DOI: 10.1002/ejoc.200701232

Facile Endoperoxypropellane Synthesis by Manganese(III) Acetate-Mediated Aerobic Oxidation

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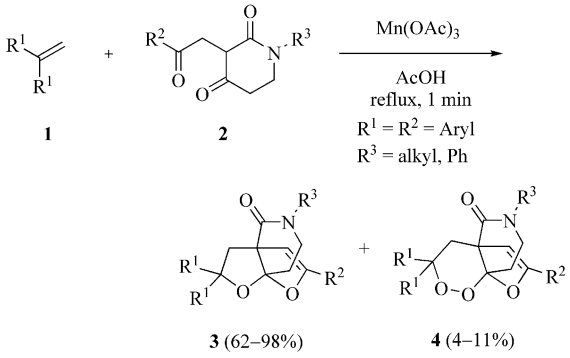
Dedicated to Professor emeritus Kazu Kurosawa

Keywords: Nitrogen heterocycles / Peroxides / Radicals / Cyclization / Oxidation

Manganese(III)-catalyzed aerobic oxidation of combinations of 3-(2-oxoethyl)piperidine-2,4-diones and 1,1-diarylethenes at room temperature produced structurally interesting trioxaaza[4.4.3]propellanes in good yields. Similar reactions using 2-(2-oxoethyl)cyclohexane-1,3-diones also produced the corresponding endoperoxy[4.4.3]propellanes. On the other hand, 3-oxopropyl-substituted cycloalkane-1,3-diones did not give the desired propellanes, 1,2-dioxabicyclic propellane precursors were formed instead in excellent yields. The precursors could be converted into the corresponding propellanes in the presence of a Lewis acid. The mechanism for the formation of the propellanes is also described.

Introduction

A tricyclic system connected by a common carbon–carbon single bond is generally called a "propellane,"[1] and such systems are found in many different categories of natural products,[1] some of which exhibit biological and pharmacological activities.[2] Many synthetic chemists have therefore investigated the synthesis of these natural products,[3] as well as their physical characteristics.[4] Very recently, we developed a convenient synthesis of heterocyclic propellanes **3** through the oxidation of 2-oxoethyl-substituted piperidine-2,4-diones and their derivatives with manganese(III) acetate in the presence of 1,1-diarylethenes (Scheme 1).[5] In these reactions, small amounts of the unique endoperoxypropellanes **4** were produced at the same time.[6] Although the formation of **4** could be avoided by removal of the dissolved molecular oxygen in the reaction solvent,[5,6] we were very interested in the nitrogen-containing endoperoxypropellanes **4** as an attractive synthetic target, since the endoperoxide skeleton is found in metabolites and biologically active substances,[7] such as the naturally occurring artemisinin, a well known potent antimalarial agent.[8] In addition, a wide variety of natural azapropellanes have also been isolated and synthesized.[9] In this paper we describe the full results of the selective synthesis of endoperoxypropellanes, and the related reaction.[10]



Scheme 1. Oxidation of 2-oxoethyl-substituted piperidine-2,4-diones **2** with manganese(III) acetate in the presence of 1,1-diarylethenes **1** at reflux temperature.

Results and Discussion

We first adopted conventional aerobic oxidation conditions[6] for the reactions between alkenes **1** and piperidinediones **2**. The reaction between 1,1-diphenylethene (**1a**) (0.25 mmol) and 1-isopropyl-3-(2-oxo-2-phenylethyl)piperidine-2,4-dione (**2a**, 0.5 mmol), for example, was carried out in the presence of manganese(III) acetate dihydrate (0.2 mmol) in glacial acetic acid (10 mL) at room temperature in air. After chromatographic separation, the desired azatrioxa[4.4.3]propellane **4aa** was isolated in a 42% yield, along with by-product **5aa** (30%) (Scheme 2 and Scheme 3, and Table 1, Entry 1).

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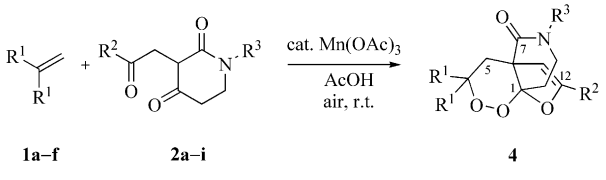
Table 1. Reactions between 1,1-diarylethenes **1a**–**f** and 3-(2-oxoethyl)piperidine-2,4-diones **2a**–**i** in the presence of manganese(III) acetate.[a]

Entry	Alkene **1**	Piperidinedione **2**	**1/2**/$Mn(OAc)_3$[b]	Time (h)	Product (% yield)[c]		
1[d]	**1a**	**2a**	1:2:0.8	4.5	**4aa** (42)	**5aa** (30)	
2	**1a**	**2a**	1:2:0.8	7.5	**4aa** (67)		
3	**1a**	**2b**	1:1.5:0.8	7.5	**4ab** (67)		
4	**1a**	**2c**	1:2:0.7	7.5	**4ac** (75)		
5	**1a**	**2d**	1:2:0.7	7.5	**4ad** (68)		
6	**1a**	**2e**	1:2:1	7.5	**4ae** (58)		
7	**1a**	**2f**	1:2:1	7.5	**4af** (66)		
8	**1a**	**2g**	1:2:1	7.5	**4ag** (67)		
9	**1a**	**2h**	1:2:0.7	7.5	**4ah** (62)		
10	**1b**	**2b**	1:1.6:0.7	7.5	**4bb** (67)		
11	**1c**	**2b**	1:1.4:0.7	7.5	**4cb** (58)		
12	**1d**	**2b**	1:1.6:0.7	7.5	**4db** (63)		
13	**1e**	**2b**	1:1.6:0.7	7.5	**4eb** (11)		**6eb** (83)
14[e]	**1e**	**2b**	1:1.6:0.7	5	**4eb** (53)	**5eb** (38)	
15	**1e**	**2i**	1:1.6:0.7	7.5	**4ei** (8)[f]		**6ei** (65)
16[e]	**1e**	**2i**	1:1.6:0.7	3.5	**4ei** (19)[g]	**5ei** (60)	
17	**1f**	**2i**	1:2:0.7	7.5	**4fi** (71)[h]		
18[e]	**1f**	**2i**	1:2:0.7	6	**4fi** (26)[i]	**5fi** (64)	

[a] The reactions between compounds **1** (0.25 mmol) and compounds **2** were carried out in glacial acetic acid (10 mL) in the presence of manganese(III) acetate dihydrate in air at room temperature for 7 h, followed by heating at 100 °C for 30 min, except in the cases of Entries 1, 14, 16, and 18. [b] Molar ratio. [c] Isolated yield based on the amount of the alkene **1** used. [d] The reaction mixture was stirred in air for 4.5 h at room temperature, and the solvent was then removed in vacuo. [e] The reaction was carried out in air at room temperature until the alkene **1** had been completely consumed, followed by rapid quenching with water. [f] The corresponding dioxapropellane **3ei** was also isolated in 16% yield.[5] [g] The corresponding dioxapropellane **3ei** was also isolated in 11% yield.[5] [h] The corresponding dioxapropellane **3fi** was also isolated in 12% yield.[5] [i] The corresponding dioxapropellane **3fi** was also isolated in 4% yield.[5]



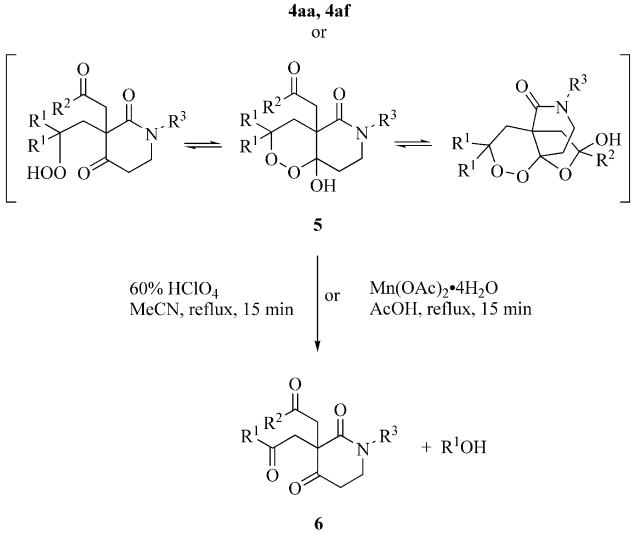
1a–f **2a–i** **4**

1a R^1 = Ph
1b R^1 = 4-ClC_6H_4
1c R^1 = 4-FC_6H_4
1d R^1 = 4-MeC_6H_4
1e R^1 = 4-$MeOC_6H_4$
1f R^1 = 2-naphthyl

2a R^2 = Ph, R^3 = *i*Pr
2b R^2 = Ph, R^3 = Bn
2c R^2 = 4-ClC_6H_4, R^3 = Bn
2d R^2 = 4-MeC_6H_4, R^3 = Bn
2e R^2 = Ph, R^3 = Me
2f R^2 = Ph, R^3 = Et
2g R^2 = Ph, R^3 = Pr
2h R^2 = Ph, R^3 = Ph
2i R^2 = *t*Bu, R^3 = *t*Bu

4aa R^1 = Ph, R^2 = Ph, R^3 = *i*Pr
4ab R^1 = Ph, R^2 = Ph, R^3 = Bn
4ac R^1 = Ph, R^2 = 4-ClC_6H_4, R^3 = Bn
4ad R^1 = Ph, R^2 = 4-MeC_6H_4, R^3 = Bn
4ae R^1 = Ph, R^2 = Ph, R^3 = Me
4af R^1 = Ph, R^2 = Ph, R^3 = Et
4ag R^1 = Ph, R^2 = Ph, R^3 = Pr
4ah R^1 = Ph, R^2 = Ph, R^3 = Ph
4bb R^1 = 4-ClC_6H_4, R^2 = Ph, R^3 = Bn
4cb R^1 = 4-FC_6H_4, R^2 = Ph, R^3 = Bn
4db R^1 = 4-MeC_6H_4, R^2 = Ph, R^3 = Bn
4eb R^1 = 4-$MeOC_6H_4$, R^2 = Ph, R^3 = Bn
4ei R^1 = 4-$MeOC_6H_4$, R^2 = *t*-Bu, R^3 = *t*Bu
4fi R^1 = 2-naphthyl, R^2 = *t*Bu, R^3 = *t*Bu

Scheme 2. Mn^{III}-mediated aerobic oxidation of a combination of 1,1-diarylethenes **1** and 3-(2-oxoethyl)piperidine-2,4-diones **2** at room temperature.



5aa, 6aa: R^1 = Ph, R^2 = Ph, R^3 = *i*Pr
6af : R^1 = Ph, R^2 = Ph, R^3 = Et
5eb, 6eb: R^1 = 4-$MeOC_6H_4$, R^2 = Ph, R^3 = Bn
5ei, 6ei : R^1 = 4-$MeOC_6H_4$, R^2 = *t*Bu, R^3 = *t*Bu
5fi : R^1 = 2-Naphthyl, R^2 = *t*Bu, R^3 = *t*Bu
6'fi : R^1 = 2-Naphthyl, R^2 = *t*Bu, R^3 = H

Scheme 3. Acid-catalyzed decomposition of azatrioxapropellanes **4aa**, **4af** or the propellane precursors **5**.

