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Formation of Seven- and Eight-Membered Rings by Mn(III)-Based Oxidative Free-Radical Cyclization.

Barry B. Snider* and John E. Merritt

Department of Chemistry, Brandeis University, Waltham, MA 02254-9110

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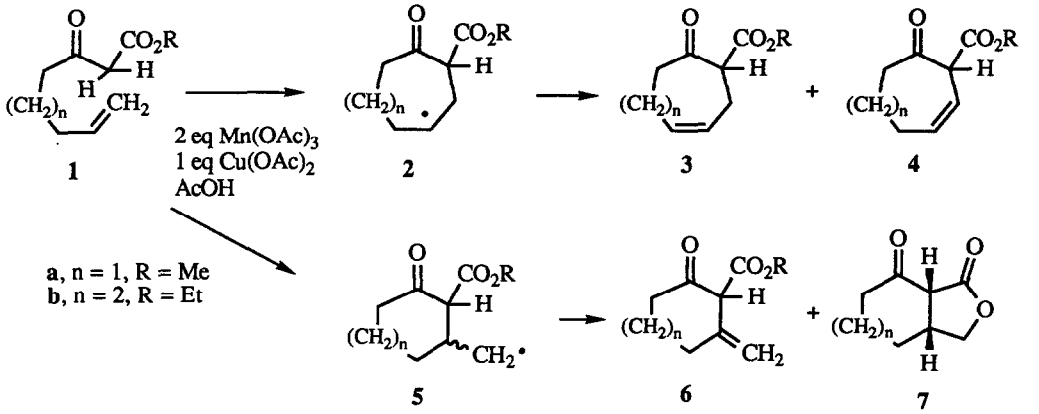
Abstract: *Oxidative free-radical cyclizations of acetoacetates* ***1, 8, 17, and 20*** *with* $Mn(OAc)_3 \cdot 2H_2O$ *and* $Cu(OAc)_2 \cdot H_2O$ *in acetic acid provide cycloheptenes and cyclooctenes in moderate to good yield. Tandem cyclizations of* ***28, 35 and 51*** *provide bicyclo[4.2.1]nonanes, bicyclo[5.2.1]decanes, bicyclo[5.3.0]decanes and bicyclo[6.3.0]undecanes.*

We have recently described Mn(III)-based oxidative free-radical cyclizations which are initiated by oxidation of a β-dicarbonyl compound to a radical by $Mn(OAc)_3 \cdot 2H_2O$ and terminated by oxidative β-hydride elimination from a radical to give an alkene with $Cu(OAc)_2 \cdot H_2O$.[1-3] These cyclizations lead to more highly functionalized products than are formed from typical radical cyclizations which are initiated and terminated by reductive steps.[4] We have previously demonstrated that Mn(III)-based oxidative free radical cyclizations can be used to produce cyclopentanes and cyclohexanes and that tandem and triple cyclizations can be carried out in high yield. Free-radical cyclizations have been of the greatest utility for the preparation of cyclopentanes and cyclohexanes. They have rarely been used for the formation of cycloheptanes,[5] and the formation of cyclooctanes is virtually unknown.[6] Recently, free-radical cyclizations have been used with good success for the formation of macrocycles.[7] We report here our results demonstrating that Mn(III)-based oxidative cyclizations can be used to prepare both cycloheptanes and cyclooctanes.[8]

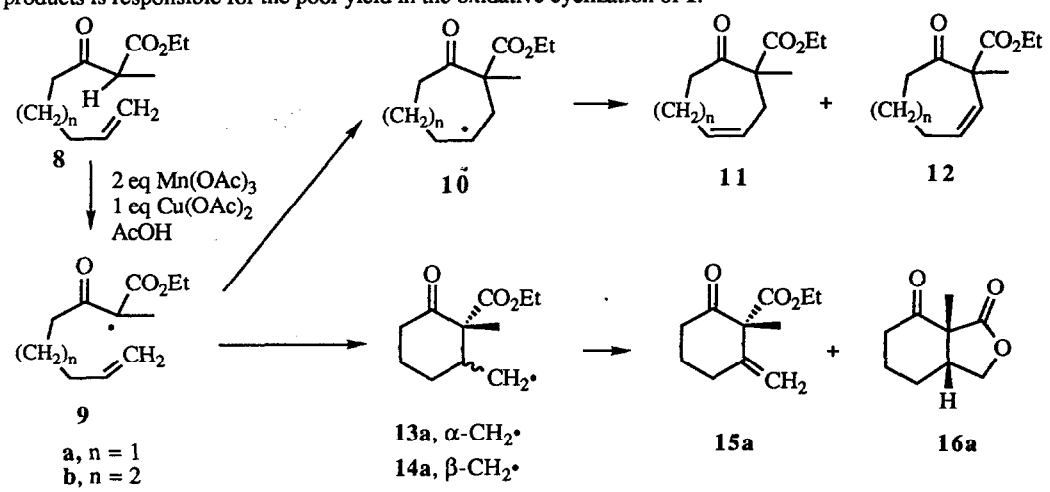
The starting materials for these oxidative cyclizations are readily prepared by alkylation of the dilithium or sodium/lithium dianion of the appropriate acetoacetate ester with an unsaturated bromide or iodide in the presence of 2 equiv of HMPA.[9] Higher yields are obtained with methyl acetoacetate itself than with α-substituted acetoacetates; the yields of these alkylations are not optimized. Reaction of α-unsubstituted acetoacetate **1a**, as a 0.1 M solution in acetic acid, with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and 1 equiv of $Cu(OAc)_2 \cdot H_2O$ for 44 h at 25 °C affords 13% of cycloheptene **3a**. These conditions were used for all reactions, except where otherwise indicated. Similar oxidative cyclization of **1b** affords 17% of **3b**. Oxidative cyclization should give cycloalkyl radical **2**, which should be oxidized to cycloalkenes **3** and **4** and cycloalkanemethyl radical **5** which should be oxidized to methylenecycloalkane **6** and lactone **7**. All of these products are enolizable β-keto esters susceptible to further oxidation by Mn(III). We have previously shown that 2-oxocyclohexanecarboxylate esters are stable to the reaction conditions, while oxidation of 2-oxocyclopentanecarboxylate ester occurs at a rate comparable to the initial cyclization.[10] It is likely that **3**, **4**, **6** and perhaps **7** are formed, and that **4** and **6**, with more acidic allylic hydrogens, are more readily oxidatively destroyed, resulting in the apparently selective formation of **3** in low yield. Competing dimerization or oxidative dehydration of an acyclic radical precursor to **2** and **5** is unlikely since the alkene is involved in the rate

determining step of oxidative cyclization of α-unsubstituted acetoacetates indicating that the acyclic free radical is probably not an intermediate.[10]



1 2 3 4 5 6 7

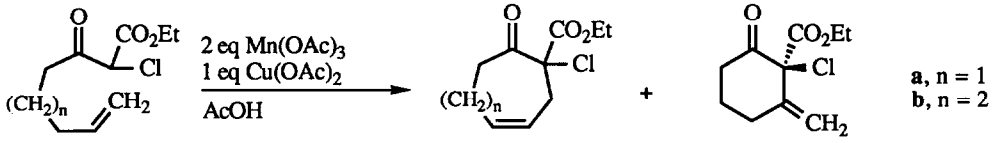
Oxidative cyclization of **8** was examined to determine the yield and nature of products when overoxidation is not possible. Oxidative cyclization of α-substituted acetoacetate **8a** affords 46% of 3:1:1 mixture of **11a**, **12a** and **15a** and 5% of **16a**. Oxidation of **8a** gives acyclic radical **9a** which cyclizes to a ≈2.5:1 mixture of cycloheptyl radical **10a** and cyclohexanemethyl radicals **13a** and **14a**. The regiochemistry of the cyclization of 6-heptenyl radicals is very substrate dependent. The parent radical gives almost exclusively the cyclohexanemethyl radical,[5a] while some more complex 6-heptenyl radicals give exclusively cycloheptyl radicals.[5c-e] Cycloheptyl radical **10a** is oxidized by Cu(II) to a 3:1 mixture of cycloheptenes **11a** and **12a**. Cyclohexanemethyl radical **14a** is oxidized exclusively to methylenecyclohexane **15a**. Cyclohexanemethyl radical **13a** is oxidized to a mixture of **15a** and lactone **16a**. The analogous lactone is the major product in the oxidation of analogous primary cyclopentanemethyl radicals.[1b,e] Oxidative cyclization of **8b** affords 38% of cyclooctene **11b**. Cyclization of 7-octenyl radical **9b** gives exclusively cyclooctyl radical **10b** which is oxidized exclusively to cyclooctene **11b**. The higher yield of adducts obtained from **8** suggests that overoxidation of the products is responsible for the poor yield in the oxidative cyclization of **1**.



8 9 10 11 12 13a 14a 15a 16a

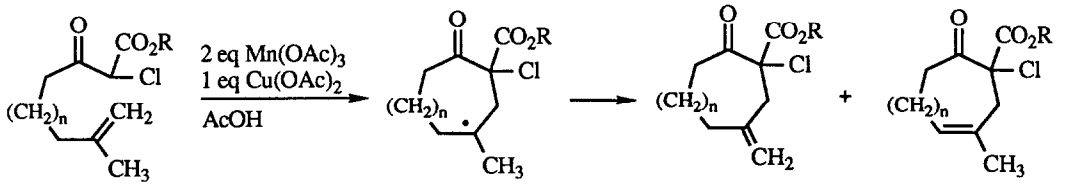
Oxidative cyclization of **17a** was examined since we have demonstrated that oxidative cyclization of α-chloroacetoacetates followed by reductive dechlorination is an effective method for preparing 2-oxocyclopent-

anecarboxylate esters which cannot be prepared directly.[10] Oxidative cyclization of **17a** affords 50% of **18a** and 18% of **19a**. Oxidative cyclization of **17b** affords 47% of **18b**. Reduction of **18b** with zinc dust in acetic acid affords **3b** in good yield. Since the solvent for the oxidative cyclization is acetic acid, zinc dust can be added prior to work up affording 41% of **3b** from **17b** in a one-pot procedure. As in the cyclization of **8**, **17a** gives a 2.8:1 mixture of seven- and six-membered ring products while **17b** gives exclusively eight-membered ring product. No lactone is formed from **17a** and the position of the endocyclic double bond is controlled by the electron withdrawing effects of the α-chlorine atom.[10]



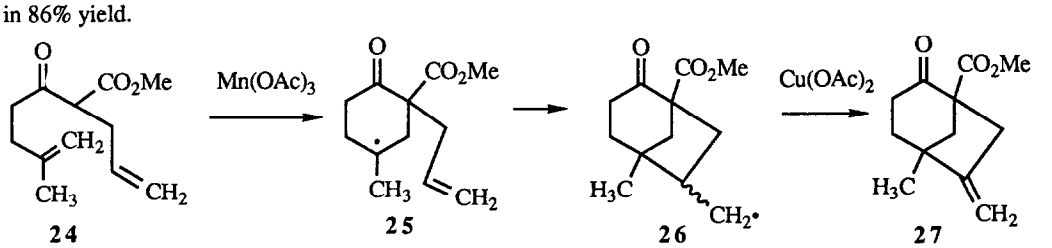
17 **18** **19a**

6-*endo*-Cyclization is favored by introduction of a methyl group onto the internal alkene carbon.[1] Methyl substitution also improves the yield since the more nucleophilic alkene adds more rapidly to the electrophilic radical. We therefore investigated the oxidative cyclization of **20**. Oxidative cyclization of **20a** affords 69% of a 2.5:1 mixture of **22a** and **23a**, while oxidative cyclization of **20b** provides 20% of **22b** and 49% of **23b**. Oxidative cyclization gives exclusively the tertiary radical **21**. Oxidation of **21a** gives primarily the methylenecycloheptane **22a** while oxidation of **21b** affords primarily methylcyclooctene **23b**. Initial attempts at the synthesis of larger rings by this oxidative cyclization procedure were unsuccessful. We were unable to obtain any cyclic products from oxidative cyclization of **17**, n = 3, 5, or 7 or **20**, n = 3.



