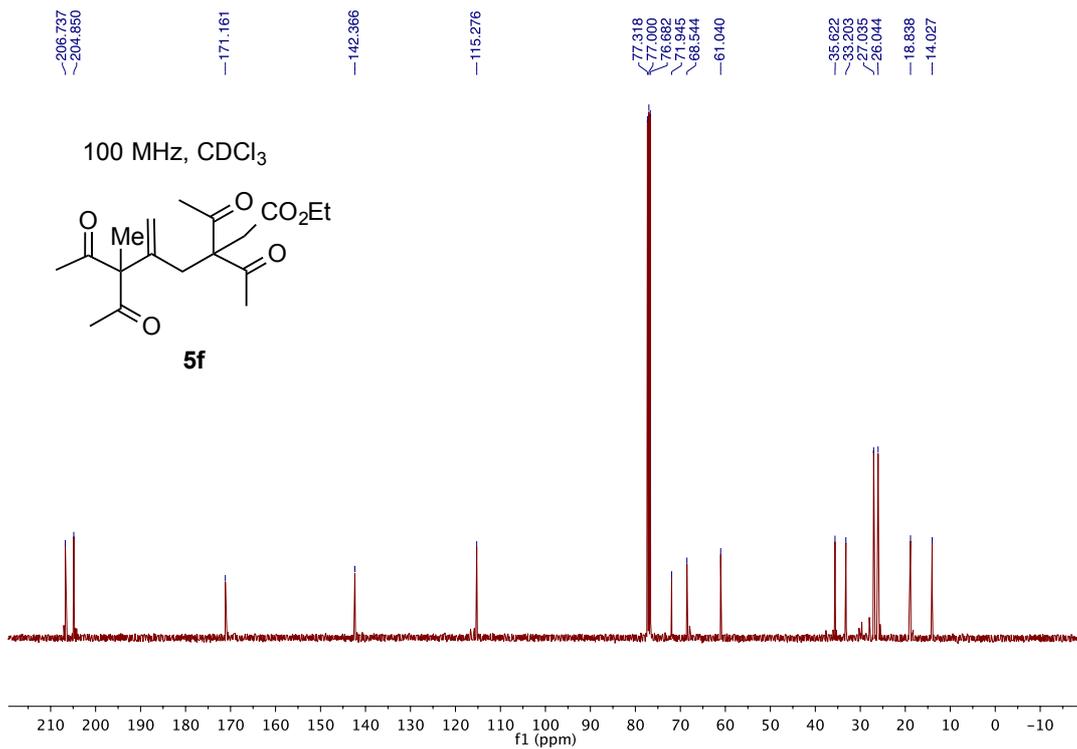
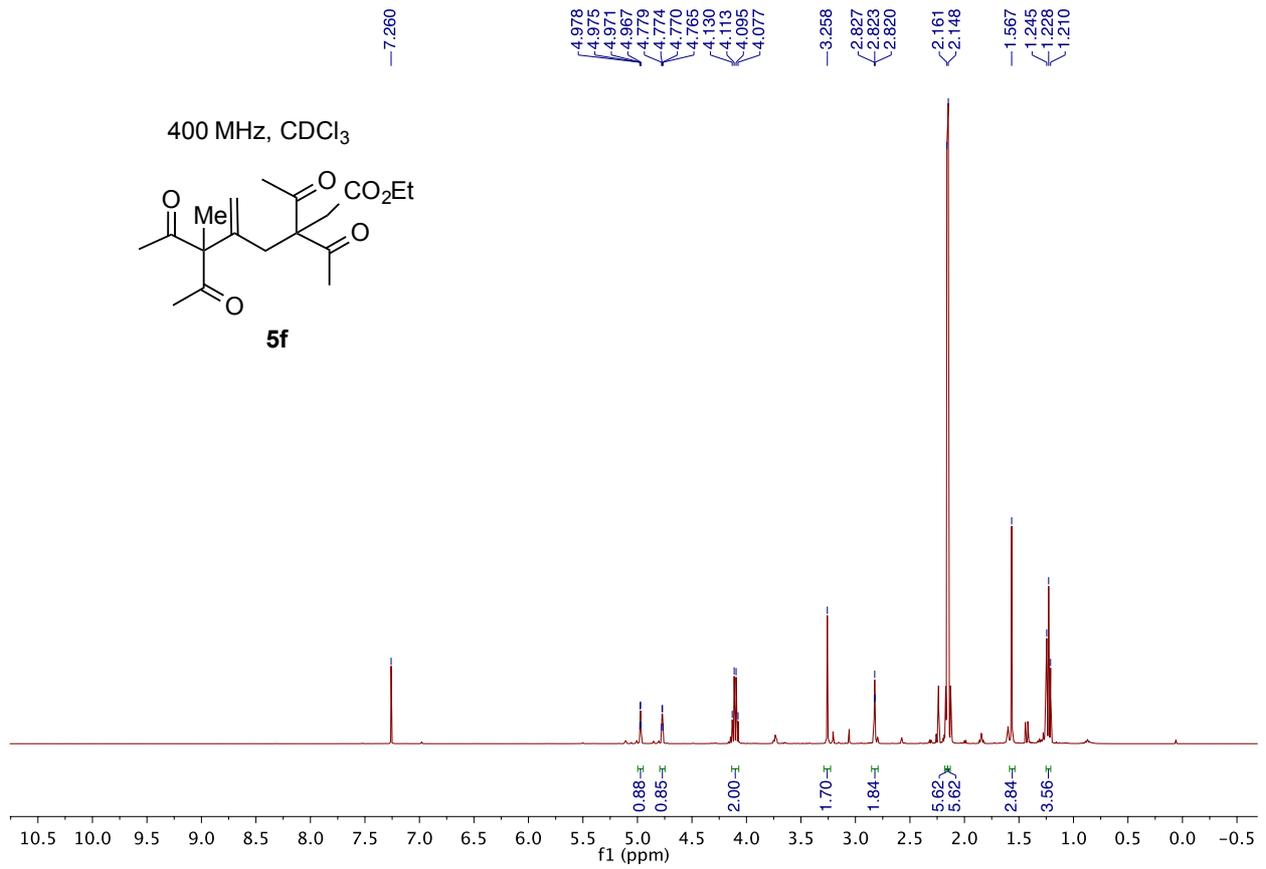


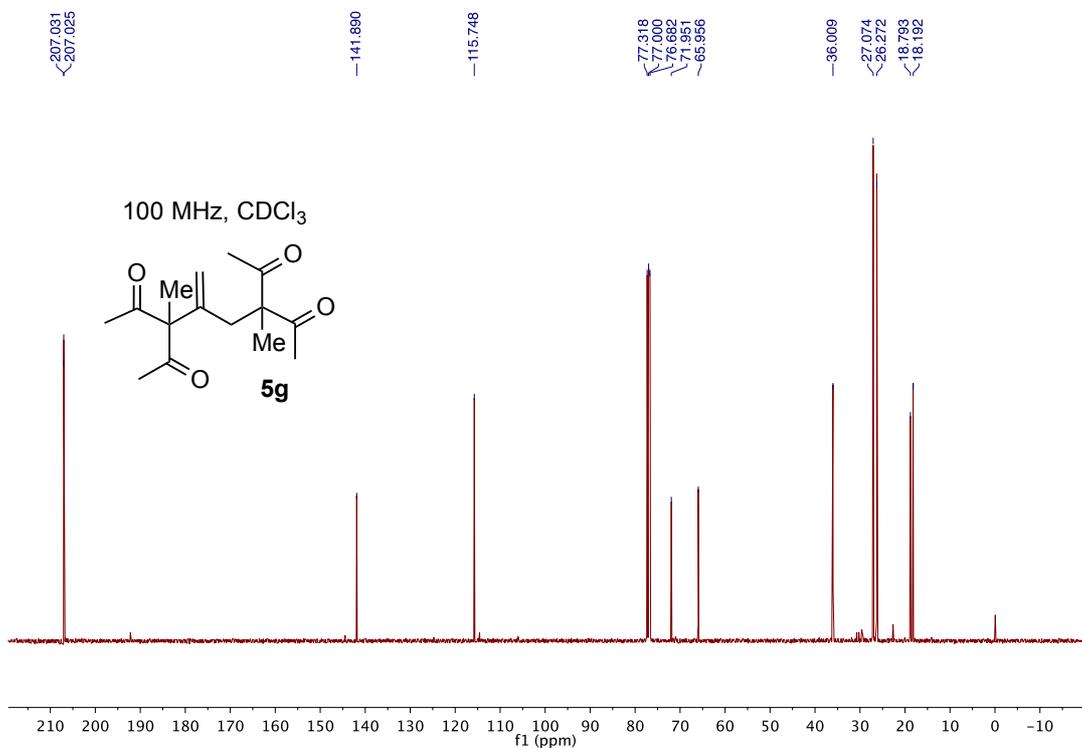
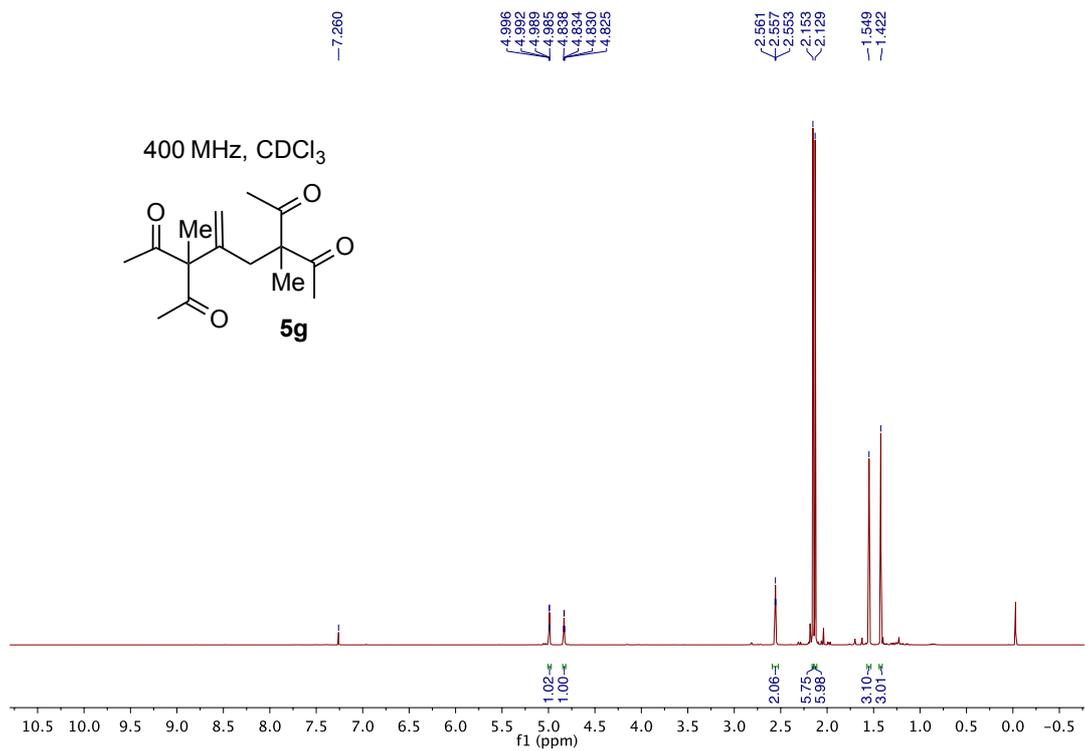


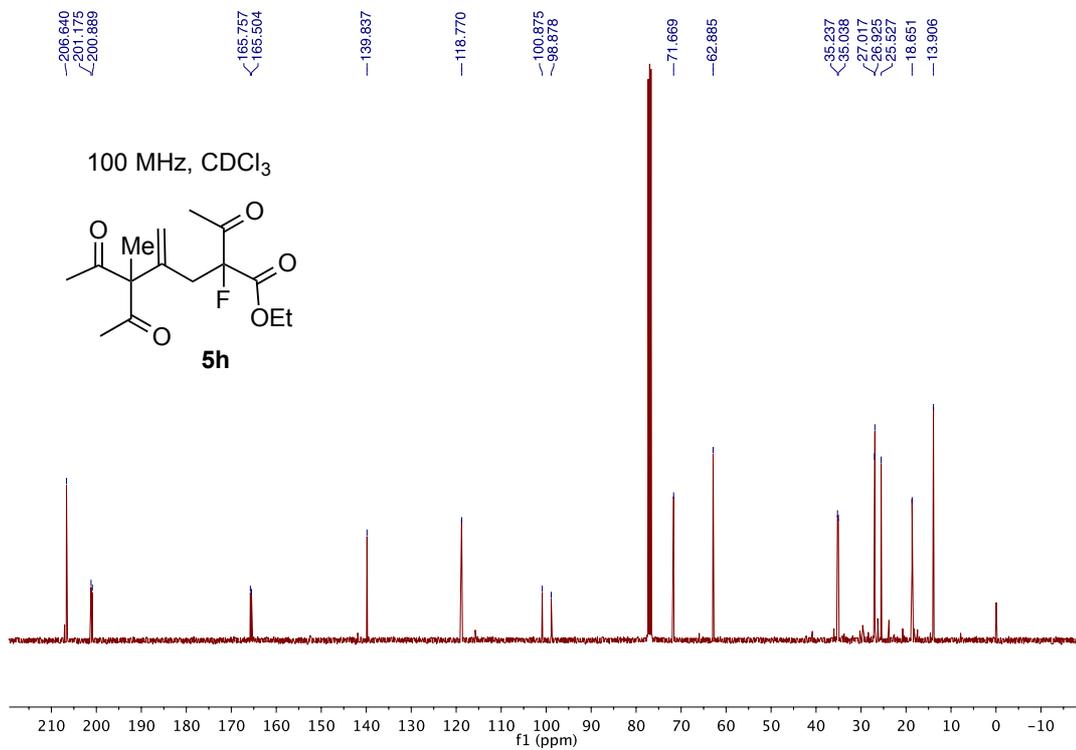
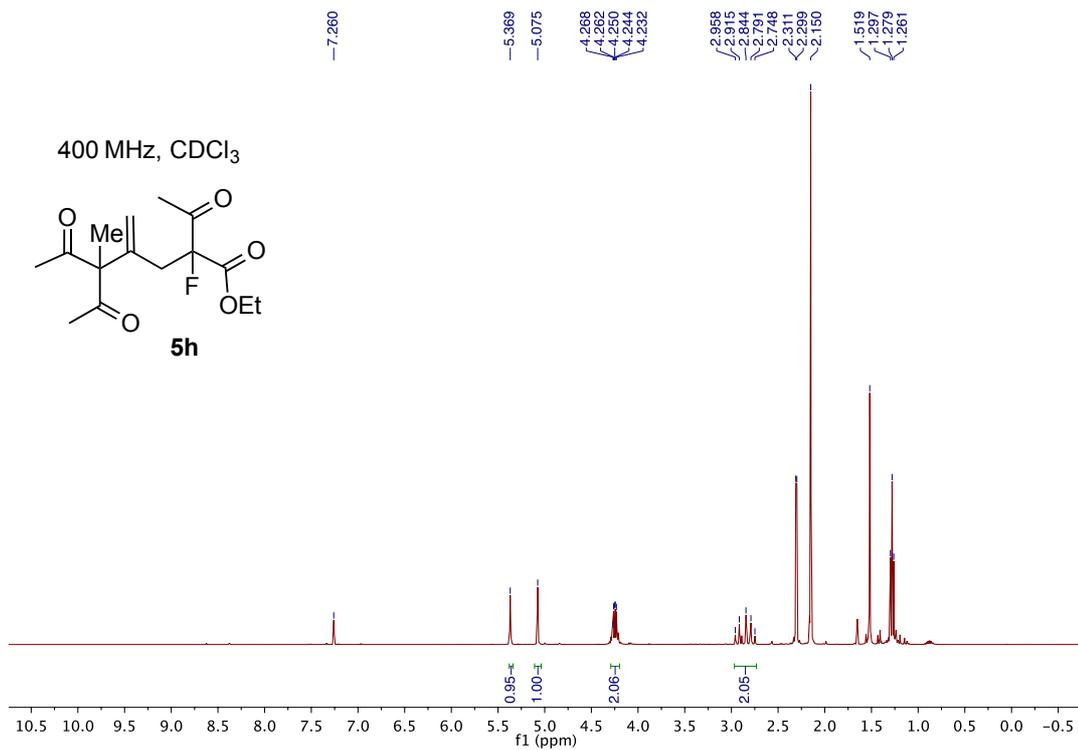


