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Mn(III)-Based Oxidative Free-Radical Cyclizations of γ,γ-Bis(Allylic) Acetoacetates

Mark A. Dombroski and Barry B. Snider*

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

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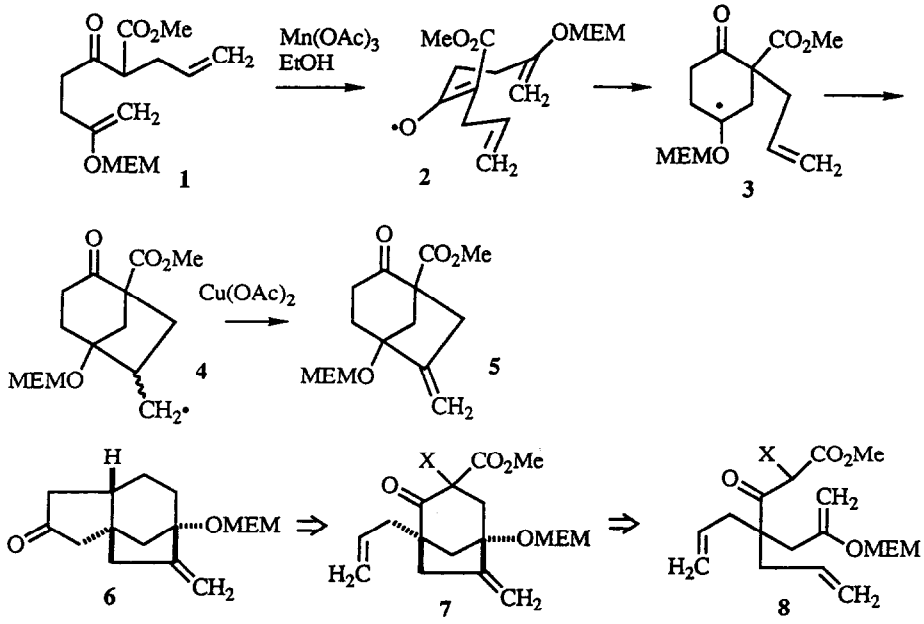
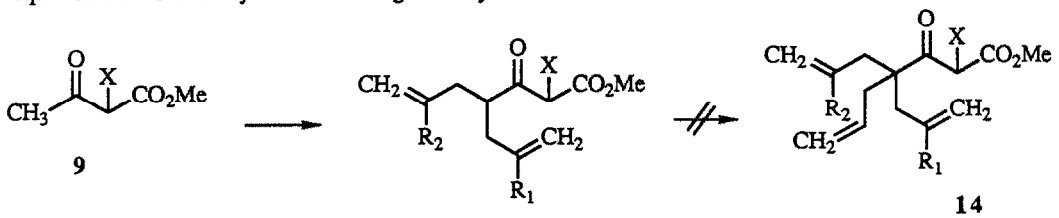
Abstract: Oxidative free-radical cyclizations of γ,γ-(bis)allylic acetoacetates demonstrate that 1,1-disubstituted double bonds are much more reactive than mono- or chloroalkyl-substituted double bonds. The products isolated suggests that bicyclo[3.2.1]octanes 25, 31, 33 and 36 are formed from boat cyclohexyl radical 42 and tandem cyclization products 30, 37 and 38 are obtained from boat cyclohexyl radical 41.

We have previously described the oxidative cyclization[1] of enol ether **1** with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and 1 equiv of $Cu(OAc)_2 \cdot H_2O$ in EtOH to give 52% of bicyclo[3.2.1]octanone **5**, containing the fully functionalized CD ring system of gibberellic acid.[1h] Oxidation of **1** by Mn(III) forms the Mn-free enol radical **2** with the geometry shown.[1g,2] The electrophilic enol radical adds to the nucleophilic enol ether to give cyclohexyl radical **3**. A second cyclization gives bicyclic radical **4** as a mixture of stereoisomers, which are both oxidized to



5 by Cu(II). The ketone and ester groups in 5 provide functionality which might allow the conversion of 5 to Corey's gibberellic acid intermediate 6.[3] However, a more intriguing approach to 6 involves the oxidative cyclization of enol ether 8 that should give the bicyclo[3.2.1]octane 7, containing all the carbon atoms needed for the construction of 6. Decarboxylation of the β-keto ester and oxidation of the propenyl side chain to the methyl ketone, aldol condensation and reduction should provide 6. This route to 6 is short and should provide further opportunity to explore the scope of Mn(III)-based oxidative cyclizations.

Bis(allylic) acetoacetate **10a** can be prepared routinely by two successive dianion alkylations.[4] We developed a more efficient one-pot procedure consisting of alkylation of the dilithium salt of the dianion of methyl acetoacetate with 1 equiv of allyl bromide in the presence of two equiv of DMPU, addition of an additional 1 equiv of LDA and 2 equiv of DMPU, and finally addition of 1 equiv of allyl bromide. This procedure affords 58% of **10a** in a single step. Unfortunately, all attempts to alkylate the dianion of **10a** for a third time to prepare **14** gave only recovered **10a**, presumably due to steric hindrance to the removal of the hindered methine hydrogen. Treatment of the monoanion of **10a** with 1 equiv of the less hindered base *n*-BuLi, 2 equiv of DMPU and allyl bromide also gives only unreacted **10a**.



9 **14**

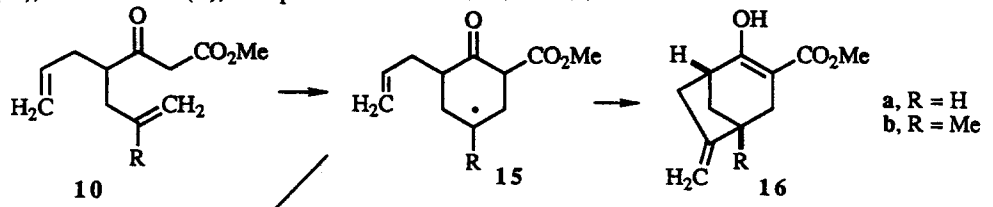
10a, X = H, R_1 = H, R_2 = H
10b, X = H, R_1 = Me, R_2 = H
11a, X = Cl, R_1 = H, R_2 = H
11b, X = Cl, R_1 = Me, R_2 = H
12, X = $PhCH_2$, R_1 = Me, R_2 = H (Et ester)
13a, X = allyl, R_1 = Me, R_2 = H
13b, X = allyl, R_1 = Me, R_2 = Cl
13c, X = allyl, R_1 = Cl, R_2 = H

Even though we were unable to prepare **14**, we thought that a study of the oxidative cyclizations of bis(allylic) acetoacetates **10-13** would provide valuable information on the scope of Mn(III)-based oxidative cyclizations and that examination of unsymmetrical substrates would permit the determination of the relative reactivity of alkenes in a radical cyclization by an intramolecular competition. The required starting materials **10b** (57%), **11a** (77%), **11b** (52%), **12** (22%), **13a** (20%), **13b** (63%), and **13c** (33%) were prepared by the one-pot procedure described above.

Oxidative cyclization of **10a** with 2 equiv of $Mn(OAc)_3 \cdot 2H_2O$ and 1 equiv of $Cu(OAc)_2 \cdot H_2O$ in AcOH for 38 h at rt gives 3% of a 2:1 mixture of salicylate **23a** and diene **17a**, 8% of bicyclo[3.2.1]octane **16a**, 11% of a 2:1 mixture of bicyclic dienes **21a** and **22a** and 26% of recovered **10a**. Oxidative cyclization of **10a** gives the secondary cyclohexyl radical **15a**. Cyclization of radical **15a** followed by oxidation of the primary radical by Cu(II) gives **16a** which exists in the enol tautomer. Oxidation of secondary radical **15a** by Cu(II) to give **17a** and **18a** occurs at a rate competitive with the second cyclization. Dienes **17a** and **18a** still contain an enolizable hydrogen and may be oxidized further by Mn(III) to the enol radical **20a**.[1d] Loss of a hydrogen atom from **20a** and enolization gives **23a** as we have previously demonstrated in the development of a general approach to salicylates by oxidative cyclization.[1e] 6-Endo cyclization of **20a**, followed by oxidation of the secondary radical by Cu(II) produces **21a** and **22a**.