20 a, n = 1, R = Et; b, n = 2, R = Me **21** **22** **23**

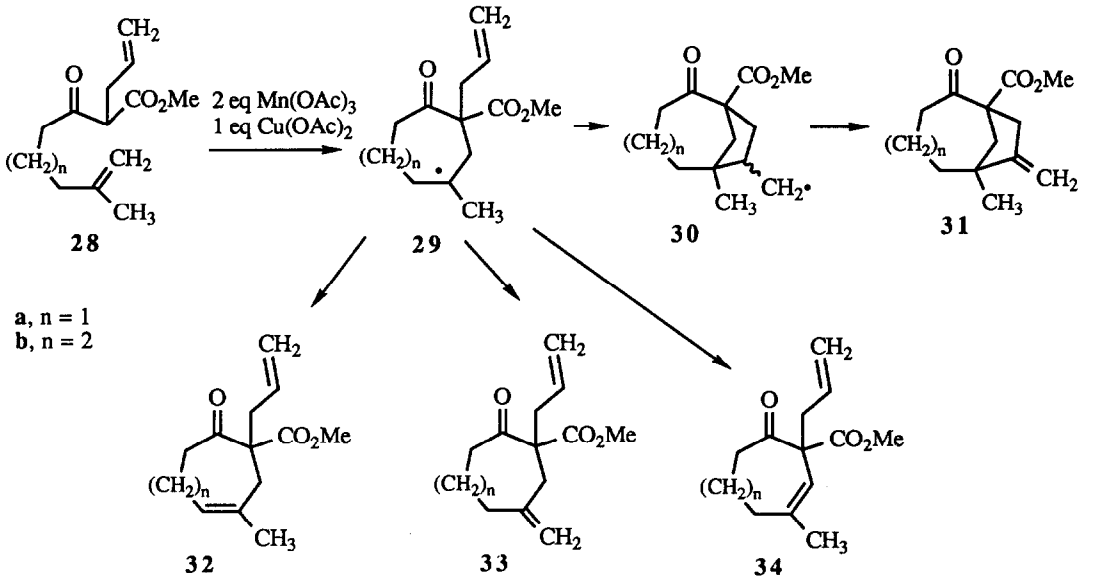
Tandem Cyclization. We have previously demonstrated that tandem oxidative cyclization of unsaturated α-allylacetoacetates provides a versatile route to bicyclo[3.2.1]octanes.[1b] Oxidative cyclization of **24** affords the tertiary cyclohexyl radical **25**, which undergoes a second cyclization to give a mixture of cyclopentanemethyl radicals **26**. Oxidation by Cu(II) converts both stereoisomers to methylenecyclopentane **27**, which is obtained in 86% yield.



24 **25** **26** **27**

Comparable tandem cyclizations should provide bicyclo[4.2.1]nonanes and bicyclo[5.2.1]decanes. Oxidative cyclization of **28a** affords 68% of bicyclo[4.2.1]nonane **31a**. Similar oxidation of **28b** affords 70% of bicyclo[5.2.1]decane **31b** and traces of monocyclic products **32b** (4%), **33b** (1%) and **34b** (3%).

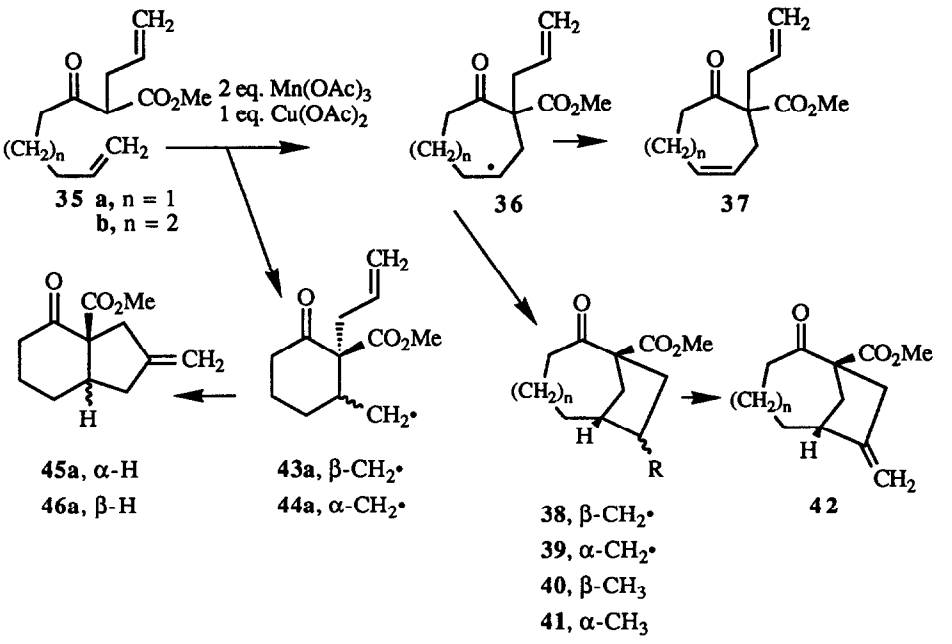
Oxidative cyclization gives exclusively the cyclic tertiary radical **29**, which cyclizes, as expected to give **30** which is oxidized by Cu(II) to **31**. Cyclization of tertiary cycloheptyl radical **29a** is much faster than its oxidation by Mn(III) or Cu(II) to **32a-34a**. Oxidation of tertiary cyclooctyl radical **29b** is competitive with cyclization to **30b**. Presumably, steric constraints imposed by the eight-membered ring slow down the cyclization of the 5-hexenyl radical of **29b** compared to that of the cyclohexyl radical **25** or the cycloheptyl radical **29a**.



Oxidation of terminal alkenes **35a** and **35b** proceed in lower yield since the less nucleophilic alkene adds more slowly to the electrophilic enol radical. Oxidative cyclization of **35a** affords 4% of **37a**, 32% of **42a**, 8% of **45a** and 4% of **46a**.[11] Similar oxidation of **35b** provides 17% of **37b** and 11% of **42b**. These results indicate that, as observed above, the 6-heptenyl radical derived from **35a** cyclizes to a 3:1 mixture of the cycloheptyl radical **36a** and the cyclohexanemethyl radicals **43a** and **44a**, while the 7-octenyl radical derived from **35b** cyclizes only to **36b**. The secondary 5-hexenyl radical **36** cyclizes to give a mixture of **38** and **39** which is oxidized by Cu(II) to **42**. Oxidation of the secondary radical **36** by Cu(II) provides **37**.

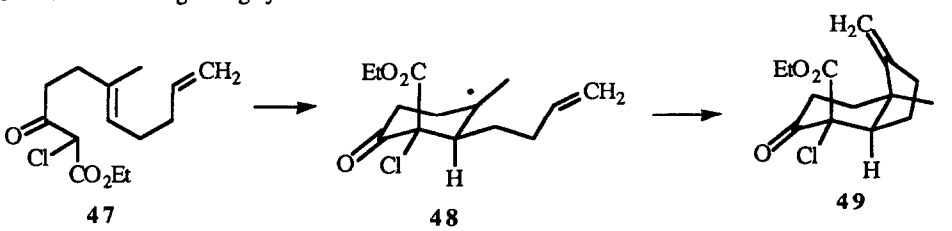
The second cyclization is very much faster than oxidation for tertiary radicals **25** and **29a** and is significantly faster than oxidation of the tertiary cyclooctyl radical **29b**. On the other hand, oxidation of secondary radical **36a** and the secondary radical corresponding to **25**[1e] is a significant side reaction, and oxidation of the secondary cyclooctyl radical **36b** is actually faster than cyclization. Two generalizations can be made from these data. First, either the oxidation of cyclooctyl radicals is fast or, more likely, the cyclization of 3-allylcyclooctyl radicals is slow. Second, secondary radicals appear to be oxidized more readily than tertiary radicals. This observation is counterintuitive. As we have discussed previously,[1e] the oxidation of secondary radicals by Cu(II) is probably faster than the oxidation of tertiary radicals by either Mn(III) or Cu(II).[12]

All of the reactions described above have been carried out with 1 equiv of $Cu(OAc)_2 \cdot H_2O$, even though the reaction should be catalytic in Cu(II) since the second equiv of Mn(III) reoxidizes Cu(I) to Cu(II). The amount of Cu(II) is of no importance if the second cyclization is much faster than oxidation of the monocyclic radical by Cu(II). If this condition is not met, the amount of Cu(II) is critical. The rate of cyclization of **36b** is independent of the Cu(II) concentration, while the rate of oxidation is proportional to the Cu(II) concentration. We therefore reduced the amount of $Cu(OAc)_2 \cdot H_2O$ in an attempt to favor the formation of **42b** at the expense of **37b**. Oxidative cyclization of **35b** with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and only 0.05 equiv of $Cu(OAc)_2 \cdot H_2O$

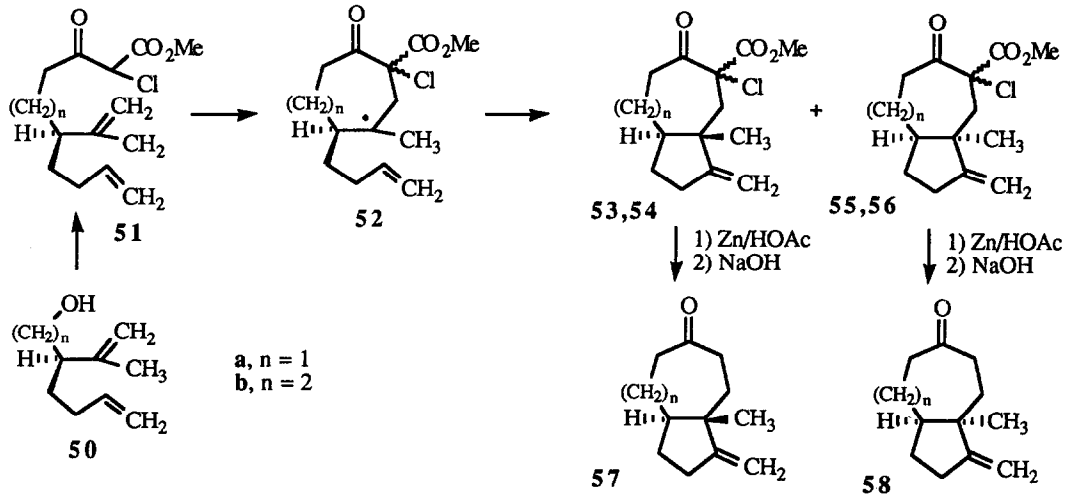


affords 7% of **37b** and 22% of **42b**, indicating that formation of **37b** can be suppressed by decreasing the amount of Cu(II). Oxidative cyclization with only 0.01 equiv of $Cu(OAc)_2 \cdot H_2O$ affords a 1:4 mixture of **37b** and **42b**. Unfortunately, at this low copper concentration, hydrogen abstraction to give **40b** and **41b** becomes a significant side reaction. In the complete absence of Cu(II), 27% of an inseparable 4:1 mixture of **40b** and **41b** is obtained. The stereochemistry of **40b** and **41b** was assigned by analysis of the ^{13}C NMR spectra. The CH_3 group of the *endo*-isomer **41b** absorbs at δ 14.8, while the methyl group of the *exo*-isomer **40b**, which is less susceptible to shielding by γ substituents, absorbs at δ 22.2.[15d] This assignment was confirmed by hydrogenation of **42b**, which provides a 1:5 mixture of **40b** and **41b** quantitatively. Hydrogenation should, and does, occur selectively from the less hindered *exo*-face to provide mainly the more hindered *endo*-isomer **41b**. Cyclization should,[1b] and does, occur selectively to give the less hindered *exo*-isomer **40b** as the major product.