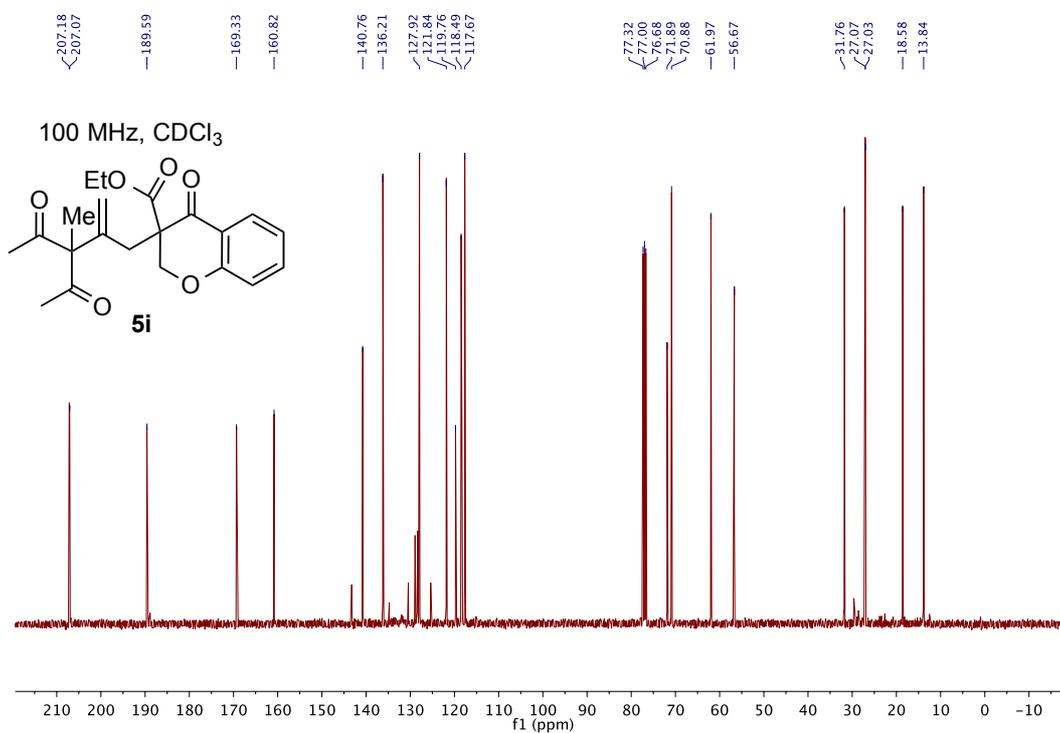
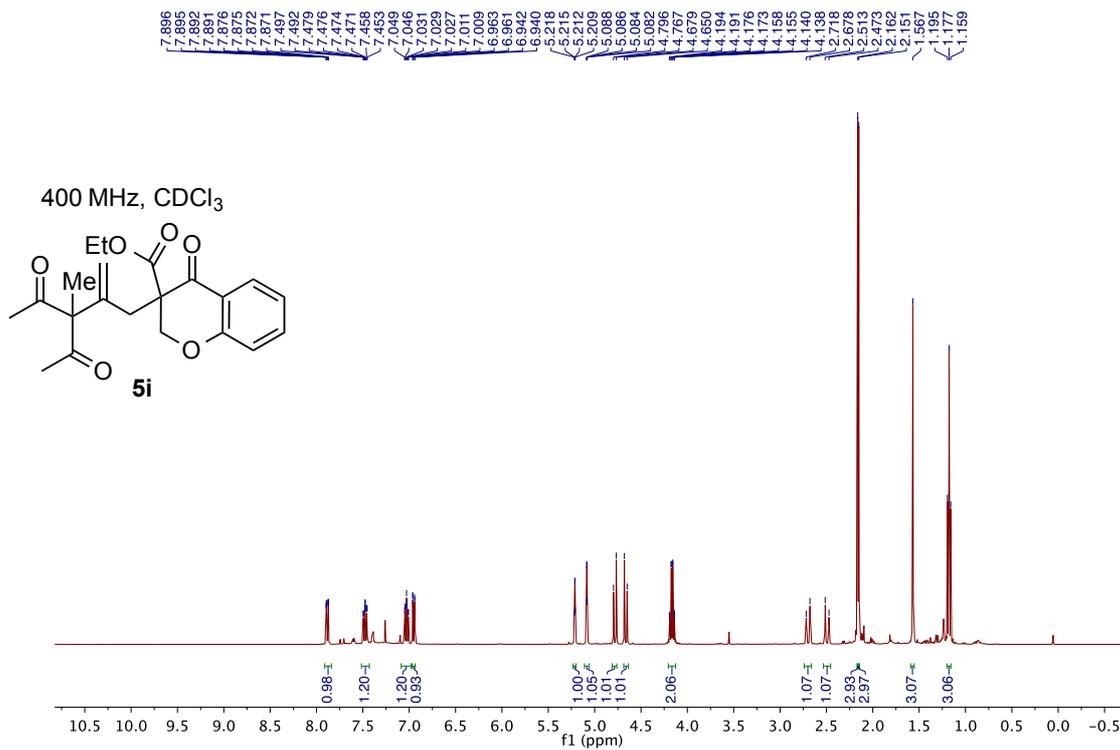


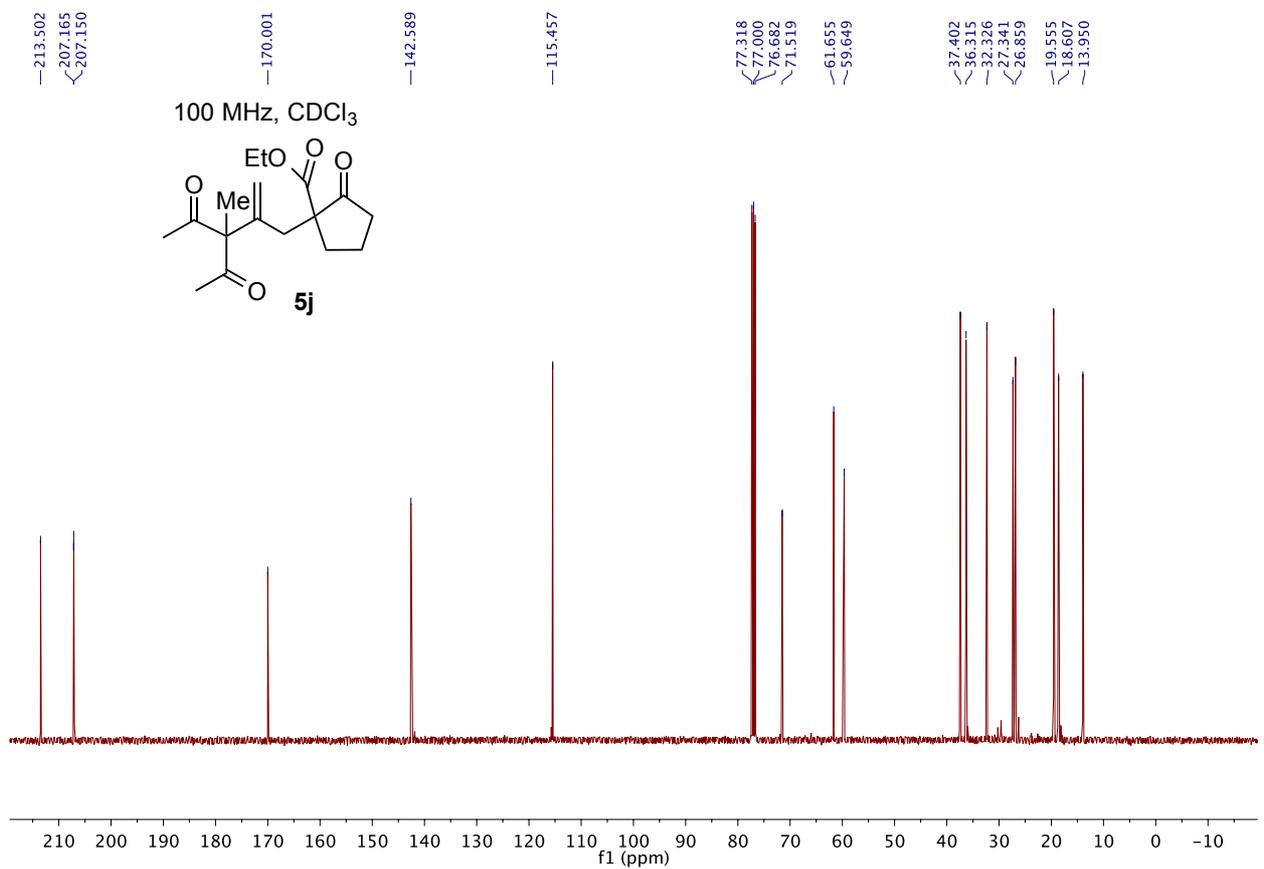
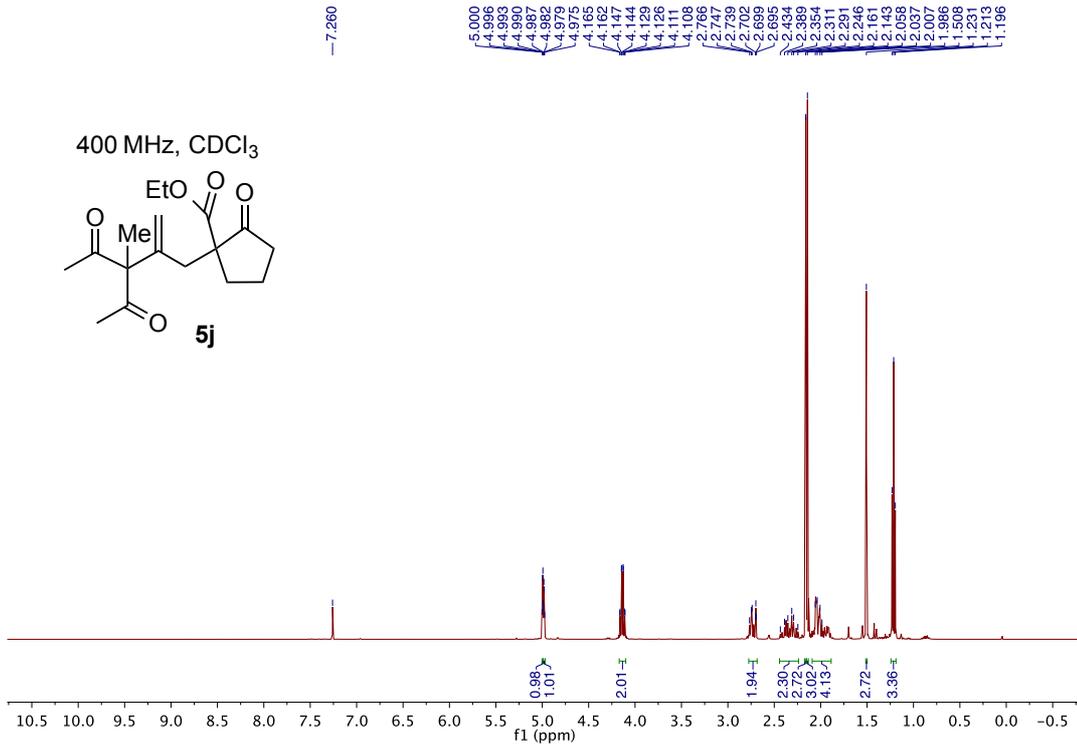


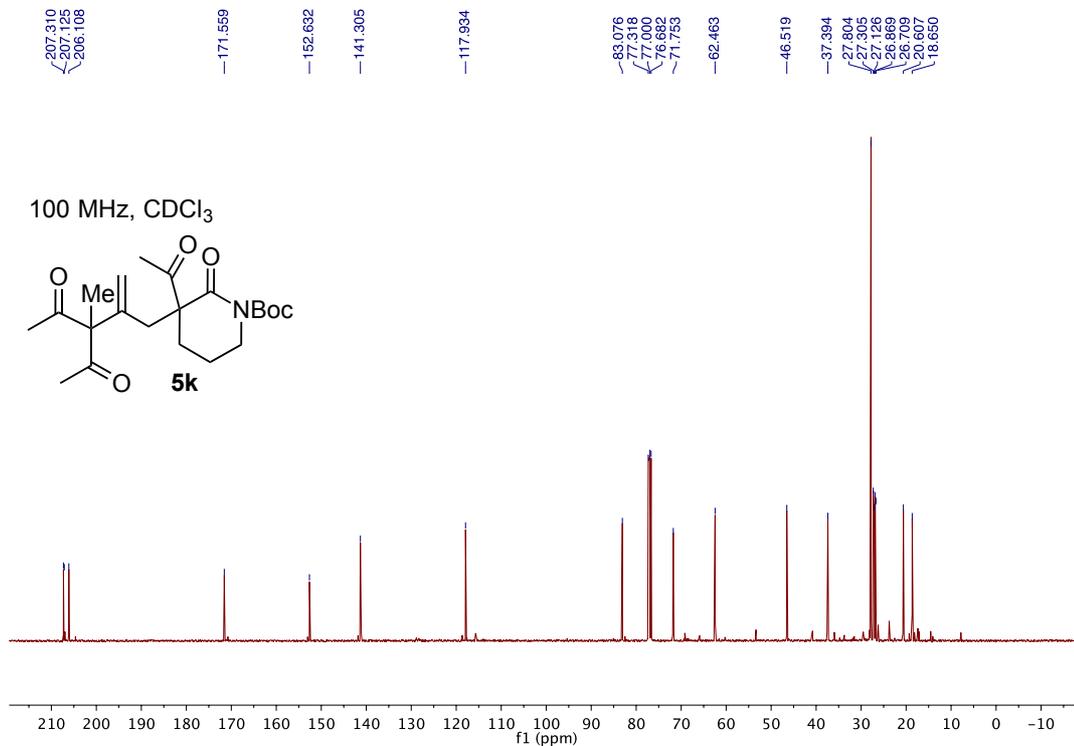
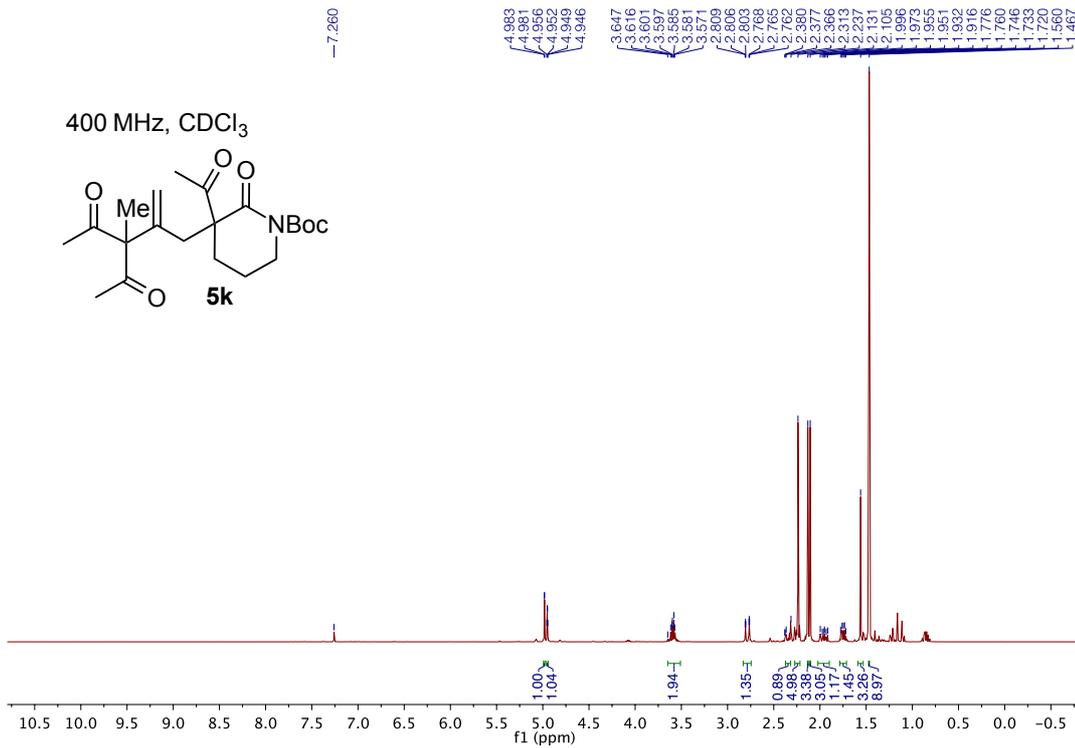