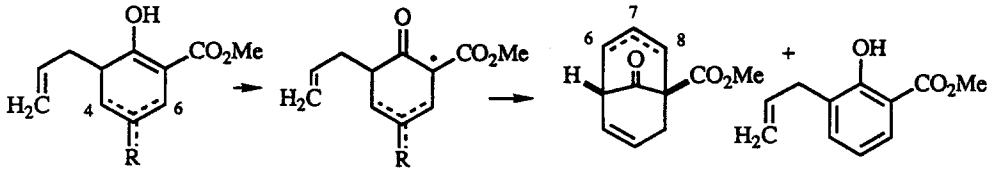
Oxidative cyclization of β-keto ester **10b** gives 41% of a 6:1 mixture of bicyclo[3.2.1]octane **16b** and monocyclic diene **19b** indicating, as expected, that the 1,1-disubstituted double bond is much more reactive than the monosubstituted double bond in the cyclization. The yield of **16b** is much greater than that of **16a**. This is consistent with our previous observation that oxidation of tertiary radicals does not usually compete with the second cyclization while oxidation of secondary radicals is typically a significant side reaction.[1h,i] The most likely explanation for this observation is that, because of steric hindrance, Cu(II) oxidizes secondary radical **15a**

to give **17a** and **18a** more rapidly than it oxidizes tertiary radical **15a**. Use of only a catalytic amount of $Cu(OAc)_2 \cdot H_2O$ in the oxidative cyclization of **11b** does not change the ratio of **16b** to **19b** suggesting that Mn(III), rather than Cu(II), is responsible for the oxidation of **15b**.



a, R = H
b, R = Me

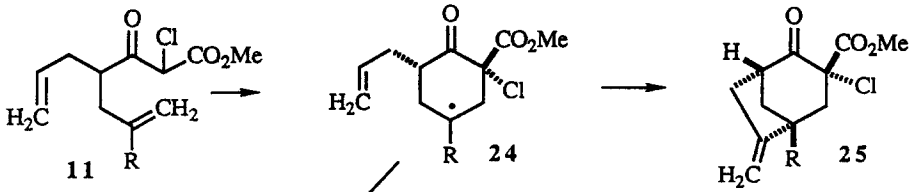
10 **15** **16**



17, $\Delta^{4,5}$
18, $\Delta^{5,6}$
19b, R = CH_2

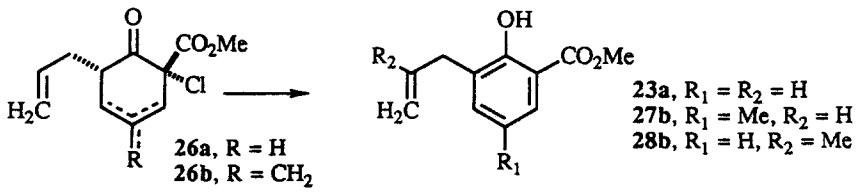
20 **21a**, $\Delta^{6,7}$ **22a**, $\Delta^{7,8}$ **23a**

The initial products of the oxidative cyclization of **10a** and **10b** contain an enolizable hydrogen and are therefore susceptible to further oxidation by Mn(III). Dienes **21a** and **22a** and salicylate **23a** are derived from a second oxidation of **17a** or **18a**. Oxidation of **19b** will give a triene that will polymerize.[1e] We have shown that oxidative cyclization of α-chloro β-keto esters gives products that are not susceptible to further oxidation.[1d] We therefore examined the oxidative cyclization of **11a**, which gives 24% of salicylate **23a**. Cyclization produces monocyclic radical **24a**, which reacts with Cu(II) to produce monocyclic diene **26a**. Elimination of HCl from **26a** and enolization gives salicylate **23a**. Salicylate **23a** is the only product, even when only 0.1 equiv of Cu(II) is used, indicating that oxidation of secondary radical **24a** is much faster than cyclization leading to **25a**.



11 **24** **25**

a, R = H
b, R = Me



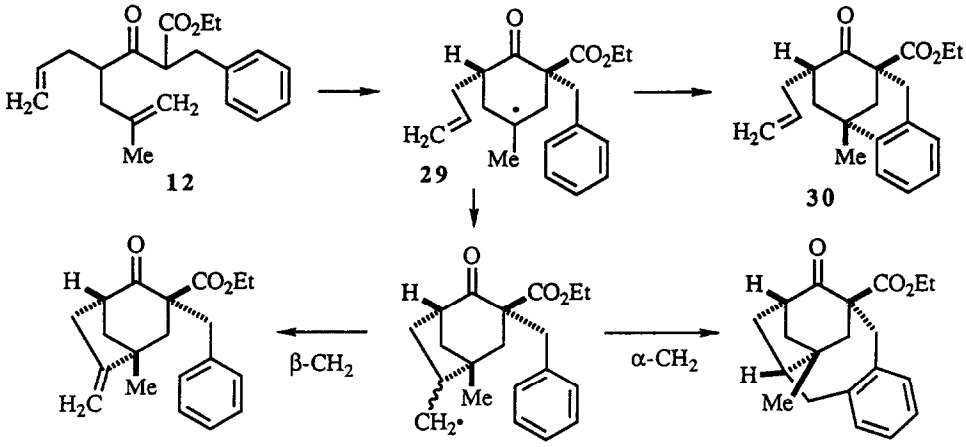
26a, R = H
26b, R = CH_2

23a, $R_1 = R_2 = H$
27b, R_1 = Me, R_2 = H
28b, R_1 = H, R_2 = Me

Oxidative free-radical cyclization of β-keto ester **11b** gives 2% of a 3:2 mixture of salicylates **28b** and **27b**, 33% of monocyclic diene **26b** and 35% of bicyclo[3.2.1]octane **25b**. Oxidative cyclization of **11b** gives predominantly tertiary radical **24b**; a second cyclization will give **25b**. Oxidation of radical **24b** to give diene **26b**, which is isolated, and the corresponding endocyclic dienes, which lose HCl to form **27b**, is a major reaction even though the monocyclic radical is tertiary. The only product isolated from an initial cyclization on the monosubstituted double bond is salicylate **28b**. The selectivity for addition of the enol radical to the disubstituted bond rather than the monosubstituted double bond in the initial cyclization is therefore approximately 35:1. Oxidative cyclization with only 0.1 equiv of Cu(II) gives a 3:1 mixture of **25b** and **26b** suggesting that Cu(II) is responsible for the oxidation of **24b**, as we have shown for other β-chloro tertiary radicals.[1d]

The assignment of stereochemistry to **25b** and **26b** is based on mechanistic considerations and confirmed by the effect of the chlorine on the carbonyl stretch of the ketone. The enol radical should cyclize through the geometry shown in **2** to give **24b** with an axial ester and equatorial allyl and chlorine substituents. Oxidation of **24b** will give **26b** with an equatorial chlorine. Chair inversion prior to the second cyclization will give **25b** with an axial chlorine. An axial chlorine has no effect on the carbonyl stretch, while an equatorial chlorine increases the frequency by 14 cm^{-1}.[5] The ketone C=O stretch of **26b** is 1747 cm^{-1}, consistent with an equatorial chlorine. The ketone C=O stretch of **25b** is 1729 cm^{-1}, consistent with an axial chlorine.