The by-product **5aa** showed very complicated NMR spectra in $CDCl_3$ or [D_6]DMSO. In the IR spectrum, the absorption band of the hydroxy group appeared at 3150–3600 cm^{-1}. However, the absorption band due to the carbonyl group only appeared at $\tilde{\nu}$ = 1618 cm^{-1}. From these spectroscopic data, the by-product **5aa** seemed to be an equilibrium mixture of the hydroperoxide and a pair of hemiketals (see Scheme 3 and Supporting Information). In order to confirm the structure of **5aa**, its acid-catalyzed decomposition was examined in perchloric acid/acetonitrile or manganese(II) acetate/acetic acid at reflux temperature, and quantitatively gave the corresponding 3,3-bis(2-oxoethyl)-piperidine-2,4-dione **6aa** and phenol (Scheme 3 and Table 2, Entry 1).[6c,11] A similar reaction of **4aa** also gave the same product (Table 2, Entry 2). It was postulated that a typical

hydroperoxide and endoperoxide rearrangement had occurred, and we therefore concluded that the by-product **5aa** was the precursor of **4aa**. Furthermore, combustion analysis of **5aa** also agreed with the molecular formula (see Exp. Sect.). Since continuous heating (10 min) after the oxidation was effective for the dioxapropellane synthesis,[5] we attempted heating at 100 °C after the aerobic oxidation in order to convert the precursor **5aa** into the endoperoxypropellane **4aa** in situ. As a result, the single product **4aa** was isolated in 67% yield (Table 1, Entry 2).

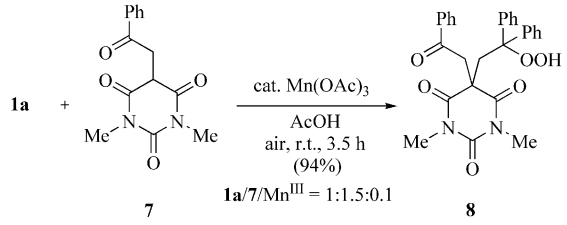
Table 2. Acid-catalyzed decomposition of azatrioxapropellanes **4aa** and **4af** and hydroperoxide intermediates **5aa**, **5eb**, **5ei**, and **5fi**.[a]

Entry	Substrate	Reagent	Solvent	Time	Product (% yield)[b,c]
1	**5aa**	60% $HClO_4$ aq.	CH_3CN	15 min	**6aa** (quant.)
2	**4aa**	60% $HClO_4$ aq.	CH_3CN	15 min	**6aa** (quant.)
3	**4af**	60% $HClO_4$ aq.	CH_3CN	15 min	**6af** (92)
4	**5eb**	$Mn(OAc)_2{\cdot}4H_2O$	AcOH	15 min	**6eb** (75)
5	**5ei**	$Mn(OAc)_2{\cdot}4H_2O$	AcOH	2 h	**6ei** (63)
6	**5fi**	60% $HClO_4$ aq.	CH_3CN	15 min	**6′fi** (96)

[a] The reactions of **4** or **5** (0.1 mmol) were carried out in CH_3CN or AcOH (2 mL) in the presence of perchloric acid aqueous solution (60%, 0.3 mL) or manganese(II) acetate tetrahydrate (2 equiv.) at reflux temperature. [b] Isolated yield based on the amount of the substrate used. [c] The corresponding phenol was also produced.

Similar reactions of other combinations of alkenes **1a**–**f** and piperidinediones **2b**–**i** were next investigated, and the corresponding azatrioxapropellanes **4** were produced in moderate to good yields except when **1e** was used (Table 1, Entries 3–14 and 17). Even under optimized conditions, the endoperoxypropellane **4eb** was only produced in 11% yield in this last case, along with a large amount of the rearrangement product **6eb** (83%) (Table 1, Entry 13). This would presumably be due to the electron-releasing properties of the 4-methoxyphenyl group, which would accelerate rearrangement.[11a] The problem was partially avoided by rapid quenching with water after the alkene **1e** had been completely consumed during the aerobic oxidation (Table 1, Entry 14). The use of the bulky substituents in the alkene **1f** and the piperidinedione **2i** also led to the production of a large amount of the propellane precursors **5ei** and **5fi**, respectively (Table 1, Entries 16 and 18). Although the NMR spectra of **5ei** and **5fi** were also complicated, the precursors **5ei** and **5fi** underwent acid-catalyzed decomposition to give **6ei** and **6′fi** (Scheme 3 and Table 2, Entries 5,6).[12] Incidentally, it is well known that the aerobic oxidation of barbituric acids does not give the endoperoxides, but hydroperoxides.[13] In fact, 5-(2-oxoethyl)barbituric acid (**7**) produced the corresponding hydroperoxide **8** under the same conditions (Scheme 4). These results also supported the structure of the intermediates **5**.

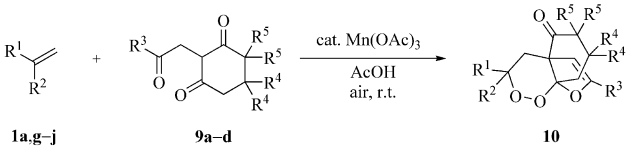
The obtained azatrioxa[4.4.3]propellanes **4** were characterized by spectroscopic methods and elemental analysis. For example, the ^1H NMR spectrum of **4ab** showed the presence of two sets of an AB quartet of benzyl protons and H-5 methylene protons at δ = 4.71 (d, J = 14.9 Hz, 1 H), 4.37 (d, J = 14.9 Hz, 1 H), 3.86 (d, J = 14.3 Hz, 1 H), and 2.69 ppm (d, J = 14.3 Hz, 1 H), respectively. One of



Scheme 4. Mn^{III}-catalyzed aerobic oxidation of a combination of 1,1-diphenylethene (**1a**) and 5-(2-oxoethyl)barbituric acid **7** at room temperature.

the H-5 methylene protons (δ = 2.69 ppm) seemed to be shielded by the anisotropic effect for the alkenic double bond of the dihydrofuran ring. The most characteristic peak of the sp^2 proton (H-13) appeared at δ = 5.13 ppm (s, 1 H). In the ^{13}C NMR spectrum, the characteristic downfield peak at δ = 111.8 ppm was assigned to the C-1 quaternary ketal carbon together with an amide carbonyl carbon (δ = 169.3 ppm) and an sp^2 carbon (C-12) attached to the furan oxygen (δ = 156.3 ppm). The quaternary carbon (C-4) connected to the endoperoxy oxygen and the quaternary carbon (C-6) at the ring junction also appeared at δ = 86.0 and δ = 54.7 ppm, respectively. All the peaks in the NMR spectra were correlated by the H-H COSY and H-C COSY spectra. In addition, the absorption band at 1639 cm^{-1} was assigned to the amide carbonyl in the IR spectrum, while the positive FAB mass spectrum and the elemental analysis agreed with the molecular formula. Therefore, the structure of **4ab** was determined to be 8-benzyl-4,4,12-triphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.$0^{1,6}$]tridec-12-en-7-one.

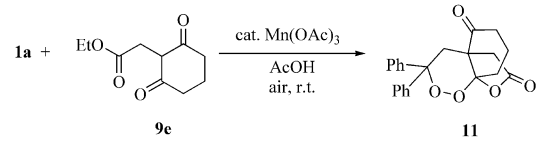
Having established the optimum conditions, we applied the endoperoxypropellane formation to various 2-(2-oxoethyl)cycloalkane-1,3-diones **9a**–**e** (Scheme 5). Firstly, the



1a $R^1 = R^2 =$ Ph
1g R^1 = Ph, R^2 = Me
1h R^1 = Ph, R^2 = H
1i $R^1 = R^2$ = Et
1j R^1 = N(Bn)Boc, R^2 = CO_2Me

9a R^3 = Ph, $R^4 = R^5$ = H
9b R^3 = Ph, R^4 = Me, R^5 = H
9c R^3 = Ph, R^4 = H, R^5 = Me
9d R^3 = 2-Naphthyl, $R^4 = R^5$ = H

10aa $R^1 = R^2 = R^3$ = Ph, $R^4 = R^5$ = H
10ab $R^1 = R^2 = R^3$ = Ph, R^4 = Me, R^5 = H
10ac $R^1 = R^2 = R^3$ = Ph, R^4 = H, R^5 = Me
10ad $R^1 = R^2$ = Ph, R^3 = 2-naphthyl, $R^4 = R^5$ = H
10ga R^1 = Ph, R^2 = Me, R^3 = Ph, $R^4 = R^5$ = H
10ha R^1 = Ph, R^2 = H, R^3 = Ph, $R^4 = R^5$ = H
10ia $R^1 = R^2$ = Et, R^3 = Ph, $R^4 = R^5$ = H
10ja R^1 = N(Bn)Boc, R^2 = CO_2Me, R^3 = Ph, $R^4 = R^5$ = H



Scheme 5. Mn^{III}-catalyzed aerobic oxidation of a combination of alkenes **1** and 2-(2-oxoethyl)cyclohexane-1,3-diones **9** at room temperature.

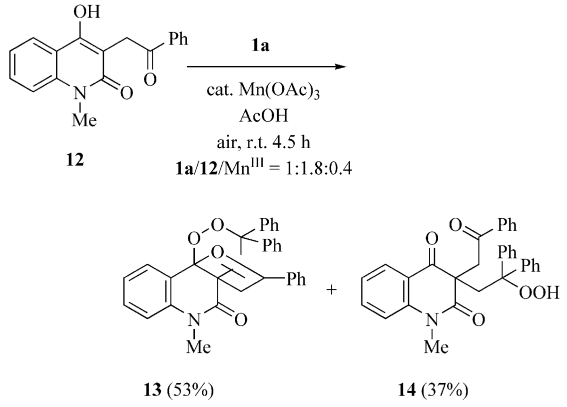
reaction between 2-(2-oxo-2-phenylethyl)cyclohexane-1,3-dione (**9a**) and **1a** was examined, and the desired propellane **10aa** was obtained in 45% yield (Table 3, Entry 1).

Table 3. Similar aerobic oxidations with 2-(2-oxoethyl)cycloalkane-1,3-diones **9a**–**e**.[a]

Entry	Substrate		Molar ratio[b]	Time [h]	Product (% yield)[c]
1	**1a**	**9a**	1:2:0.4	10.5	**10aa** (45)
2	**1a**	**9a**	1:2:0.4	5.5	**10aa** (67)
3	**1a**	**9a**	1:2:0.4	1	**10aa** (83)
4	**1a**	**9b**	1:2:0.4	1	**10ab** (75)
5	**1a**	**9c**	1:2:0.4	2	**10ac** (78)[d]
6	**1a**	**9d**	1:2:0.4	2	**10ad** (75)
7	**1a**	**9e**	1:2:0.1	2.5	**11** (85)
8[e]	**1g**	**9a**	1:2:0.4	1.25	**10ga** (61)[f]
9	**1h**	**9a**	1:2:0.4	1.5	**10ha** (28)[g]
10[e]	**1i**	**9a**	5:1:0.3	1.75	**10ia** (9)
11[h]	**1j**	**9a**	1:2:0.1	5.5	**10ja** (32)[f]

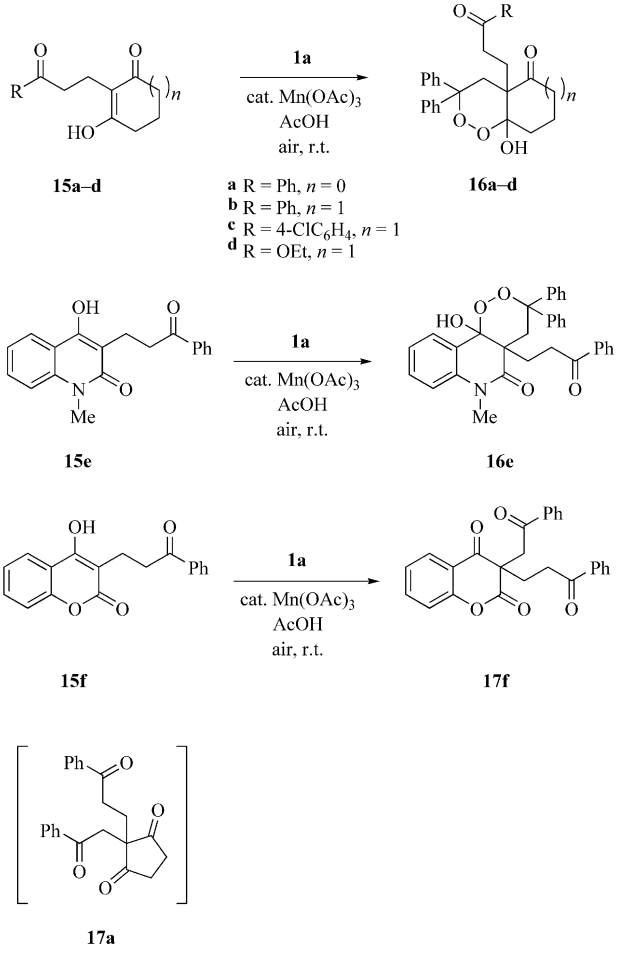
[a] The reactions between compounds **1** (0.25 mmol) and compounds **9** were carried out in glacial acetic acid (10 mL) in the presence of manganese(III) acetate dihydrate in air at room temperature for 0.5–10 h, followed by heating at 100 °C for 30 min, except in the cases of Entries 8 and 10. [b] **1**/**9**/$Mn(OAc)_3$. [c] Isolated yield based on the amount of the alkene **1** used. [d] A single regioisomer was obtained. [e] After stirring for 1–1.5 h, the reaction mixture was heated at 100 °C for 15 min. [f] Two diastereoisomers were isolated in a ratio of ca. 1:2. [g] One diastereoisomer was produced. [h] The alkene **1j** (42%) was recovered.