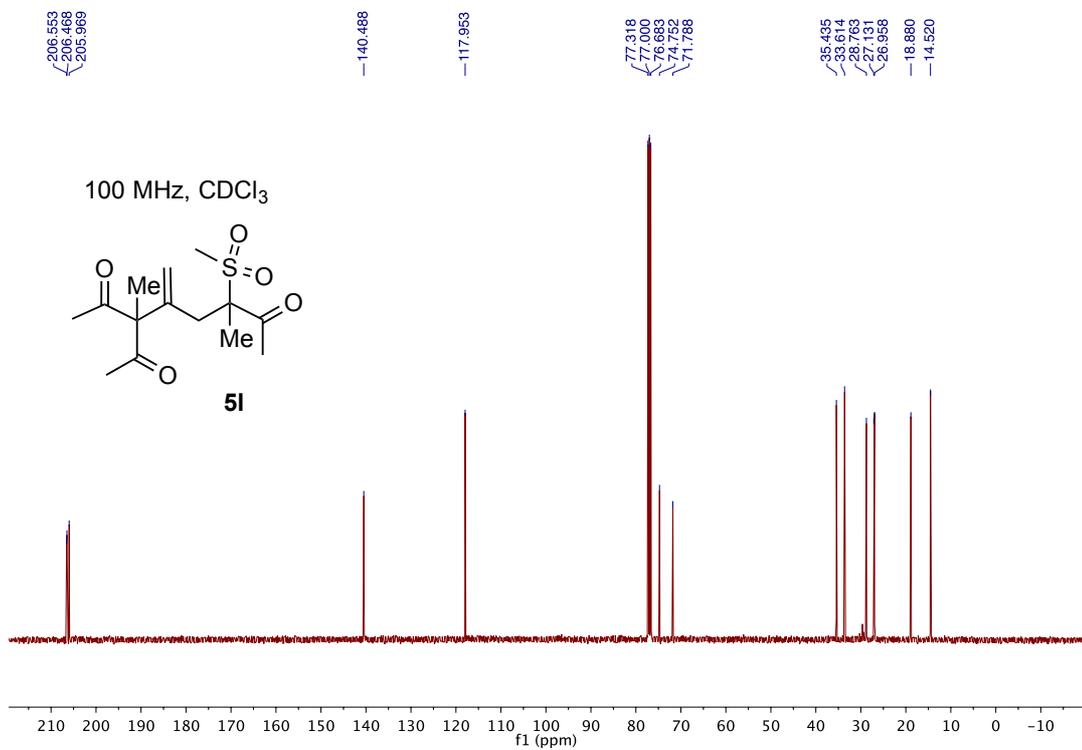
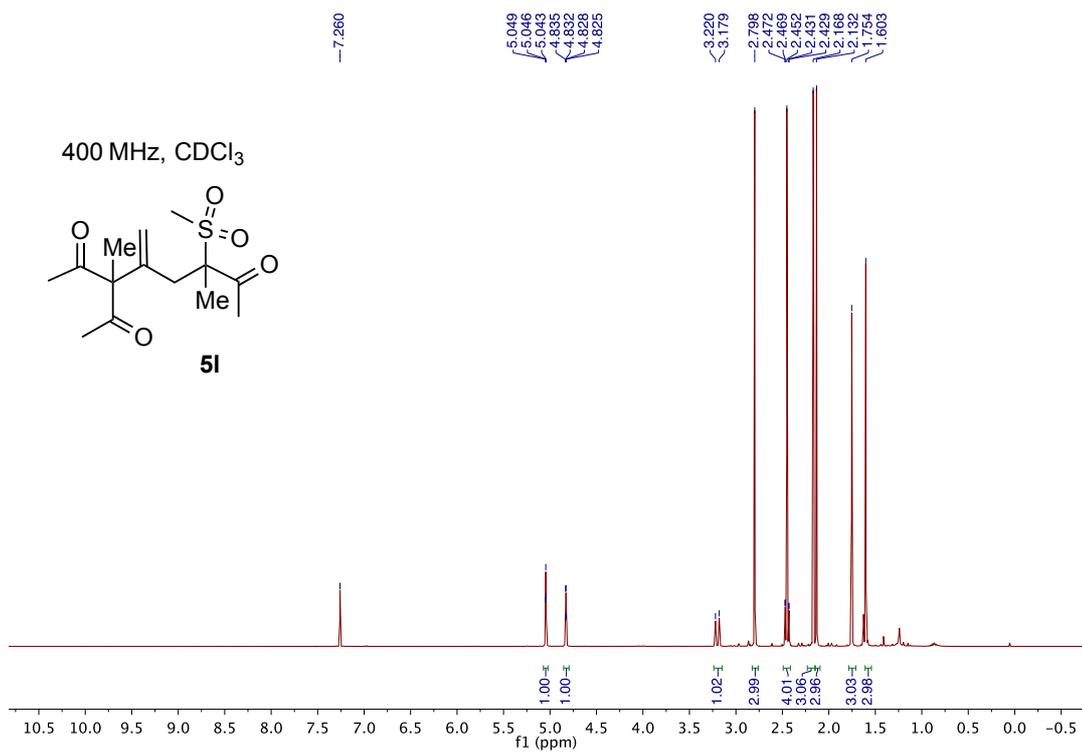


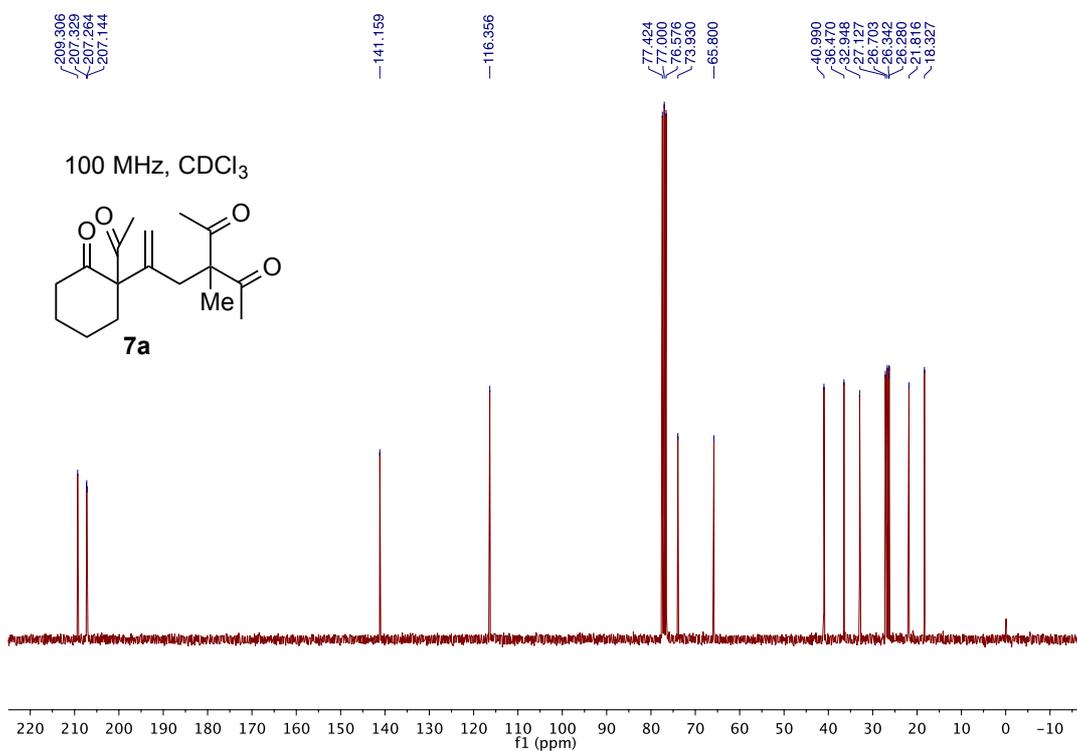
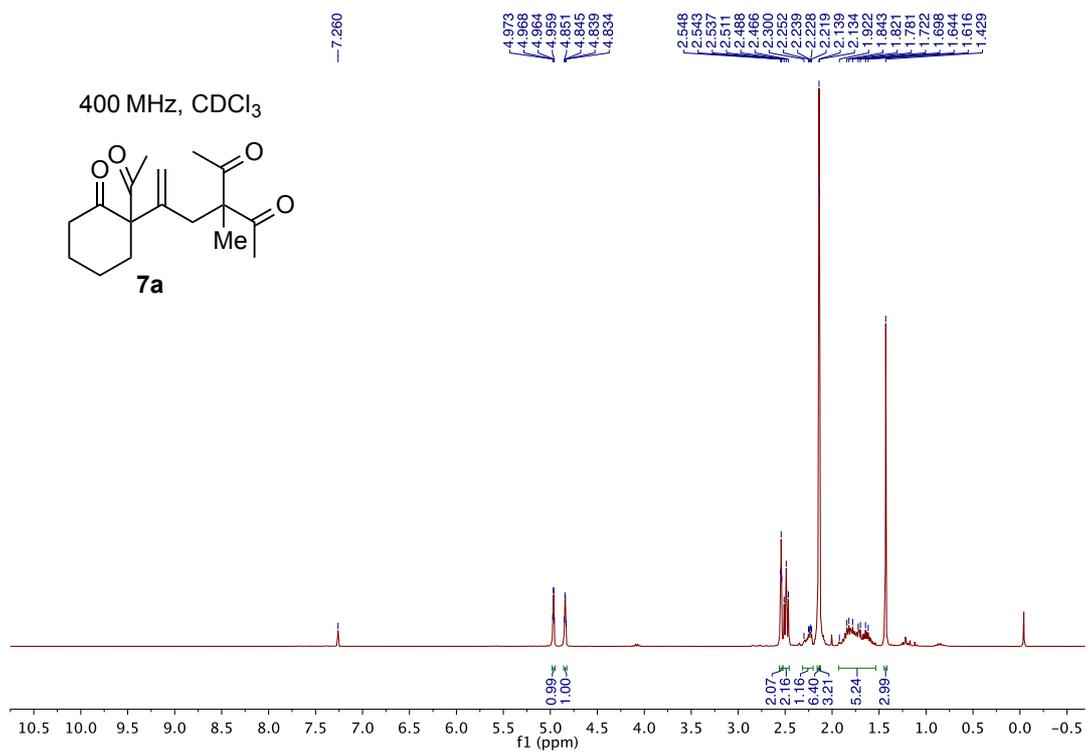


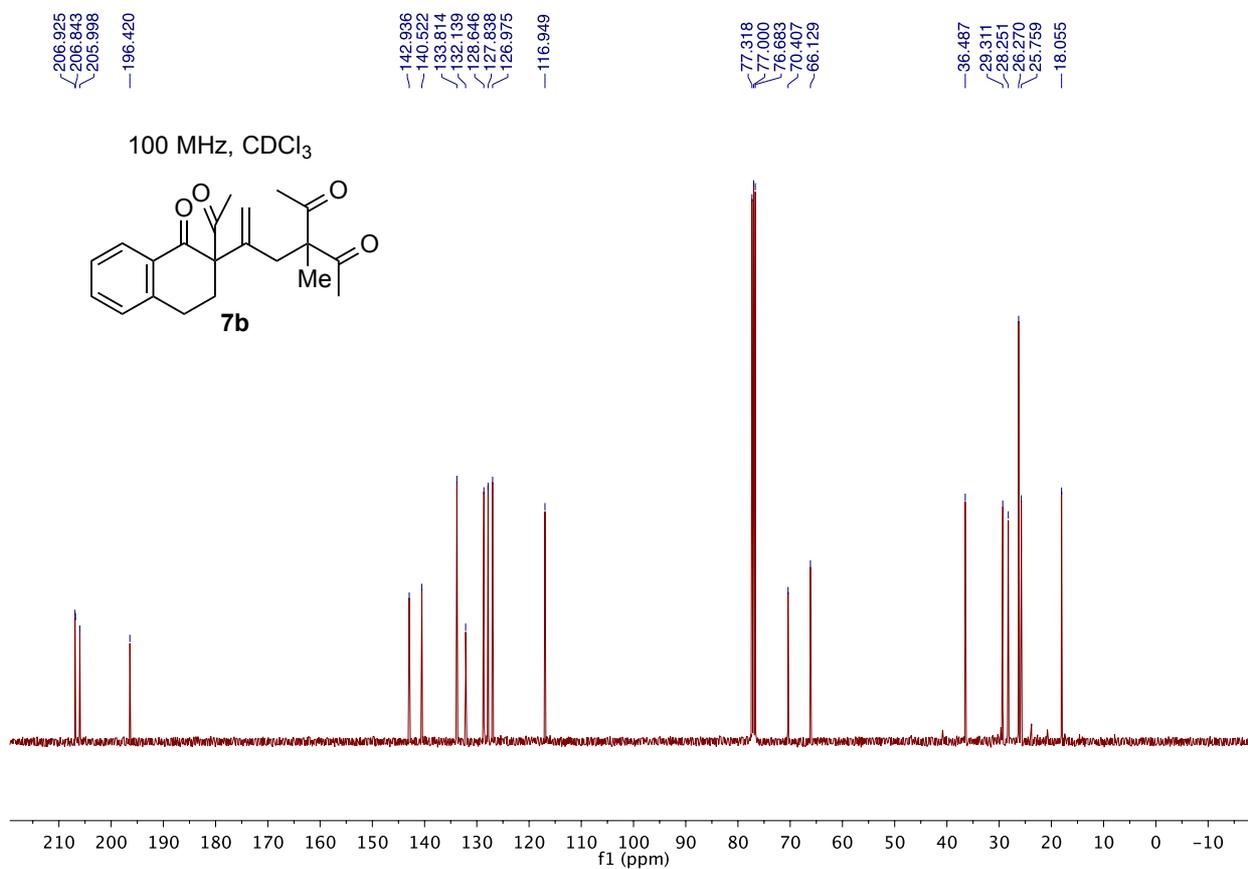
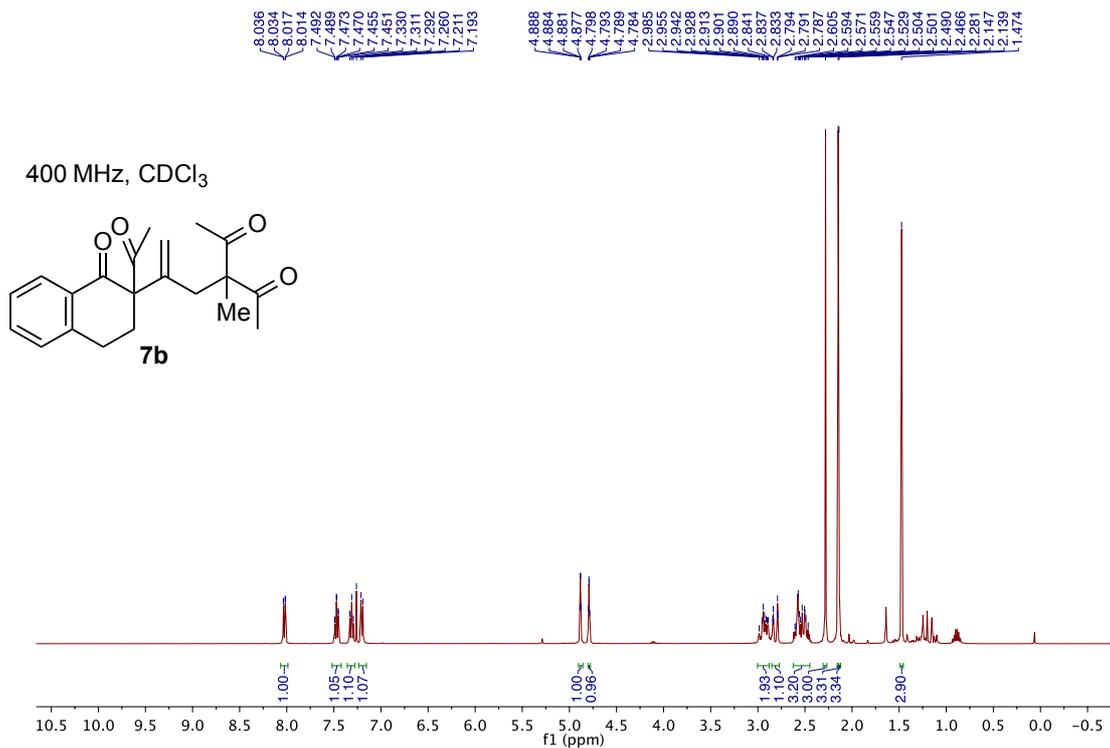


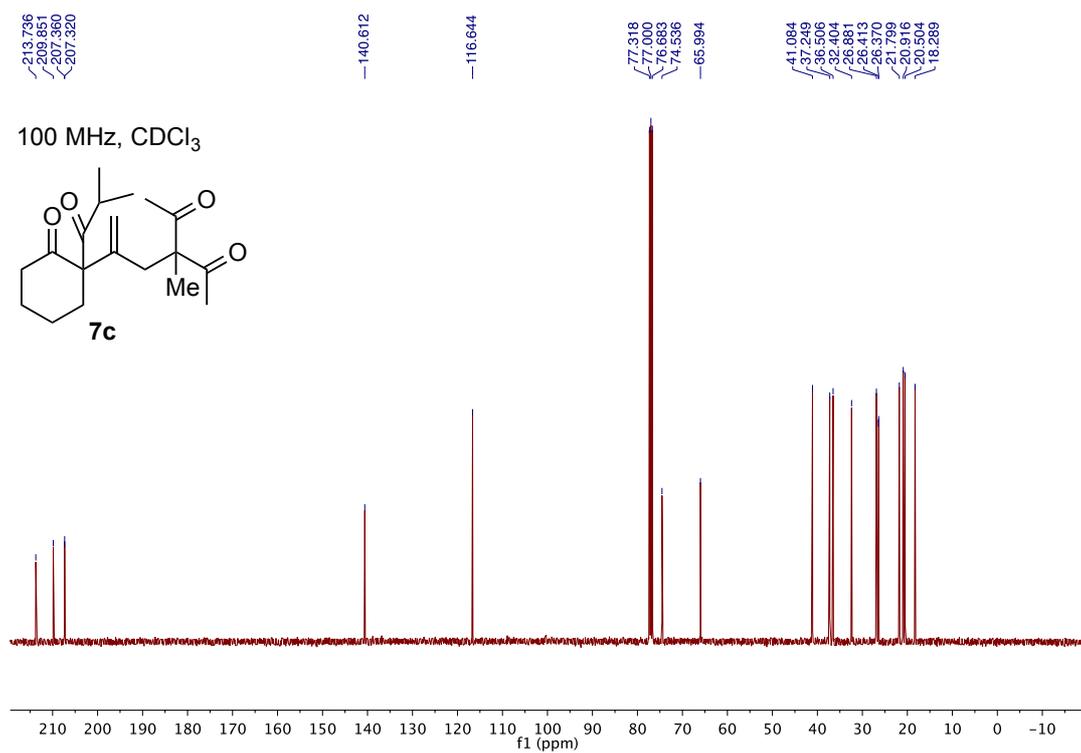
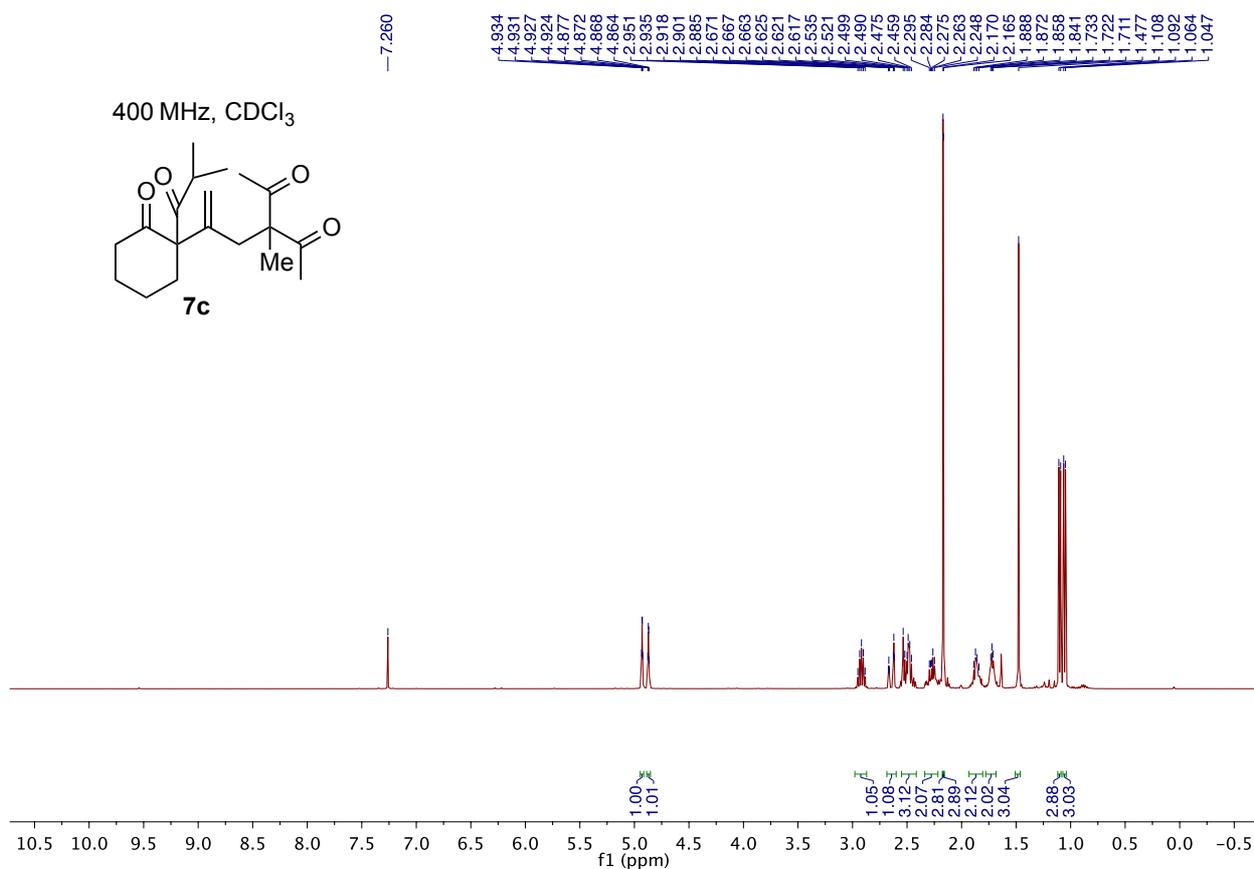