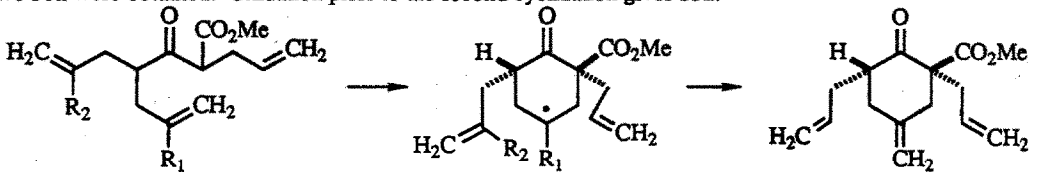
Oxidative free-radical cyclization of **12** affords 39% of a 3.2:2:1 mixture of bicyclo[3.3.1]nonane **30**, bicyclo[3.2.1]octane **31** and a compound tentatively identified as **33** based on the absence of alkene carbons and protons in the NMR spectra. Addition of the enol radical to the disubstituted double bond gives tertiary cyclohexyl radical **29** selectively. Cyclization of the tertiary radical to the aromatic ring and oxidation gives **30**. Cyclization of the tertiary radical to the propenyl substituent gives a mixture of primary radicals **32**. Both isomers can be oxidized by Cu(II) to give **31**. The endo isomer can cyclize to the phenyl ring to give **33** after oxidation.



The cyclization of the endo radical **32** to the aromatic ring to give **33** is formally a 6-phenylhexyl radical cyclization. No examples of 6-phenylhexyl radical cyclizations are known, but they should be much slower than the cyclization of the 7-octenyl radical which occurs with a rate of 10^2-10^3 sec^{-1}.[6] At first glance, it is surprising that **32** cyclizes to **33**, since the rate of oxidation of primary radicals by 0.1 M Cu(II) is 10^5 sec^{-1}. Examination of models suggests that the cyclization of **32** should be relatively rapid since the primary radical and phenyl group are held in close proximity. If **32** is formed as a 2:1 exo-endo mixture, as has been observed in other cases,[1g] the endo radical **32** must undergo cyclization almost exclusively, since a 2:1 mixture of **31** and **33** is formed. Therefore the rate of cyclization of **32** is probably $\geq 10^6$ sec^{-1}.

The formation of **30** as the major product was unanticipated since unconstrained 5-hexenyl radicals cyclize with a rate of 10^5 sec^{-1} and unconstrained 4-phenylbutyl radicals cyclize with a rate of 10^3 sec^{-1}.[6,7b] We had therefore expected cyclization to **32** to be much faster than cyclization to **30** since, at first glance, the steric constraints appear to be similar in the two cases. Asymmetry is introduced by the ester group and the difference between the benzyl and allyl groups. We therefore examined the cyclization of **13a**, which should give tertiary radical **34a** in which the only asymmetry is that due to the ester group.

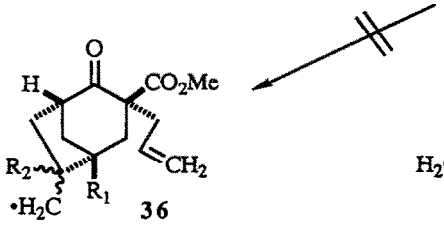
Oxidative cyclization of β-keto ester **13a** gives 5% of monocyclic triene **35a** and 52% of a 1:3 mixture of **37a** and **38a**. Cyclization of the enol radical to the disubstituted double bond gives tertiary radical **34a** selectively. Since cyclization occurs through the enol geometry shown in **2**, the two allyl groups are cis in **34a**. 5-Hexenyl radical cyclization of the tertiary radical of **34a** to the allyl group α to the ester, followed by oxidation, gives a 5:1 mixture of **37a** and **38a**. No products derived from cyclization to the other allyl group to give **36a** were obtained. Oxidation prior to the second cyclization gives **35a**.



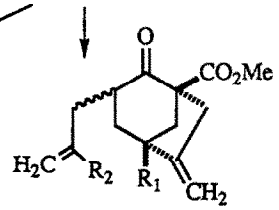
13a, R_1 = Me, R_2 = H
13b, R_1 = Me, R_2 = Cl
13c, R_1 = Cl , R_2 = H

34a, R_1 = Me, R_2 = H
34b, R_1 = Me, R_2 = Cl
34c, R_1 = Cl , R_2 = H
34d, R_1 = H, R_2 = Cl

35a



36



37, α-CH_2=$C(R_2)CH_2$
38, β-CH_2=$C(R_2)CH_2$
a, R_1 = Me, R_2 = H
b, R_1 = Me, R_2 = Cl
c, R_1 = Cl , R_2 = H
d, R_1 = H , R_2 = Cl

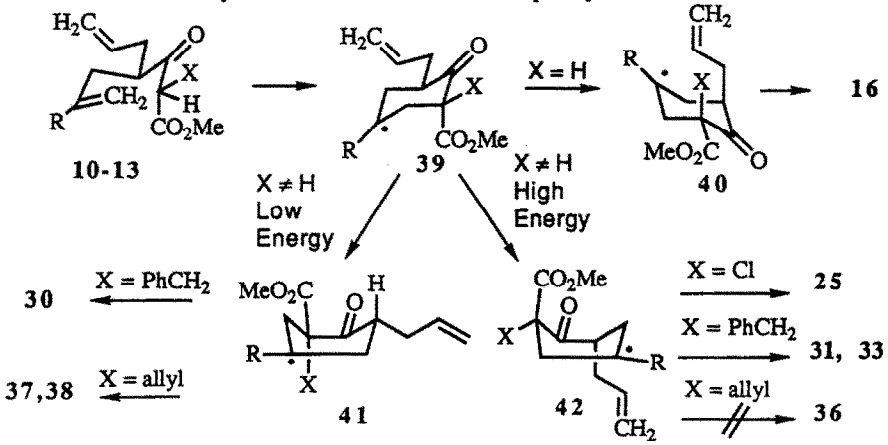
As we have previously reported for the analogs of **37** and **38** with a methyl substituent,[1g] isomer **37** with an axial substituent is the major kinetic product indicating that the monocyclic radical has the geometry shown in **34**. Partial equilibration of the initial 5:1 mixture to a 1:3 mixture of **37a** and **38a** occurs on chromatography. Treatment with K_2CO_3 in MeOH gives exclusively the much more stable equatorial isomer **38a**.

The cyclization of tertiary radicals **29** and **34a** gives consistent results. Radical **34a** cyclizes exclusively to the allyl group α to the ester while radical **29b** cyclizes equally to the benzyl group α to the ester and the allyl group γ to the ester even though cyclization to the allyl group should be 10-100 times faster. Examination of likely transition states provides a possible explanation for this observation. Radicals **29** and **34a** are formed as chair cyclohexanes **39** with axial ester groups. Chair inversion will give chair cyclohexanes **40** with axial allyl and X substituents. If X = H, this chair is relatively stable so that cyclization to give **16** can occur. If X ≠ H, this conformation is very unstable since there are two axial substituents in a 1,3-relationship. Boat conformers **41** and **42** could be lower in energy than **40**. Cyclization to the α allyl or benzyl group will take place through boat conformer **41** to give **30** from **29** and **37a** and **38a** from **34a**. Cyclization to the γ allyl group will take place through boat conformer **42** to give **31** and **33**. The ester group occupies a pseudo-equatorial position in boat conformer **41** and a "flagpole" position in boat conformer **42**. Boat **42** should therefore be much less stable than boat **41**.

Molecular mechanics calculations for **34a** suggest the boat transition state **41** is approximately 3 kcal/mol lower in energy than boat transition state **42** and 5-6 kcal/mol lower in energy than chair transition state **40**.[8]

Cyclization of **34a** therefore occurs exclusively through **41** to give **37a** and **38a**. On the other hand, cyclization of the **29** takes place through two different pathways. Cyclization to the allyl group must occur through the more hindered boat conformer **42** to give **31** and **33**. Cyclization to the benzyl group, which is inherently slower, occurs at about the same rate as cyclization to the allyl group, since boat conformer **41** is the least hindered conformation of **29** that can cyclize. Transition state **42** is approximately 3 kcal/mole higher in energy than **41**.[8] However, 4-phenylbutyl radical cyclizations are 100 times slower than 5-hexenyl radical cyclizations to give cyclopentylmethyl radicals.[6] This rate difference translates to a difference in $\Delta G^{\ddagger}$ for the two cyclizations of approximately 2.7 kcal/mol, which is close to the energy difference between **41** and **42**. Therefore the ratio of **30** to **31** and **33** is about 1:1. Similar interactions between the chlorine and allyl groups are probably responsible for the absence of bicyclic products from **11a** and the low yield of bicyclic products from **11b**.