Formation of Bicyclo[5.3.0]decanes and Bicyclo[6.3.0]undecanes. We have previously reported that the tandem cyclization of **47**, with both double bonds in the same chain, affords 48% of *cis*-fused bicyclo[4.3.0]nonane **49** as the only product.[1b] The initial cyclization gives cyclohexyl radical **48** stereospecifically since the enol radical exists in an extended configuration and cyclization takes place through a chair transition state. The second cyclization gives exclusively the *cis*-ring fusion. We have now examined the cyclization of **51** to determine the suitability of tandem cyclizations for the preparation of bicyclo[5.3.0]decanes and bicyclo[6.3.0]undecanes. In related radical cyclizations *cis*-fused bicyclo[4.3.0]nonanes are invariably formed.[13] With larger ring systems mixtures of stereoisomers are obtained.[13]



Treatment of 6-methyl-1,5-heptadiene with paraformaldehyde and Me_2AlCl at 0 °C affords 67% of alcohol **50a**.[14] Alcohol **50a** was converted to the iodide, which was added to the dianion[9] of methyl 2-chloroacetoacetate as described above to afford 21% of β-keto ester **51a**. Reaction of β-keto ester **51a** with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and 1 equiv of $Cu(OAc)_2 \cdot H_2O$ in acetic acid affords a partially separable mixture of the two *trans*-fused isomers **53a** (36%) and **54a** (9%), and the two *cis*-fused isomers **55a** (10%) and **56a** (10%), respectively. Reductive dechlorination of a 1:2.3 mixture of **54a** and **56a** with zinc dust in acetic acid, followed by hydrolysis with NaOH in aqueous methanol at reflux and decarboxylation provides a 1:2.3 mixture of **57a** and **58a**. Similar treatment of a 3.4:1 mixture of **53a** and **55a** affords a 3.4:1 mixture of **57a** and **58a**. The stereochemistry of the ring fusion of **53a-58a** was assigned based on analysis of the ^{13}C and ^1H NMR spectra. A methyl group on the ring fusion carbon of a *trans*-fused bicyclo[5.3.0]decane is gauche to one more carbon than a methyl group on a *cis*-fused bicyclo[5.3.0]decane and is therefore shifted upfield in both the ^1H and ^{13}C NMR spectra.[15] The methyl resonances of *trans*-fused bicyclo[5.3.0]decanes **53a** (δ 0.84, 17.6), **54a** (δ 0.85, 19.9), and **57a** (δ 0.81, 18.0) absorb upfield compared to those of *cis*-fused bicyclo[5.3.0]decanes **55a** (δ 1.18, 24.2), **56a** (δ 1.10, 26.9), and **58a** (δ 1.11, 24.8). We cannot determine the stereochemistry at the remaining stereocenter of **53a-56a**.



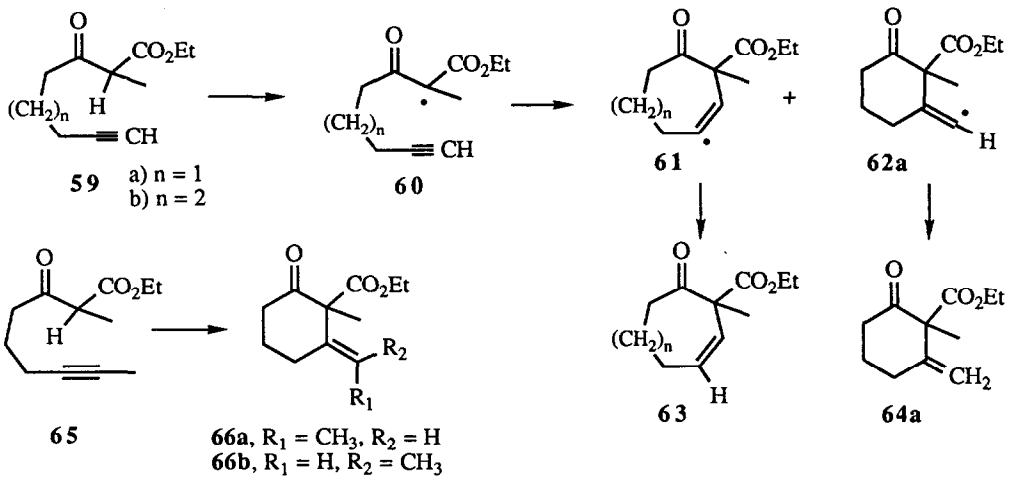
The initial cyclization of **51a** gives **52a** as a ≈ 2.4:1 mixture of stereoisomers. This lack of stereocontrol is not surprising since cycloheptyl radical **52a** should be formed through several energetically similar transition states, while cyclohexyl radical **48** is formed through a single chair-like transition state. One isomer of **52a** cyclizes to a 3.6:1 mixture of *trans*- and *cis*-isomers, while the other gives a 0.9:1 mixture of *trans*- and *cis*-isomers. A 2.5:1 mixture of *trans*- and *cis*-fused isomers are obtained. Mixtures of stereoisomers have been obtained in other radical cyclizations leading to bicyclo[5.3.0]decanes.[13a-d]

Orthoester Claisen rearrangement[16] of 2-methyl-2*E*,6-heptadien-1-ol[1b] with triethyl orthoacetate followed by LAH reduction provides 84% of alcohol **50b**. Alcohol **50b** was converted to the iodide which was added to the dianion[9] of methyl 2-chloroacetoacetate to give 26% of β-keto ester **51b**. Oxidative cyclization of **51b** affords a partially separable mixture of the two *trans*-fused isomers **53b** (48%), **54b** (9%) and the two *cis*-fused isomers **55b** (17%) and **56b** (2%). Reduction, hydrolysis and decarboxylation affords a 3:1 mixture of **57b** and **58b**. This ratio of products requires that **53b** and **54b** give rise to the major isomer **57b**.

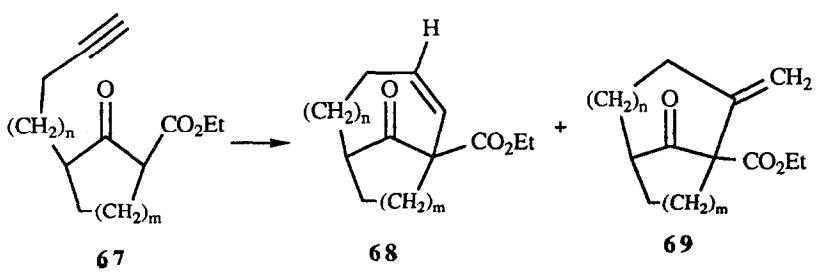
The assignment of stereochemistry to these bicyclo[6.3.0]undecanes is tentative. The methyl resonances in the ^1H and ^{13}C NMR of the major isomers **53b** (δ 1.01, 23.6), **54b** (δ 1.13, 28.2) and **57b** (δ 1.03, 20.9) are not consistently different than those of the minor isomers **55b** (δ 0.96, 25.9), **56b** (δ 0.94, 26.7) and **58b** (δ 1.00, 26.3). The most significant difference in the ^{13}C NMR spectra, which occurs in the ketones **57b** (δ 20.9)

and **58b** (δ 26.3), suggests that the major isomers are *trans*, although this assignment must be considered tentative.[17] Mixtures of *cis*- and *trans*-fused products have been observed in previous radical cyclizations which form bicyclo[6.3.0]undecanes.[13e]

Cyclizations to Alkynes to Form Medium-Sized Ring Systems. Mn(III)-based oxidative cyclization of 5-hexynyl radicals provides a general route to methylenecyclopentanes and cyclohexenes.[1e,18] Higher yields are obtained with more reactive anhyd $Mn(OAc)_3$[19] and the reaction must be carried out in ethanol as solvent[18] which acts as a hydrogen donor reducing the intermediate vinyl radical to an alkene.[1e] The oxidative cyclization of 6-heptynyl and 7-octynyl radicals afford alkylidenecyclohexanes, cycloheptenes and cyclooctenes. Treatment of **59a** with 2 equiv of anhyd $Mn(OAc)_3$[19] in ethanol affords 35% of cycloheptene **63a** and 0.2% of methylenecyclohexane **64a**. Similar cyclization of **59b** affords 34% of cyclooctene **63b**. Unlike the cyclization of the analogous 5-hexynyl radical which gives mainly 5-*exo* cyclization, 6-heptynyl radical **60a** and 7-octynyl radical **60b** give almost exclusively *endo*-cyclization. Since introduction of a terminal methyl group should favor 6-*exo* over 7-*endo* cyclization, we examined the oxidative cyclization of β-keto ester **65** which affords 59% of a 2.5:1 mixture of **66a** and **66b**. The assignment of stereochemistry is based on the shift of the allylic methylene carbon of **66a** upfield to δ 25.5 by the *cis*-methyl group from δ 34.1 in **66b**.



Oxidation of acetylenic β-keto esters such as **67** provides a simple route to unsaturated bicyclic β-keto esters. Oxidative cyclization of oxocyclohexanecarboxylate **67a** with 2 equiv of anhydrous $Mn(OAc)_3$ in ethanol affords 15% of an inseparable 12:1:12 mixture of bicyclo[3.3.1]nonene **68a**, methylenebicyclo[3.2.1]octane **69a**, and unreacted **67a**. Similar treatment of **67b** gives 21% of an inseparable 26:1:18 mixture of bicyclo[4.3.1]decene **68b**, methylenebicyclo[3.3.1]nonane **69b**, and unreacted **67b**, while **67c** provides 19% of an inseparable 1:3.3 mixture of bicyclo[5.3.1]undecene **68c** and unreacted **67c**. The



a, m = 2, n = 0
b, m = 2, n = 1
c, m = 2, n = 2
d, m = 1, n = 1
e, m = 1, n = 2

structures of the products are tentatively assigned based on the characteristic absorptions of the olefinic protons in the ^1H NMR spectrum. Oxidative cyclization of oxocyclopentanecarboxylates **67d** and **67e** gives bicyclo[4.2.1]nonene **68d** (6%) and bicyclo[5.2.1]decene **68e** (13%), respectively. In all cases *endo*-cyclization occurs mainly, or exclusively, to give **68**, although the yields are modest at best.

Conclusion. Oxidative free-radical cyclization of α-substituted acetoacetates **8**, **17** and **20** provides a viable route to cycloheptenes and cyclooctenes in moderate to good yield when overoxidation of the product is blocked. Tandem cyclization of **28a** and **28b** provides bicyclo[4.2.1]nonane **31a** and bicyclo[5.2.1]decane **31b**, respectively, while tandem cyclization of **51a** and **51b** provides bicyclo[5.3.0]decanes **53a-56a** and bicyclo[6.3.0]undecanes **53b-56b** in good yield indicating that bicyclic systems containing seven- and eight-membered rings can be prepared. Cycloheptene **63a** and cyclooctene **63b** can be prepared by oxidative cyclization of acetylenic acetoacetates.

EXPERIMENTAL SECTION

General. $Mn(OAc)_3 \cdot 2H_2O$ and $Cu(OAc)_2 \cdot H_2O$ were purchased from Aldrich. Anhydrous $Mn(OAc)_3$ was prepared by the literature procedure.[19] ^1H NMR spectra were recorded at 300 MHz in $CDCl_3$ with TMS. Chemical shifts are reported in δ. Decoupling was used for proton assignments where indicated. APT was used to assign ^{13}C NMR spectra.

Preparation of Starting Materials. 4-Bromo-1-butene, 5-bromo-1-pentene, and all β-keto esters except methyl 2-allylacetoacetate[20] were purchased from Aldrich. 4-Bromo-2-methyl-1-butene was prepared from the mesylate[21] of 3-methyl-3-buten-1-ol (Aldrich) with LiBr in DMF.[22] Ethyl 4-methyl-4-pentenoate was prepared by an orthoester Claisen rearrangement.[16] LAH reduction afforded 4-methyl-4-penten-1-ol which was converted to the bromide as described above. Reaction of 6-methyl-1,5-heptadiene, paraformaldehyde and Me_2AlCl afforded 67% of 2-(methylethenyl)-5-hexen-1-ol.[14] Reaction of the corresponding mesylate with NaI in acetone[23] provided 2-methyl-3-(iodomethyl)-1,6-heptadiene. Orthoester Claisen rearrangement of 2-methyl-2*E*,6-heptadien-1-ol[1b] afforded 84% of ethyl 3-(methylethenyl)-6-heptenonate. LAH reduction, mesylation[20] and reaction with NaI in acetone[23] afforded 2-methyl-3-(2-iodoethyl)-1,6-heptadiene. 4-Iodo-1-butyne, 5-iodo-1-pentyne and 5-iodo-2-pentyne were prepared from the mesylates[21] of the commercially available alcohols with NaI in DMF.[22]

To a stirred solution of LDA (2 mmol) in 3 mL of freshly distilled THF at 0 °C was added the β-keto ester (1 mmol).[9] The resulting pale yellow solution was stirred for 20 min at 0 °C followed by addition of HMPA (2 mmol). The alkyl halide was added and the solution was stirred for 0.5 h at 0 °C, 2 h at 25 °C, and worked up. Flash chromatography on silica gel (4-19:1 hexane-EtOAc) gave pure starting material.