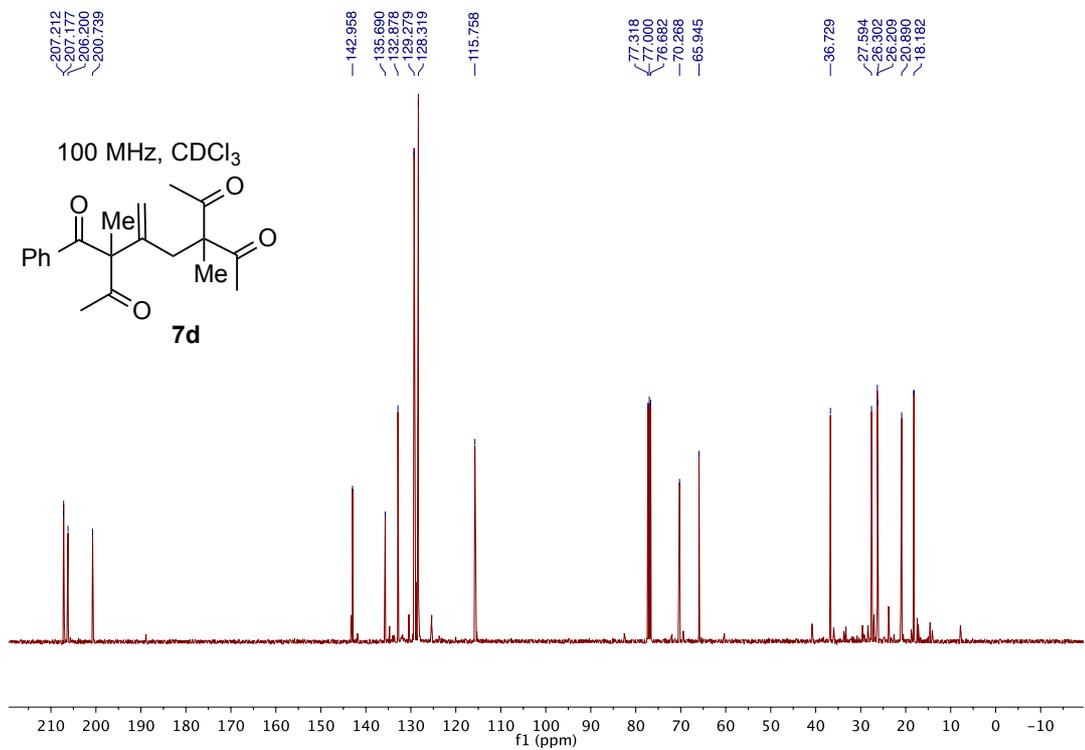
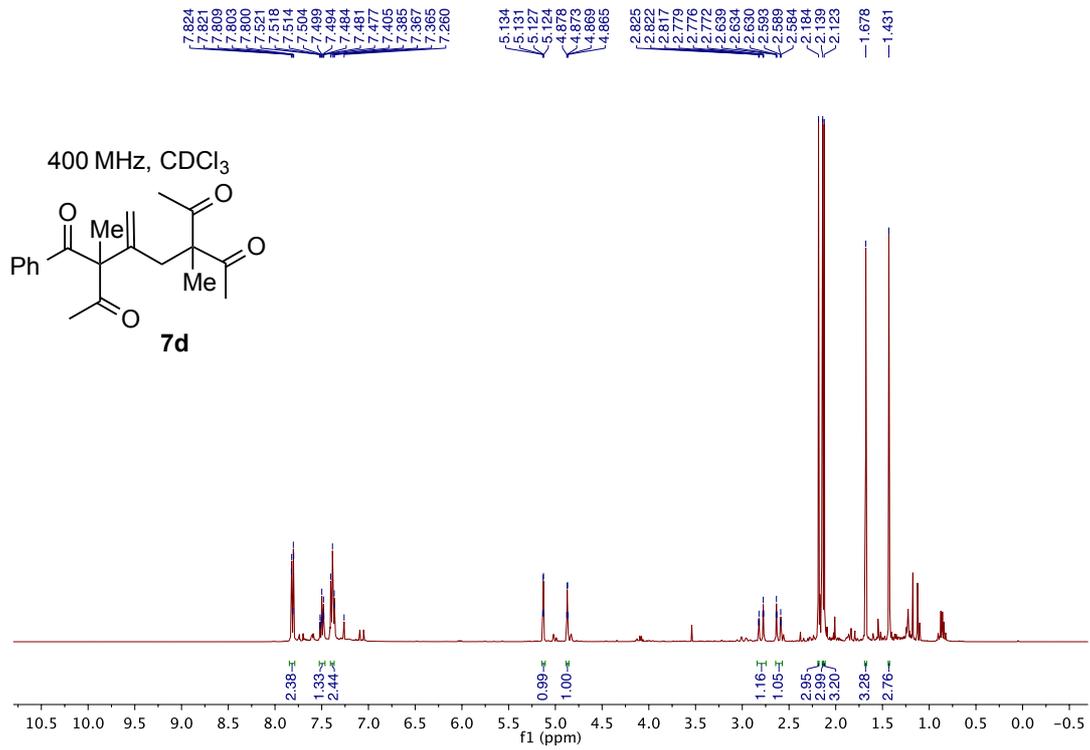


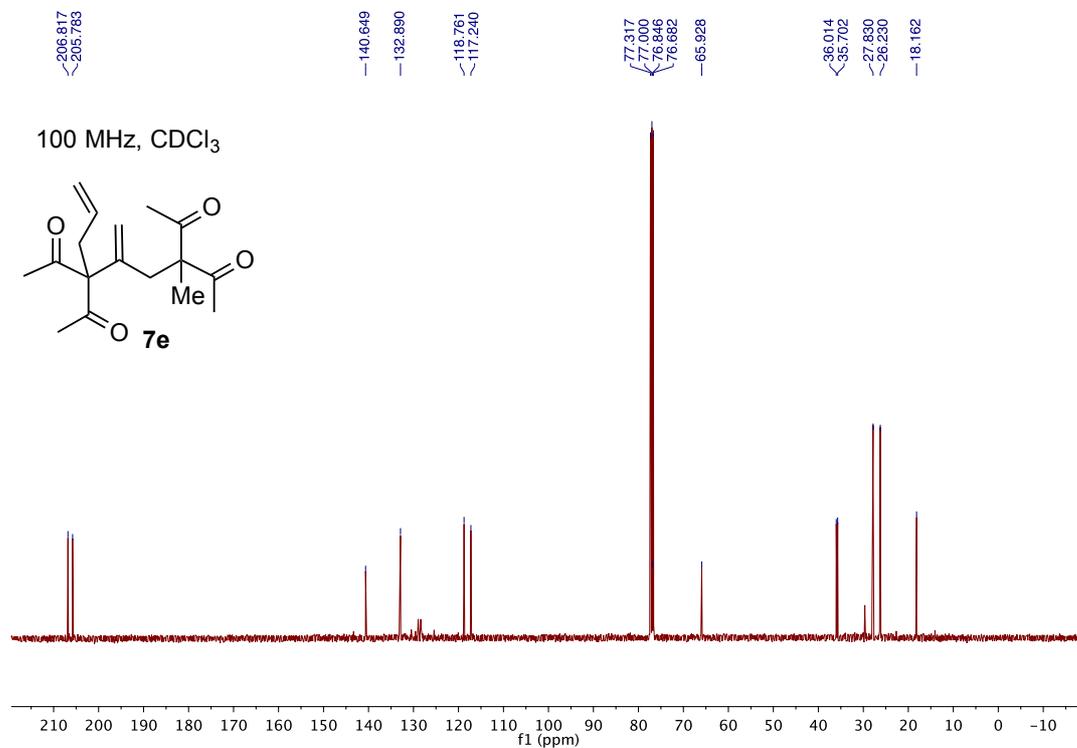
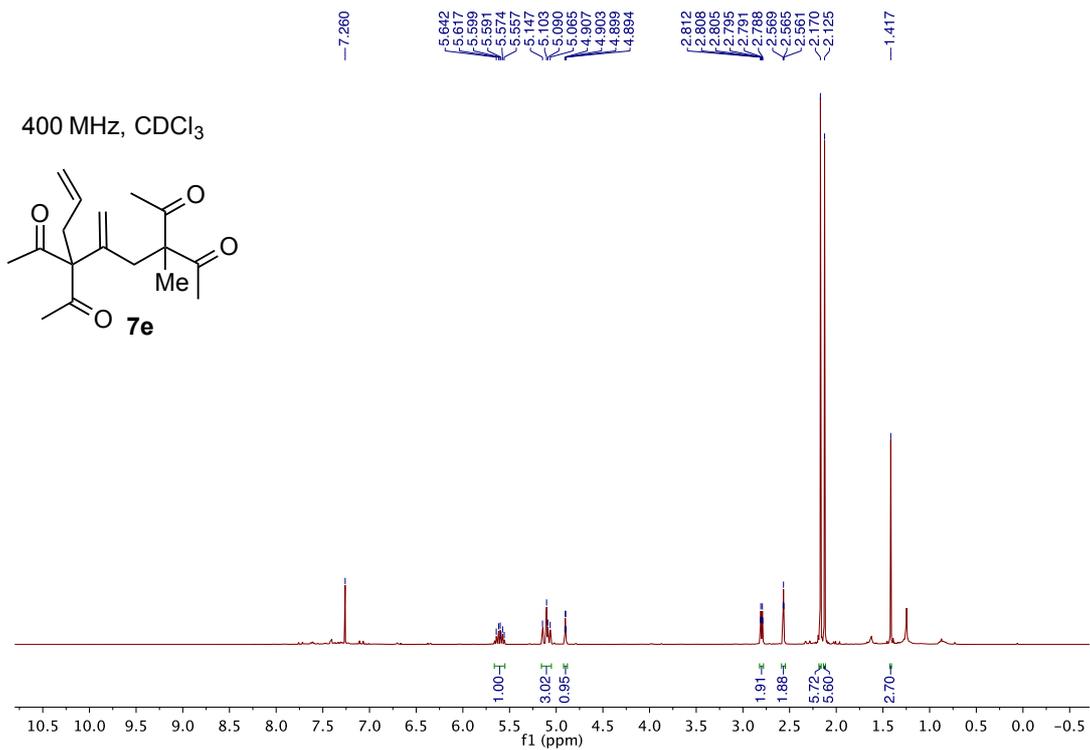


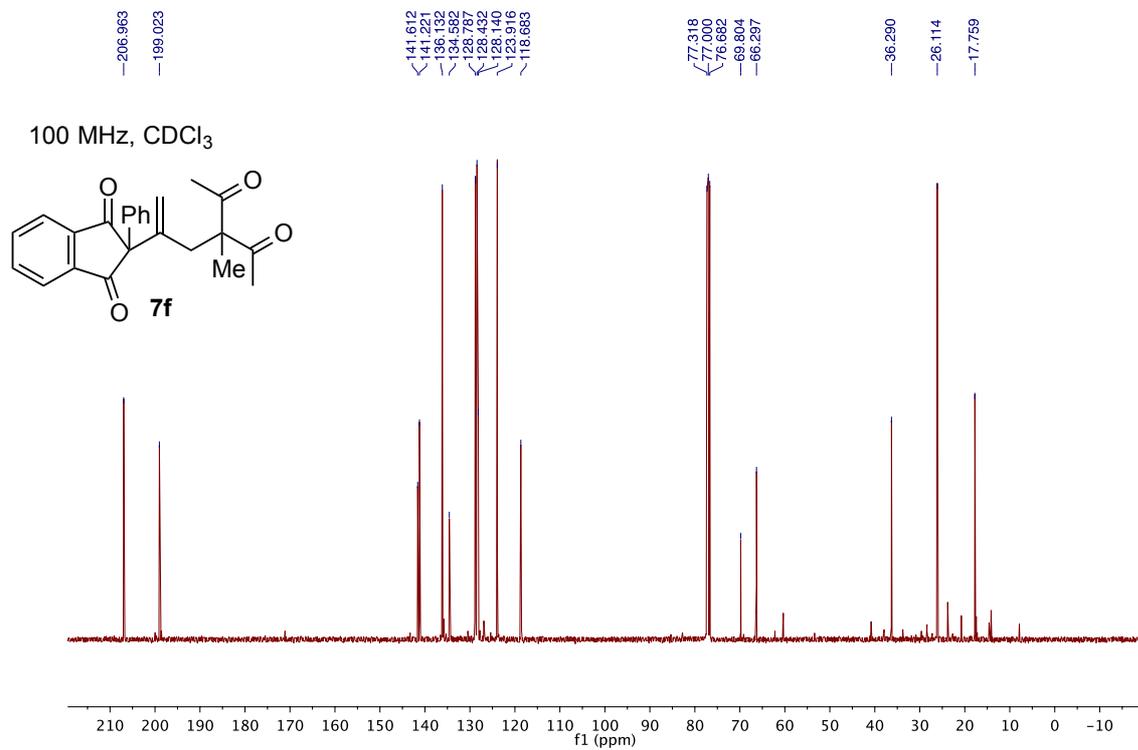
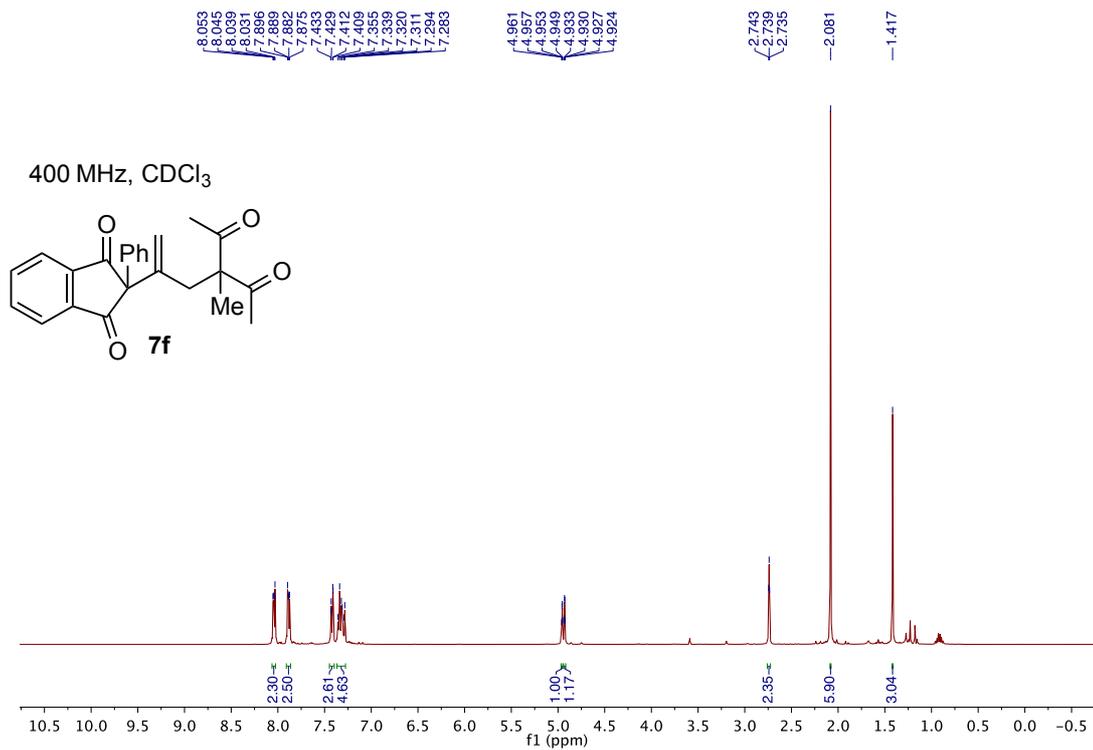