The oxidative cyclizations of **10b**, **11b**, **12** and **13a** indicate that cyclization of the enol radical to 1,1-disubstituted double bonds is much faster than addition to monosubstituted double bonds. We have recently found that chlorine substituents on the double bond control the regiochemistry of the cyclization.[9] We therefore decided to determine the relative reactivity of chloroalkenes using an intramolecular competition. Oxidative cyclization of **13b** gives a 4:1 mixture of **37b** and **38b**. As described above, partial isomerization occurs on flash chromatography giving 55% of **37b** and 36% of **38b**. Isomerization of **37b** with K_2CO_3 gives **38b** quantitatively. The formation of only **37b** and **38b** indicates that cyclization occurs exclusively to the 1,1-dialkyl substituted double bond to give **34b**. Oxidative cyclization of **13c** followed by slow flash chromatography, leading to complete equilibration, affords 15% of **38c** and 15% of **38d**. Cyclization to the monosubstituted double bond and chloroalkyl substituted double bond consequently occur at about the same rate.



In conclusion, oxidative free-radical cyclizations of γ,γ-(bis)allylic acetoacetates demonstrate that 1,1-disubstituted double bonds are much more reactive than mono- or chloroalkyl-substituted double bonds. The products isolated suggests that bicyclo[3.2.1]octanes **25**, **31**, **33** and **36** are formed from boat cyclohexyl radical **42** and tandem cyclization products **30**, **37** and **38** are obtained from boat cyclohexyl radical **41**.

Experimental Section

General. NMR spectra were run in $CDCl_3$ at 300 MHz. Chemical shifts are reported in δ and coupling constants are reported in Hz. IR spectra were run neat and are reported in cm^{-1}. $Mn(OAc)_3 \cdot 2H_2O$ was purchased from Aldrich. All oxidative cyclizations were run in acetic acid under N_2.

Preparation of Methyl 3-oxo-4-(2-propenyl)hept-6-enoate (10a). To a stirred solution of diisopropylamine (4.83 mL, 0.034 mol) in THF (40 mL) at 0 °C was added dropwise n-butyllithium (2.5 M in hexanes, 13.78 mL, 0.034 mol). The mixture was stirred at 0 °C for 0.25 h at which time methyl acetoacetate (1.86 mL, 0.017 mol) in THF

(2.5 mL) was added dropwise over 5 min. The resulting solution was stirred for 0.5 h at 0 °C. DMPU (4.16 mL, 0.034 mol) and then allyl bromide (1.49 g, 0.017 mol) were added. The mixture was stirred at 0 °C for 5 min, at which time lithium diisopropylamide (0.017 mol in 20 mL of THF) was added over 5 min. The resulting deep red solution was stirred for 0.5 h at 0 °C. DMPU (4.16 mL, 0.034 mol) and then allyl bromide (1.49 g, 0.017 mol) were added. The resulting orange solution was warmed to rt and stirred for 5 min. The reaction was quenched by the addition of water (50 mL), poured into a separatory funnel and diluted to a final volume of 600 mL with water. The mixture was acidified with 10% HCl and extracted with three portions of ether. The combined organic phases were washed with saturated $NaHCO_3$ solution, dried ($MgSO_4$) and concentrated in vacuo to give 3.120 g of crude **10a**. Purification of 3.109 g by flash chromatography (9:1 hexane-EtOAc, deactivated silica gel) gave 1.972 g (58%) of **10a** containing about 15% of the enol tautomer: ^{1}H NMR 5.71 (ddt, 2, J = 10.1, 15.4, 5.8), 5.07 (br d, 2, J = 15.4), 5.05 (br d, 2, J = 10.1), 3.73 (s, 3), 3.48 (s, 2), 2.77 (tt, 1, J = 6.6, 7.8), 2.38 (dddt, 2, J = 5.8, 7.8, 15.0, 0.9), 2.24 (dddt, 2, J = 5.8, 6.6, 15.0, 0.9); (enol) 4.96 (s, 1); ^{13}C NMR 204.7, 167.3, 134.7 (2), 117.5 (2), 52.2, 51.3, 49.0, 34.8 (2); (enol) 135.4 (2), 116.7 (2), 89.4, 51.2, 45.2, 36.2 (2), 2 C not observed. Anal. Calcd for $C_{11}H_{16}O_3$: C, 67.32; H, 8.22. Found C, 67.28; H 8.09.

Methyl 6-methyl-3-oxo-4-(2-propenyl)hept-6-enoate (10b) was prepared analogously (methallyl chloride was used for the second alkylation) in 57% yield as an 85:15 keto-enol mixture: ^{1}H NMR 5.71 (ddt, 1, J = 10.1, 15.4, 5.8), 5.07 (br d, 1, J = 15.4), 5.05 (br d, 1, J = 10.1), 4.80 (br s, 1), 4.70 (br s, 1), 3.73 (s, 3), 3.48 (s, 2), 2.77 (tt, 1, J = 6.6, 7.8), 210-2.44 (m, 4), 1.72 (br s, 3); (enol) 4.97 (s, 1); ^{13}C NMR 205.0, 167.3, 142.2, 134.7, 117.4, 112.9, 52.1, 49.8, 48.0, 38.9, 35.2, 22.2; (enol) 135.5, 116.6, 112.6, 89.3, 51.0, 43.6, 40.3, 36.5, 22.1, 3 C not observed. Anal. Calcd for $C_{12}H_{18}O_3$: C, 68.54; H, 8.63. Found C, 68.78; H 8.70.

Methyl 2-chloro-3-oxo-4-(2-propenyl)hept-6-enoate (11a) was prepared analogously from methyl 2-chloroacetoacetate in 77% yield as a 2:1 keto-enol mixture: ^{1}H NMR 5.82-5.63 (m, 2), 5.19-4.95 (m, 4), 4.90 (s, 1), 3.81 (s, 3), 3.13 (tt, 1, J = 6.5, 7.5), 2.48-2.40 (m, 4); (enol) 3.85 (s, 3), 3.3-3.4 (m, 1); ^{13}C NMR 200.2, 165.1, 134.25, 134.21, 117.9 (2), 61.2, 53.5, 48.2, 35.5, 35.3; IR 3079, 1768, 1730, 1640; (enol) 176.4, 169.9, 135.1 (2), 116.8 (2), 97.0, 52.7, 41.2, 35.9 (2). Anal. Calcd for $C_{11}H_{15}ClO_3$: C, 57.27; H, 6.55. Found C, 57.20; H 6.50.

Methyl 2-chloro-6-methyl-3-oxo-4-(2-propenyl)hept-6-enoate (11b) was prepared analogously (methallyl chloride was used for the second alkylation) from methyl 2-chloroacetoacetate in 52% yield as a 4:3 mixture of the two diastereomers of the keto tautomer and the enol tautomer: ^{1}H NMR 5.83-5.63 (m, 1), 5.11-4.98 (m, 2), 4.90 (s, 0.5•0.57•1, CHCl keto), 4.89 (s, 0.5•0.57•1, CHCl keto), 4.82 (br s, 0.5•1), 4.76 (br s, 0.5•1), 4.70 (br s, 1), 3.84 (s, 0.43•3, enol), 3.80 (s, 0.57•3, keto), 3.36 (dtt, 0.43•1, J = 1.6, 5.5, 8.5, enol), 3.30-3.21 (m, 0.57•1, keto), 2.50-2.10 (m, 4), 1.74 (br s, 3); ^{13}C NMR 200.5, 200.4, 176.7, 169.8, 165.1, 142.5, 141.8, 134.4, 134.3, 134.2, 117.9, 117.8, 117.7, 113.5, 112.3, 97.0, 61.5, 61.4, 53.5, 52.7, 46.7, 46.6, 39.8, 39.7, 36.2, 35.7, 35.6, 22.3, 22.2, 22.1; IR 1762, 1731. Anal. Calcd for $C_{12}H_{17}ClO_3$: C, 58.89; H, 7.00. Found C, 58.55; H 6.83.