General Procedure for the Oxidative Cyclization of Olefinic β-Keto Esters. To a stirred suspension of $Mn(OAc)_3 \cdot 2H_2O$ (2 mmol) and $Cu(OAc)_2 \cdot H_2O$ (1 mmol) in 7 mL of glacial acetic acid was added the acetoacetate ester (1 mmol) in 3 mL of glacial acetic acid. The reaction mixture was stirred at 25 °C until the mixture contained no starting material as determined by GC analysis or until Mn(III) was consumed. $Mn(OAc)_3$ is dark brown. After Mn(III) is consumed the solution is light blue due to Cu(II). Normal workup consisted of the addition of water (50 mL) followed by dropwise addition of a 10% solution of $NaHSO_3$ (to destroy any remaining $Mn(OAc)_3$) and extraction with CH_2Cl_2 (3 x 18 mL). The combined organic layers were washed carefully with saturated $NaHCO_3$, dried ($MgSO_4$), and concentrated in vacuo.

General Procedure for the Oxidative Cyclization of Acetylenic β-Keto Esters 59, 65 and 67. To a stirred suspension of anhydrous $Mn(OAc)_3$[19] (2 mmol) in 7 mL of degassed ethanol was added the acetoacetate ester (1 mmol) in 3 mL of solvent via cannula. The reaction mixture was stirred at 25 °C until either the Mn(III) had been consumed (the solution turned blue) or until the mixture contained no starting material and was worked up as described above.

Methyl 3-Oxo-7-octenoate (1a) is known.[9b]

Ethyl 3-Oxo-8-nonenoate (1b): 62% by evaporative distillation (90 °C, 1.3 Torr); ^1H NMR 5.79 (ddt, 1, J = 10.2, 17.0, 6.7), 5.04-4.93 (m, 2), 4.20 (q, 2, J = 7.2), 3.43 (s, 2), 2.55 (t, 2, J = 7.3), 2.06 (dtt, 2, J = 6.8, 7.3, 1.4), 1.68-1.57 (m, 2), 1.45-1.38 (m, 2), 1.28 (t, 3, J = 7.2); ^{13}C NMR 202.4, 167.2, 138.3, 114.7, 61.3, 49.3, 42.8, 33.4, 28.2, 22.8, 14.1; IR (neat) 1747, 1727, 1680 cm^{-1}. Anal. Calcd for $C_{11}H_{18}O_3$: C, 66.64; H, 9.15. Found: C, 66.05; H, 9.05.

Cyclization of 1a followed by flash chromatography on silica gel (2:1 hexane-methylene chloride) yielded 13% of methyl 7-oxocyclohept-3-ene-1-carboxylate (**3a**): ^1H NMR 5.88-5.73 (m, 2), 3.84 (dd, 1, J =

4.1, 10.6), 3.74 (s, 3), 2.84 (ddd, 1, J = 4.1, 10.6, 14.8), 2.77-2.38 (m, 4), 2.37-2.26 (m, 1); ^{13}C NMR 202.5, 167.6, 137.7, 115.4, 52.3, 49.1, 42.1, 32.8, 22.4; IR (neat) 1740, 1715, 1650 cm^{-1}.

Cyclization of 1b followed by flash chromatography on silica gel (9:1 hexane-EtOAc) gave 17% of ethyl 8-oxocycloct-3-ene-1-carboxylate (**3b**): ^{1}H NMR 5.82-5.68 (m, 2), 4.18 (q, 2, J = 7.1), 3.47 (dd, 1, J = 4.7, 10.7), 2.89 (ddd, 1, J = 8.5, 10.7, 13.7), 2.71 (ddd, 1, J = 3.4, 10.6, 12.0), 2.51 (ddd, 1, J = 4.7, 6.7, 13.7), 2.39 (ddd, 1, J = 3.3, 7.4, 12.0), 2.30-2.09 (m, 2), 1.81-1.69 (m, 1), 1.65-1.55 (m, 1), 1.27 (t, 3, J = 7.1); ^{13}C NMR 169.4, 132.4, 127.8, 62.4, 61.3, 39.6, 26.4, 24.9, 24.8, 14.1; the ketone carbon was not observed; IR (neat) 1740, 1710 cm^{-1}. Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.08; H, 8.12.

Ethyl 2-Methyl-3-oxo-7-octenoate (8a): 46%; ^{1}H NMR 5.7-5.56 (m, 1), 4.92-5.03 (m, 2), 4.16 (q, 2, J = 7.2), 3.50 (q, 1, J = 7.4), 2.55-2.33 (m, 2), 1.98-1.90 (m, 2), 1.63-1.52 (m, 2), 1.31 (d, 3, J = 7.4), 1.25 (t, 3, J = 7.2); ^{13}C NMR 205.5, 170.3, 137.6, 115.0, 61.0, 52.6, 40.2, 32.7, 22.3, 13.8, 12.5; IR (neat) 1745, 1715 cm^{-1}. Anal. Calcd for $C_{11}H_{18}O_3$: C, 66.64; H, 9.15. Found: C, 66.74; H, 9.28.

Ethyl 2-Methyl-3-oxo-8-nonenoate (8b): 58%; ^{1}H NMR 5.78 (ddt, 1, J = 10.6, 16.9, 6.7), 5.03-4.91 (m, 2), 4.17 (q, 2, J = 7.2), 3.50 (q, 1, J = 7.2), 2.58 (dt, 1, J = 17.2, 7.4), 2.49 (dt, 1, J = 17.2, 7.4), 2.04 (dtt, 2, J = 7.2, 1.3, 7.2), 1.60 (tt, 2, J = 7.0, 7.9), 1.32 (d, 3, J = 7.2), 1.42-1.23 (m, 2), 1.26 (t, 3, J = 7.2); ^{13}C NMR 205.8, 170.6, 138.4, 114.6, 61.3, 52.8, 41.1, 33.4, 28.2, 22.9, 14.1, 12.7; IR (neat) 1750, 1720, 1645 cm^{-1}. Anal. Calcd for $C_{12}H_{20}O_3$: C, 67.89; H, 9.50. Found: C, 67.93; H, 9.58.

Oxidative cyclization of 8a followed by flash chromatography on silica gel (9:1 hexane-EtOAc) afforded 46% of an inseparable 3:1:1 mixture of ethyl 1-methyl-7-oxo-3-cycloheptenecarboxylate (**11a**), ethyl 1-methyl-7-oxo-2-cycloheptenecarboxylate (**12a**) and ethyl 1-methyl-2-methylene-6-oxocyclohexanecarboxylate (**15a**). Lactone **16a** (≈5%) could not be isolated although its presence was evident from the ^{1}H NMR spectra of the crude product.

The spectral data for **12a**: ^{1}H NMR 5.76-5.74 (m, 2), 4.16 (q, 2, J = 7.2), 3.04-1.78 (m, 6), 1.37 (s, 3), 1.24 (t, 3, J = 7.2); ^{13}C NMR 209.3, 130.5, 126.5, 112.2, 61.2, 40.2, 33.5, 26.0, 21.0, 14.0; the ester carbonyl was not observed. Partial spectral data for **11a**: ^{1}H NMR 5.86 (ddd, 1, J = 11.4, 6.0, 4.0), 5.42 (dt, 1, J = 11.4, 1.4), 1.45 or 1.47 (s, 3); ^{13}C NMR 132.1, 128.2. Partial spectral data for **15a**: ^{1}H NMR 5.05 (br s, 1), 4.95 (br s, 1), 1.47 or 1.45 (s, 3), ^{13}C NMR 147.3, 112.2. Partial spectral data for **16a**: ^{1}H NMR 4.41 (dd, 1, J = 10.0, 6.5), 4.08 (dd, 1, J = 10.0, 5.5).

Oxidative cyclization of 8b followed by flash chromatography (4:1 hexane-EtOAc) afforded 38% of ethyl 8-oxo-1-methylcyclooct-3-ene-1-carboxylate (**11b**): ^{1}H NMR 5.79-5.68 (m, 2), 4.19 (q, 2, J = 7.1), 3.08 (dd, 1, J = 9.6, 13.4), 2.66 (ddd, 1, J = 3.5, 11.5, 12.5), 2.36-2.19 (m, 1), 2.24 (dd, 1, J = 6.2, 13.5), 2.14-2.10 (m, 2), 1.74-1.64 (m, 2), 1.32 (s, 3), 1.25 (t, 3, J = 7.1); ^{13}C NMR 173.4, 133.4, 127.3, 63.2, 61.6, 40.0, 31.6, 27.0, 25.5, 19.0, 14.4; the ketone carbonyl was not observed; IR (neat) 1740, 1715 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.51; H, 8.68

Ethyl 2-Chloro-3-oxo-7-octenoate (17a): 32% as a 4.5:1 mixture of the keto and enol tautomers; ^{1}H NMR (keto tautomer) 5.76 (ddt, 1, J = 10.0, 17.1, 6.8), 5.07-4.95 (m, 2), 4.78 (s, 1), 4.29 (q, 2, J = 7.1), 2.73 (dt, 1, J = 14.4, 7.3), 2.71 (dt, 1, J = 14.4, 7.3), 2.09 (dtt, 2, J = 6.8, 1.1, 7.2), 1.74 (tt, 2, J = 7.2, 7.5), 1.32 (t, 3, J = 7.1); ^{1}H NMR (enol tautomer) 12.32 (s, 1), 4.30 (q, 2, J = 7.1), 2.53 (t, 2, J = 7.3), 1.36 (t, 3, J = 7.1); ^{13}C NMR (keto tautomer) 199.3, 165.4, 137.8, 116.0, 63.5, 61.3, 38.4, 33.0, 22.8, 14.3; IR (neat) 1730, 1643, 1607 cm^{-1}.

Ethyl 2-Chloro-3-oxo-8-nonenoate (17b): 32% as a 21:1 mixture of keto and enol tautomers; ^{1}H NMR (keto tautomer) 5.78 (ddt, 1, J = 10.3, 17.1, 6.7), 5.05-4.94 (m, 2), 4.78 (s, 1), 4.29 (q, 2, J = 7.1), 2.75 (dt, 1, J = 14.4, 7.2), 2.70 (dt, 1, J = 14.4, 7.2), 2.07 (dtt, 2, J = 7.1, 1.4, 7.1), 1.70-1.27 (m, 4), 1.32 (t, 3, J = 7.1); ^{1}H NMR (enol tautomer) 12.38 (s, 1), 4.29 (q, 2, J = 7.1), 2.53 (t, 2, J = 7.4); ^{13}C NMR (keto tautomer) 199.0, 165.1, 138.2, 114.8, 63.1, 60.9, 42.5, 33.4, 28.0, 22.9, 14.0; IR (neat) 1730, 1643, 1617 cm^{-1}. Anal. Calcd for $C_{11}H_{17}ClO_3$: C, 56.77; H, 7.36. Found: C, 56.83; H, 7.56.

Oxidative cyclization of 17a followed by flash chromatography on silica gel (9:1 hexane-EtOAc) gave 50% of ethyl 1-chloro-7-oxocyclohept-3-ene-1-carboxylate (**18a**) and 18% of ethyl 1-chloro-6-methylene-2-oxocyclohexane-1-carboxylate (**19a**).

The data for **18a**: ^{1}H NMR 5.95-5.73 (m, 2), 4.28 (q, 2, J = 7.1), 3.16 (ddt, 1, J = 6.2, 16.1, 1.3), 2.98-2.81 (m, 2), 2.80 (ddt, 1, J = 6.0, 16.1, 1.2), 2.43-2.36 (m, 2), 1.29 (t, 3, J = 7.1); ^{13}C NMR 200.7, 167.3, 131.8, 125.2, 75.2, 62.9, 38.9, 35.6, 25.4, 13.8; IR (neat) 1735 cm^{-1}. Anal. Calcd for $C_{10}H_{13}ClO_3$: C, 55.44; H, 6.05; Cl, 16.36. Found: C, 55.52; H, 6.08; Cl, 16.33.