When the oxidation was scrutinized, however, it was found that the reaction was finished in 30 min, and the subsequent heating at 100 °C for 30 min gave **10aa** in 83% yield (Entry 3). Other 2-(2-oxoethyl)cyclohexane-1,3-diones **9b**–**e** also gave the corresponding propellanes **10** and **11** in good yields (Entries 4–7). In the case of **9c**, only a single regioisomer **10ac** was produced (Entry 5). The carboxylate **9e** yielded the propellanelactone **11** instead of the dihydrofuran-fused propellane (Entry 7). The reactions of α-methylstyrene (**1g**) and 2-aminoacrylate **1j** with **9a** afforded **10ga** and **10ja**, respectively, as ca. 1:2 mixture of diastereomers (Entries 8 and 11). The reaction between styrene (**1h**) and 2-ethylbut-1-ene (**1i**) became messy and a small amount of **10ha** and **10ia** was obtained (Entries 9 and 10). The approach to the trioxa[5.4.3]propellane with 2-(2-oxo-2-phenylethyl)cycloheptane-1,3-dione and **1a** failed, with a complex mixture being formed along with a large amount of recovered **1a**. 4-Hydroxy-3-(2-oxoethyl)-1*H*-quinolin-2-one **12** gave the endoperoxypropellane **13** (53% yield) together with a considerable amount of the hydroperoxide intermediate **14** (37% yield; Scheme 6). When the reaction was quenched by addition of water without subsequent heating, the hydroperoxide intermediate **14** was isolated in 76% yield. The isolation of the stable hydroperoxide **14** could be explained by our previous studies.[6a,13,14] Similar reactions with quinolinone derivatives without substituents at the 3-position yielded the stable 3,3-bis(2-hydroperoxyethyl)-1*H*-quinoline-2,4-diones.[6a] Barbituric acids and pyrazolidine-3,5-diones also provided the stable 5,5-bis(2-hydroperoxyethyl)barbituric acids[13] and 4,4-bis(2-hydroperoxyethyl)-pyrazolizine-3,5-diones,[14a,14b] respectively. The unusual stabilities of the hydroperoxy groups turned out on the basis of X-ray crystallographic analysis to be due to intramolecular hydrogen bonding between the hydroperoxy groups and the carbonyl oxygen atoms.[6,13,14]



Scheme 6. Mn^{III}-catalyzed aerobic oxidation of 4-hydroxy-3-(2-oxoethyl)-1*H*-quinolin-2-one (**12**) at room temperature.

In an attempt to apply the endoperoxypropellane synthesis to the 3-oxopropyl-substituted cyclic 1,3-diones, we examined the reaction between 2-(3-oxo-3-phenylpropyl)-cyclopentane-1,3-dione (**15a**) and **1a** under standard aerobic conditions (Scheme 7). Surprisingly, the desired pro-



Scheme 7. Similar aerobic oxidation with 3-oxopropyl-substituted cyclic 1,3-diones **15a**–**f**.

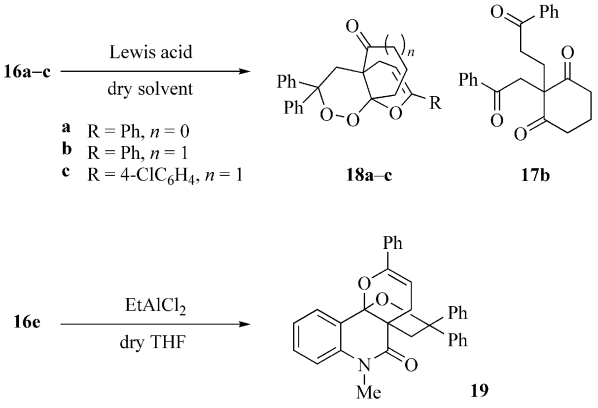
pellane was not obtained, but only the acid-decomposition product **17a** was isolated (Table 4, Entry 1). However, rapid quenching with water without the additional heating after the alkene **1a** had been consumed led to the production of the dioxabicyclic intermediate **16a**, which was the precursor of the endoperoxypropellane (Entry 2). Similar treatment of 2-(3-oxopropyl)cyclohexane-1,3-diones **15b** and **15c**, cyclohexenylpropanoate **15d**, and 3-(3-oxopropyl)quinolinone **15e** also gave the corresponding propellane precursors **16b–e** (Entries 3–6).[6a] In spite of rapid quenching with water, 3-(3-oxopropyl)coumarin **15f** quantitatively gave the acid decomposition product **17f** along with generation of the phenol. In any event, we were unable to achieve the synthesis of the endoperoxypropellanes from these 3-oxopropyl-substituted cyclic 1,3-diones under the aerobic oxidation conditions.[6c,11]

Table 4. Similar aerobic oxidation with 3-oxopropyl-substituted cyclic 1,3-diones **15a–f**.[a]

Entry	Substrate	Molar ratio[b]	Time [h]	Product (% yield)[c]
1[d]	**15a**	1:2:0.5	1.5	**17a** (34)
2	**15a**	1:2:0.5	1	**16a** (94)
3	**15b**	1:2:0.4	2	**16b** (99)
4	**15c**	1:2:0.4	3.5	**16c** (98)
5	**15d**	1:1.5:0.1	21	**16d** (64)
6	**15e**	1:2:0.5	1	**16e** (96)
7	**15f**	1:2:0.5	1	**17f** (99)

[a] The reaction between **1a** (0.25 mmol) and **15** was carried out in glacial acetic acid (10 mL) in the presence of manganese(III) acetate dihydrate in air at room temperature until **1a** had been completely consumed, followed by rapid quenching with water except for in the case of Entry 1. [b] **1**/**15**/$Mn(OAc)_3$. [c] Isolated yield based on the amount of **1a** used. [d] After stirring for 1 h, the reaction mixture was heated under reflux for 30 min.

Recently, we reported the efficient cyclization of 3-oxopropyl-substituted propellane precursors into the corresponding dioxapropellanes in the presence of Lewis acids,[5b] and so we examined cyclizations of the 3-oxopropyl-substituted dioxabicyclic intermediates **16** for conversion into the desired endoperoxypropellanes (Scheme 8 and Table 5). However, since the endoperoxides were sensitive to acids,[11] the cyclizations were scrutinized very carefully. Use of a weak Lewis acid silica gel resulted in no change in the reaction of **16b** (Table 5, Entry 1), while use of *p*-toluenesulfonic acid in dry chloroform led to the decomposition of **16b** to give the triketone **17b** (Entry 2). However, use of *p*-toluenesulfonic acid at 0 °C gave the desired endoperoxypropellane **18b** together with unchanged **16b** (Entry 4). Dry tetrahydrofuran was found to be the best solvent to afford **18b** in the presence of boron trifluoride (Entries 5–10). Finally, it was found that conducting the reaction in the presence of ethylaluminium dichloride in dry tetrahydrofuran gave the best result for cyclizing compounds **16**, with the desired endoperoxypropellanes **18a–c** being obtained in good yields (Entries 11–13). To our surprise, the quinolinone-fused endoperoxide **16e** afforded not the endoperoxypropellane, but the dioxapropellane **19**, the selective synthesis of which had already been developed in our previous study (Entry 14).[5]



Scheme 8. Cyclizations of 3-oxopropyl-substituted propellane precursors **16** in the presence of Lewis acids.

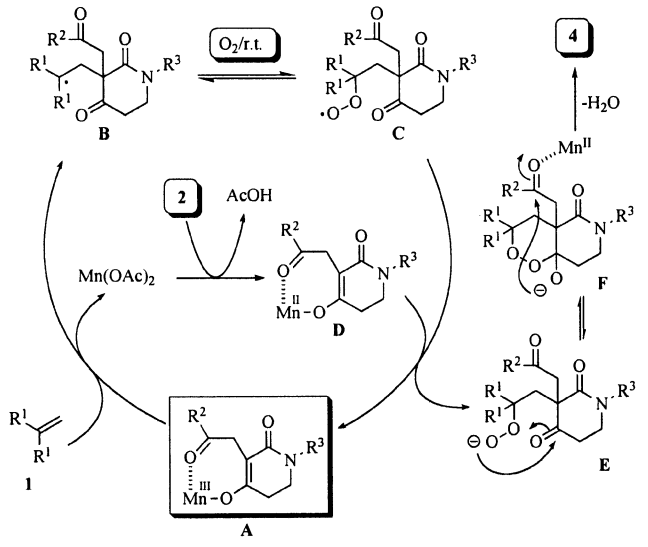
We believe that the mechanism for the formation of these endoperoxypropellanes involves the initial formation of a manganese(III) enolate complex **A** by ligand exchange of the cyclic triketones such as **2**, followed by electron transfer from the electron-rich alkene **1** to the manganese(III)

Table 5. Cyclizations of 3-oxopropyl-substituted bicyclic endoperoxides **16** in the presence of Lewis acids.[a]

Entry	Endoperoxide	Lewis acid	Solvent	Conditions	% Recovery	Product (% yield)[b]	
1	**16b**	silica gel[c]	dry $CHCl_3$	room temp. (2.5 h), reflux (2 h)	100		
2	**16b**	*p*TsOH (0.5 equiv.)	dry $CHCl_3$	reflux (15 min)		**17b** (72)	
3	**16b**	*p*TsOH (0.5 equiv.)	dry $CHCl_3$	room temp. (11 h)	25	**17b** (52)	**18b** (35)
4	**16b**	*p*TsOH (10 equiv.)	dry $CHCl_3$	0 °C (5 h)	44		**18b** (47)
5	**16b**	BF_3·OEt_2 (4 equiv.)	dry $CHCl_3$	0 °C (3 h)		**17b** (80)	
6	**16b**	BF_3·OEt_2 (3 equiv.)	dry CCl_4	0 °C (1 h)		Complex mixture	
7	**16b**	BF_3·OEt_2 (3 equiv.)	dry MeCN	0 °C (2 h)		**17b** (94)	
8	**16b**	BF_3·OEt_2 (4 equiv.)	dry THF	reflux (20 min)		**17b** (31)	**18b** (63)
9	**16b**	BF_3·OEt_2 (5 equiv.)	dry THF	30–40 °C (3 h)		**17b** (16)	**18b** (84)
10	**16b**	BF_3·OEt_2 (4 equiv.)	dry THF	0 °C (2 h), room temp. (9 h)	31		**18b** (56)
11	**16b**	$EtAlCl_2$ (5 equiv.)	dry THF	room temp. (30 min), 50–55 °C (1 h)			**18b** (95)
12	**16a**	$EtAlCl_2$ (4 equiv.)	dry THF	room temp. (30 min), 60 °C (1 h)			**18a** (65)
13	**16c**	$EtAlCl_2$ (4 equiv.)	dry THF	room temp. (30 min), 60 °C (1 h)			**18c** (97)
14	**16e**	$EtAlCl_2$ (4 equiv.)	dry THF	room temp. (30 min), 60 °C (1 h)			**19** (66)

[a] The cyclization of **16** (0.1 mmol) was carried out in dry solvent (2 mL) in air. [b] Isolated yield based on the amount of **16** used. [c] Wakogel B-10 was used.

enolate complex to produce the carbon radical **B** (Scheme 9).[11,15,16] Trapping with the triplet molecular oxygen dissolved in the solvent would produce the peroxy radical **C**, which would be reduced by manganese(II) species **D** in the reaction mixture to generate the peroxy anion **E**.[6b,6c] Cyclization at the most favourable position of the carbonyl group in **E** would result in the equilibrium with the endoperoxide anion **F**. Subsequent attack of the anion **F** on the terminal carbonyl group gives the endoperoxypropellane **4** by dehydration. As a result, since the manganese(III) species **A** could be reproduced, the autoxidation system would be completed in the presence of the Mn^{III}–Mn^{II} redox catalysts. The thirty minute heating at 100 °C after the autoxidation was needed to allow the intramolecular cyclization followed by dehydration, and finally to produce the thermodynamically stable endoperoxypropellanes **4**.