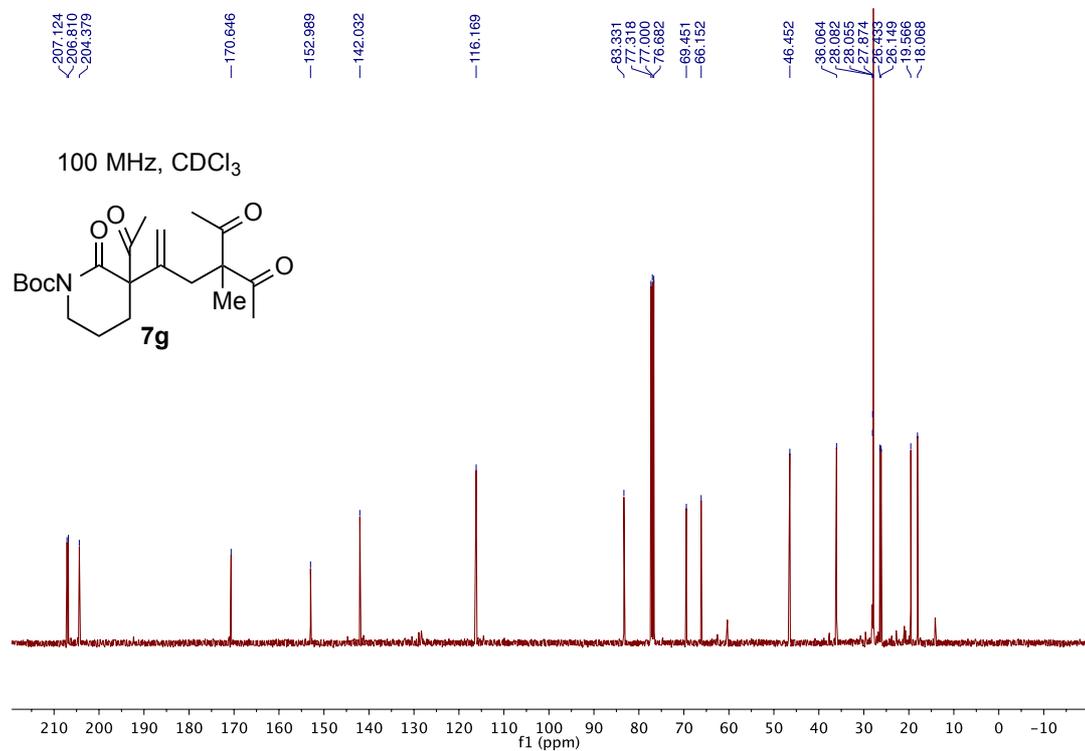
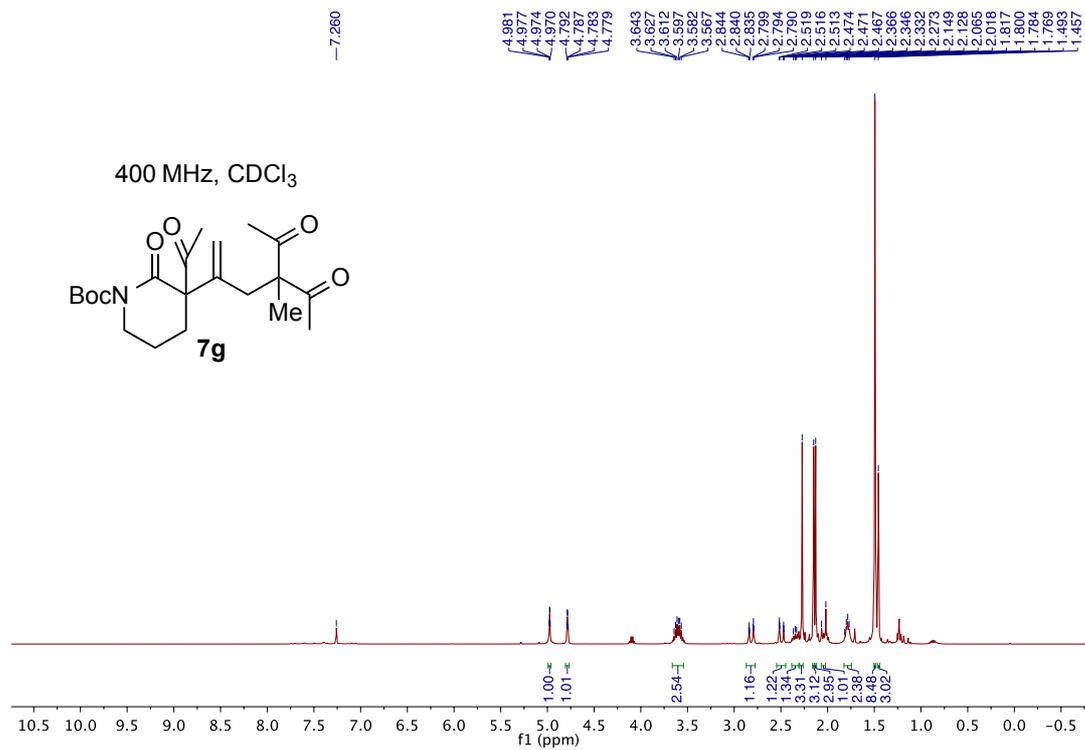


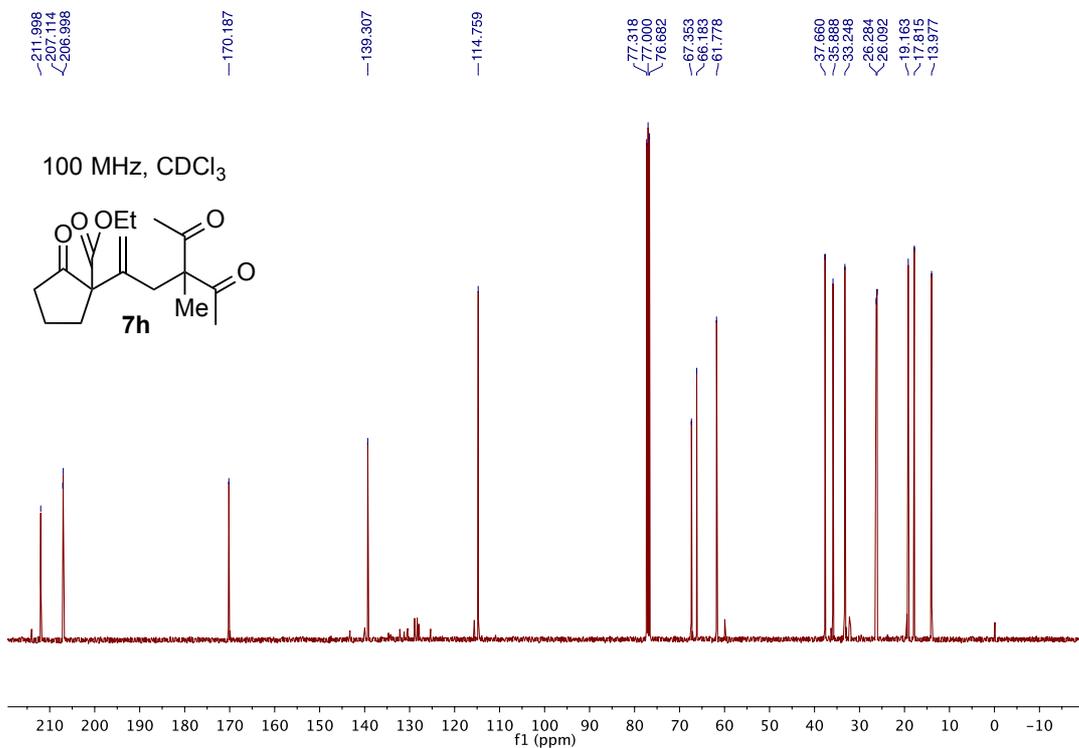
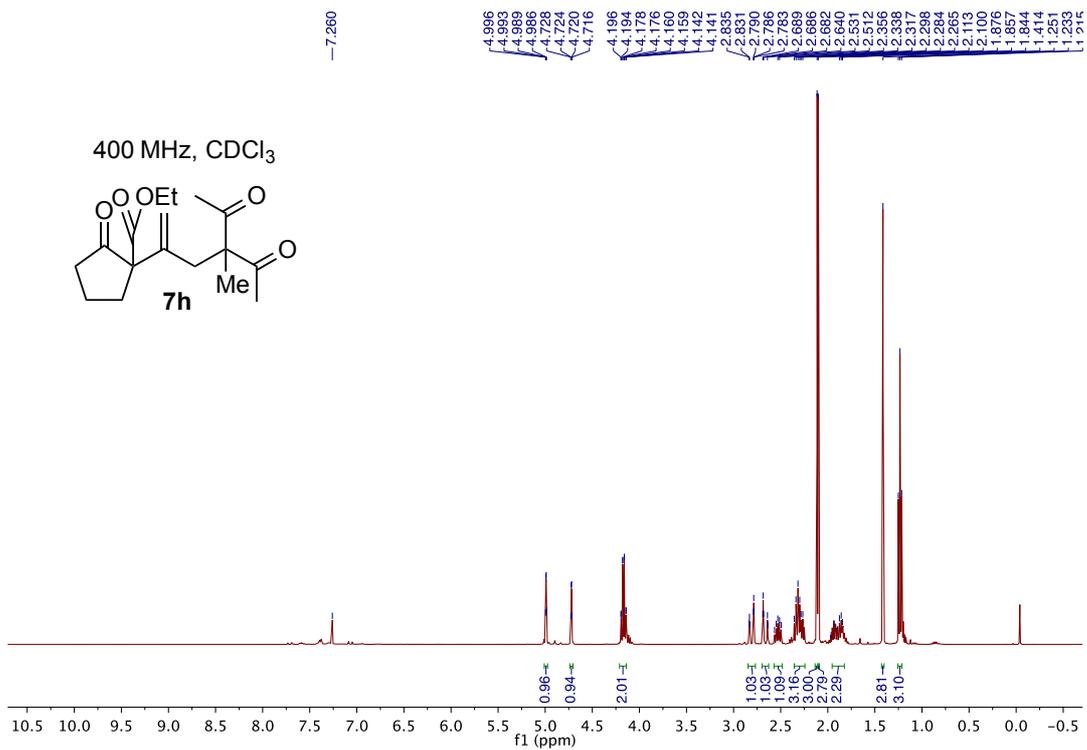


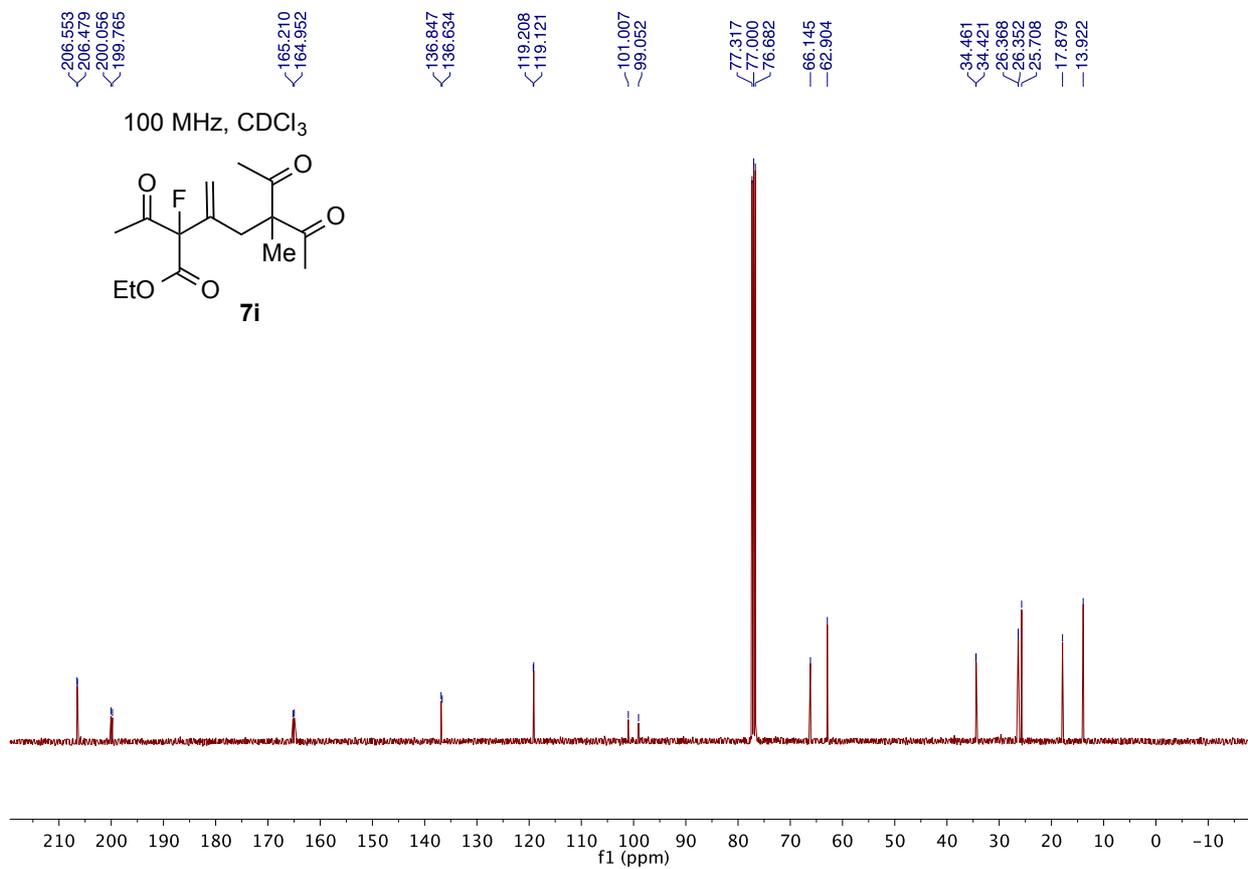
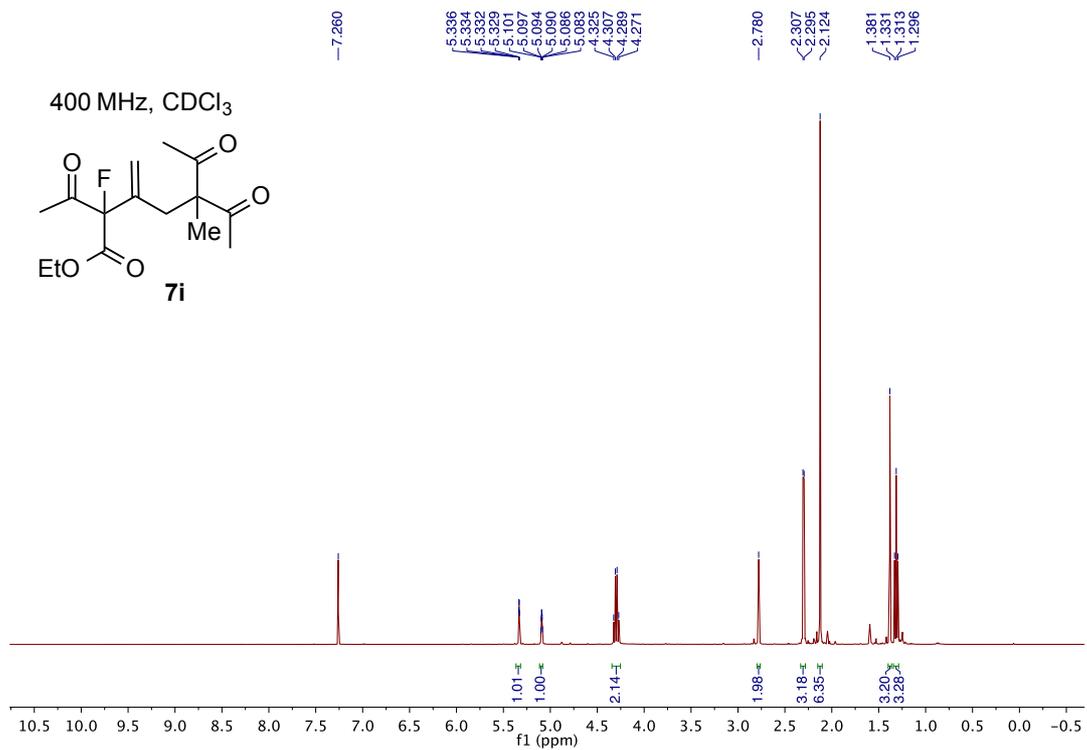