The data for **19a**: ^{1}H NMR 5.40 (s, 1), 5.23 (s, 1), 4.31 (q, 2, J = 7.2), 2.94-2.61 (m, 3), 2.51-2.41 (m, 1), 2.25-1.97 (m,1), 1.82-1.67 (m, 1), 1.31 (t, 3, J = 7.2); ^{13}C NMR 115.6, 63.2, 39.0, 32.2, 24.1, 13.8; the C=O and quaternary carbons were not observed; IR (neat) 1755-1730, 1650 cm^{-1}.

Oxidative cyclization of 17b followed by flash chromatography on silica gel (8:2 hexane-EtOAc) gave 47% of ethyl 1-chloro-8-oxocyclooct-3-ene-1-carboxylate (**18b**): ^{1}H NMR 5.92-5.75 (m, 2), 4.29 (q, 2, J = 7.1), 3.30 (dd, 1, J = 8.2, 14.3), 2.83 (dd, 1, J = 6.7, 14.3), 2.73-2.65 (m, 1), 2.58-2.48 (m, 1), 2.24-2.16 (m, 2), 1.79-1.71 (m, 2), 1.30 (t, 3, J = 7.1); ^{13}C NMR 167.3, 134.3, 125.6, 62.8, 38.0, 33.6, 26.6, 25.2, 13.8; the ketone and quaternary carbons were not observed; IR (neat) 1740 cm^{-1}. Anal. Calcd for $C_{11}H_{15}ClO_3$: C, 57.27; H, 6.55. Found: C, 57.16; H, 6.44.

Ethyl 2-Chloro-3-oxo-7-methyl-7-octenoate (20a): 35% as a 5.7:1 mixture of keto and enol tautomers; ^{1}H NMR (keto tautomer) 4.78 (s, 1), 4.75 (br s, 1), 4.68 (br s, 1), 4.29 (q, 2, J = 7.2), 2.73 (dt, 1, J = 17.6, 7.3), 2.69 (dt, 1, J = 17.6, 7.3), 2.04 (t, 2, J = 7.3), 1.78 (tt, 2, J = 7.3, 7.3), 1.71 (br s, 3), 1.32 (t, 3, J = 7.2); ^{1}H NMR (enol tautomer) 12.33 (s, 1), 4.71 (br s, 1), 4.30 (q, 2, J = 7.2), 2.52 (t, 2, J = 7.6), 2.09 (t, 2, J = 6.7), 1.72 (s, 3), 1.37 (t, 3, J = 7.2); ^{13}C NMR (keto tautomer) 198.9, 165.0, 144.5, 110.9, 63.1, 60.9, 38.2, 36.6, 22.1, 21.2, 13.9; ^{13}C NMR (enol tautomer) 110.5, 62.1, 60.9, 36.6, 21.2, 14.1; IR (neat) 1760, 1730, 1650 cm^{-1}. Anal. Calcd for $C_{11}H_{17}ClO_3$: C, 56.77; H, 7.36. Found: C, 56.54; H, 7.48.

Methyl 2-Chloro-3-oxo-8-methyl-8-nonenoate (20b): 76% as a 1.9:1 mixture of keto and enol tautomers; ^{1}H NMR (keto tautomer) 4.81 (s, 1), 4.71 (br s, 1), 4.67 (br s, 1), 3.84 (s, 3), 2.73 (dt, 1, J = 17.7, 7.1), 2.70 (dt, 1, J = 17.7, 7.1), 2.03 (tt, 2, J = 7.4, 7.4), 1.71 (s, 3), 1.66-1.58 (m, 2), 1.53-1.40 (m, 2); ^{1}H NMR (enol tautomer) 12.33 (s, 1), 3.85 (s, 3), 2.54 (t, 2, J = 7.4) ^{13}C NMR (keto tautomer) 198.8, 165.5, 145.2, 110.2, 60.7, 53.7, 38.7, 37.3, 26.6, 23.0, 22.2; ^{13}C NMR (enol tautomer) 175.8, 145.3, 110.0, 60.7, 52.7, 38.7, 32.7, 27.0, 25.3; IR (neat) 3070, 2950, 2935, 2860, 1770-1730, 1650, 1605, 1435 cm^{-1}. Anal. Calcd. for $C_{11}H_{17}ClO_3$: C, 56.77; H, 7.36. Found: C, 56.58; H, 7.12.

Oxidative cyclization of 20a followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 69% of a 2.5:1 mixture of ethyl 1-chloro-6-methylene-2-oxocycloheptane-1-carboxylate (**22a**) and ethyl 1-chloro-3-methyl-7-oxocyclohept-3-ene-1-carboxylate (**23a**).

The data for **22a**: ^{1}H NMR 5.05 (br s, 1), 5.04 (br s, 1), 4.28 (q, 2, J = 7.2), 3.18 (dd, 1, J = 0.9, 14.6), 2.88-2.68 (m, 2), 2.74 (d, 1, J = 14.6), 2.42 (ddd, 1, J = 5.4, 5.4, 13.8), 2.27-2.16 (m, 1), 1.97-1.72 (m, 2), 1.30 (t, 3, J = 7.2); ^{13}C NMR 201.5, 167.6, 141.6, 118.8, 74.4, 62.9, 44.3, 40.1, 37.1, 24.8, 13.9; IR (neat) 1736, 1730, 1643 cm^{-1}.

The data for **23a**: ^{1}H NMR 5.69-5.63 (m, 1), 4.28 (q, 2, J = 7.2), 2.34-2.27 (m, 1), 1.87 (d, 3, J = 1.5), 1.31 (t, 3, J = 7.2); ^{13}C NMR 134.0, 125.3, 74.9, 62.9, 40.5, 39.1, 27.1, 24.9, 13.9; the ketone and ester carbonyl were not observed; IR (neat) 1750-1720, 1643 cm^{-1}.

Oxidative cyclization of 20b followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 14% of methyl 1-chloro-3-methyl-8-oxocyclooct-3-ene-1-carboxylate (**23b**), 44% of a 4:1 mixture of **23b** and methyl 1-chloro-3-methylene-8-oxocyclooctane-1-carboxylate (**22b**), and 11% of **22b**.

The data for **22b**: ^{1}H NMR 5.14 (br s, 1), 5.09 (br s, 1), 3.83 (s, 3), 3.38 (d, 1, J = 14.5), 2.88 (ddd, 1, J = 4.4, 7.6, 13.5), 2.80 (dd, 1, J = 0.7, 14.5), 2.55 (ddd, 1, J = 4.3, 9.4, 13.5), 2.20-2.07 (m, 2), 2.02-1.77 (m, 2), 1.75-1.54 (m, 2); ^{13}C NMR 204.6, 167.9, 142.1, 118.4, 75.6, 53.5, 44.3, 37.8, 34.6, 26.9, 26.1; IR (neat) 1740, 1728 cm^{-1}. Anal. Calcd. for $C_{11}H_{15}ClO_3$: C, 57.27; H, 6.51. Found: C, 57.40; H, 6.63.

The data for **23b**: ^{1}H NMR 5.58 (t, 1, J = 8.2), 3.83 (s, 3), 3.44 (d, 1, J = 14.9), 2.72 (ddd, 1, J = 3.8, 7.5, 16.4), 2.68 (d, 1, J = 14.9), 2.43 (ddd, 1, J = 3.8, 9.8, 12.8), 2.17-1.97 (m, 2), 1.91 (s, 3), 1.88-1.56 (m, 2); ^{13}C NMR 201.0, 168.1, 133.5, 128.3, 78.3, 53.6, 37.7, 37.5, 27.1, 26.2, 24.9; IR (neat) 1737, 1730 cm^{-1}. Anal. Calcd. for $C_{11}H_{15}ClO_3$: C, 57.27; H, 6.51. Found: C, 57.03; H, 6.77.

Methyl 2-(2-Propenyl)-3-oxo-7-methyl-7-octenoate (28a): 44%; ^{1}H NMR 5.73 (ddt, 1, J = 10.2, 17.1, 6.9), 5.09 (ddt, 1, J = 1.6, 17.1, 1.6), 5.05 (ddt, 1, J = 1.6, 10.2, 1.1), 4.73 (br s, 1), 4.66 (br s, 1), 3.72 (s, 3), 3.55 (t, 1, J = 7.4), 2.63-2.41 (m, 4), 2.00 (t, 2, J = 7.4), 1.73 (tt, 2, J = 7.4, 7.4), 1.70 (s, 3); ^{13}C NMR 204.4 (C=O), 169.7 (OC=O), 144.8 (C7), 134.2 (HC=), 117.5 (=CH_2), 110.6 (=CH_2), 58.4 (C2), 52.3 (OCH_3), 41.4 (CH_2), 36.8 (CH_2), 32.2 (CH_2), 22.1 (CH_3), 21.0 (CH_2); IR (neat) 1753, 1725, 1650 cm^{-1}. Anal. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99. Found: C, 69.54; H, 9.05.

Methyl 2-(2-Propenyl)-3-oxo-8-methyl-8-nonenoate (28b): 65%; ^{1}H NMR 5.73 (ddt, 1, J = 10.2, 17.1, 6.9), 5.09 (ddt, 1, J = 1.6, 17.1, 1.5), 5.04 (ddt, 1, J = 1.6, 10.2, 1.1), 4.70 (br s, 1), 4.66 (br s, 1), 3.73 (s, 3), 3.56 (t, 1, J = 7.4), 2.65-2.43 (m, 4), 2.01 (t, 2, J = 7.4), 1.70 (s, 3), 1.58 (tt, 2, J = 7.4, 7.4), 1.41 (tt, 2, J = 7.4, 7.4); ^{13}C NMR 204.4 (C=O), 169.7 (OC=O), 145.4 (C8), 134.2 (HC=), 117.4 (=CH_2), 110.0 (=CH_2), 58.3 (C2), 52.3 (OCH_3), 42.0 (CH_2), 37.4 (CH_2), 32.2 (CH_2), 26.8 (CH_2), 22.9

(CH_2), 22.5 (CH_3); IR (neat) 1752, 1720, 1648 cm^{-1}. Anal. Calcd for $C_{14}H_{22}O_3$: C, 70.56; H, 9.30. Found: C, 70.49; H, 9.38.

Oxidative cyclization of 28a followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 68% of methyl 7-methylene-6-methyl-2-oxobicyclo[4.2.1]nonane-1-carboxylate (**31a**): mp 55-56 °C; ^1H NMR 5.02 (dd, 1, J = 1.9, 1.9), 4.82 (dd, 1, J = 1.9, 3.1), 3.69 (s, 3), 3.34 (ddd, 1, J = 2.9, 2.9, 18.1), 2.89-2.78 (m, 1), 2.78 (ddd, 1, J = 1.9, 3.8, 18.1), 2.54-2.49 (m, 1), 2.44 (dd, 1, J = 1.8, 13.9), 1.94 (dd, 1, J = 1.2, 13.9), 1.81-1.58 (m, 4), 1.23 (s, 3); ^{13}C NMR 172.7 (OC=O), 154.9 (C7), 106.3 (=CH_2), 63.2 (C1), 52.4 (OCH_3), 47.1 (CH_2), 46.7 (CH_2), 44.2 (CH_2), 43.0 (CH_2), 42.4 (CH_2), 29.1 (CH_3), 21.7 (CH_2); the ketone carbon was not observed; IR (neat) 1745, 1700, 1660 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_3$: C, 70.25; H, 8.16. Found: C, 70.31; H, 8.08.

Oxidative cyclization of 28b followed by flash chromatography on silica gel (19:1 hexane-EtOAc) afforded 8% of a 3.6:1:3.3 mixture of methyl 1-(2-propenyl)-3-methyl-8-oxocyclooct-3-ene-1-carboxylate (**32b**), methyl 1-(2-propenyl)-3-methylene-8-oxocyclooctane-1-carboxylate (**33b**), methyl 1-(2-propenyl)-3-methyl-8-oxocyclooct-2-ene-1-carboxylate (**34b**), followed by 70% of methyl 8-methylene-7-methyl-2-oxobicyclo[5.2.1]decane-1-carboxylate (**31b**).