Ethyl 2-benzyl-6-methyl-3-oxo-4-(2-propenyl)hept-6-enoate (12) was prepared analogously (methallyl chloride was used for the second alkylation) from ethyl 2-benzylacetoacetate in 22% yield as a 1.1:1 mixture of diastereomers: ^{1}H NMR 7.30-7.13 (m, 5), 5.64 (ddt, 0.5•1, J = 10.0, 16.9, 6.5), 5.50 (ddt, 0.5•1, J = 10.1, 17.1, 6.5), 5.05-4.86 (m, 2), 4.77-4.72 (br s, 1), 4.67-4.65 (br s, 0.5•1), 4.60-4.58 (m, 0.5•1), 4.20-4.05 (m, 2), 3.88 (t, 0.5•1, J = 7.5), 3.84 (t, 0.5•1, J = 7.5), 3.12 (d, 2, J = 7.7), 2.96-2.84 (m, 1), 2.40-2.30 (m, 1), 2.19-2.00 (m, 2 + 0.5•1), 1.93 (dd, 0.5•1, J = 14, 7), 1.64 (br s, 0.5•3), 1.62 (br s, 0.5•3), 1.19 (t, 3, J =7.3); ^{13}C NMR (206.3, 206.1), (168.5, 168.4), (142.4, 142.1), 138.4, (135.2, 134.7), (129.0 (2), 128.9 (2)), 128.4 (2), 126.5, (117.4, 117.0), (113.1, 112.8), (61.4, 61.2), 61.0, 49.3, (39.2, 38.2), (35.2, 34.7), (33.7, 33.7), (22.3, 22.0), 14.0; IR (neat) 1750, 1718, 1646, 1610. Anal. Calcd for $C_{20}H_{26}O_3$: C, 76.40; H, 8.34. Found: C, 76.25; H, 8.51.

Methyl 6-methyl-3-oxo-2,4-bis-(2-propenyl)hept-6-enoate (13a) was prepared analogously (methallyl chloride was used for the second alkylation) from methyl 2-allylacetoacetate[10] in 20% yield as a 1.1:1 mixture of diastereomers: ^{1}H NMR 5.78-5.58 (m, 2), 5.14-4.94 (m, 4), 4.81-4.79 (br s, 0.5•1), 4.79-4.76 (br s, 0.5•1), 4.71-4.69 (br s, 0.5•1), 4.68-4.66 (br s, 0.5•1), 3.706 (s, 0.5•3), 3.704 (s, 0.5•3), 3.65 (dd, 0.5•1, J = 8, 7), 3.62 (dd, 0.5•1, J = 8, 7), 3.04-2.92 (m, 1), 2.60-2.49 (m, 2), 2.44-2.02 (m, 4), 1.75 (br s, 0.5•3), 1.69 (br s, 0.5•3); ^{13}C NMR (206.2, 206.0), (169.1, 169.0), 142.1, (135.2, 134.8), 134.4, (117.5, 117.4), (117.4, 117.0), (113.3, 112.8), (59.0, 58.7), 52.2, (49.2, 49.1), (39.6, 38.5), (35.5, 34.9), (31.9, 31.8), (22.2, 22.1); IR 1755, 1720, 1650. Anal. Calcd for $C_{15}H_{22}O_3$: C, 71.97; H, 8.86. Found: C, 71.91; H, 9.11.

Methyl 4-(2-chloro-2-propenyl)-6-methyl-3-oxo-2-(propenyl)hept-6-enoate (13b) was prepared analogously (2,3-dichloropropene was used for the second alkylation) from methyl 2-allylacetoacetate[10] followed by flash chromatography on silica gel (20:1 hexane-EtOAc) gave 58% of a 1:1 mixture of two diastereomers of **13b**, followed by 5% of the more polar diastereomer of **13b**.

The data for the more polar diastereomer: ^{1}H NMR 5.73 (dddd, 1, J = 6.9, 17.1, 10.1, 6.9), 5.19 (d, 1, J = 1.3), 5.16 (dd, 1, J = 1.9, 1.0), 5.10 (dq 1, J = 17.1, 1.5), 5.06 (dq, 1, J = 10.1, 1.5), 4.83 (br s, 1), 4.72 (br s, 1), 3.72 (s, 3), 3.68 (dd, 1, J = 6.4, 8.1), 3.32 (dddd, 1, J = 5.2, 6.3, 7.9, 8.6), 2.63 (dd, 1, J = 6.4, 8.1), 2.53 (m, 2), 2.36 (m, 2), 2.04 (dd, 1, J = 7.9, 14.2), 1.73 (s, 3). ^{13}C NMR 206.1, 169.0, 141.6, 139.5, 134.25, 117.55, 115.1, 113.6, 58.9, 52.27, 46.9, 40.5, 38.9, 31.9, 21.9; IR 1750, 1720. Anal. Calcd for $C_{15}H_{21}ClO_3$: C, 63.26; H, 7.43. Found: C, 63.42; H, 7.42.

The data for the less polar diastereomer were determined from the mixture: ^{1}H NMR 5.73 (m, 1), 5.19 (br s, 1), 5.15 (br s, 1), 5.10 (br d, 1, J = 17.1), 5.05 (br d, 1, J = 10.1), 4.84 (br s, 1), 4.73 (br s, 1), 3.73 (s, 3), 3.65 (m, 1), 3.32 (m, 1), 2.73 (dd, 1, J = 8.3, 14.1), 2.53 (m, 2), 2.36 (m, 2), 2.01 (dd, 1, J = 7.7, 13.8), 1.78 (s, 3). ^{13}C NMR 205.4, 168.8, 141.5, 139.6, 134.34, 117.5, 114.8, 113.9, 59.0, 52.4, 46.6, 39.8, 39.7, 31.6, 21.8; IR 1750, 1720.

Oxidative Cyclization of 10a. To a stirred solution of $Mn(OAc)_3 \cdot 2H_2O$ (1.093 g, 4.08 mmol) and $Cu(OAc)_2 \cdot H_2O$ (407 mg, 2.04 mmol) in glacial acetic acid (20 mL) under N_2 was added **10a** (400 mg, 2.04 mmol). The reaction mixture was stirred at rt for 38 h. Water (100 mL) and 10% $NaHSO_3$ solution to reduce any residual Mn(III) were added. The mixture was extracted with three 30 mL portions of CH_2Cl_2. The combined organic layers were washed with satd $NaHCO_3$ solution, dried (Na_2SO_4) and concentrated in vacuo to give 375 mg of crude product. Flash chromatography of 340 mg on silica gel (20:1 hexane-EtOAc) gave 11 mg of a 1:2 mixture of methyl 3-(2-propenyl)-2-oxocyclohexa-1,4-diene-1-carboxylate (**17a**) and methyl 3-(2-propenyl)-salicylate (**23a**) (3%), followed by 32.2 mg (8%) of methyl 6-methylene-2-oxobicyclo[3.2.1]octane-3-carboxylate (**16a**) (8%), 102 mg (26%) of recovered **10a**, followed by 42.5 mg (11%) of a 2:1 mixture of methyl 9-oxobicyclo[3.3.1]nona-3,6-diene-1-carboxylate (**21a**) and methyl 9-oxobicyclo[3.3.1]nona-3,7-diene-1-carboxylate (**22a**).

The data for **17a** were determined from the mixture: ^{1}H NMR 12.29 (s, 1, OH), 5.85-5.70 (m, 2), 5.78 (dddd, 1, J = 1.7, 2.1, 3.8, 10.0, =CH), 5.06-5.00 (m, 2), 3.77 (s, 3, -OCH_3), 3.12-3.02 (m,. 1), 2.91-2.84 (m, 2), 2.57-2.33 (m, 2); ^{13}C NMR 171.1 (C_2), 136.2 (C_1), 134.7 (=CH), 125.6 (C_4 or C_5), 124.3 (C_5 or C_4), 117.2 (=CH_2), 95.9 (C_2), 51.5 (OCH_3), 38.8 (C_3), 37.5 (C_6), 25.3 (allylic CH_2).