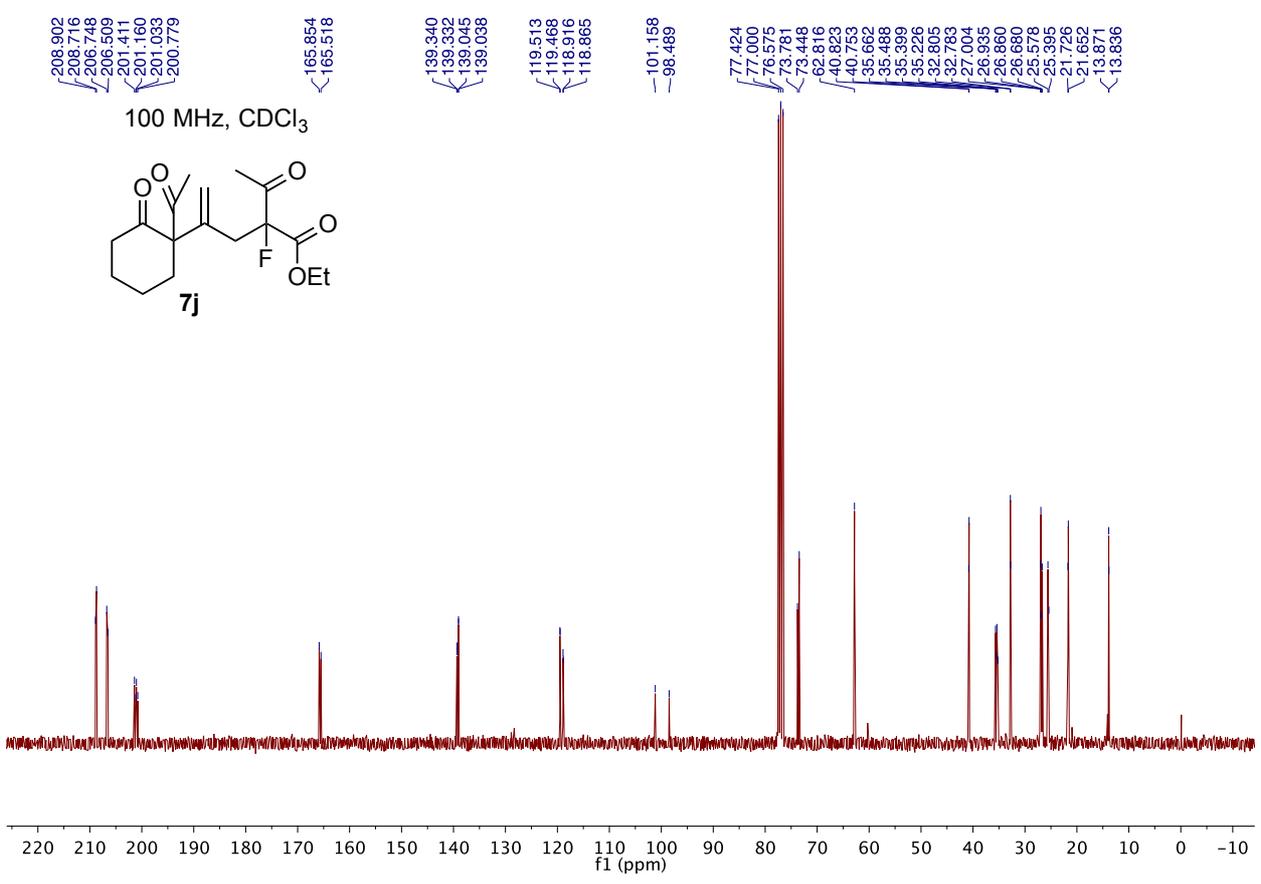
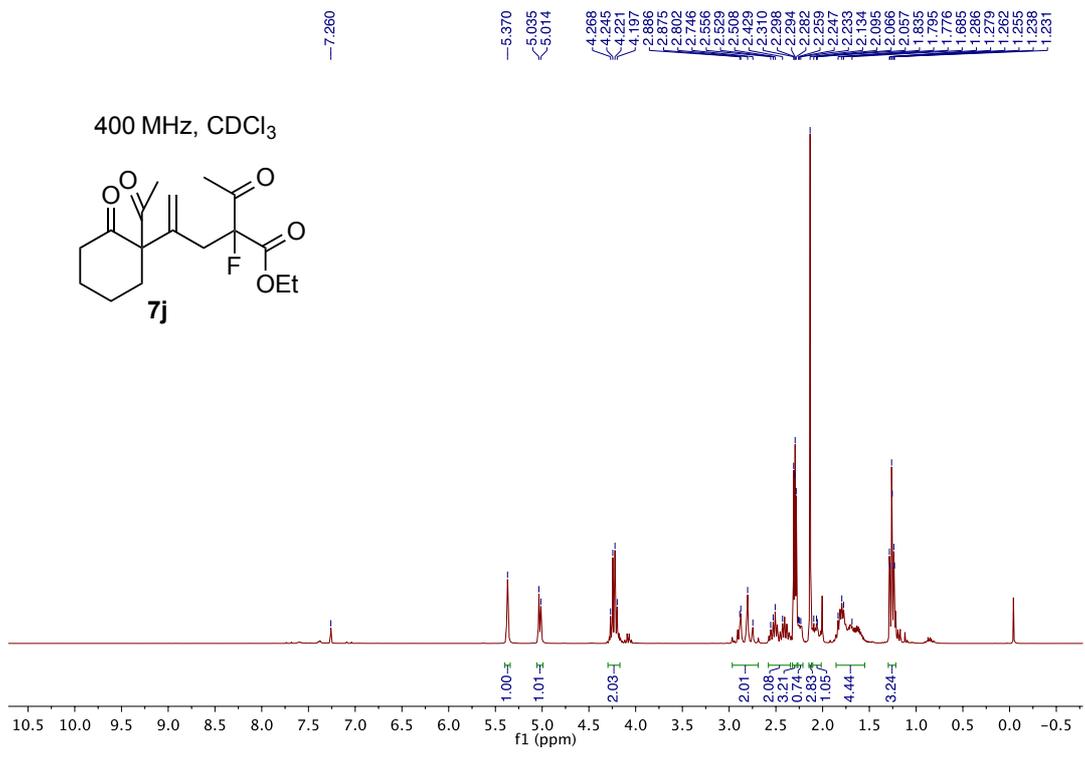


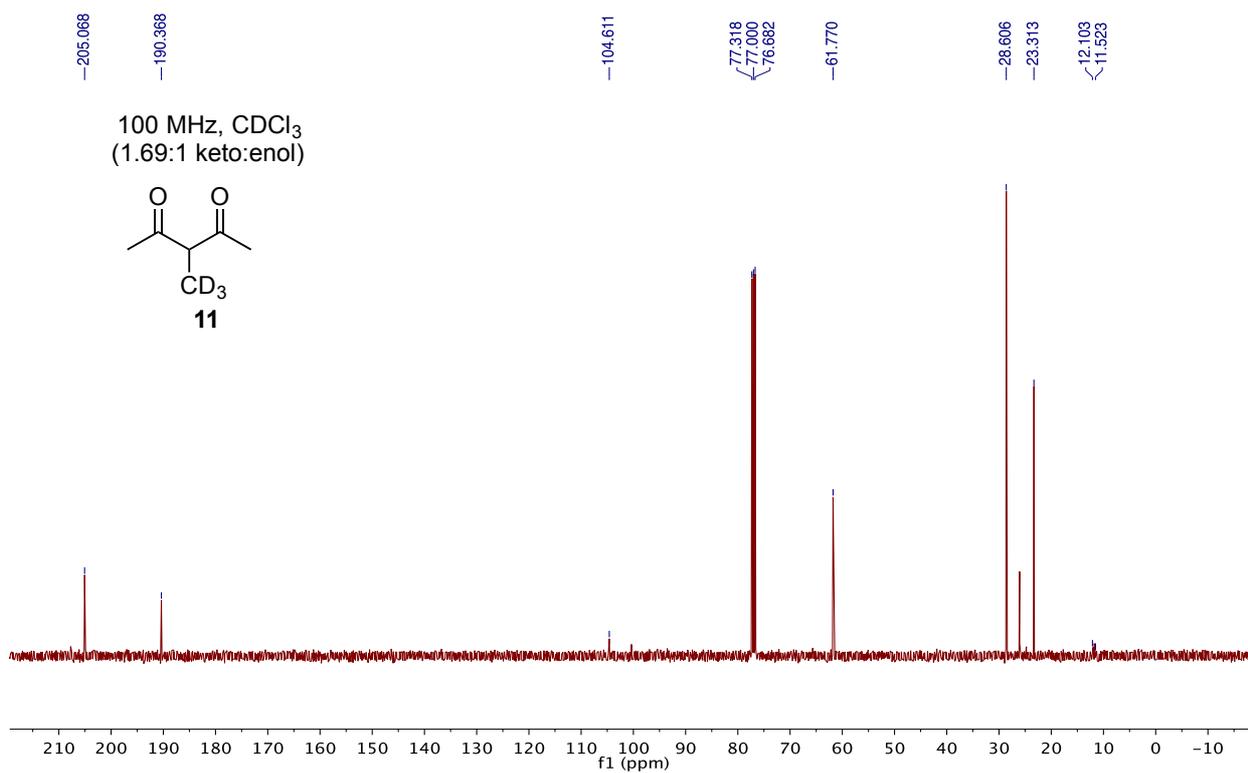
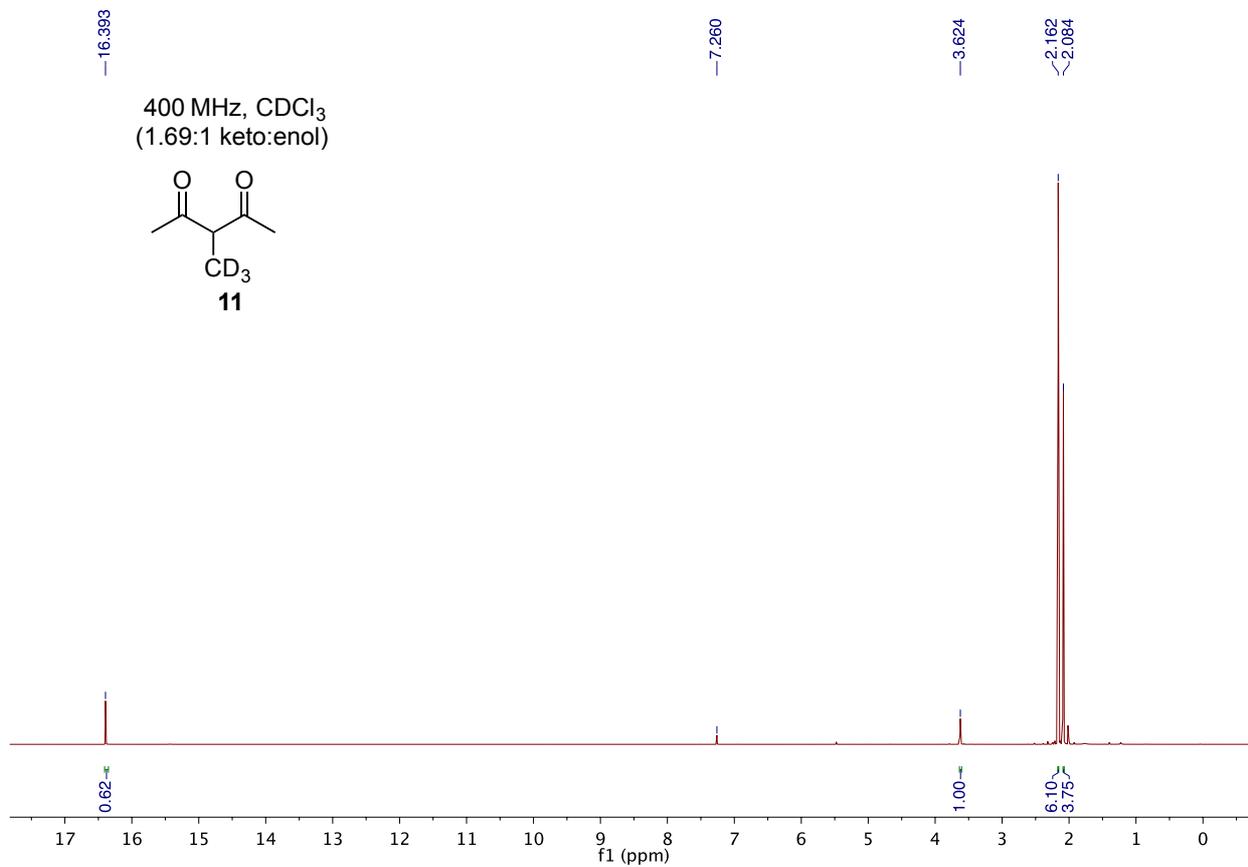




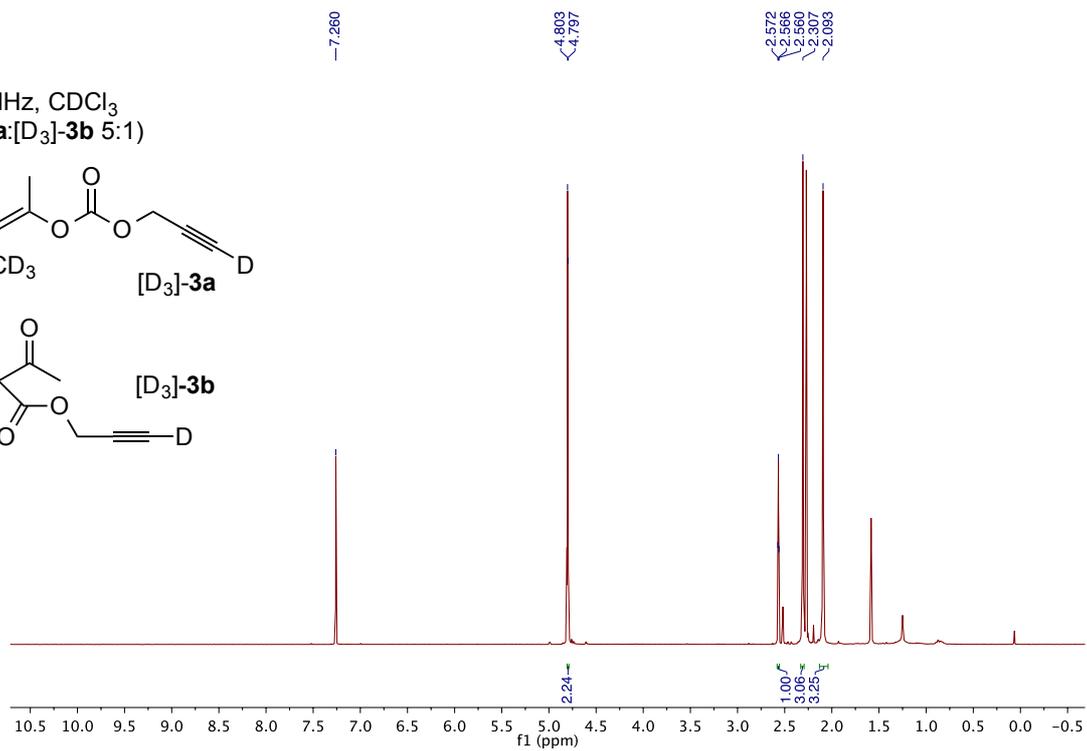
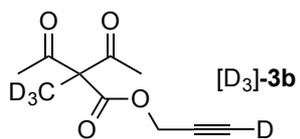
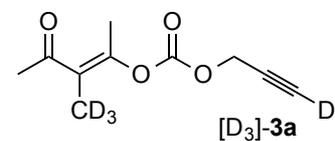




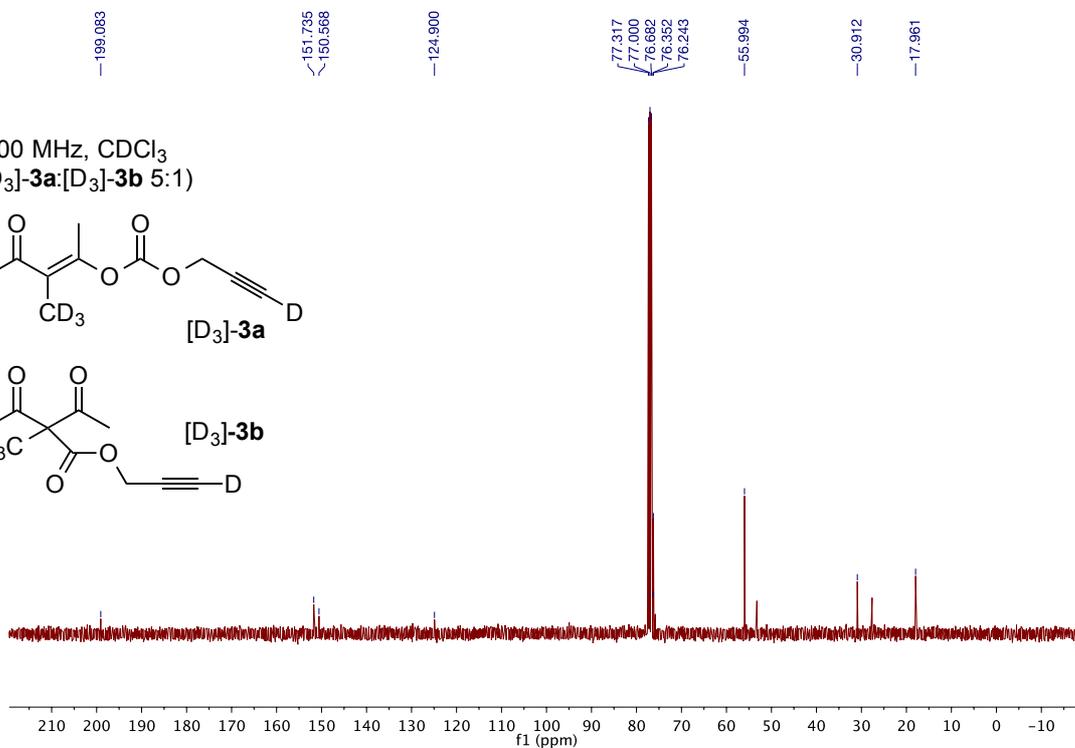
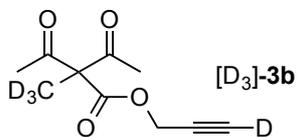
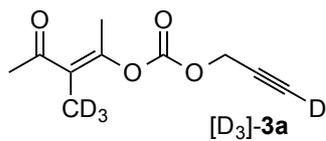