The data for **31b**: mp 76-77 °C; ^1H NMR 4.79 (dd, 1, J = 2.1, 2.1), 4.71 (dd, 1, J = 2.4, 2.4), 3.69 (s, 3), 3.41 (ddd, 1, J = 2.2, 2.2, 17.7), 3.10 (ddd, 1, J = 4.5, 12.0, 12.0), 2.90 (ddd, 1, J =2.3, 2.3, 17.7), 2.79 (dd, 1, J = 1.9, 13.5), 2.42 (ddd, 1, J = 4.6, 4.6, 11.3) 2.00-1.90 (m, 1), 1.85 (dd, 1, J = 1.2, 13.5), 1.74-1.30 (m, 4), 1.1 (s, 3), 0.83 (dd, 1, J = 8.4, 16.0); ^{13}C NMR 212.2 (C=O), 172.5 (OC=O), 156.7 (C8), 103.4 (=CH_2), 62.6 (C1), 52.7 (OCH_3), 45.8 (CH_2), 44.2 (CH_2), 39.0 (CH_2), 38.8 (CH_2), 37.6 (CH_2), 30.0 (CH_2), 25.0 (CH_3), 22.9 (CH_2); IR (neat) 1745, 1706 cm^{-1}. Anal. Calcd for $C_{14}H_{20}O_3$: C, 71.16; H, 8.53. Found: C, 71.32; H, 8.57.

Partial data for **32b**: ^1H NMR 5.79-5.64 (m, 1), 5.51 (t, 1, J = 8.3), 5.12-5.04 (m, 2), 3.70 (s, 3), 3.08 (d, 1, J = 14.2), 2.28 (d, 1, J = 14.2), 1.57 (s, 3). Partial data for **33b**: ^1H NMR 5.79-5.64 (m, 1), 5.12-5.04 (m, 2), 4.98 (br s, 1), 4.88 (br s, 1), 3.69 (s, 3), 3.15 (d, 1, J = 14.2), 2.42 (d, 1, J =14.2). Partial data for **34b**: ^1H NMR 5.79-5.64 (m, 1), 5.12-5.04 (m, 2), 4.93 (br s, 1), 3.70 (s, 3), 1.79 (s, 3).

Methyl 3-Oxo-2-(2-propenyl)-7-octenoate (35a): 54%; ^1H NMR 5.80-5.68 (m, 2), 5.13-4.95 (m, 4), 3.72 (s, 3), 3.55 (t, 1, J = 7.4), 2.64-2.43 (m, 4), 2.06 (dtt, 2, J = 7.0, 7.0, 1.3), 1.69 (tt, 2, J = 7.3, 7.3); ^{13}C NMR 204.3, 169.6, 137.7, 134.2, 117.4, 115.3, 58.3, 52.3, 41.3, 32.8, 32.2, 22.3; IR (neat) 1720, 1645 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C,68.55; H, 8.63. Found: C, 68.56; H, 8.70.

Methyl 3-Oxo-2-(propenyl)-8-nonenoate (35b): 62%; ^1H NMR 5.85-5.66 (m, 2), 5.13-4.92 (m, 4), 3.72 (s, 3), 3.55 (t, 1, J = 7.5), 2.64-2.42 (m, 4), 2.05 (dtt, 2, J = 7.2, 7.2, 1.3), 1.65-1.55 (m, 2), 1.42-1.32 (m, 2); ^{13}C NMR 204.4, 169.7, 138.3, 134.2, 117.4, 114.7, 58.3, 52.3, 42.0, 33.4, 32.2, 28.1, 22.8; IR (neat) 1750, 1720, 1645 cm^{-1}. Anal. Calcd for $C_{13}H_{20}O_3$: C, 69.61; H, 8.99. Found: C, 69.68; H, 9.06.

Oxidative cyclization of 35a followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 6% of a 1:2 mixture of methyl 1-(2-propenyl)-7-oxocyclohept-3-ene-1-carboxylate (**37a**) and methyl *trans*-2-methylene-4-oxo-hexahydroindene-3a-carboxylate (**45a**), 13% of an inseparable 1:3:2 mixture of **37a**, **45a**, and methyl *cis*-2-methylene-4-oxo-hexahydroindene-3a-carboxylate (**46a**), followed by 30% of methyl 7-methylene-2-oxobicyclo[4.2.1]nonane-1-carboxylate (**42a**).

The data for **37a**: ^1H NMR 5.85-5.60 (m, 3), 5.20-5.05 (m, 2), 3.71 (s, 3), 2.93-1.55 (m, 8); ^{13}C NMR 171.8, 133.4, 130.5, 126.7, 118.7, 64.7, 52.3, 40.5, 39.1, 30.5, 25.8; the ketone carbonyl was not observed.

The data for **42a**: mp 58.5-59.0 °C; ^1H NMR 5.05 (br s, 1, =CH_2), 4.93 (br s, 1, =CH_2), 3.70 (s, 3), 3.20 (ddd, 1, J = 2.9, 2.9, 18.0, H_{8a}), 3.14-3.07 (m, 1, H_6), 2.83 (ddd, 1, J = 2.8, 12.3, 13.8, H_{3a}), 2.74 (dddd, 1, J = 1.9, 3.4, 3.9, 18.0, H_{8b}), 2.53-2.44 (m, 1, H_{3b}), 2.38 (dd, 1, J = 1.9, 13.9, H_{9a}), 2.17 (ddd, 1, J = 1.0, 8.7, 13.8, H_{9b}), 1.96-1.87 (m, 1, H_{5a}), 1.84-1.61 (m, 3, H_{5b}, H_{4a}, H_{4b}); ^{13}C NMR 212.8, 172.6, 151.0, 107.8, 65.1, 52.4, 43.4, 42.6 (2), 39.4, 36.0, 20.5; IR (neat) 1745, 1700, 1660 cm^{-1}. Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.18; H, 7.78.

The data for **45a**: ^1H NMR 4.90 (br s, 2), 3.70 (s, 3), 3.23-1.55 (m, 11); ^{13}C NMR 205.7, 171.4, 146.6, 108.3, 66.4, 52.1, 51.4, 39.7, 37.7, 35.7, 27.0, 24.7; the ketone carbonyl was not observed.

The data for **46a**:[11] ^1H NMR 4.80 (br s, 2), 3.73 (br s, 3), 3.23-1.55 (m, 11); ^{13}C NMR 172.3, 146.7, 107.6, 65.9, 52.6, 46.2, 39.7, 38.3, 35.8, 25.2, 23.2; the ketone carbonyl was not observed.

Oxidative cyclization of 35b with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and 1.0 equiv of $Cu(OAc)_2 \cdot H_2O$ followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 14.4% of methyl 8-oxo-1-(2-propenyl)-cyclooct-3-ene-1-carboxylate (**37b**), followed by 3.9% of a 1:1 mixture of **37b** and methyl 8-methylene-2-oxobicyclo-[5.2.1]-decane-1-carboxylate (**42b**), 9.1% of **42b**, and 56% of oligomeric material.

Oxidative cyclization of **35b** with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and only 0.05 equiv of $Cu(OAc)_2 \cdot H_2O$ afforded 4.6% of **37b**, 4.8% of a 1:1 mixture of **37b** and **42b** and 20% of **42b**.

The data for **37b**: ^1H NMR 5.75-5.45 (m, 3), 5.02-4.93 (m, 2), 3.60 (s, 3), 2.91 (dd, 1, J = 10.1, 13.9), 2.61 (ddt, 1, J = 6.2, 14.2, 1.2), 2.51 (ddd, 1, J = 3.7, 8.4, 15.5), 2.23 (dd, 1, J = 6.9, 13.9), 2.26-2.08 (m, 3), 2.60-1.54 (m, 1), 1.68-1.48 (m, 2); ^{13}C NMR 208.3, 172.2, 133.8, 133.5, 127.0, 118.9, 67.4, 52.5, 40.1, 36.4, 28.5, 26.9, 25.5; IR (neat) 1745, 1715, 1643 cm^{-1}.

The data for **42b**: ^1H NMR 4.87 (br s, 1, $=CH_2$), 4.82 (br s, 1, $=CH_2$), 3.69 (s, 3), 3.32 (br d, 1, J = 17.3, H_{9a}), 3.07 (ddd, 1, J = 5.5, 11.5, 11.7, H_{3a}), 2.79-2.69 (m, 3, H_7, H_{9b}, H_{10a}), 2.42 (ddd, 1, J = 5.0, 5.5, 11.5, H_{3b}), 2.19 (dd, 1, J = 7.6, 13.7, H_{10b}), 1.94-1.80 (m, 2, H_{4a}, H_{6a}), 1.76-1.56 (m, 2, H_{4b}, H_{5a}), 1.47-1.35 (m, 1, H_{5b}), 0.95 (dddd, 1, J = 1.2, 8.8, 8.8, 15.6, H_{6b}); ^{13}C NMR 212.0, 172.4, 152.9, 106.0, 64.4, 52.6, 42.4, 38.5, 38.0, 37.6, 33.0, 29.0, 23.0; IR (neat) 1745, 1710, 1660 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_3$: C, 70.27; H, 8.11. Found: C, 70.33; H, 8.24.

Oxidative cyclization of 35b with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ without $Cu(OAc)_2 \cdot H_2O$ followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 27% of an inseparable 4:1 mixture of methyl 8-*exo*-methyl-2-oxobicyclo-[5.2.1]-decanecarboxylate (**40b**) and methyl 8-*endo*-methyl-2-oxobicyclo-[5.2.1]-decanecarboxylate (**41b**).

The data for **40b**: ^1H NMR 3.67 (s, 3), 3.04 (ddd, 1, J = 4.8, 11.6, 11.6), 2.86 (ddd, 1, J = 1.7, 8.0, 13.6), 2.62 (br d, 1, J = 13.7), 2.38 (ddd, 1, J = 4.8, 4.8, 11.6), 2.16 (dd, 1, J = 7.2, 13.8), 1.96-1.28 (m, 8), 1.02 (d, 3, J = 7.0), 0.65-0.50 (m, 1); ^{13}C NMR 173.2, 65.6, 52.6, 45.0, 39.3, 38.8, 38.5, 35.5, 32.3, 29.8, 23.6, 22.2; the ketone carbon was not observed.

The data for **41b**: ^1H NMR 3.67 (s, 3), 3.07 (ddd, 1, J = 3.9, 11.4, 13.0), 2.77 (br d, 1, J = 13.2), 2.38 (ddd, 1, J = 4.4, 4.4, 10.9), 2.26-1.24 (m, 10), 0.89 (d, 3, J = 6.8), 0.42-0.27 (m, 1); ^{13}C NMR 173.6, 64.5, 52.6, 42.2, 39.7, 39.2, 37.7, 37.6, 30.6, 24.6, 23.8, 14.8; the ketone carbon was not observed.

Hydrogenation of 42b. A solution of **42b** (19.1 mg, 0.086 mmol) in 5 mL of ether containing 20 mg of 10% Pd on C was stirred 4 h under a hydrogen atmosphere. The solution was filtered through celite and silica gel and evaporated to give 18.5 mg (96%) of a 1:5 mixture of **40b** and **41b**.

Methyl 2-Chloro-3-oxo-6-(methylethenyl)-9-decenoate (51a): 28% as a 1.8:1 mixture of keto and enol tautomers: ^1H NMR (keto tautomer) 5.78 (ddt, 1, J = 10.3, 17.0, 6.8), 4.99 (ddt, 1, J = 2.1, 17.0, 1.1), 4.94 (ddt, 1, J = 2.1, 10.2, 1.0), 4.81 (br s, 1), 4.79 (s, 1), 4.69 (br s, 1), 3.83 (s, 3), 2.63 (t, 2, J = 7.3), 2.48-2.33 (m, 1), 2.14-1.88 (m, 2), 1.79-1.54 (m, 2), 1.58 (s, 3), 1.49-1.40 (m, 2); ^1H NMR (enol tautomer) 12.32 (s, 1), 3.85 (s, 3), 1.63 (s, 3); ^{13}C NMR (keto tautomer) 165.6, 145.9, 138.6, 114.5, 113.2, 60.8, 53.7, 46.0, 37.1, 32.5, 31.5, 26.6, 17.5; the ketone carbon was not observed; ^{13}C NMR (enol tautomer) 176.1, 138.7, 114.5, 113.2, 60.8, 52.7, 46.7, 37.1, 32.4, 31.2, 29.0, 17.6; IR (neat) 1765-1725, 1640, 1601 cm^{-1}. Anal. Calcd for $C_{14}H_{21}ClO_3$: C, 61.65; H, 7.76. Found: C, 61.52; H, 7.75.