Scheme 9. Proposed mechanism for the Mn^{III}-catalyzed aerobic oxidation of 3-(2-oxoethyl)piperidine-2,4-diones **2** in the presence of alkenes **1**.

Conclusions

We have accomplished the selective synthesis of the azatrioxa- (**4**, **13**) and trioxa[4.4.3]propellanes **10** and **11** by manganese(III)-catalyzed aerobic oxidation with 1,1-diarylethenes and cyclic 1,3-dicarbonyl compounds possessing oxoethyl substituents. The reaction is very simple and convenient, and can be performed under mild reaction conditions, although a thirty-minute heating period at 100 °C is needed after the oxidation in order to complete the propellane formation except in certain cases. The oxopropyl-substituted diketones **15** did not afford the desired propellanes, but rather the dioxabicyclic intermediates **16**. However, we have achieved the transformation of the acid-sensitive dioxabicyclic intermediates **16** into the corresponding endoperoxypropellanes **18** by Lewis acid-induced intramolecular cyclization.

Experimental Section

General: The NMR spectra were recorded with a JNM EX300 FT NMR spectrometer at 300 MHz for ^1H and at 75 MHz for ^{13}C, with tetramethylsilane as the internal standard. The chemical shifts are reported in δ values (ppm). The IR spectra of neat samples were measured by the ATR method with a Shimadzu 8400 FT IR spectrophotometer and MIRacle A, and are expressed in cm^{-1}. The EI MS spectra were recorded with a Shimadzu QP-5050A gas chromatograph/mass spectrometer at the ionizing voltage of 70 eV. The high-resolution mass spectra were measured at the Institute for Materials Chemistry and Engineering, Kyushu University, Fukuoka, Japan. The elemental analyses were performed at the Analytical Center of Kumamoto University, Kumamoto, Japan. Manganese(II) acetate tetrahydrate was purchased from Wako Pure Chemical Ind., Ltd. Manganese(III) acetate dihydrate was prepared by the method described in the literature.[5,6,16] The alkenes **1** were synthesized as described in the literature,[16c,17] except for **1g**, **1h** and **1i**, which were purchased from Tokyo Kasei Co., Ltd. 3-(2-Oxoethyl)piperidine-2,4-diones **2a**–**i**, 2-(2-oxoethyl)cycloalkane-1,3-diones **9a**–**e**, 3-(2-oxoethyl)-1*H*-quinolin-2-one **12**, 2-(3-oxopropyl)cycloalkane-1,3-diones **15a**–**d**, 3-(3-oxopropyl)-1*H*-quinolin-2-one **15e** and 3-(3-oxopropyl)coumarin derivative **15f** were prepared by treatment of the corresponding cyclic 1,3-diones with the appropriate 2-bromoethanones or 1-aryl-3-(dimethylamino)propan-1-ones.[5,18,19]

Manganese(III)-Catalyzed Aerobic Oxidation of Combinations of Alkenes 1a–f and 3-(2-Oxoethyl)piperidine-2,4-diones 2a–i at Room Temperature in Air (General Procedure): An alkene **1** (0.25 mmol), a 3-(2-oxoethyl)piperidine-2,4-dione **2** (0.5 mmol) and glacial acetic acid (10 mL) were placed in a 50 mL round-bottomed flask, and manganese(III) acetate dihydrate (0.17–0.25 mmol) was added. The mixture was stirred at room temperature in air until the alkene **1** had been completely consumed (normally for 7 h or less), and was then heated at 100 °C for 30 min. The solvent was removed in vacuo, and the residue was triturated with water followed by extraction with chloroform (10 mL × 3). The combined extracts were dried with anhydrous magnesium sulfate and were then concentrated to dryness. The products were separated by TLC on silica gel (Wakogel B-10) with elution with chloroform. The obtained endoperoxypropellanes **4** were further purified by recrystallization from the appropriate solvents.

8-Isopropyl-4,4,12-triphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]-tridec-12-en-7-one (4aa): R_f = 0.40 (chloroform). Colourless oil. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.55–7.52 (m, 2 H, arom. H), 7.42–7.11 (m, 13 H, arom. H), 5.08 (s, 1 H, 13-H), 4.77 [sept., J = 6.8 Hz, 1 H, N–C*H*$(CH_3)_2$], 3.77 (d, J = 14.3 Hz, 1 H, 5-H), 3.25–3.18 (m, 2 H, 9-H), 2.64 (d, J = 14.3 Hz, 1 H, 5-H), 2.32 (ddd, J = 13.6, 3.5, 3.1 Hz, 1 H, 10-H), 1.93 (ddd, J = 13.6, 8.4, 7.2 Hz, 1 H, 10-H), 1.07 [d, J = 6.8 Hz, 3 H, N–CH(C*H*$_3)_2$], 1.03 [d, J = 6.8 Hz, 3 H, N–CH(C*H*$_3)_2$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.5 (C=O), 156.0 (C-12), 146.9, 143.8, 129.4 (3 C, arom. C), 129.0, 128.4, 128.3, 128.0, 127.1, 127.0, 125.5, 125.4, 125.3 (15 C, arom. *C*H), 111.6 (C-1), 100.7, 100.5 (1 C, C-13), 86.0 (C-4), 54.7 (C-6), 44.6 [N-*C*H(CH$_3)_2$], 37.2 (C-9), 35.3 (C-5), 28.5 (C-10), 19.3, 19.2, 19.1 [2 C, N–CH(*C*H$_3)_2$] ppm. IR (neat): $\tilde{\nu}$ = 1636 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{30}H_{29}NO_4$ 468.2175 (M + 1); found 468.2155.

8-Benzyl-4,4,12-triphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ab): R_f = 0.32 (chloroform). Colourless microcrystals (from diethyl ether), m.p. 166.5 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.57–7.54 (m, 2 H, arom. H), 7.43–7.12 (m, 18 H, arom. H), 5.13 (s, 1 H, 13-H), 4.71 (d, J = 14.9 Hz, 1 H, Ph–C*H*$_2$),

4.37 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 3.86 (d, J = 14.3 Hz, 1 H, 5-H), 3.38 (ddd, J = 12.7, 11.8, 2.8 Hz, 1 H, 9-H), 3.11 (ddd, J = 12.7, 4.6, 3.5 Hz, 1 H, 9-H), 2.69 (d, J = 14.3 Hz, 1 H, 5-H), 2.23 (ddd, J = 13.6, 3.5, 2.8 Hz, 1 H, 10-H), 1.95 (ddd, J = 13.6, 11.8, 4.6 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.3 (C=O), 156.3 (C-12), 146.8, 143.7, 136.3, 129.3 (4 C, arom. C), 129.1, 128.7, 128.34, 128.27, 128.0, 127.7, 127.6, 127.1, 127.0, 125.42, 125.35, 125.2 (20 C, arom. *C*H), 111.8 (C-1), 100.5, 100.4 (1 C, C-13), 86.0 (C-4), 54.7 (C-6), 50.6 (Ph–*C*H$_2$), 41.4 (C-9), 37.1 (C-5), 27.9 (C-10) ppm. IR (neat): $\tilde{\nu}$ = 1639 (C=O) cm^{-1}. $C_{34}H_{29}NO_4$ (515.60): calcd. C 79.20, H 5.67, N 2.72; found C 79.33, H 5.60, N 2.74.

8-Benzyl-12-(4-chlorophenyl)-4,4-diphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ac): R_f = 0.64 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 205–206 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.61–7.59 (m, 2 H, arom. H), 7.55–6.99 (m, 17 H, arom. H), 5.11 (s, 1 H, 13-H), 4.70 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 4.38 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 3.86 (d, J = 14.3 Hz, 1 H, 5-H), 3.36 (ddd, J = 12.7, 11.7, 2.6 Hz, 1 H, 9-H), 3.11 (ddd, J = 12.7, 4.4, 3.7 Hz, 1 H, 9-H), 2.67 (d, J = 14.3 Hz, 1 H, 5-H), 2.22 (ddd, J = 13.6, 3.7, 2.6 Hz, 1 H, 10-H), 1.96 (ddd, J = 13.6, 11.7, 4.4 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.1 (C=O), 155.3 (C-12), 146.8, 143.7, 136.3, 134.9 (4 C, arom. C), 130.1, 128.9, 128.8, 128.6, 128.4, 128.3, 128.1 (arom. *C*H), 127.8 (arom. C), 127.7, 127.2, 127.1, 126.7, 125.3, 125.1 (arom. *C*H), 112.0 (C-1), 101.1 (1 C, C-13), 86.1 (C-4), 54.8 (C-6), 50.7 (Ph–*C*H$_2$), 41.5 (C-9), 37.0 (C-5), 27.9 (C-10) ppm. IR (KBr): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. $C_{34}H_{28}ClNO_4$ (550.04): calcd. C 74.24, H 5.13, N 2.55; found C 74.08, H 5.41, N 2.51.

8-Benzyl-12-(4-methylphenyl)-4,4-diphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ad): R_f = 0.62 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 190–191 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.82–7.79 (m, 2 H, arom. H), 7.56–7.02 (m, 17 H, arom. H), 5.06 (s, 1 H, 13-H), 4.69 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 4.37 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 3.84 (d, J = 14.3 Hz, 1 H, 5-H), 3.38 (ddd, J = 12.3, 11.9, 2.4 Hz, 1 H, 9-H), 3.09 (ddd, J = 12.3, 4.6, 3.5 Hz, 1 H, 9-H), 2.68 (d, J = 14.3 Hz, 1 H, 5-H), 2.22 (ddd, J = 13.6, 3.5, 2.4 Hz, 1 H, 10-H), 1.94 (ddd, J = 13.6, 11.9, 4.6 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.5 (C=O), 156.5 (C-12), 146.9, 143.8, 139.2, 136.4 (4 C, arom. C), 129.0, 128.8, 128.4, 128.0, 127.7, 127.6, 127.1, 127.0 (arom. *C*H), 126.6 (arom. C), 125.5, 125.3, 125.2 (arom. *C*H), 111.8 (C-1), 99.6 (C-13), 86.0 (C-4), 54.7 (C-6), 50.6 (Ph–*C*H$_2$), 41.5 (C-9), 37.1 (C-5), 28.0 (C-10), 21.4 (*C*H$_3$) ppm. IR (KBr): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. $C_{35}H_{31}NO_4$ (529.62): calcd. C 79.37, H 5.90, N 2.64; found C 79.52, H 5.97, N 2.52.