The data of **23a** are identical to those of a sample prepared from **11a**.

The data for **16a**: ^{1}H NMR 12.00 (s, 1, OH), 5.04 (br s, 1,=CH_2), 4.91 (br s, 1, =CH_2), 3.72 (s, 3, -OCH_3), 2.94-2.88 (m, 1, H_5), 2.67-2.58 (m, 3), 2.54 (ddt, 1, J = 8.4, 13.6, 2.7, $H_{4\ exo}$), 2.51 (br dd, 1, J = 4.7, 15.4, $H_{8\ anti}$), 2.13 (dd, 1, J = 2.1, 15.4, $H_{8\ syn}$), 1.82-1.78 (m, 1); ^{13}C NMR 177.7 (C_3), 173.1 (OC=O), 154.2 (C_6), 107.0 (=CH_2), 92.9 (C_2), 51.2 (-OCH_3), 40.8 (C_4), 40.4 (C_1 or C_5), 39.9 (C_5 or C_1), 34.4 (C_7), 33.3 (C_8).

The data for **21a** were determined from the mixture: ^{1}H NMR 5.91 (ddt, 2, J = 6.1, 9.2, 1.9, H_4 and H_6), 5.81 (dt, 2, J = 9.2, 3.5, H_3 and H_7), 3.81 (s, 3, OCH_3), 3.38 (br d, 2, J = 18.2, H_4 and H_6), 3.23 (t, 1, J = 6.1, H_5), 2.68 (ddd, 2, J = 1.9, 3.5, 18.1, H_4 and H_6); ^{13}C NMR 206.6 (C_9), 171.1 (OC=O), 129.2 (2, C_2 and C_8), 126.4 (2, C_3 and C_7), 56.4 (C_1), 52.6 (OCH_3), 47.1 (C_5), 41.2 (2, C_4 and C_6).

The data for **22a** were determined from the mixture: ^{1}H NMR 5.90-5.86 (m, 1, =CH), 5.82-5.76 (m, 2, =CH), 5.70 (dddd, 1, J = 0.5, 2.7, 5.3, 10.1, =CH), 3.80 (s, 3, OCH_3), 3.28-3.20 (m, 1), 3.01 (br t, 1, J = 5.3, H_5), 2.82-2.72 (m, 1), 2.60 (dd, 1, J = 4.6, 18.1, $H_{6\ endo}$), 2.51 (ddd, 1, J = 1.6, 4.9, 17.8, $H_{6\ exo}$); ^{13}C NMR 207.3 (C_9), 172.3 (OC=O), 129.4 (CH=), 129.3 (CH=), 125.8 (CH=), 125.4 (CH=), 59.1 (C_1), 52.6 (OCH_3), 46.0 (C_5), 38.6 (C_6), 35.4 (C_2).

Oxidative Cyclization of 10b. Reaction of **10b** (400 mg, 1.90 mmol), $Mn(OAc)_3 \cdot 2H_2O$ (1.020 g, 3.80 mmol), and $Cu(OAc)_2 \cdot H_2O$ (380 mg, 1.90 mmol) in glacial acetic acid (19 mL) for 10.5 h followed by normal workup gave 406 mg of crude product. Flash chromatography on silica gel of 389 mg (30:1 hexane-EtOAc) gave 158 mg (41%) of a 6:1 mixture of methyl 5-methyl-6-methylenebicyclo[3.2.1]octane-3-carboxylate (**16b**) and methyl 5-methylene-2-oxo-3-(2-propenyl)-cyclohexane-1-carboxylate (**19b**) followed by 48 mg (12%) of recovered **10b**.

The data for **16b** were determined from the mixture: ^{1}H NMR 11.93 (s, 1, OH), 4.91 (br d, 1, J = 2.6, =CH_2), 4.90 (br d, 1, J = 1.8, =CH_2), 3.70 (s, 3, OCH_3), 2.68-2.57 (m, 3), 2.30 (d, 1, J = 15.0, $H_{4\ exo}$), 2.04 (dd, 1, J = 1.5, 15.0, $H_{4\ endo}$), 1.76 (br d, 1, J = 11.3, $H_{8\ syn}$), 1.65 (ddd, 1, J = 1.5, 3.5, 11.3, $H_{8\ anti}$), 1.25 (s, 3, CH_3); ^{13}C NMR 177.5 (OC=O), 157.0 (C_6), 105.7 (C_3), 105.3 (=CH_2), 93.8 (C_2), 51.2 (OCH_3), 41.9 (C_4), 41.7 (C_7), 40.6 (C_8), 38.9 (C_1), 24.5 (C_5-CH_3); IR 1755, 1720, 1652.

Partial data for **19b** were determined from the mixture: ^{1}H NMR 12.23 (s, 1, OH), 5.78 (ddt, 1, J = 10.2, 17.4, 6.0, =CH), 5.11-5.01 (m, 4, =CH_2), 3.77 (s, 3, OCH_3), 2.97-2.94 (m, 1); ^{13}C NMR 172.9 (OC=O), 154.0 (C=), 135.9 (=CH), 117.2 (=CH_2), 106.2 (CH_2), 52.4 (OCH_3), 48.7 (C_3), 45.1 (CH_2), 43.6 (CH_2), 36.7 (CH_2), two C were not observed; IR 1755, 1720, 1652 1630.

Oxidative Cyclization of 11a. Reaction of **11a** (400 mg, 1.74 mmol), $Mn(OAc)_3 \cdot 2H_2O$ (930 mg, 3.47 mmol), and $Cu(OAc)_2 \cdot H_2O$ (346 mg, 1.74 mmol) in glacial acetic acid (17 mL) for 30 h at rt followed by normal workup gave 363 mg of crude product. Flash chromatography on silica gel of 339 mg (40:1 hexane-EtOAc) gave 81 mg (24%) of **23a**: ^{1}H NMR 11.03 (s, 1, -OH), 7.72 (dd, 1, J = 2.0, 8.2, H6), 7.32 (ddd, 1, J = 0.9, 2.0, 7.8, H4), 6.82 (dd, 1, J = 7.8, 8.2, H5), 6.01 (ddt, 1, J = 9.6, 17.0, 6.8, =CH), 5.09 (br d, 1, J = 17.0, =CH_2), 5.07 (br d, 1, J = 9.6, =CH_2), 3.97 (s, 3, -OCH_3), 3.43 (br d, 2, J = 6.8, allylic CH_2); ^{13}C NMR 170.9 (OC=O), 159.5 (C_2), 136.2 (C_1), 135.7 (C_6), 128.5 (=CH), 127.9 (C_4), 118.6 (=CH_2), 115.8 (C_5), 111.9 (C_3), 52.2 (OC=O), 33.6 (allylic CH_2); IR 1745, 1685, 1650, 1620. The data are identical to those previously reported.[11]

Oxidative Cyclization of 11b. Reaction of **11b** (200 mg, 0.82 mmol), $Mn(OAc)_3 \cdot 2H_2O$ (438 mg, 1.63 mmol), and $Cu(OAc)_2 \cdot H_2O$ (163 mg, 0.82 mmol) in glacial acetic acid (8 mL) for 14 h at rt followed by normal workup gave 197 mg of crude product. Flash chromatography of 183 mg on silica gel (20:1 hexane-EtOAc) gave 4 mg (2%) of a 1:1.5 mixture of methyl 5-methyl-3-(2-propenyl)-salicylate (**27b**) and methyl 3-(2-methyl-2-propenyl)-salicylate (**28b**) followed by 60 mg (33%) of methyl 1-β-chloro-5-methylene-2-oxo-3β-(2-propenyl)-cyclohexane-1α-carboxylate (**26b**) and 65 mg (35%) of methyl 3-*endo*-chloro-5-methyl-6-methylene-2-oxobicyclo[3.2.1]octane-3-*exo*-carboxylate (**25b**).