Methyl 2-Chloro-3-oxo-7-(methylethenyl)-10-undecenoate (51b): 38% as a 1.1:1 mixture of keto and enol tautomers: ^1H NMR (keto tautomer) 5.79 (ddt, 1, J = 10.4, 17.0, 6.6), 5.02-4.92 (m, 2), 4.79 (s, 1), 4.77 (br s, 1), 4.70 (br s, 1), 3.85 (s, 3), 2.74-2.66 (m, 2), 2.10-1.87 (m, 4), 1.65-1.28 (m, 5), 1.58 (s, 3); ^1H NMR (enol tautomer) 12.32 (s, 1), 5.78 (ddt, 1, J = 10.3, 17.0, 6.6), 3.84 (s, 3), 2.50 (t, 2, J = 6.9), 1.59 (s, 3); ^{13}C NMR (keto tautomer) 198.8, 175.9, 146.6, 138.9, 114.4, 112.3, 60.7, 52.7, 46.5, 38.8, 32.8, 32.5, 31.6, 23.7, 21.4, 17.6; ^{13}C NMR (enol tautomer) 169.7, 146.5, 138.8, 114.4, 112.4, 60.7, 53.7, 46.5, 38.8, 32.7, 32.5, 23.7, 21.4, 17.6; IR (neat) 1774-1735, 1648, 1609 cm^{-1}. Anal. Calcd for $C_{15}H_{23}ClO_3$: C, 62.82; H, 8.08. Found: C, 62.65; H, 8.14.

Oxidative cyclization of 51a followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 12% of a 1.4:1 mixture of one stereoisomer of methyl (3aβ,8aα)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxoazulene-5-carboxylate (**54a**) and one stereoisomer of methyl (3aβ,8aβ)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxoazulene-5-carboxylate (**56a**), 7% of a 1:2.3 mixture of **54a** and **56a**, 3% of one stereoisomer of methyl (3aβ,8aα)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxoazulene-5-carboxylate (**53a**) and 43% of a 3.4:1 mixture of **53a** and one stereoisomer of methyl (3aβ,8aβ)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxoazulene-5-carboxylate (**55a**).

The data for **53a**: ^1H NMR 4.84 (dd, 1, J = 2.2, 2.2), 4.82 (dd, 1, J = 2.5, 2.5), 3.82 (s, 3), 2.85 (ddd, 1, J = 2.8, 6.3, 11.6), 2.83 (d, 1, J = 16.3), 2.59-2.47 (m, 1), 2.53 (d, 1, J = 16.3), 2.43-2.27 (m, 1), 1.97-1.82 (m, 2), 1.79-1.68 (m, 1), 1.65-1.38 (m, 3), 0.84 (s, 3); ^{13}C NMR 200.5 (C=O), 168.5 (OC=O), 159.6 (C3), 104.1 ($=CH_2$), 76.6 (C5), 53.8 (OCH_3), 53.2 (C8a), 46.8 (C3a), 46.4 (CH_2), 40.5 (CH_2), 29.4 (CH_2), 27.5 (CH_2), 26.0 (CH_2), 17.6 (CH_3).

The data for **54a**: ^1H NMR 4.88-4.83 (m, 2), 3.85 (s, 3), 3.22 (d, 1, J = 15.2), 3.13-3.03 (m, 1), 2.72-2.29 (m, 2), 2.04 (d, 1, J = 15.2), 2.01-1.69 (m, 4), 1.55-1.32 (m, 2), 0.85 (s, 3); ^{13}C NMR 201.6 (C=O),

169.2 (OC=O), 161.2 (C3), 104.8 (=CH_2), 74.2 (C5), 53.6 (OCH_3), 49.7 (C8a), 48.4 (CH_2), 47.1 (C3a), 38.3 (CH_2), 30.3 (CH_2), 28.9 (CH_2), 24.9 (CH_2), 19.9 (CH_3).

The data for **55a**: ^{1}H NMR 4.85 (dd, 1, J = 2.2, 2.2), 4.84-4.81 (m, 1), 3.81 (s, 3), 2.75 (d, 1, J = 16.3), 2.22 (d, 1, J = 16.3), 1.18 (s, 3); no other protons were identifiable in the mixture; ^{13}C NMR 199.8 (C=O), 168.4 (OC=O), 161.0 (C3), 105.1 (=CH_2), 75.8 (C5), 53.8 (OCH_3), 47.8 (C3a), 47.2 (C8a), 42.1 (CH_2), 36.7 (CH_2), 29.2 (CH_2), 27.3 (CH_2), 26.3 (CH_2), 24.2 (CH_3).

The data for **56a**: ^{1}H NMR 4.88 (dd, 1, J = 2.1, 2.1), 4.84 (dd, 1, J = 2.4, 2.4), 3.86 (s, 3), 3.06 (ddd, 1, J = 4.3, 8.4, 15.7), 2.71 (d, 1, J = 15.5), 2.73-2.55 (m, 1), 2.45-2.33 (m, 1), 2.33 (d, 1, J = 15.5), 2.00-1.68 (m, 4), 1.57-1.36 (m, 2), 1.10 (s, 3); ^{13}C NMR 201.2 (C=O), 169.1 (OC=O), 161.2 (C3), 105.4 (=CH_2), 72.6 (C5), 53.5 (OCH_3), 48.5 (C8a), 47.7 (C3a), 45.2 (CH_2), 37.7 (CH_2), 30.7 (CH_2), 29.1 (CH_2), 26.9 (CH_3), 25.8 (CH_2).

Ketones 57a and 58a. To a stirred solution of a 1:2.3 mixture of **54a** and **56a** (18.3 mg, 0.068 mmol) in 0.8 mL of glacial acetic acid was added zinc dust (66.2 mg, 1.01 mmol) at 25 °C. The reaction mixture was stirred for 3 h at 25 °C and filtered through celite. The celite was washed with CH_2Cl_2 (2 x 3.0 mL). The solution was extracted with water and saturated $NaHCO_3$ dried ($MgSO_4$), and evaporated in vacuo giving 15.5 mg of crude dechlorinated material. A solution of NaOH (35.3 mg, 0.78 mmol) in 0.6 mL of water and this material in 0.8 mL of methanol was heated at reflux for 20 h. The reaction mixture was cooled to 0 °C and acidified with 4 mL of saturated NaH_2PO_4 solution. The resulting solution was extracted with EtOAc (5 x 4.0 mL). The combined organic layers were dried over $MgSO_4$. Removal of solvent in vacuo afforded 9.1 mg (75%) of a 1:2.3 mixture of (3aβ,8aα)-octahydro-3a-methyl-3-methylene-6-(1*H*)-azulenone (**57a**) and (3aβ,8aβ)-octahydro-3a-methyl-3-methylene-6-(1*H*)-azulenone (**58a**).

The data for **57a**: ^{1}H NMR 4.77 (dd, 1, J = 2.2, 2.2), 4.73 (dd, 1, J = 2.2, 2.2), 2.70-2.24 (m, 5), 1.99 (ddd, 1, J = 4.5, 4.5, 14.2), 1.93-1.30 (m, 7), 0.81 (s, 3). ^{13}C NMR 161.1 (C3), 103.1 (=CH_2), 52.0 (CH_2), 46.5 (C3a), 43.7 (CH_2), 40.4 (CH_2), 33.6 (C8a), 29.5 (CH_2), 28.4 (CH_2), 23.5 (CH_2), 18.0 (CH_3); the ketone carbon was not observed.

The data for **58a**: ^{1}H NMR 4.88 (dd, 1, J = 2.2, 2.2), 4.74 (dd, 1, J = 2.2, 2.2), 1.11 (s, 3); no other protons were identifiable in the mixture. ^{13}C NMR 160.3 (C3), 104.4 (=CH_2), 49.1 (CH_2), 47.5 (C3a), 39.8 (CH_2), 39.0 (CH_2), 31.7 (C8a), 30.1 (CH_2), 27.8 (CH_2), 26.6 (CH_2), 24.8 (CH_3); the ketone carbon was not observed.

Oxidative cyclization of 51b followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 2% of a single stereoisomer of methyl (3aβ,9aβ)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxo-(6*H*)-cyclopentacyclooctene-5-carboxylate (**56b**), 33% of a single stereoisomer of methyl (3aβ,9aα)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxo-(6*H*)-cyclopentacyclooctene-5-carboxylate (**53b**), 20% of a 3:1 mixture of **53b** and a single stereoisomer of methyl (3aβ,9aα)-5-chlorodecahydro-3a-methyl-3-methylene-6-oxo-(6*H*)-cyclopentacyclooctene-5-carboxylate (**54b**), 16% of a 1:3 mixture of **54b** and a single stereoisomer of methyl (3aβ,9aβ)-5-chloro-3a-methyl-3-methylene-6-oxo-(6*H*)-cyclopentacyclooctene-5-carboxylate (**55b**), and 5% of **55b**.

The data for **53b**: ^{1}H NMR 4.83 (dd, 1, J = 1.7, 2.6), 4.76 (dd, 1, J = 1.9, 2.8), 3.72 (s, 3), 2.90 (ddd, 1, J = 4.1, 8.3, 13.4), 2.70 (s, 2), 2.54 (ddd, 1, J = 4.0, 9.3, 13.4), 2.34 (dddd, 1, J = 1.4, 1.4, 8.3, 16.1), 2.28-2.10 (m, 2), 1.80-1.55 (m, 4), 1.45-1.25 (m, 2), 1.01 (s, 3); ^{13}C NMR 204.1 (C=O), 167.8 (OC=O), 161.0 (C3), 103.8 (=CH_2), 73.6 (C5), 53.0 (OCH_3), 49.2 (CH_2), 46.2 (C9a), 45.9 (C3a), 36.9 (CH_2), 31.8 (CH_2), 30.8 (CH_2), 27.3 (CH_2), 26.7 (CH_2), 23.6 (CH_3); IR (neat) 1760-1710 cm^{-1}.

The data for **54b**: ^{1}H NMR 4.91 (dd, 1, J = 1.7, 1.7), 4.87 (dd, 1, J = 2.4, 2.4), 3.81 (s, 3), 1.13 (s, 3); no other protons were identifiable in the mixture; ^{13}C NMR 201.2 (C=O), 168.2 (OC=O), 159.6 (C3), 104.7 (=CH_2), 76.3 (C5), 53.8 (OCH_3), 47.3 (C9a), 47.2 (C3a), 40.6 (CH_2), 39.2 (CH_2), 33.1 (CH_2), 33.0 (CH_2), 28.6 (CH_2), 28.2 (CH_3), 27.7 (CH_2); IR (neat) 1760-1725 cm^{-1}.

The data for **55b**: ^{1}H NMR 4.92-4.88 (m, 2), 3.81 (s, 3), 2.87 (d, 2, J = 1.0), 2.85-2.79 (m, 1), 2.56 (ddd, 1, J = 3.9, 7.6, 13.3), 2.35-2.28 (m, 2), 2.05-1.83 (m, 3), 1.74-1.47 (m, 2), 1.43-1.25 (m, 2), 0.96 (s, 3); ^{13}C NMR 204.7 (C=O), 168.3 (OC=O), 159.8 (C3), 104.6 (=CH_2), 76.4 (C5), 53.9 (OCH_3), 45.8 (CH_2), 45.2 (C3a), 44.3 (C9a), 39.1 (CH_2), 31.3 (CH_2), 31.0 (CH_2), 27.8 (CH_2), 27.4 (CH_2), 25.9 (CH_3); IR (neat) 1760, 1736 cm^{-1}.

The data for **56b**: ^{1}H NMR 4.92 (dd, 1, J = 1.9, 1.9), 4.89 (dd, 1, J = 2.8, 2.8), 3.83 (s, 3), 3.26-3.18 (m, 1), 3.14 (d, 1, J = 15.3), 2.49-2.28 (m, 2), 2.32 (d, 1, J = 15.3), 2.18-2.06 (m, 1), 1.98-1.80 (m, 2), 1.76-1.37 (m, 5), 0.94 (s, 3); ^{13}C NMR 160.0 (C3), 105.1 (=CH_2), 70.6 (C5), 53.3 (OCH_3), 47.6 (C3a), 46.4 (C9a), 44.3 (CH_2), 38.3 (CH_2), 32.1 (CH_2), 31.9 (CH_2), 29.4 (CH_2), 26.7 (CH_3), 25.9 (CH_2); the ketone and ester carbons were not observed; IR (neat) 3085, 3020-2845, 1770-1720, 1470-1430 cm^{-1}.