8-Methyl-4,4,12-triphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ae): R_f = 0.27 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 178–179 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.54–7.51 (m, 2 H, arom. H), 7.43–7.09 (m, 13 H, arom. H), 5.09 (s, 1 H, 13-H), 3.72 (d, J = 14.3 Hz, 1 H, 5-H), 3.48 (ddd, J = 12.5, 11.6, 2.9 Hz, 1 H, 9-H), 3.12 (ddd, J = 12.5, 4.6, 3.9 Hz, 1 H, 9-H), 2.92 (s, 3 H, N–CH_3), 2.69 (d, J = 14.3 Hz, 1 H, 5-H), 2.29 (ddd, J = 13.6, 3.9, 2.9 Hz, 1 H, 10-H), 2.05 (ddd, J = 13.6, 11.6, 4.6 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.1 (C=O), 155.9 (C-12), 146.6, 143.8, 129.3 (3 C, arom. C), 129.1, 128.3, 128.0, 127.1, 127.0, 125.4, 125.3 (15 C, arom. *C*H), 111.7 (C-1), 100.9, 100.7 (1 C, C-13), 85.9 (C-4), 54.2 (C-6), 44.2 (C-9), 37.1 (C-5), 35.55, 35.48 (1 C, N–*C*H$_3$), 27.7 (C-10) ppm. IR (neat): $\tilde{\nu}$ = 1639 (C=O) cm^{-1}. $C_{28}H_{25}NO_4$ (439.50): calcd. C 76.52, H 5.73, N 3.19; found C 76.51, H 5.89, N 3.16. FAB HRMS (acetone-NBA): calcd. for $C_{28}H_{26}NO_4$ 440.1862 (M + 1); found 440.1763.

8-Ethyl-4,4,12-triphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4af): R_f = 0.24 (chloroform). Colourless needles (from diethyl ether/hexane), m.p. 153–154 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.54–7.52 (m, 2 H, arom. H), 7.42–7.18 (m, 11 H, arom. H), 7.16–7.11 (m, 2 H, arom. H), 5.08 (s, 1 H, 13-H), 3.76 (d, J = 14.3 Hz, 1 H, 5-H), 3.45 (ddd, J = 12.7, 11.7, 2.9 Hz, 1 H, 9-H), 3.37 (dq, J = 21.7, 7.2 Hz, 2 H, N–CH_2CH$_3$), 3.15 (ddd, J = 12.7, 4.7, 3.7 Hz, 1 H, 9-H), 2.64 (d, J = 14.3 Hz, 1 H, 5-H), 2.31 (ddd, J = 13.6, 3.7, 2.9 Hz, 1 H, 10-H), 2.01 (ddd, J = 13.6, 11.7, 4.6 Hz, 1 H, 10-H), 1.06 (t, J = 7.2 Hz, 3 H, N–CH$_2$CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.5 (C=O), 155.9 (C-12), 146.8, 143.7, 129.3 (3 C, arom. C), 129.0, 128.3, 128.2, 127.9, 127.0, 126.9, 125.4, 125.3, 125.2 (15 C, arom. *C*H), 111.8 (C-1), 100.62, 100.58 (1 C, C-13), 85.9 (C-4), 54.4 (C-6), 42.6 (N–*C*H$_2$CH$_3$), 41.6 (C-9), 37.0 (C-5), 28.0 (C-10), 12.2 (N–CH$_2$*C*H$_3$) ppm. IR (neat): $\tilde{\nu}$ = 1636 (C=O) cm^{-1}. $C_{29}H_{27}NO_4 \cdot 17/20\,H_2O$ (468.84): calcd. C 74.29, H 6.17, N 2.99; found C 74.46, H 6.47, N 2.83. FAB HRMS (acetone-NBA): calcd. for $C_{29}H_{28}NO_4$ 454.2018 (M + 1); found 454.2010.

4,4,12-Triphenyl-8-propyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ag): R_f = 0.31 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 135–137 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.55–7.52 (m, 2 H, arom. H), 7.42–7.11 (m, 13 H, arom. H), 5.07 (s, 1 H, 13-H), 3.78 (d, J = 14.3 Hz, 1 H, 5-H), 3.46 (ddd, J = 12.8, 11.8, 2.2 Hz, 1 H, 9-H), 3.44–3.34 (m, 1 H, N–CH_2CH$_2$CH$_3$), 3.26–3.19 (m, 1 H, N–CH_2CH$_2$CH$_3$), 3.15 (ddd, J = 12.8, 4.4, 3.5 Hz, 1 H, 9-H), 2.63 (d, J = 14.3 Hz, 1 H, 5-H), 2.30 (ddd, J = 13.6, 3.5, 2.2 Hz, 1 H, 10-H), 2.02 (ddd, J = 13.6, 11.7, 4.4 Hz, 1 H, 10-H), 1.56–1.44 (m, 2 H, N–CH$_2$CH_2CH$_3$), 0.84 (t, J = 7.5 Hz, 3 H, N–CH$_2$CH$_2$CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.9 (C=O), 156.0 (C-12), 146.9, 143.8, 129.3 (3 C, arom. C), 129.0, 128.3, 128.0, 127.1, 126.9, 125.4, 125.3, 125.2 (15 C, arom. *C*H), 111.8 (C-1), 100.7, 100.6 (1 C, C-13), 86.0 (C-4), 54.6 (C-6), 49.3 (N–*C*H$_2$CH$_2$CH$_3$), 42.2 (C-9), 37.0 (C-5), 28.0 (C-10), 20.4 (N–CH$_2$*C*H$_2$CH$_3$), 11.2, 11.0 (1 C, N–CH$_2$CH$_2$*C*H$_3$) ppm. IR (neat): $\tilde{\nu}$ = 1639 (C=O) cm^{-1}. $C_{30}H_{29}NO_4$ (467.56): calcd. C 77.06, H 6.25, N 3.00; found C 77.21, H 6.36, N 2.99. FAB HRMS (acetone/NBA): calcd. for $C_{30}H_{30}NO_4$ 468.2175 (M + 1); found 468.2090.

4,4,8,12-Tetraphenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ah): R_f = 0.40 (chloroform). Colourless needles (from diethyl ether), m.p. 216 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.57–7.55 (m, 2 H, arom. H), 7.54–7.12 (m, 18 H, arom. H), 5.17 (s, 1 H, 13-H), 3.84 (ddd, J = 12.5, 11.4, 2.8 Hz, 1 H, 9-H), 3.79 (d, J = 14.3 Hz, 1 H, 5-H), 3.54 (ddd, J = 12.5, 4.4, 4.2 Hz, 1 H, 9-H), 2.82 (d, J = 14.3 Hz, 1 H, 5-H), 2.43 (ddd, J = 13.6, 4.2, 2.8 Hz, 1 H, 10-H), 2.24 (ddd, J = 13.6, 11.4, 4.4 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.0 (C=O), 156.3 (C-12), 146.6, 143.7, 142.6, 132.4 (4 C, arom. C), 130.0, 129.23, 129.19, 128.4, 128.3, 128.2, 128.0, 127.1, 127.02, 126.96, 125.6, 125.43, 125.38, 125.3 (20 C, arom. *C*H), 111.7 (C-1), 100.4 (C-13), 85.9 (C-4), 55.0 (C-6), 45.6 (C-9), 37.3 (C-5), 28.8 (C-10) ppm. IR (neat): $\tilde{\nu}$ = 1653 (C=O) cm^{-1}. $C_{33}H_{27}NO_4$ (501.57): calcd. C 79.02, H 5.43, N 2.79; found C 79.16, H 5.46, N 2.78.

8-Benzyl-4,4-bis(4-chlorophenyl)-12-phenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4bb): R_f = 0.47 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 150–151 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.57–7.13 (m, 18 H, arom. H), 5.11 (s, 1 H, 13-H), 4.72 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 4.37 (d, J = 14.9 Hz, 1 H, Ph–CH_2), 3.77 (d, J = 14.3 Hz, 1 H, 5-H), 3.39 (ddd, J = 12.7, 11.7, 2.4 Hz, 1 H, 9-H), 3.13 (ddd, J = 12.7, 4.4, 3.5 Hz, 1 H, 9-H), 2.64 (d, J = 14.3 Hz, 1 H, 5-H), 2.24 (ddd, J = 13.8, 3.5, 2.4 Hz, 1 H, 10-H), 1.94 (ddd, J = 13.8, 11.7,

4.4 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.0 (C=O), 156.7 (C-12), 145.0, 141.8, 136.2, 133.3, 133.2 (5 C, arom. C), 129.4 (arom. *C*H), 129.0 (arom. C), 128.9, 128.8, 128.7, 128.5, 128.3, 128.1, 128.0, 127.7, 127.0, 126.7, 125.4 (17 C, arom. *C*H), 111.9 (C-1), 100.0 (C-13), 85.4 (C-4), 54.6 (C-6), 50.7 (Ph–*C*H$_2$), 41.4 (C-9), 36.9 (C-5), 27.8 (C-10) ppm. IR (neat): $\tilde{\nu}$ = 1645 (C=O) cm^{-1}. $C_{34}H_{27}Cl_2NO_4$ (584.49): calcd. C 69.87, H 4.66, N 2.40; found C 69.87, H 4.45, N 2.33.

8-Benzyl-4,4-bis(4-fluorophenyl)-12-phenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4cb): R_f = 0.62 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 177–178 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50–7.14 (m, 14 H, arom. H), 7.05–7.00 (m, 2 H, arom. H), 6.89–6.84 (m, 2 H, arom. H), 5.12 (s, 1 H, 13-H), 4.70 (d, *J* = 14.7 Hz, 1 H, Ph–C*H*$_2$), 4.39 (d, *J* = 14.7 Hz, 1 H, Ph–C*H*$_2$), 3.78 (d, *J* = 14.3 Hz, 1 H, 5-H), 3.39 (ddd, *J* = 12.7, 11.7, 2.6 Hz, 1 H, 9-H), 3.14 (ddd, *J* = 12.7, 4.6, 3.5 Hz, 1 H, 9-H), 2.64 (d, *J* = 14.3 Hz, 1 H, 5-H), 2.20 (ddd, *J* = 13.6, 3.5, 2.6 Hz, 1 H, 10-H), 1.95 (ddd, *J* = 13.6, 11.7, 4.6 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.1 (C=O), 163.5, 163.3, 160.2, 160.0 (2 C, arom. C), 156.5 (C-12), 142.5, 139.4, 136.3, 136.2, 132.6 (3 C, arom. C), 129.3 (arom. *C*H), 129.1 (arom. C), 128.8, 128.4, 127.7, 127.4, 127.3, 127.1, 126.9, 125.3 115.4, 115.2, 115.1, 114.8 (17 C, arom. *C*H), 111.8 (C-1), 100.2 (C-13), 85.5 (C-4), 54.7 (C-6), 50.7 (Ph–*C*H$_2$), 41.5 (C-9), 37.2 (C-5), 27.9 (C-10) ppm. IR (neat): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. $C_{34}H_{27}F_2NO_4$ (551.58): calcd. C 74.04, H 4.93, N 2.54; found C 74.16, H 5.07, N 2.47.

8-Benzyl-4,4-bis(4-methylphenyl)-12-phenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4 db): R_f = 0.58 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 160–161 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.46–7.13 (m, 16 H, arom. H), 6.97–6.95 (m, 2 H, arom. H), 5.19 (s, 1 H, 13-H), 4.72 (d, *J* = 14.9 Hz, 1 H, Ph–C*H*$_2$), 4.35 (d, *J* = 14.9 Hz, 1 H, Ph–C*H*$_2$), 3.81 (d, *J* = 14.3 Hz, 1 H, 5-H), 3.38 (ddd, *J* = 12.5, 11.9, 2.8 Hz, 1 H, 9-H), 3.13 (ddd, *J* = 12.5, 4.6, 3.7 Hz, 1 H, 9-H), 2.66 (d, *J* = 14.3 Hz, 1 H, 5-H), 2.30 (s, 3 H, C*H*$_3$), 2.28 (ddd, *J* = 13.6, 3.7, 2.8 Hz, 1 H, 10-H), 2.23 (s, 3 H, C*H*$_3$), 1.94 (ddd, *J* = 13.6, 11.9, 4.6 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.5 (C=O), 156.2 (C-12), 144.3, 142.9, 140.9, 136.7, 136.6, 136.4, 135.2 (5 C, arom. C), 130.2 (arom. *C*H), 129.4 (arom. C), 129.04, 129.01, 128.9, 128.74, 128.66, 128.3, 127.7, 127.6 (17 C, arom. *C*H), 111.8 (C-1), 100.7 (C-13), 86.0 (C-4), 54.7 (C-6), 50.6 (Ph–*C*H$_2$), 41.5 (C-9), 37.2 (C-5), 28.0 (C-10), 21.7, 21.0 (2 C, *C*H$_3$) ppm. IR (neat): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. $C_{36}H_{33}NO_4$ (543.65): calcd. C 79.53, H 6.12, N 2.58; found C 79.44, H 6.21, N 2.57.