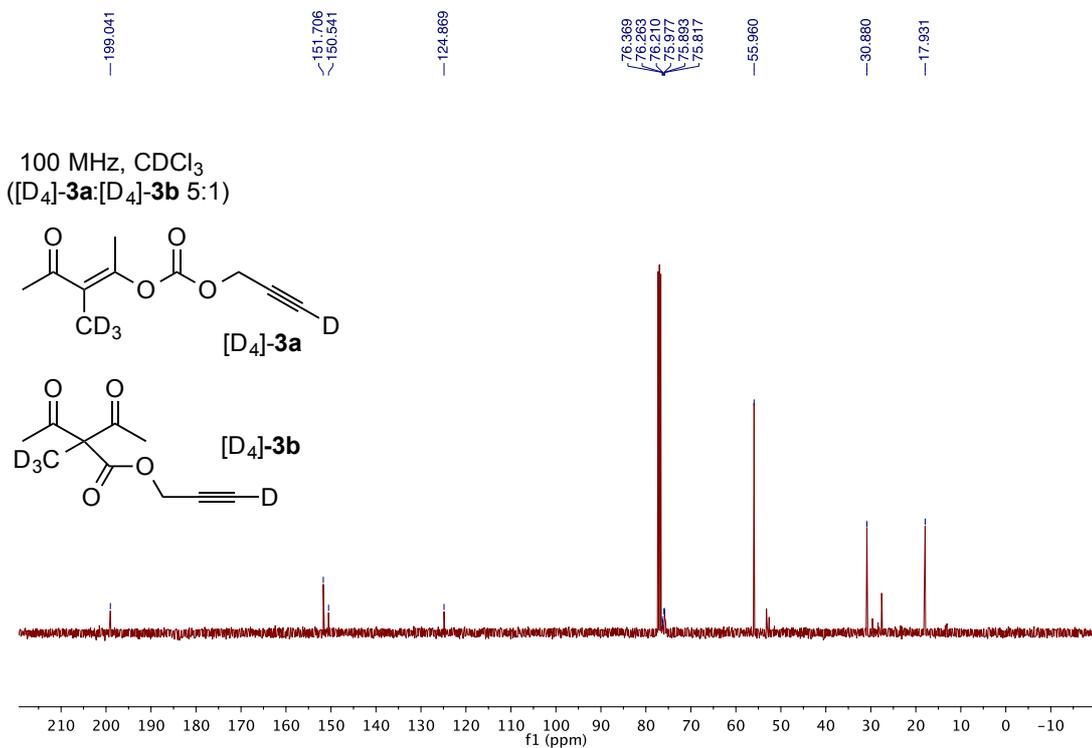
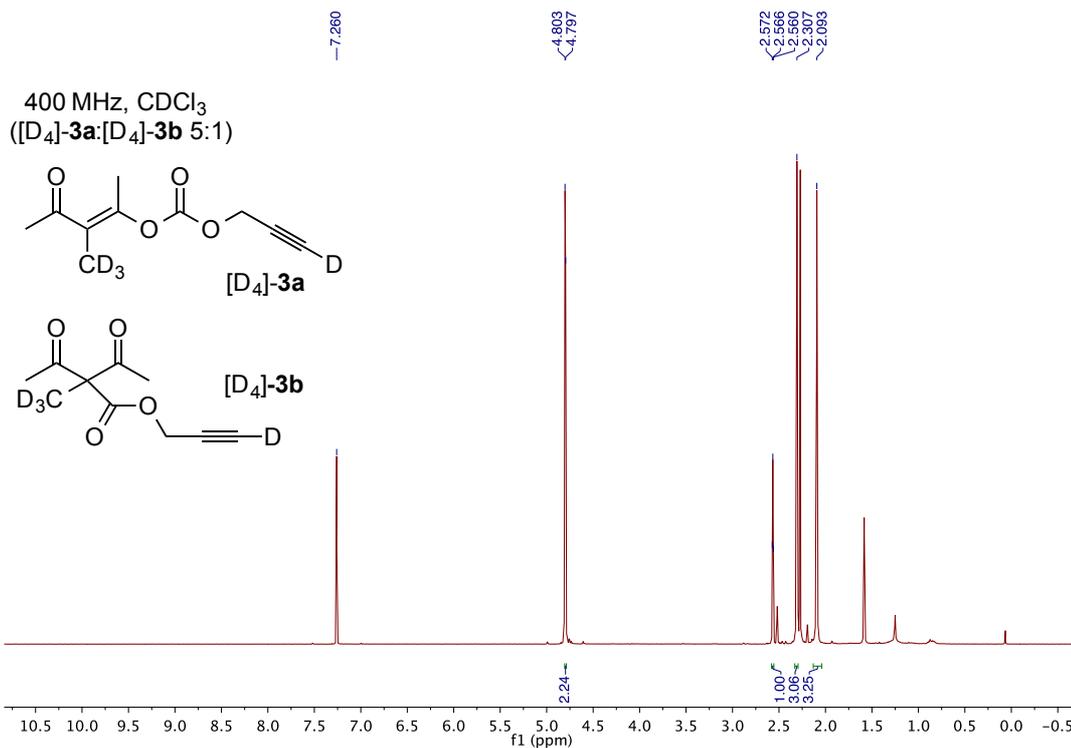


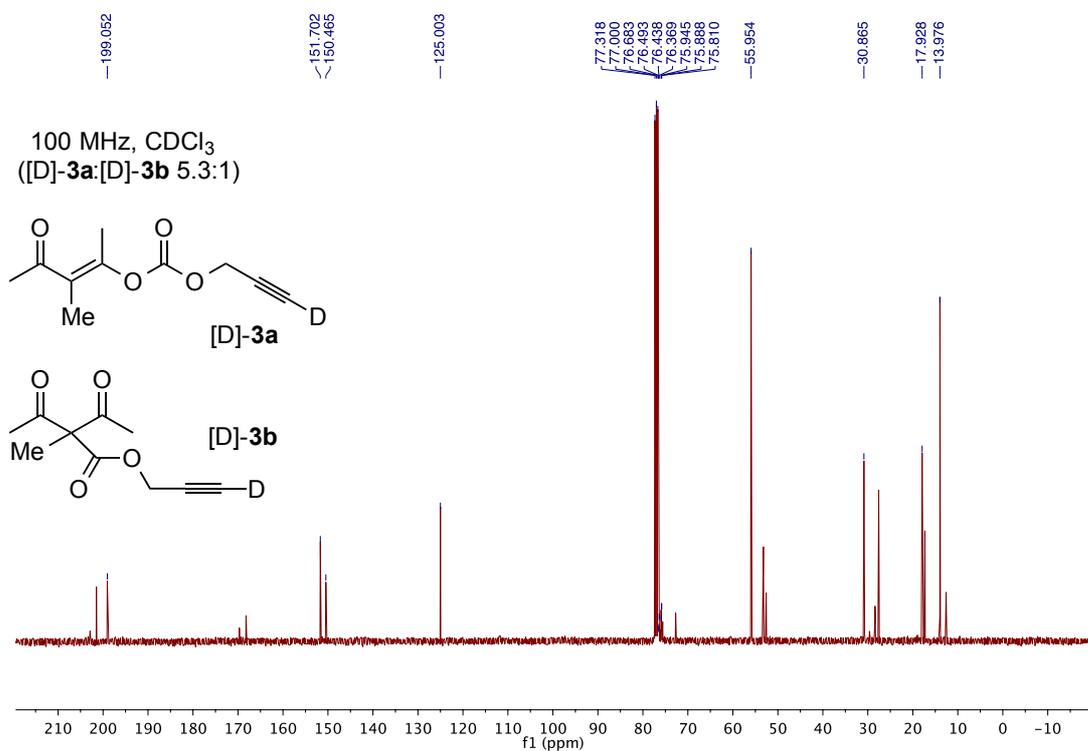
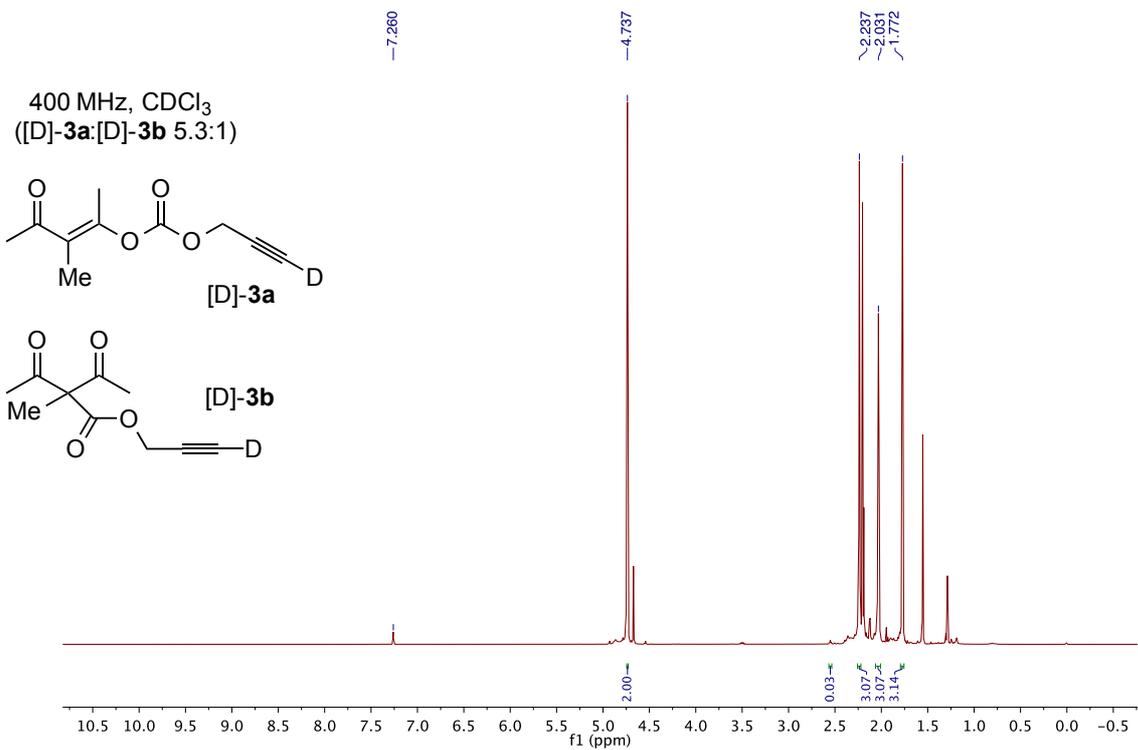
400 MHz, CDCl<sub>3</sub>  
([D<sub>3</sub>]-**3a**: [D<sub>3</sub>]-**3b** 5:1)

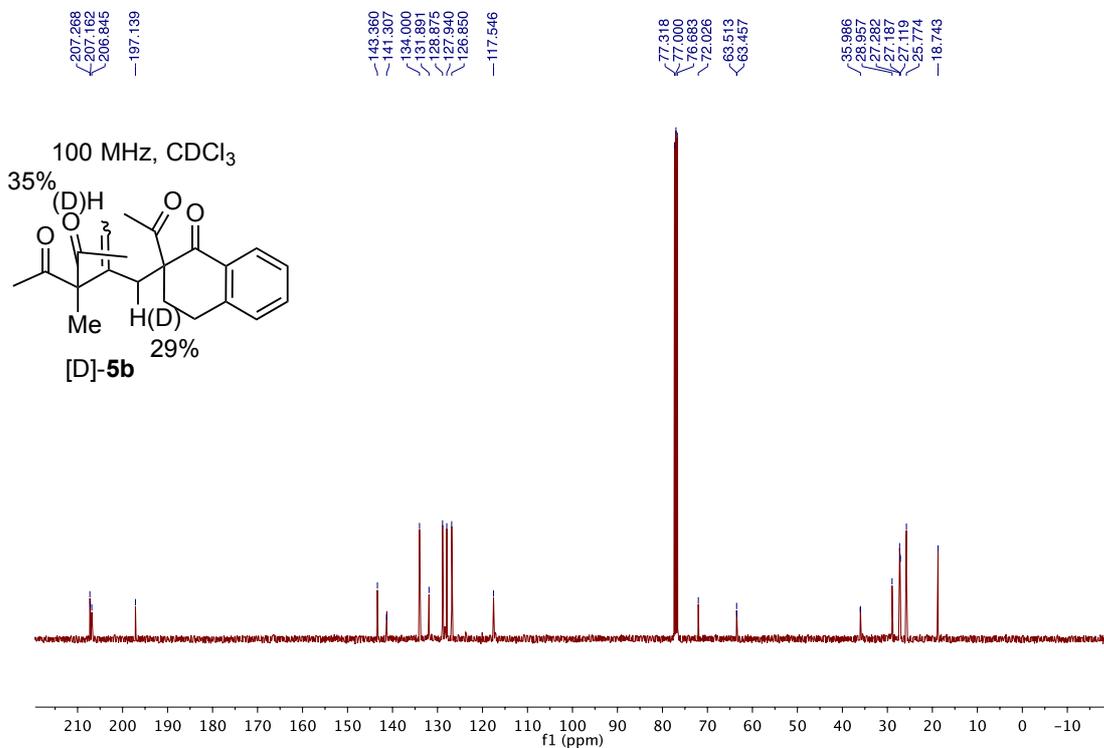
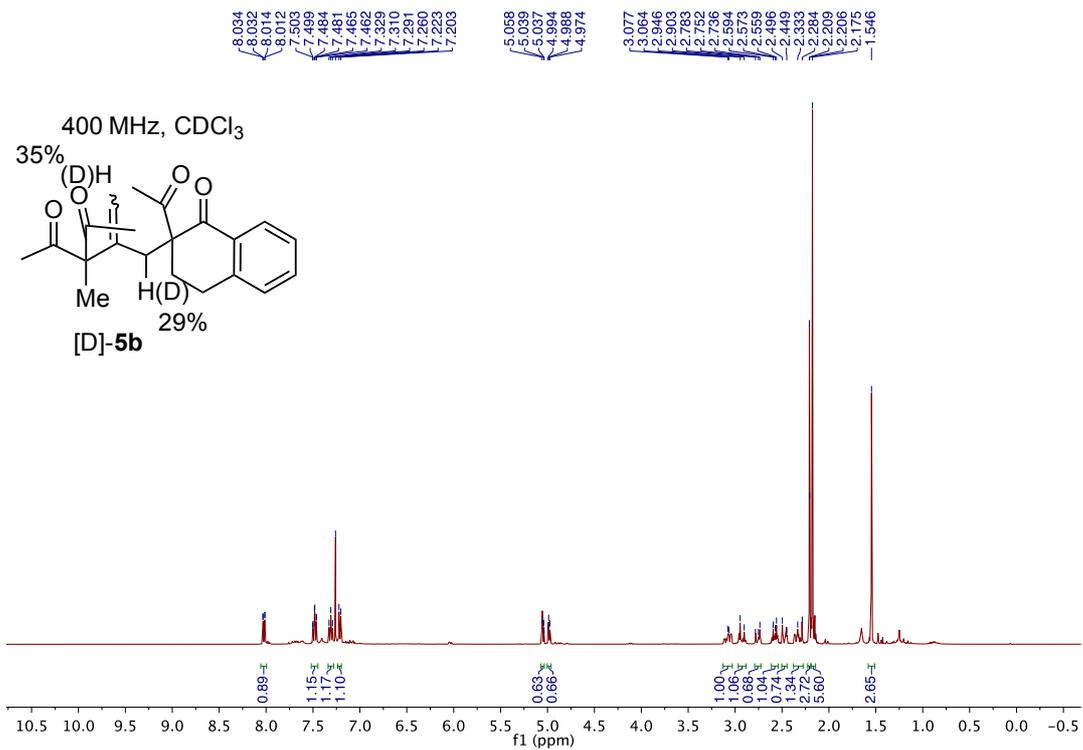