The data for **27b** were determined from the mixture: ^{1}H NMR 7.52 (br d, 1, J = 2.0, H_6), 7.15 (br d, 1, J = 2, H_4), 6.01 (ddt, 1, J = 9.8, 15.8, 6.4, =CH_2), 5.09 (ddd, 1, J = 2.0, 3.6, 15.8, =CH_2), 5.08 (ddd, 1, J = 2.0, 3.8, 9.8, =CH_2), 3.94 (s, 3, -OCH_3), 3.40 (d, 2, J = 6.4, allylic CH_2), 2.27 (s, 3 C_5-CH_3).

The data for **28b** were determined from the mixture: ^{1}H NMR 7.74 (dd, 1, J = 2.0, 8.0, H_6), 7.33 (br dd, 1, J = 2.0, 8.0, H_4), 6.83 (dd, 1, J = 8.0, 8.0, H_5), 4.82 (br s, 1, =CH_2), 4.66 (br s, 1, =CH_2), 3.95 (s, 3, -OCH_3), 3.38 (s, 2, allylic CH_2), 1.76 (br s, 3, -CH_3). The data are identical to those previously reported.[11]

The data for **26b**: ^{1}H NMR 5.78 (ddt, 1, J = 10.6, 18.6, 6.0, =CH), 5.09 (br d, 1, J = 18.6, CH =CH_2), 5.07 (br d, 1, J = 10.6, CH=CH_2), 5.06 (br s, 1, =CH_2), 5.03 (br dd, 1, J = 1.4, 3.1, =CH_2), 3.70 (s, 3, -OCH_3), 3.50 (dd, 1, J = 2.4, 13.7, allylic CH_2), 2.70 (ddd, 1, J = 1.4, 3.1, 13.7, allylic CH_2), 2.70-2.59 (m, 3), 2.21-2.05 (m, 2); ^{13}C NMR 198.3 (C_2), 167.4 (OC=O), 139.1 (C_5), 135.0 (=CH), 117.3 (=CH_2), 115.4 (=CH_2), 73.1 (C_1), 53.7 (-OCH_3), 48.8 (C_6), 47.4 (C_3), 39.7 (C_4), 33.9 (allylic CH_2); IR 3099, 1770, 1747, 1666, 1650, 915. Anal. Calcd for $C_{12}H_{15}ClO_3$: C, 59.39; H, 6.23. Found: C, 59.59; H, 6.44.

The data for **25b**: ^{1}H NMR 5.08-5.05 (m, 2, =CH_2), 3.82 (s, 3, -OCH_3), 2.99 (br dddd, 1, J = 2.1, 4.0, 4.4, 7.6, H_1), 2.95 (ddd, 1, J = 1.5, 4.0, 17.2, $H_{7\ endo}$), 2.76 (ddt, 1, J = 7.6, 17.8, 3.0, $H_{7\ exo}$), 2.76 (d, 1, J = 14.0, $H_{4\ exo}$), 2.21 (dd, 1, J = 3.4, 14.8, $H_{4\ endo}$), 2.01 (dd, 1, J = 3.4, 12.2, $H_{8\ syn}$), 1.87 (ddd, 1, J = 3.4, 4.4, 12.2, $H_{8\ anti}$), 1.28 (s, 3, C_5-CH_3); ^{13}C NMR 202.2 (C_2), 169.1 (OC=O), 152.9 (C_6), 107.1 (=CH_2), 67.7 (C_3), 53.9 (C_1), 52.5 (-OCH_3), 47.7 (C_4), 42.5 (C_5), 42.3 (C_7), 37.7 (C_8), 23.7 (C_5-CH_3); IR 3090, 1770, 1729, 1665. Anal. Calcd for $C_{12}H_{15}ClO_3$: C, 59.39; H, 6.23. Found: C, 59.46; H, 6.12.

Oxidative Cyclization of 12. Reaction of **12** (200 mg, 0.64 mmol), $Mn(OAc)_3$•$2H_2O$ (341 mg, 1.27 mmol) and $Cu(OAc)_2$•H_2O (127 mg, 0.64 mmol) in glacial acetic acid (7 mL) for 14 h at rt followed by normal workup gave 204 mg of crude product. Flash chromatography on silica gel of 200 mg (30:1 hexane-EtOAc) gave 20 mg of a complex mixture which contained primarily recovered starting material (10%), followed by 77 mg (39%) of a 3.2:2:1 mixture of ethyl 6,7-benzo-5-methyl-2-oxo-3-*endo*-(2-propenyl)-bicyclo[3.3.1]nonane-1-carboxylate (**30**), ethyl 3-*endo* -benzyl-5-methyl-6-methylene-2-oxobicyclo[3.2.1]octane-3-exo-carboxylate (**31**) and **32**.

Partial data for **30** were determined from the mixture: ^{1}H NMR 7.33-7.10 (m, 4), 5.56 (dddd, 1, J = 6.0, 7.6, 10.0, 17.8, =CH), 4.95-4.82 (m, 4), 4.20 (q, 2, J = 7.0, -OCH_2), 3.39 (dd, 1, J = 2.4, 16.8, benzylic CH_2), 3.20 (d, 1, J = 16.8, benzylic CH_2), 2.68 (dd, 1, J = 2.4, 13.2, one carbon bridge), 1.49 (s, 3, bridgehead CH_3), 1.28 (t, 3, J = 7.0, CH_2CH_3); ^{13}C NMR 211.8 (C_2), 171.6 (OC=O), 143.9 (Ph C), 135.8 (=CH), 133.2 (Ph C), 131.0 (Ph CH), 127.9 (Ph CH), 126.4 (Ph CH), 126.1 (Ph CH), 116.5 (=CH_2), 61.5 (-OCH_2), 55.5 (C_1), 48.7 (C_5), 45.3 (C_9), 44.3 (C_3), 41.2 (allylic CH_2), 37.0 (C8-benzylic CH_2), 34.2 (C_4), 30.3 (C_5-CH_3), 14.0; IR 1744, 1710.

Partial data for **31** were determined from the mixture: ^{1}H NMR 7.42-7.08 (m, 5), 4.94 (br t, 1, J = 1.2, =CH_2), 4.74 (br s, 1, =CH_2), 4.27 (q, 2, J = 7.2, -OCH_2), 3.17 (d, 1, J = 13.4, benzylic CH_2), 3.00 (d, 1, J = 13.4, benzylic CH_2), 1.23 (t, 3, J = 7.2, -OCH_2CH_3), 1.23 (s, 3, C_5-CH_3); ^{13}C NMR 155.7 (C_6), 136.6 (Ph C), 129.2 (Ph CH), 127.1 (Ph CH), 126.7 (Ph CH), 105.6 (=CH_2), 61.7 (-OCH_2), 48.0 (C_3), 44.3 (C_8), 41.3 (C_7), 39.6 (C_4), 37.2 (benzylic CH_2), 24.9 (C_5-CH_3), 13.9; C_1, C_2, C_5, and OC=O could not be assigned; IR 1744, 1710.

Partial data for **33** were determined from the mixture: ^{1}H NMR 7.42-7.08 (m, 4), 4.17 (dq, 1, J = 10.7, 7.1, -OCH_2), 4.12 (dq, 1, J =10.7, 7.1, -OCH_2), 1.33 (t, 3, J =7.1, -OCH_2CH_3); ^{13}C NMR 135.7, 130.9, 128.6, 126.9, 126.7, 124.8, 61.2, 42.6, 35.6, 34.7, 33.2, 31.6, 27.0, 13.9, 6 C not observed; IR 1744, 1710.