8-Benzyl-4,4-bis(4-methoxyphenyl)-12-phenyl-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4eb): R_f = 0.49 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 173–174 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.47–7.12 (m, 14 H, arom. H), 6.87–6.84 (m, 2 H, arom. H), 6.70–6.67 (m, 2 H, arom. H), 5.22 (s, 1 H, 13-H), 4.67 (d, *J* = 14.9 Hz, 1 H, Ph–C*H*$_2$), 4.37 (d, *J* = 14.9 Hz, 1 H, Ph–C*H*$_2$), 3.76 (s, 3 H, OC*H*$_3$), 3.75 (d, *J* = 14.3 Hz, 1 H, 5-H), 3.70 (s, 3 H, OC*H*$_3$), 3.36 (ddd, *J* = 12.5, 11.7, 2.8 Hz, 1 H, 9-H), 3.08 (ddd, *J* = 12.5, 4.4, 3.9 Hz, 1 H, 9-H), 2.68 (d, *J* = 14.3 Hz, 1 H, 5-H), 2.21 (ddd, *J* = 13.6, 3.9, 2.8 Hz, 1 H, 10-H), 1.94 (ddd, *J* = 13.6, 11.7, 4.4 Hz, 1 H, 10-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 169.4 (C=O), 158.4, 158.2 (2 C, arom. C), 156.1 (C-12), 139.3, 136.3, 136.1, 129.3 (4 C, arom. C), 129.0, 128.7, 128.2, 127.6, 127.5, 126.9, 126.5, 125.3, 113.5, 113.2 (18 C, arom. *C*H), 111.6 (C-1), 100.7 (C-13), 85.7 (C-4), 55.14, 55.08 (2 C, O*C*H$_3$), 54.6 (C-6), 50.5 (Ph–*C*H$_2$), 41.4 (C-9), 37.3 (C-5), 27.9 (C-10) ppm. IR (KBr): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. $C_{36}H_{33}NO_6$ (575.65): calcd. C 75.11, H 5.78, N 2.43; found C 74.88, H 5.86, N 2.46.

8,12-Di-*tert*-butyl-4,4-bis(4-methoxyphenyl)-2,3,11-trioxa-8-azatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (4ei): R_f = 0.62 (chloroform/methanol, 98:2, v/v). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.40–7.25 (m, 4 H, arom. H), 6.84–6.74 (m, 4 H, arom. H), 4.34 (s, 1 H, 13-H), 3.75 (s, 3 H, OC*H*$_3$), 3.74 (s, 3 H, OC*H*$_3$), 3.66 (d, *J* = 14.5 Hz, 1 H, 5-H), 3.39 (ddd, *J* = 12.7, 4.2, 3.8 Hz, 1 H, 9-H), 3.20 (ddd, *J* = 12.7, 11.5, 2.4 Hz, 1 H, 9-H), 2.34 (d, *J* = 14.5 Hz, 1 H, 5-H), 2.13 (ddd, *J* = 13.7, 3.8, 2.4 Hz, 1 H, 10-H), 1.85 (ddd, *J* = 13.7, 11.5, 4.2 Hz, 1 H, 10-H), 1.39 [s, 9 H, N–C(C*H*$_3$)$_3$], 0.97 [s, 9 H, C(C*H*$_3$)$_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ = 171.1 (C=O), 167.0 (C-12), 158.3, 158.2, 140.3, 136.3 (4 C, arom. C), 126.9, 126.1, 113.5, 113.0 (8 C, arom. *C*H), 111.1 (C-1), 97.7 (C-13), 85.8 (C-4), 57.8, 55.9 [2 C, C-6, N–*C*(CH$_3$)$_3$], 55.2, 55.1 (2 C, O*C*H$_3$), 38.5 (C-9), 35.8 (C-5), 31.9 [*C*(CH$_3$)$_3$], 29.2 (C-10), 28.2 [3 C, N–C(*C*H$_3$)$_3$], 27.2 [3 C, C(*C*H$_3$)$_3$] ppm. IR (KBr): $\tilde{\nu}$ = 1647 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{31}H_{40}NO_6$ 522.2856 (M + 1); found 522.2855.

8,12-Di-*tert*-butyl-4,4-di(naphth-2-yl)-2,3,11-trioxa-8-azatricyclo-[4.4.3.0^{1,6}]tridec-12-en-7-one (4fi): R_f = 0.42 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 190–191 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.14–7.39 (m, 14 H, arom. H), 4.34 (s, 1 H, 13-H), 3.96 (d, *J* = 14.7 Hz, 1 H, 5-H), 3.41 (ddd, *J* = 12.8, 4.4, 3.7 Hz, 1 H, 9-H), 3.22 (ddd, *J* = 12.8, 11.7, 2.6 Hz, 1 H, 9-H), 2.61 (d, *J* = 14.7 Hz, 1 H, 5-H), 2.17 (ddd, *J* = 13.6, 3.7, 2.6 Hz, 1 H, 10-H), 1.87 (ddd, *J* = 13.6, 11.7, 4.4 Hz, 1 H, 10-H), 1.39 [s, 9 H, N–C(C*H*$_3$)$_3$], 0.93 [s, 9 H, C(C*H*$_3$)$_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 171.1 (C=O), 167.4 (C-12), 144.6, 140.9, 133.0, 132.7, 132.4, 132.2 (6 C, arom. C), 128.3, 128.2, 128.1, 127.7, 127.5, 126.09, 126.05, 126.0, 125.9, 124.2, 124.1, 123.9, 123.3 (14 C, arom. *C*H), 111.3 (C-1), 97.6 (C-13), 86.4 (C-4), 57.9, 56.1 [2 C, C-6, N–*C*(CH$_3$)$_3$], 38.5 (C-9), 35.5 (C-5), 32.0 [*C*(CH$_3$)$_3$], 29.1 (C-10), 28.2 [3 C, N–C(*C*H$_3$)$_3$], 27.3 [3 C, C(*C*H$_3$)$_3$] ppm. IR (KBr): $\tilde{\nu}$ = 1645 (C=O) cm^{-1}. $C_{37}H_{39}NO_4$ (561.71): calcd. C 79.11, H 7.00, N 2.49; found C 79.32, H 7.10, N 2.63.

Equilibrium Mixture 5aa: $C_{30}H_{31}NO_5$ (485.57): calcd. C 74.21, H 6.43, N 2.88; found C 73.91, H 6.37, N 2.97.

Equilibrium Mixture 5eb: $C_{36}H_{35}NO_7$ (593.67): calcd. C 72.83, H 5.94, N 2.36; found C 72.78, H 5.84, N 2.41.

Equilibrium Mixture 5ei: $C_{31}H_{41}NO_7 \cdot 2/5\,H_2O$ (546.87): calcd. C 68.08, H 7.71, N 2.56; found C 68.05, H 7.74, N 2.55.

Equilibrium Mixture 5fi: $C_{37}H_{41}NO_5$ (579.73): calcd. C 76.66, H 7.13, N 2.42; found C 76.36, H 7.22, N 2.44.

General Procedure for the Acid-Catalyzed Decomposition of Trioxa-azapropellanes 4 and Hydroperoxide Intermediates 5: A perchloric acid solution (60%, 0.3 mL) was added to a solution of **4aa**, **4af**, **5aa** or **5fi** (0.1 mmol) in acetonitrile (2 mL), and the mixture was heated under reflux for 15 min. Water (20 mL) was added to the resulting solution to quench it, and the resulting aqueous solution was extracted with chloroform (3 × 10 mL). The combined chloroform extracts were dried with anhydrous magnesium sulfate and concentrated to dryness. The obtained crude products were purified by TLC on silica gel with elution with chloroform, giving **6aa** (32.0 mg, quant.), **6af** (34.7 mg, 92%) or **6′fi** (36.4 mg, 96%), respectively. The obtained products were further purified by recrystallization from the appropriate solvents. The **5eb** or **5ei** (0.1 mmol) was also heated under reflux in acetic acid (2 mL) in the presence of manganese(II) acetate tetrahydrate (0.2 mmol) for 15 min or 2 h. Water (80 mL) was added to the resulting mixture, and the aqueous solution was extracted with chloroform (3 × 10 mL). The combined extracts were dried with anhydrous magnesium sulfate and concentrated to dryness. The obtained

crude products were purified by TLC on silica gel with elution with chloroform, giving **6eb** (35.2 mg, 75%) or **6ei** (26.2 mg, 63%). The obtained products were further purified by recrystallization from the appropriate solvents.

1-Isopropyl-3,3-bis(2-oxo-2-phenylethyl)piperidine-2,4-dione (6aa): R_f = 0.44 (chloroform). Colourless microcrystals (from diethyl ether/hexane). m.p. 135–136 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.91–7.88 (m, 4 H, arom. H), 7.58–7.27 (m, 6 H, arom. H), 4.85 [hep, J = 6.6 Hz, 1 H, N–C*H*$(CH_3)_2$], 3.98 (d, J = 17.2 Hz, 2 H, Bz–C$H_2\times2$), 3.80 (t, J = 6.6 Hz, 2 H, 6-H), 3.60 (d, J = 17.2 Hz, 2 H, Bz–C$H_2\times2$), 3.14 (t, J = 6.6 Hz, 2 H, 5-H), 1.14 [d, J = 6.6 Hz, 6 H, N–CH(C$H_3)_2$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 209.8, 197.0, 169.9 (4 C, C=O), 135.9 (2 C, arom. C), 133.5, 128.5, 128.1 (10 C, arom. *C*H), 52.8 (C-3), 48.8 (2 C, Bz–*C*H_2), 45.0 [N-*C*H$(CH_3)_2$], 37.6, 36.5 (2 C, C-5, C-6), 19.0 [2 C, N–CH-(*C*$H_3)_2$] ppm. IR (KBr): $\tilde{\nu}$ = 1717, 1693, 1630 (C=O) cm^{-1}. $C_{24}H_{25}NO_4$ (391.46): calcd. C 73.64, H 6.44, N 3.58; found: C 3.35, H 6.47, N 3.58.

1-Ethyl-3,3-bis(2-oxo-2-phenylethyl)piperidine-2,4-dione (6af): R_f = 0.60 (diethyl ether). Colourless microcrystals (from ethyl acetate/hexane), m.p. 98.0 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.97–7.87 (m, 4 H, arom. H), 7.56–7.38 (m, 6 H, arom. H), 4.00 (d, J = 17.3 Hz, 2 H, Bz–C$H_2\times2$), 3.91 (t, J = 6.6 Hz, 2 H, 6-H), 3.62 (d, J = 17.3 Hz, 2 H, Bz–C$H_2\times2$), 3.52 (q, J = 7.2 Hz, 2 H, N–CH_2CH$_3$), 3.19 (t, J = 6.6 Hz, 2 H, 5-H), 1.08 (t, J = 7.2 Hz, 3 H, N–CH$_2$C*H*$_3$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 209.6, 196.8, 169.8 (4 C, C=O), 135.5 (2 C, arom. C), 133.4, 128.4, 127.9 (10 C, arom. *C*H), 52.2 (C-3), 48.7 (2 C, Bz–*C*H_2), 42.7, 42.6 (2 C, C-6, N–*C*H_2CH$_3$), 37.3 (C-5), 11.7 (N–CH$_2$*C*H$_3$) ppm. IR (KBr): $\tilde{\nu}$ = 1713, 1686, 1632 (C=O) cm^{-1}. $C_{23}H_{23}NO_4$ (377.43): calcd. C 73.19, H 6.14, N 3.71; found C 73.11, H 6.17, N 3.73.