Ketones 57b and 58b. A mixture of crude **53b-56b** (16.7 mg, 0.06 mmol) was reduced, hydrolyzed and decarboxylated as described above to give 14.1 mg of a yellow oil. Flash chromatography on silica gel (4:1 hexane-EtOAc) gave 5.9 mg (59%) of a 2.8:1 mixture of (3aβ,9aα)-decahydro-3-methylene-3a-methyl-(6*H*)-cyclopentacycloocten-6-one (**57b**) and (3aβ,9aβ)-decahydro-3-methylene-3a-methyl-(6*H*)-cyclopentacycloocten-6-one (**58b**).

The data for **57b**: ^{1}H NMR 4.80 (dd, 1, J = 1.9, 1.9), 4.67 (dd, 1, J = 2.2, 2.2), 2.80 (ddd, 1, J = 3.1, 11.4, 13.3), 2.50 (ddd, 1, J = 3.1, 7.2, 15.0), 2.36-2.13 (m, 4), 1.97-1.73 (m, 4), 1.70-1.42 (m, 4), 1.35-1.22 (m, 1), 1.03 (s, 3); ^{13}C NMR 162.9 (C3), 103.7 (=CH_2), 47.8 (C9a), 46.3 (C3a), 45.4 (CH_2), 42.8 (CH_2), 40.3 (CH_2), 37.3 (CH_2), 32.6 (CH_2), 31.7 (CH_2), 29.8 (CH_2), 24.4 (CH_2), 20.9 (CH_3).

The data for **58b**: ^{1}H NMR 4.88 (dd, 1, J = 2.1, 2.1), 4.77 (dd, 1, J = 2.5, 2.5), 2.72-2.60 (m, 1), 1.00 (s, 3); no other protons were identifiable in the mixture; ^{13}C NMR 160.4 (C3), 104.0 (=CH_2), 47.8 (C9a), 42.2 (CH_2), 39.9 (CH_2), 32.8 (CH_2), 32.7 (CH_2), 30.6 (CH_2), 29.4 (CH_2), 29.1 (CH_2), 26.3 (CH_3).

Ethyl 2-Methyl-3-oxo-7-octynoate (59a): 65%; ^{1}H NMR 4.21 (q, 2, J = 7.0), 3.53 (q, 1, J = 7.1), 2.76 (dt, 1, J = 18.0, 7.0), 2.65 (dt, 1, J = 18.0, 7.0), 2.24 (dt, 2, J = 2.8, 7.0), 1.96 (t, 1, J = 2.8), 1.82 (tt, 2, J = 7.0, 7.0), 1.35 (d, 3, J = 7.3), 1.28 (t, 3, J = 7.1); ^{13}C NMR 205.2 (C=O), 170.4 (OC=O), 83.4 (C7), 69.1 (C8), 61.3 (OCH_2), 52.9 (C2), 39.6 (CH_2), 22.0 (CH_2), 17.5 (CH_2), 14.0 (CH_3), 12.7 (CH_3); IR (neat) 3300, 1744, 1715 cm^{-1}.

Ethyl 2-Methyl-3-oxo-8-nonynoate (59b): 58%; ^{1}H NMR 4.19 (q, 2, J =7.1), 3.52 (q, 1, J =7.2), 2.63 (dt, 1, J = 17.6, 7.2), 2.52 (dt, 1, J = 17.6, 7.1), 2.20 (dt, 2, J = 2.6, 7.0), 1.95 (t, 1, J = 2.6), 1.77-1.67 (m, 2), 1.58-1.48 (m, 2), 1.34 (d, 3, J = 7.2), 1.27 (t, 3, J = 7.1); ^{13}C NMR 205.5 (C=O), 170.5 (OC=O), 83.9 (C8), 68.6 (C9), 61.3 (OCH_2), 52.8 (C2), 40.7 (CH_2), 27.7 (CH_2), 22.5 (CH_2), 18.2 (CH_2), 14.1 (CH_3), 12.7 (CH_3); IR (neat) 3290, 1745, 1715 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.64; H, 8.64.

Oxidative cyclization of 59a followed by flash chromatography on silica gel (9:1 hexane-EtOAc) gave 0.4% of a 1:1 mixture of ethyl 1-methyl-5-methylene-2-oxocyclohexane-1-carboxylate (**64a**) and unreacted **59a** followed by 35% of ethyl 1-methyl-7-oxo-2-cycloheptene-1-carboxylate (**63a**).

Partial data for **64a**: ^{1}H NMR 5.05 (br s, 1), 4.95 (br s, 1). The data are identical to those of **15a**.

The data for **63a**: ^{1}H NMR 5.89 (ddd, 1, J = 4.3, 6.0, 11.5), 5.43 (ddd, 1, J = 1.5, 2.2, 11.5), 4.22 (q, 2, J = 7.1), 2.93 (dddd, 1, J = 0.9, 5.2, 10.6, 15.9), 2.60-2.44 (m, 1), 2.46-2.34 (m, 1), 2.17-2.03 (m, 1), 1.88-1.79 (m, 2), 1.45 (s, 3), 1.28 (t, 3, J = 7.1); ^{13}C NMR 205.6 (C=O), 173.2 (OC=O), 132.1 (HC=), 128.2 (HC=), 61.5 (OCH_2), 59.8 (C1), 41.5 (CH_2), 28.1 (CH_2), 22.9 (CH_3), 21.2 (CH_2), 14.0 (CH_3); IR (neat) 1745, 1710 cm^{-1}. Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found: C, 67.39; H, 7.98.

Oxidative cyclization of 59b followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 34% of ethyl 1-methyl-8-oxocyclooct-2-ene (**63b**): ^{1}H NMR 5.82-5.65 (m, 2), 4.18 (q, 2, J = 7.1), 2.74-2.66 (m, 1), 2.50-2.42 (m, 1), 2.09-1.53 (m, 6), 1.45 (s, 3), 1.25 (t, 3, J = 7.1); ^{13}C NMR 211.4, 171.6, 131.3, 130.1, 61.5, 61.1, 38.8, 27.0, 25.5, 25.1, 21.8, 13.9; IR (neat) 1741, 1715 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.47; H, 8.45.

Ethyl 2-Methyl-3-oxo-7-nonynoate (65): 31%; ^{1}H NMR 4.19 (q, 2, J = 7.1), 3.53 (q, 1, J = 7.2), 2.72 (dt, 1, J = 17.9, 7.2), 2.62 (dt, 1, J = 17.9, 7.2), 2.18-2.14 (m, 2), 1.78-1.74 (m, 2), 1.77 (t, 3, J = 2.5), 1.34 (d, 3, J = 7.2), 1.28 (t, 3, J = 7.1); ^{13}C NMR 205.5, 170.5, 78.1, 76.3, 61.3, 52.9, 40.0, 22.7, 17.9, 14.0, 12.7, 3.4; IR (neat) 1745, 1715, 1640-1585 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.60; H, 8.50.

Oxidative cyclization of 65 followed by flash chromatography on silica gel (19:1 hexane-EtOAc) gave 59% of a 2.5:1 mixture of the (*E*)- (**66a**) and (*Z*)- (**66b**) isomers of ethyl 1-methyl-2-ethylidene-6-oxocyclohexane-1-carboxylate.

The data for **66a**: ^{1}H NMR 5.49 (br q, 1, J = 7.0), 4.18 (q, 2, J = 7.1), 2.74-2.61 (m, 2), 2.49-2.40 (m, 1), 2.26-2.14 (m, 1), 2.04-1.88 (m, 1), 1.68 (d, 3, J = 7.0), 1.67-1.54 (m, 1), 1.43 (s, 3), 1.25 (t, 3, J = 7.1); ^{13}C NMR 206.5 (C=O), 172.6 (OC=O), 137.2 (C2), 120.8 (=CH), 63.7 (C1), 61.4 (OCH_2), 39.6 (CH_2), 25.5 (CH_2), 23.5 (CH_2), 18.1 (CH_3), 13.9 (CH_3), 13.4 (CH_3).

The data for **66b**: ^{1}H NMR 5.42 (qt, 1, J = 7.0, 1.5), 4.18 (q, 2, J = 7.1), 2.74-2.35 (m, 3), 2.26-2.14 (m, 1), 2.04-1.88 (m, 1), 1.69 (d, 3, J = 7.0), 1.67-1.54 (m, 1), 1.50 (s, 3), 1.25 (t, 3, J = 7.1); ^{13}C NMR 206.5 (C=O), 172.6 (OC=O), 138.3 (C2), 121.7 (=CH), 63.7 (C1), 61.3 (OCH_2), 37.9 (CH_2), 34.1 (CH_2), 21.6 (CH_2), 21.3 (CH_3), 13.9 (CH_3), 13.2 (CH_3).

The data for **66a** and **66b** mixture: IR (neat) 1740, 1715 cm^{-1}. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.55; H, 8.63. Found: C, 68.40; H, 8.36.

Ethyl 3-(3-Butynyl)-2-oxocyclopentane-1-carboxylate (67d): 31%; ^{1}H NMR 4.17 (q, 2, J = 7.1), 3.15 (dd, 1, J = 8.5, 11.2), 2.49-1.71 (m, 7), 1.98 (t, 1, J = 2.6), 1.61-1.42 (m, 2), 1.29 (t, 3, J = 7.1); ^{13}C NMR 212.5, 169.4, 83.2, 69.2, 61.3, 54.9, 48.1, 28.3, 27.1, 25.0, 16.5, 14.1; IR (neat) 3293, 1755, 1728 cm^{-1}. Anal. Calcd for $C_{12}H_{16}O_3$: C, 69.21; H, 7.74. Found: C, 69.38; H, 7.59.

Ethyl 3-(4-Pentynyl)-2-oxocyclopentane-1-carboxylate (67e): 36%; ^{1}H NMR 4.19 (q, 2, J = 7.1), 3.13 (dd, 1, J = 8.4, 11.0), 2.35-2.05 (m, 6), 1.96 (t, 1, J = 2.6), 1.94-1.80 (m, 1), 1.66-1.38 (m, 4), 1.29 (t, 3, J = 7.1); ^{13}C NMR 212.7, 169.5, 83.8, 68.7, 61.3, 54.9, 48.9, 28.8, 27.4, 26.3, 25.1, 18.4, 14.1; IR (neat) 3300, 1753, 1725, 1660, 1620 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_3$: C, 70.25; H, 8.16. Found: C, 70.27; H, 8.22.

Oxidative cyclization of 67d followed by evaporative distillation (130 °C, 16 Torr) gave 6% of ethyl 9-oxobicyclo[4.2.1]non-2-ene-1-carboxylate (**68d**): ^{1}H NMR 6.30 (dd, 1, J = 2.6, 11.7), 5.90 (ddd, 1, J = 4.5, 7.6, 11.7), 4.23 (q, 2, J = 7.1), 2.83-2.73 (m, 1), 2.64-2.41 (m, 1), 2.31-1.48 (m, 7), 1.28 (t, 3, J = 7.1); ^{13}C NMR 171.5, 130.8, 130.2, 62.4, 61.9, 48.2, 34.2, 32.0, 24.0, 23.2, 14.5; the ketone carbon was not observed; IR (neat) 1750, 1728 cm^{-1}.

Oxidative cyclization of 67e followed by evaporative distillation (130 °C, 16 Torr) gave 13% of ethyl 10-oxobicyclo[5.2.1]dec-2-ene-1-carboxylate (**68e**): ^{1}H NMR 5.86 (ddd, 1, J = 8.9, 8.9, 12.0), 5.32 (d, 1, J = 12.0), 4.21 (q, 2, J = 7.1), 2.53-2.32 (m, 2), 2.17-1.83 (m, 5), 1.80-1.58 (m, 4), 1.29 (t, 3, J = 7.1); ^{13}C NMR 171.1, 131.1, 127.4, 63.6, 61.4, 45.6, 32.4, 30.3, 24.0, 23.6, 20.7, 14.1; the ketone carbon was not observed; IR (neat) 1753, 1730 cm^{-1}. Anal. Calcd for $C_{13}H_{18}O_3$: C, 70.25; H, 8.16. Found: C, 70.14; H, 8.23.

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