Oxidative Cyclization of 13a. Reaction of **13a** (300 mg, 1.20 mmol), $Mn(OAc)_3$•$2H_2O$ (643 mg, 2.40 mmol), and $Cu(OAc)_2$•H_2O (239 mg, 1.20 mmol) in glacial acetic acid (12 mL) for 12 h at rt followed by normal workup gave 310 mg of crude product which contained **37a** and **38a** in a 5:1 ratio. Flash chromatography on silica gel of 268 mg (20:1 hexane-EtOAc) gave 12 mg (5%) of methyl 5-methylene-2-oxo-1β, 3β-bis-(2-propenyl)-cyclohexane-1α-carboxylate (**35a**), followed by 136 mg (52%) of a 1:3 mixture of methyl 5-methyl-6-methylene-2-oxo-3-*endo*-(2-propenyl)-bicyclo[3.2.1]octane-1-carboxylate (**37a**) and methyl 5-methyl-6-methylene-2-oxo-3-*exo*-(2-propenyl)-bicyclo[3.2.1]octane-1-carboxylate (**38a**).

The data for **35a**: ^{1}H NMR 5.77 (ddt, 1, J = 10.1, 16.6, 7.1), 5.59 (ddt, 1, J = 9.5, 17.4, 7.1), 5.12-4.94 (m, 4), 4.86 (tt, 1, J = 1.6, 1.6), 4.72-4.68 (br s, 1), 3.71 (s, 3), 2.71-2.65 (m, 5), 2.48-2.56 (m, 2), 2.28-2.38 (m, 2); ^{13}C NMR 205.5, 172.5, 140.6, 137.0, 132.4, 119.1, 115.5, 115.3, 62.9, 52.2, 39.4, 38.6, 36.2, 27.7, 23.5.

The data for **37a** were determined from the mixture: ^{1}H NMR 5.72-5.60 (m, 1), 5.25-4.92 (m, 4), 3.72 (s, 3), 3.01 (dt, 1, J = 17.5, 2.9, $H_{7\ endo}$), 2.68 (ddd, 1, J = 2.2, 4.2, 17.5, $H_{7\ exo}$), 2.63-2.42 (m, 2), 2.29 (dd, 1, J = 2.2, 11.9, $H_{8\ syn}$), 2.15 (br dt, 1, J = 13.8, 7.0, allylic CH_2), 2.03 (dd, 1, J = 10.6, 13.2, $H_{4\ endo}$), 1.89 (dd, 1, J = 2.7, 11.9, $H_{8\ anti}$), 1.48 (ddd, 1, J = 2.4, 5.3, 13.2, $H_{4\ exo}$), 1.26 (s, 3, C_5-CH_3); ^{13}C NMR 208.1 (C_2), 171.8 (OC=O), 154.7 (C_6), 135.7 (=CH), 117.1 (=CH_2), 106.1 (=CH_2), 61.7 (C_1), 52.2 (-OCH_3), 44.4 (C_8), 44.2 (C_4), 43.0 (C_5), 41.6 (C_3), 39.8 (C_7), 36.5 (allylic CH_2), 24.7, (C_5-CH_3); IR 1746, 1713, 1660, 1642.

A solution of 10 mg of a 1:3 mixture of **37a** and **38a** in anh MeOH (1.5 mL) containing of suspended K_2CO_3 (30 mg) was stirred for 3 h at rt. Normal workup gave 9 mg of pure **38a**: ^{1}H NMR 5.71 (dddd, 1, J = 6.5, 7.4, 10.8, 16.9, =CH), 5.06-4.98 (m, 4, =CH_2), 3.74 (s, 3), 2.89 (dt, 1, J = 18.2, 2.6, $H_{7\ exo}$), 2.86 (ddd, 1, J = 2.2, 4.4, 18.2, $H_{7\ endo}$), 2.68-2.58 (m, 2), 2.10 (dd, 1, J = 3.6, 12.2, $H_{8\ anti}$), 2.04-1.97 (m, 2), 1.82 (ddd, 1, J = 3.3, 7.4, 12.3, $H_{4\ endo}$), 1.45 (dd, 1, J = 12.0, 12.0, $H_{4\ exo}$), 1.24 (s, 3, C_5-CH_3); ^{13}C NMR 208.2 (C_2), 171.9 (OC=O), 153.9 (C_6), 135.7 (=CH), 116.8 (=CH_2), 106.1 (=CH_2), 62.1 (C_1), 52.0 (-OCH_3), 47.6 (C_4), 47.3 (C_8), 44.2 (C_5), 43.8 (C_3), 39.8 (C_7),

33.5 (allylic CH_2), 22.5 (C_5-CH_3); IR 1746, 1713, 1660, 1642. Anal. Calcd for $C_{15}H_{20}O_3$: C, 72.55; H, 8.12. Found: C, 72.38; H, 8.34.

Oxidative Cyclization of 13b. Reaction of **13b** (285 mg, 1.0 mmol), $Mn(OAc)_3 \cdot 2H_2O$ (540 mg, 1.0 mmol), and $Cu(OAc)_2 \cdot H_2O$ (200 mg, 1.0 mmol) in glacial acetic acid (10 mL) for 16 h at rt followed by normal work up gave 284.0 mg of crude product which contained **28a** and **28b** in a 4:1 ratio. Flash chromatography on silica gel (30:1 hexane-EtOAc) of 100.0 mg gave 55.0 mg (55.0%) of pure methyl 5-methyl-6-methylene-2-oxo-3-*endo*-(2-chloro-2-propenyl)-bicyclo[3.2.1]octane-1-carboxylate (**28a**) followed by 36.0 (36.0%) of pure methyl 5-methyl-6-methylene-2-oxo-3-*exo*-(2-chloro-2-propenyl)-bicyclo[3.2.1]octane-1-carboxylate (**28b**).

The data for **28a**: ^{1}H NMR 5.22 (t, 1, J = 0.8), 5.14 (t, 1, J = 1.2), 4.99 (dd, 1, J = 1.8, 2.9), 4.94 (br s, 1), 3.73 (s, 3), 3.04 (dt, 1, J = 17.4, 2.9), 2.96 (m, 1), 2.84 (dddd, 1, J = 0.8, 1.2, 4.3, 14.3), 2.65 (ddd, 1, J = 1.8, 3.9, 17.4), 2.37 (dd, 1, J = 12.0, 2.2), 2.27 (dd, 1, J = 10.5, 14.3), 2.10 (dd, 1, J = 10.6, 13.4), 1.89 (dd, 1, J = 2.2, 12.0), 1.38 (ddd, 1, J = 2.2, 6.0, 13.4), 1.28 (s, 3). ^{13}C NMR 209.9, 171.3, 155.0, 139.9, 114.8, 106.4, 61.7, 52.3, 44.1, 42.7, 41.7, 41.3, 41.0, 40.3, 24.8; IR (neat) 3080, 2960, 2930, 2870, 1745, 1715, 1660, 1635, 1435, 1330, 1270, 1190, 1145, 1125, 1045, 990, 960, 890.

The data for **28b**: ^{1}H NMR 5.19 (t, 1, J = 1.0), 5.17 (t, 1, J = 1.0), 5.09 (t, 1, J = 2.1), 5.04 (t, 1, J = 2.5), 3.75 (s, 3), 2.91 (br s, 2), 2.81-2.98 (m, 2), 2.20 (dd, 1, J = 14.6, 9.0), 2.12 (dd, 1, J = 12.4, 3.6), 2.03 (br d, 1, J = 12.4), 1.86 (ddd, 1, J = 12.2, 7.0, 3.6), 1.38 (dd, 1, J = 12.2, 12.2), 1.24 (s, 3); ^{13}C NMR 207.6, 171.7, 153.2, 139.8, 114.5, 106.5, 62.1, 52.1, 47.7, 46.8, 44.1, 41.6, 39.7, 39.0, 22.5; IR (neat) 3080, 2960, 2930, 2870, 1745, 1715, 1660, 1635, 1435, 1320, 1270, 1200, 1160, 1040, 1010, 960, 880. Anal. Calcd. for $C_{15}H_{19}ClO_3$: C, 63.72; H, 6.77. Found: C, 63.57; H, 6.88.

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