3-(3,3-Dimethyl-2-oxobutyl)-3-[2-oxo-2-(naphth-2-yl)ethyl]piperidine-2,4-dione (6′fi): R_f = 0.27 (chloroform/methanol, 98:2, v/v). Colourless needles (from diethyl ether/hexane), m.p. 185 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.43 (br. s, 1 H, arom. H), 7.95–7.84 (m, 4 H, arom. H), 7.63–7.52 (m, 2 H, arom. H), 6.38 (br. s, 1 H, N*H*), 4.02 (d, J = 17.4 Hz, 1 H, CH_2), 3.96–3.78 (m, 2 H, 6-H), 3.68 (d, J = 17.4 Hz, 1 H, CH_2), 3.56 (d, J = 17.8 Hz, 1 H, CH_2), 3.25 (d, J = 17.8 Hz, 1 H, CH_2), 3.13 (br. t, J = 6.4 Hz, 2 H, 5-H), 1.13 [s, 9 H, C(C$H_3)_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 213.4, 209.7, 196.8, 173.5 (4 C, C=O), 135.7, 132.9, 132.3 (3 C, arom. C), 130.2, 129.6, 128.7, 128.5, 127.7, 126.9, 123.5 (7 C, arom. *C*H), 52.4 (C-3), 48.9, 47.8 (2 C, *C*H_2), 43.5 [*C*$(CH_3)_3$], 37.4, 36.8 (2 C, *C*H_2), 26.2 [3 C, C(*C*$H_3)_3$] ppm. IR (KBr): $\tilde{\nu}$ = 3221 (NH), 1707, 1684, 1665 (C=O) cm^{-1}. $C_{23}H_{25}NO_4$ (379.45): calcd. C 72.80, H 6.64, N 3.69; found C 72.66, H 6.73, N 3.67.

1-Benzyl-3-[2-(4-methoxyphenyl)-2-oxoethyl]-3-(2-oxo-2-phenylethyl)piperidine-2,4-dione (6eb): R_f = 0.40 (chloroform/methanol, 98:2, v/v). Colourless prisms (from diethyl ether/hexane), m.p. 141–143 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.92–7.88 (m, 4 H, arom. H), 7.56–7.24 (m, 8 H, arom. H), 6.92–6.89 (m, 2 H, arom. H), 4.72 (d, J = 15.0 Hz, 1 H, Ph–CH_2), 4.65 (d, J = 15.0 Hz, 1 H, Ph–CH_2), 4.07 (d, J = 13.0 Hz, 1 H, CH_2), 4.01 (d, J = 12.7 Hz, 1 H, CH_2), 3.84 (s, 3 H, OCH_3), 3.83 (t, J = 6.6 Hz, 2 H, 6-H), 3.68 (d, J = 13.0 Hz, 1 H, CH_2), 3.62 (d, J = 12.7 Hz, 1 H, CH_2), 3.15 (t, J = 6.6 Hz, 2 H, 5-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 209.7, 197.0, 195.3, 171.1 (4 C, C=O), 163.9, 136.7, 135.8 (3 C, arom. C), 133.6, 130.6 (arom. *C*H), 128.8 (arom. C), 128.6, 128.5, 128.2, 127.8, 127.2, 113.8 (arom. *C*H), 55.4 (O*C*H$_3$), 52.7 (C-3), 50.9 (Ph–*C*H$_2$), 49.2, 48.9 (2 C, Bz–*C*H$_2$, 4-MeO-C$_6$H$_4$-*C*H$_2$), 42.8 (C-6), 37.4 (C-5) ppm. IR (KBr): $\tilde{\nu}$ 1713, 1684, 1636 (C=O) cm^{-1}. $C_{29}H_{27}NO_5$ (469.53): calcd. C 74.18, H 5.80, N 2.98; found C 73.97, H 5.85, N 2.96.

1-*tert*-Butyl-3-(3,3-dimethyl-2-oxobutyl)-3-[2-(4-methoxyphenyl)-2-oxoethyl]piperidine-2,4-dione (6ei): R_f = 0.44 (chloroform/methanol, 98:2, v/v). Colourless prisms (from ethyl acetate/hexane), m.p. 124.0–124.5 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.88–7.85 (m, 2 H, arom. H), 6.91–6.88 (m, 2 H, arom. H), 3.85 (s, 3 H, OCH_3), 3.87–3.82 (m, 2 H, 6-H), 3.77 (d, J = 16.5 Hz, 1 H, CH_2), 3.50 (d, J = 17.6 Hz, 1 H, CH_2), 3.34 (d, J = 16.5 Hz, 1 H, CH_2), 3.10 (d, J = 17.6 Hz, 1 H, CH_2), 3.07 (br. t, J = 6.2 Hz, 2 H, 5-H), 1.38 [s, 9 H, N–C(C$H_3)_3$], 1.11 [s, 9 H, C(C$H_3)_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 213.4, 210.5, 195.6, 171.1 (4 C, C=O), 163.7 (arom. C), 130.5 (2 C, arom. *C*H), 129.2 (arom. C), 113.7 (2 C, arom. *C*H), 58.2 [N–*C*$(CH_3)_3$], 55.4 (O*C*H$_3$), 53.7 (C-3), 48.4, 48.1 (2 C, *C*H$_2$), 43.4 [*C*$(CH_3)_3$], 39.6, 38.3 (2 C, *C*H$_2$), 28.1 [3 C, N–C(*C*$H_3)_3$], 26.2 [3 C, C(*C*$H_3)_3$] ppm. IR (KBr): $\tilde{\nu}$ = 1713, 1678, 1636 (C=O) cm^{-1}. $C_{24}H_{33}NO_5$ (415.52): calcd. C 69.37, H 8.00, N 3.37; found C 69.22, H 8.15, N 3.30.

Reaction of 1,3-Dimethyl-5-(2-oxo-2-phenylethyl)barbituric Acid (7): The barbituric acid **7** was prepared by treatment of 1,3-dimethylbarbituric acid (1 mmol) with 2-bromo-1-phenylethanone (1.5 mmol) at reflux temperature in dry THF (5 mL) in the presence of sodium hydride (50%, 2.5 mmol) for 40 min. The crude **7** product was separated by TLC on silica gel with elution with 70% chloroform/diethyl ether, and was further purified by recrystallization from chloroform/diethyl ether. The obtained **7** (207.5 mg, 0.7566 mmol) was allowed to react with **1a** (93.4 mg, 0.518 mmol) in glacial acetic acid (20 mL) in the presence of manganese(III) acetate dihydrate (15.0 mg, 0.0559 mmol) at room temperature in air. After **1a** had been consumed (3.5 h), the reaction was quenched by addition of water (80 mL). The resulting aqueous solution was extracted with chloroform (3 × 5 mL), and the combined extracts were washed with water (50 mL), dried with anhydrous magnesium sulfate, and concentrated to dryness. The products were separated by TLC on silica gel with elution with chloroform, and the obtained hydroperoxide **8** was further purified by recrystallization from chloroform/hexane (235.9 mg, 0.4849 mmol, 94%).

1,3-Dimethyl-5-(2-oxo-2-phenylethyl)barbituric Acid (7): R_f = 0.33 (chloroform/diethyl ether, 7:3, v/v). Colourless prisms (from chloroform/diethyl ether), m.p. 200.0 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.94–7.92 (m, 2 H, arom. H), 7.61–7.43 (m, 3 H, arom. H), 4.01 (m, 2 H, Bz–CH_2), 3.60 (m, 1 H, 5-H), 3.34 (s, 6 H, C$H_3\times2$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 196.8, 167.8, 151.5 (3 C, C=O), 135.0 (arom. C), 133.8, 128.6, 128.1 (5 C, arom. *C*H), 44.3 (C-5), 37.6 (Bz–*C*H$_2$), 28.6 (2 C, *C*H$_3\times2$) ppm. IR (KBr): $\tilde{\nu}$ = 1697, 1660 (C=O) cm^{-1}. $C_{14}H_{14}N_2O_4$ (274.27): calcd. C 61.31, H 5.14, N 10.21; found C 61.24, H 5.26, N 10.12.

5-(2-Hydroperoxy-2,2-diphenylethyl)-1,3-dimethyl-5-(2-oxo-2-phenylethyl)barbituric Acid (8): R_f = 0.29 (chloroform). Colourless microcrystals (from chloroform/hexane), m.p. 232–233 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.64 (br. s, 1 H, OO*H*), 7.88–7.86 (m, 2 H, arom. H), 7.60–7.21 (m, 13 H, arom. H), 4.07 (s, 2 H, Bz–CH_2), 3.48 (s, 2 H, CH_2), 3.00 (s, 6 H, C$H_3\times2$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 196.5, 172.9, 150.5 (3 C, C=O), 142.1, 134.9 (3 C, arom. C), 134.0, 128.7, 128.5, 128.2, 127.5, 125.4 (15 C, arom. *C*H), 86.4 (Ph$_2$*C*), 52.2 (Bz–*C*H$_2$), 48.9 (C-5), 43.4 (*C*H$_2$), 28.8 (2 C, *C*H$_3\times2$) ppm. IR (KBr): $\tilde{\nu}$ = 3600–3200 (OOH), 1672, 1663 (C=O) cm^{-1}. $C_{28}H_{26}N_2O_6$ (486.52): calcd. C 69.12, H 5.39, N 5.76; found C 69.12, H 5.52, N 5.81.

Aerobic Oxidation with Cycloalkane-1,3-diones 9a–e and Quinolinone 12: Cyclohexane-1,3-dione **9** or quinolinone **12** (0.5 mmol) was allowed to react with the alkene **1** (0.25 mmol) in the presence

of manganese(III) acetate dihydrate (0.025–0.1 mmol) in glacial acetic acid (10 mL) in air until the alkene **1** had been consumed (normally for 0.5–1.5 h). After the reaction, the mixture was heated at 100 °C for 30 min, and the normal workup was done. The obtained products **10**, **11**, **13**, and **14** were further purified by recrystallization from the appropriate solvents.

4,4,12-Triphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10aa): R_f = 0.62 (chloroform). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.51–7.09 (m, 15 H, arom. H), 4.83 (s, 1 H, 13-H), 3.46 (d, J = 14.1 Hz, 1 H, 5-H), 2.61–2.53 (m, 1 H, 10-H), 2.53 (d, J = 14.1 Hz, 1 H, 5-H), 2.34–2.22 (m, 2 H, 8-H, 10-H), 1.90–1.83 (m, 2 H, 9-H), 1.75 (ddd, J = 13.4, 11.9, 4.4 Hz, 1 H, 8-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.7 (C=O), 156.7 (C-12), 146.9, 143.8 (2 C, arom. C), 130.0 (2 C, arom. *C*H), 129.3 (arom. C), 129.1, 128.3, 128.23, 128.20, 128.15, 127.9, 127.7, 127.1, 126.9, 125.4, 125.3, 125.2, 125.1 (13 C, arom. *C*H), 113.7 (C-1), 98.6, 98.5 (1 C, C-13), 85.8 (C-4), 59.8 (C-6), 36.4 (C-10), 35.9 (C-5), 28.2 (C-8), 16.3 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1703 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{28}H_{25}O_4$ 425.1753 (M + 1); found 425.1784.

9,9-Dimethyl-4,4,12-triphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ab): R_f = 0.67 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 182 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.50–6.95 (m, 15 H, arom. H), 5.05 (s, 1 H, 13-H), 3.30 (d, J = 13.9 Hz, 1 H, 5-H), 2.53 (d, J = 13.9 Hz, 1 H, 5-H), 2.39 (d, J = 15.2 Hz, 1 H, 10-H), 2.23 (br. d, J = 14.8 Hz, 2 H, 8-H, 10-H), 1.76 (d, J = 14.3 Hz, 1 H, 8-H), 1.02 (s, 3 H, CH_3), 0.96 (s, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 209.2 (C=O), 155.0 (C-12), 146.9, 143.7, 129.5 (3 C, arom. C), 129.0, 128.3, 128.2, 128.0, 127.1, 127.0, 125.2, 125.0 (15 C, arom. *C*H), 114.0 (C-1), 99.6 (C-13), 85.3 (C-4), 58.8 (C-6), 50.6 (C-10), 40.5 (C-5), 36.8 (C-8), 31.5 (CH_3), 31.0 (C-9), 27.0 (CH_3) ppm. IR (neat): $\tilde{\nu}$ = 1711 (C=O) cm^{-1}. $C_{30}H_{28}O_4$ (452.54): calcd. C 79.62, H 6.24; found C 79.36, H 6.34.