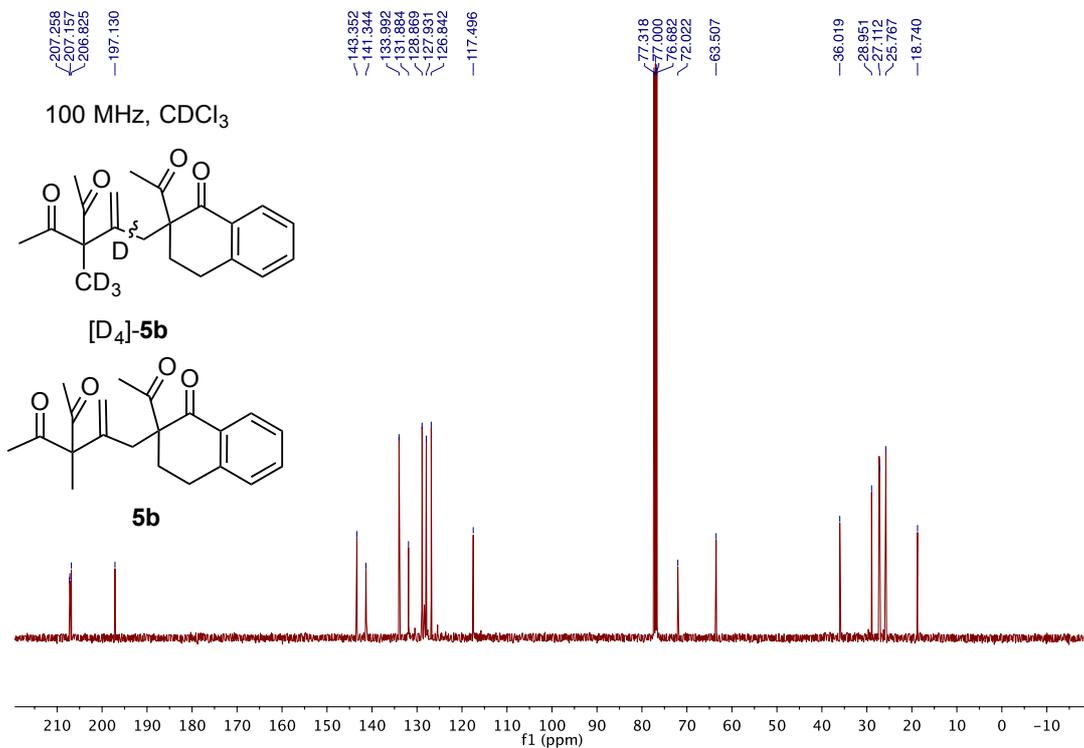
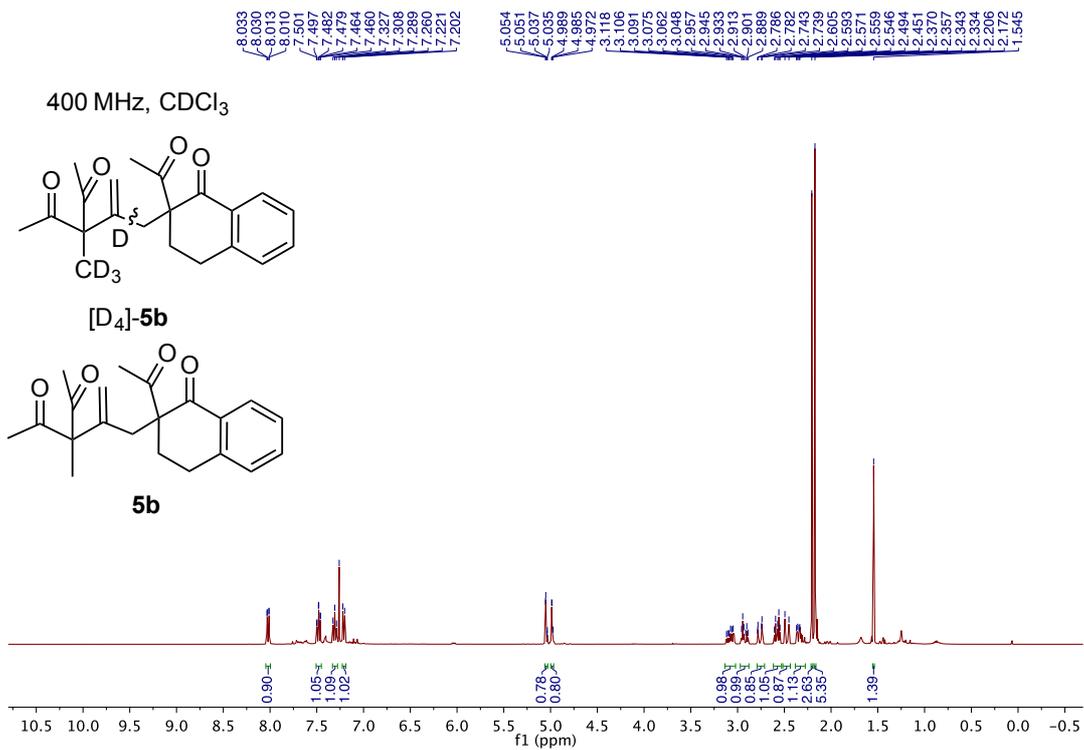
100 MHz, CDCl<sub>3</sub>  
([D<sub>3</sub>]-**3a**: [D<sub>3</sub>]-**3b** 5:1)







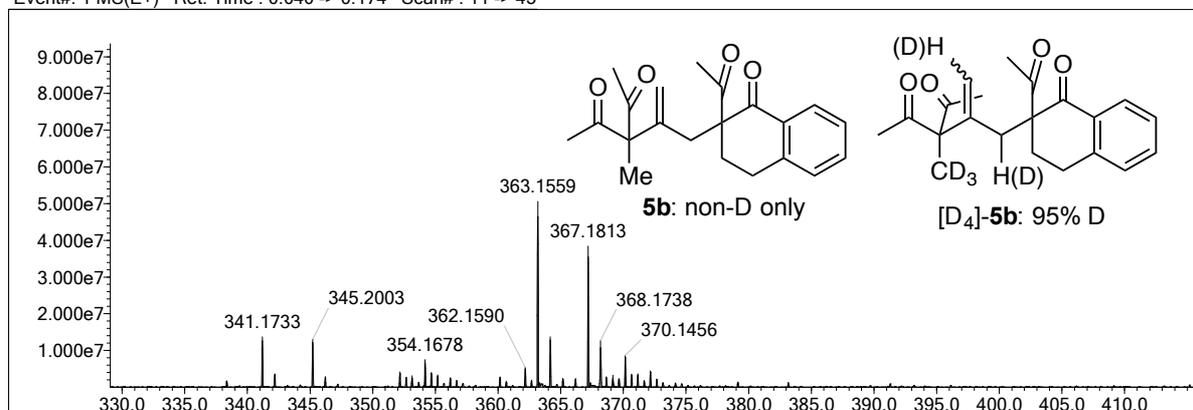




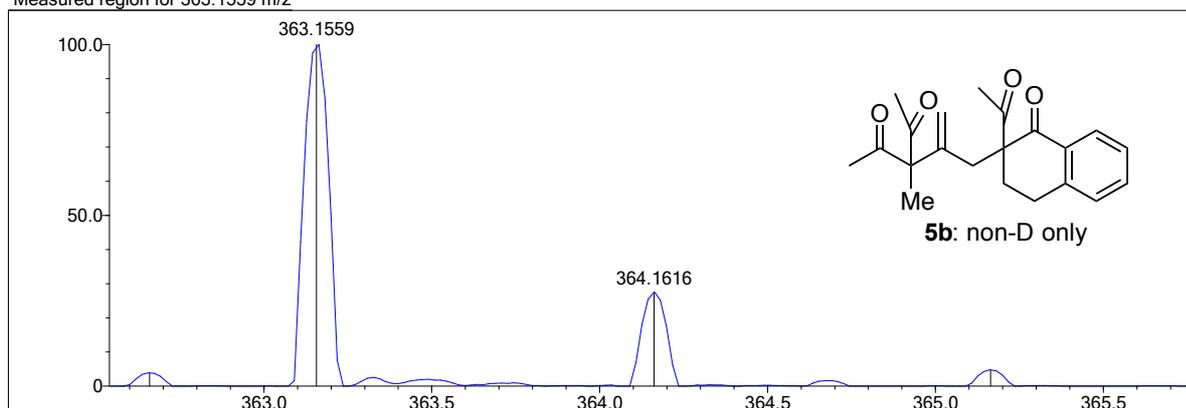
## 7. Deuterium-Labeling Studies: Mass Spectrometry Data.

### A. Enolate Crossover.

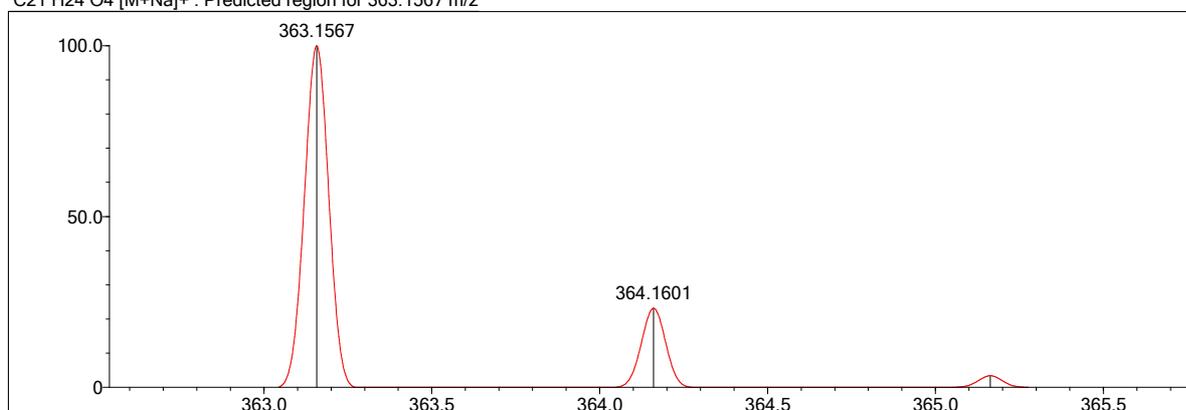
Event#: 1 MS(E+) Ret. Time : 0.040 -> 0.174 Scan# : 11 -> 45



Measured region for 363.1559 m/z

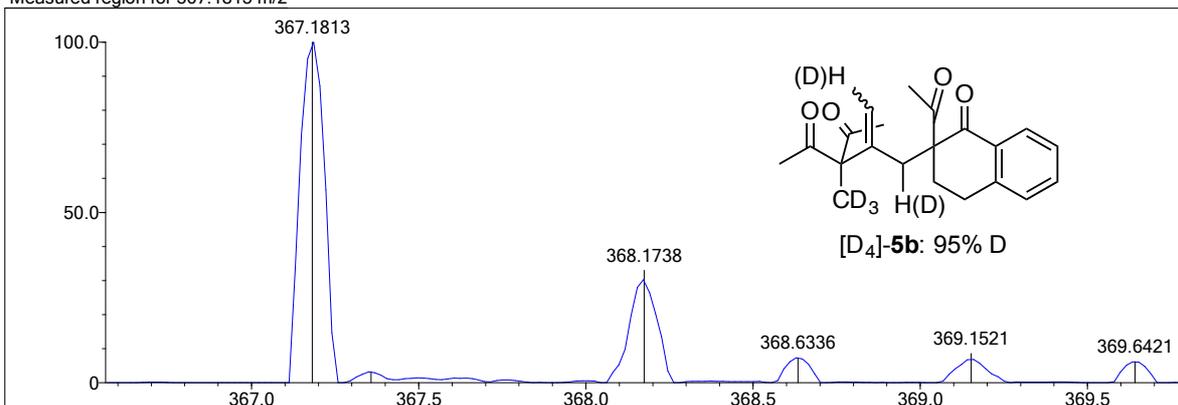


C21 H24 O4 [M+Na]+ : Predicted region for 363.1567 m/z

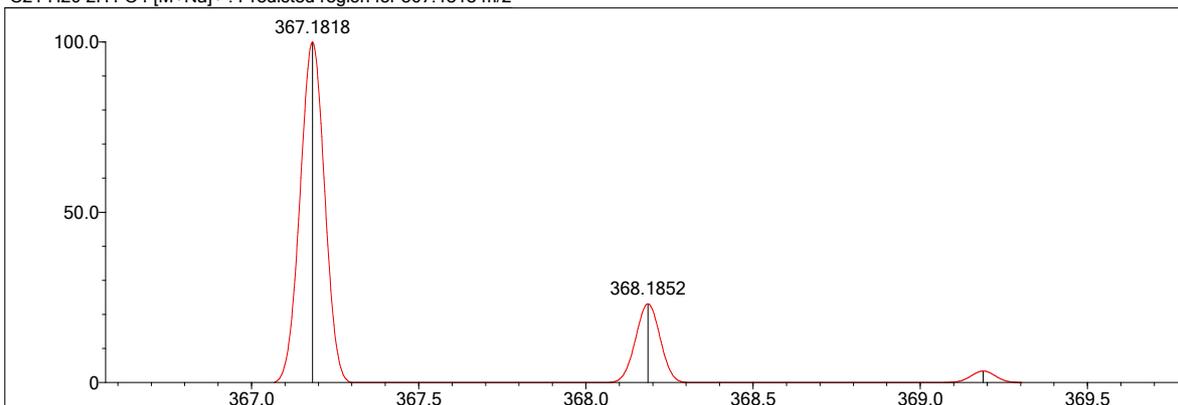


Rank	Score	Formula (M)	Ion	Meas. m/z	Pred. m/z	Df. (mDa)	Df. (ppm)	Iso	DBE
5	90.92	C21 H24 O4	[M+Na] <sup>+</sup>	363.1559	363.1567	-0.8	-2.20	93.74	10.0

Measured region for 367.1813 m/z



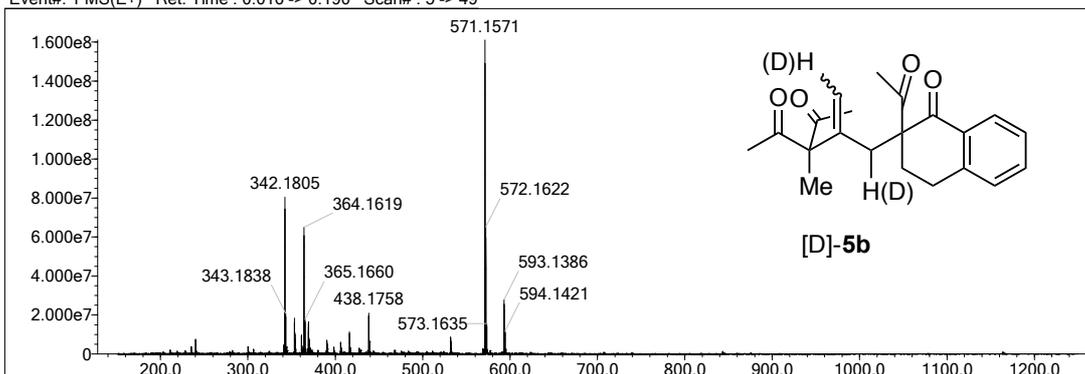
C<sub>21</sub>H<sub>20</sub>2H<sub>4</sub>O<sub>4</sub> [M+Na]<sup>+</sup> : Predicted region for 367.1818 m/z



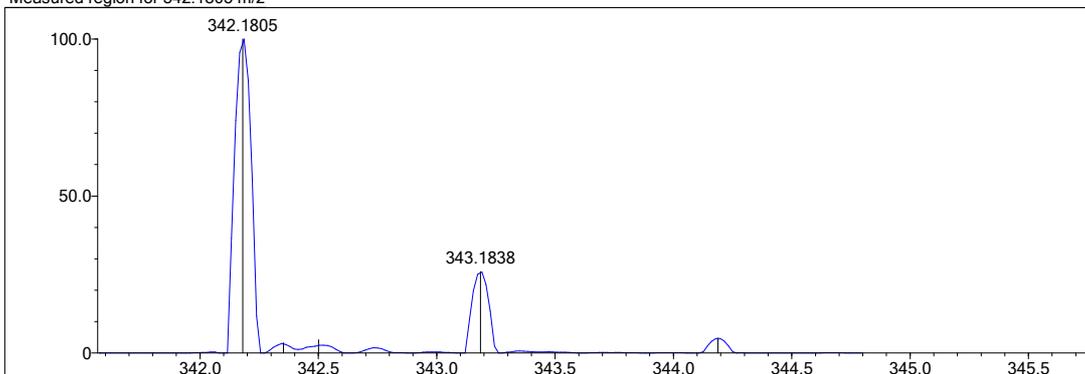
Rank	Score	Formula (M)	Ion	Meas. m/z	Pred. m/z	Df. (mDa)	Df. (ppm)	Iso	DBE
1	62.36	C <sub>21</sub> H <sub>20</sub> 2H <sub>4</sub> O <sub>4</sub>	[M+Na] <sup>+</sup>	367.1813	367.1818	-0.5	-1.36	62.93	10.0

## B. Symmetrical $\pi$ -Allylpalladium(II) Intermediate.

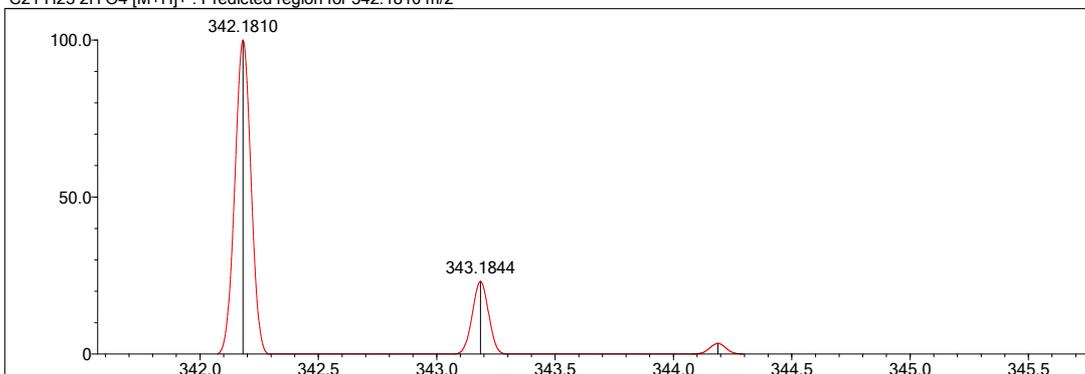
Event#: 1 MS(E+) Ret. Time : 0.016 -> 0.190 Scan# : 5 -> 49



Measured region for 342.1805 m/z



C21 H23 2H O4 [M+H]<sup>+</sup> : Predicted region for 342.1810 m/z



Rank	Score	Formula (M)	Ion	Meas. m/z	Pred. m/z	Df. (mDa)	Df. (ppm)	Iso	DBE
1	98.85	C21 H23 2H O4	[M+H] <sup>+</sup>	342.1805	342.1810	-0.5	-1.46	100.00	10.0