8,8-Dimethyl-4,4,12-triphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ac): R_f = 0.29 (chloroform/hexane, 5:5, v/v). Colourless microcrystals (from diethyl ether/hexane), m.p. 160–163 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.56–7.00 (m, 15 H, arom. H), 4.78 (s, 1 H, 13-H), 3.56 (d, J = 14.3 Hz, 1 H, 5-H), 2.46 (d, J = 14.3 Hz, 1 H, 5-H), 2.22–2.67, 1.93–1.80, 1.70–1.61 (m, 4 H, 9-H, 10-H), 1.10 (s, 6 H, CH_3 × 2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 212.3 (C=O), 156.4 (C-12), 147.0, 143.9, 129.3 (3 C, arom. C), 129.1, 128.3, 128.2, 127.1, 125.4, 125.3, 125.1 (15 C, arom. *C*H), 113.8 (C-1), 99.1 (C-13), 85.8 (C-4), 59.3 (C-6), 42.8 (C-8), 36.9 (C-5), 31.1 (C-10), 28.6, 26.7 (2 C, *C*H$_3$ × 2), 25.9 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1697 (C=O) cm^{-1}. $C_{30}H_{28}O_4$ (452.54): calcd. C 79.62, H 6.24; found C 79.48, H 6.30.

12-(Naphth-2-yl)-4,4-diphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ad): R_f = 0.51 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 153 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.08–7.70 (m, 5 H, arom. H), 7.56–7.10 (m, 12 H, arom. H), 4.96 (s, 1 H, 13-H), 3.50 (d, J = 14.3 Hz, 1 H, 5-H), 2.64–2.55 (m, 1 H, 10-H), 2.57 (d, J = 14.3 Hz, 1 H, 5-H), 2.36–2.24 (m, 2 H, 8-H, 10-H), 1.96–1.74 (m, 3 H, 8-H, 9-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.7 (C=O), 156.8 (C-12), 146.9, 143.9, 133.5, 133.0, 130.0 (5 C, arom. C), 128.5, 128.4, 128.2, 128.0, 127.9, 127.6, 127.1, 126.9, 126.7, 126.5, 125.3, 125.2, 124.8, 122.9 (17 C, arom. *C*H), 113.9 (C-1), 99.4 (C-13), 85.9 (C-4), 59.9 (C-6), 36.6 (C-10), 36.0 (C-5), 28.3 (C-8), 16.3 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1701 (C=O) cm^{-1}. $C_{32}H_{26}O_4$ (474.55): calcd. C 80.99, H 5.52; found C 80.74, H 5.25.

4-Methyl-4,12-diphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ga) (Stereoisomer 1): R_f = 0.56 (chloroform). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.69–7.66 (m, 2 H, arom. H), 7.43–7.18 (m, 8 H, arom. H), 5.37 (s, 1 H, 13-H), 2.88 (d, J = 13.9 Hz, 1 H, 5-H), 2.64–2.55 (m, 1 H, CH_2), 2.32–2.20 (m, 2 H, CH_2), 2.08 (d, J = 13.9 Hz, 1 H, 5-H), 1.92–1.83 (m, 2 H, CH_2), 1.71–1.61 (m, 1 H, CH_2), 1.46 (s, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.8 (C=O), 157.4 (C-12), 147.8 (arom. C), 129.33 (2 C, arom. *C*H), 129.26 (arom. C), 128.4, 128.3, 126.8, 125.4, 124.0 (8 C, arom. *C*H), 113.2 (C-1), 98.0 (C-13), 83.2 (C-4), 59.8 (C-6), 36.5, 36.1 (2 C, C-5, C-10), 30.1 (*C*H$_3$), 28.4 (C-8), 16.2 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1701 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{23}H_{22}O_4$ 362.1518 (M); found 362.1503.

4-Methyl-4,12-diphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ga) (Stereoisomer 2): R_f = 0.44 (chloroform). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.56–7.16 (m, 10 H, arom. H), 4.68 (s, 1 H, 13-H), 2.82 (d, J = 13.9 Hz, 1 H, 5-H), 2.63–2.54 (m, 1 H, CH_2), 2.39–2.27 (m, 2 H, CH_2), 2.06 (d, J = 13.9 Hz, 1 H, 5-H), 1.99–1.82 (m, 3 H, CH_2), 1.68 (s, 3 H, CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 207.9 (C=O), 156.7 (C-12), 145.4, 129.4 (2 C, arom. C), 129.1, 128.3, 127.9, 126.6, 125.4, 124.5 (10 C, arom. *C*H), 113.4 (C-1), 98.6 (C-13), 82.8 (C-4), 59.8 (C-6), 37.5, 36.4 (2 C, C-5, C-10), 30.1 (*C*H$_3$), 28.4 (C-8), 16.4 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1705 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{23}H_{23}O_4$ 363.1596 (M + 1); found 363.1592.

4,12-Diphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ha): R_f = 0.50 (chloroform). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.70–7.66 (m, 2 H, arom. H), 7.43–7.27 (m, 8 H, arom. H), 5.42 (s, 1 H, 13-H), 5.28 (dd, J = 10.6, 7.0 Hz, 1 H, 4-H), 2.79 (dd, J = 13.9, 7.0 Hz, 1 H, 5-H), 2.67–2.58 (m, 1 H, CH_2), 2.41–2.23 (m, 2 H, CH_2), 2.01–1.83 (m, 3 H, CH_2), 1.97 (dd, J = 13.9, 10.6 Hz, 1 H, 5-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.2 (C=O), 158.1 (C-12), 141.8 (arom. C), 129.5 (2 C, arom. *C*H), 129.1 (arom. C), 128.6, 128.5, 127.8, 125.6, 125.1 (8 C, arom. *C*H), 113.6 (C-1), 97.1 (C-13), 80.1 (C-4), 59.8 (C-6), 36.6 (C-10), 31.5 (C-5), 28.4 (C-8), 16.5 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1705 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{22}H_{21}O_4$ 349.1440 (M + 1); found 349.1425.

4,4-Diethyl-12-phenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (10ia): R_f = 0.49 (chloroform). Colourless oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.62–7.60 (m, 2 H, arom. H), 7.40–7.33 (m, 3 H, arom. H), 5.23 (s, 1 H, 13-H), 2.65–2.56 (m, 1 H, CH_2), 2.40–2.22 (m, 2 H, CH_2), 2.37 (d, J = 14.3 Hz, 1 H, 5-H), 1.96–1.74 (m, 4 H, CH_2), 1.61–1.44 (m, 3 H, CH_2), 1.45 (d, J = 14.3 Hz, 1 H, 5-H), 0.85 (t, J = 7.7 Hz, 3 H, CH$_2$CH_3), 0.83 (t, J = 7.7 Hz, 3 H, CH$_2$CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.5 (C=O), 157.0 (C-12), 129.4 (arom. C), 129.2, 128.4, 125.4 (5 C, arom. *C*H), 113.2 (C-1), 98.5 (C-13), 84.6 (C-4), 59.7 (C-6), 36.4 (C-10), 33.1, 29.2, 28.8, 27.3 (4 C, C-5, C-8, *C*H$_2$CH$_3$), 16.3 (C-9), 7.52, 7.35 (2 C, CH$_2$*C*H$_3$) ppm. IR (KBr): $\tilde{\nu}$ = 1703 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{20}H_{25}O_4$ 329.1753 (M + 1); found 329.1703.

Methyl 4-[Benzyl(*tert*-butoxycarbonyl)amino]-7-oxo-12-phenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-ene-4-carboxylate (Stereoisomer 1, 10ja): R_f = 0.51 (diethyl ether/hexane 1:1, v/v). Colourless microcrystals (from diethyl ether/hexane), m.p. 128–129 °C. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.58–7.55 (m, 2 H, arom. H), 7.34–7.17 (m, 8 H, arom. H), 5.35 (s, 1 H, 13-H), 4.78 (d, J = 16.5 Hz, 1 H, Ph–CH_2), 4.70 (d, J = 16.5 Hz, 1 H, Ph–CH_2), 3.63 (d, J = 15.0 Hz, 1 H, 5-H), 3.60 (s, 3 H, CO$_2$CH_3), 2.60–2.51 (m, 1 H, CH_2), 2.29–2.17 (m, 1 H, CH_2), 2.08–2.03 (m, 1 H, CH_2), 1.85 (d, J = 15.0 Hz, 1 H, 5-H), 1.82–1.70 (m, 2 H, CH_2), 1.41 [s, 9 H,

$C(CH_3)_3$], 1.36–1.28 (m, 1 H, CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 206.6 (C=O), 166.6 (C=O), 156.1, 154.3 (2 C, C=O, C-12), 139.7, 129.3 (2 C, arom. C), 129.2, 128.3, 127.9, 127.2, 126.5, 125.4 (10 C, arom. *C*H), 113.0 (C-1), 98.9 (C-13), 93.6 (C-4), 81.8 [*C*$(CH_3)_3$], 58.8 (C-6), 53.0 (CO_2CH_3), 47.0 (Ph–CH_2), 36.2 (C-8), 33.0 (C-10), 28.2 [3 C, C$(CH_3)_3$], 28.1 (C-5), 16.0 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1763, 1705 (C=O) cm^{-1}. $C_{30}H_{33}NO_8$ (535.58): calcd. C 67.28, H 6.21, N 2.62; found C 67.14, H 6.27, N 2.60.

Methyl 4-[Benzyl(*tert*-butoxycarbonyl)amino]-7-oxo-12-phenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridec-12-ene-4-carboxylate (Stereoisomer 2, 10ja): R_f = 0.38 (diethyl ether/hexane, 1:1, v/v). Colourless oil. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.99–7.09 (m, 10 H, arom. H), 5.19 (s, 1 H, 13-H), 4.54 (d, J = 16.5 Hz, 1 H, Ph–CH_2), 4.46 (d, J = 16.5 Hz, 1 H, Ph–CH_2), 3.74 (s, 3 H, CO_2CH_3), 3.04 (d, J = 15.0 Hz, 1 H, 5-H), 2.63–2.54 (m, 1 H, CH_2), 2.57 (d, J = 15.0 Hz, 1 H, 5-H), 2.49–2.37 (m, 1 H, CH_2), 2.27–2.22 (m, 1 H, CH_2), 2.06–1.87 (m, 3 H, CH_2), 1.35 [s, 9 H, C$(CH_3)_3$] ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 206.9 (C=O), 169.2 (C=O), 157.2, 154.1 (2 C, C=O, C-12), 138.7 (2 C, arom. C), 129.7, 128.5, 127.9, 127.1, 126.6, 125.5 (10 C, arom. *C*H), 113.3 (C-1), 99.2 (C-13), 91.4 (C-4), 82.4 [*C*$(CH_3)_3$], 58.8 (C-6), 52.8 (CO_2CH_3), 46.7 (Ph–CH_2), 36.7 (C-8), 32.6 (C-10), 29.3 (C-5), 28.0 [3 C, C$(CH_3)_3$], 16.3 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 1753, 1709 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{30}H_{33}NO_8$ 536.2284 (M + 1); found 536.2384.

4,4-Diphenyl-2,3,11-trioxatricyclo[4.4.3.0^{1,6}]tridecane-7,12-dione (11): R_f = 0.42 (chloroform/methanol, 98:2, v/v). Colourless microcrystals (from chloroform/hexane), m.p. 218–219 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.44–7.20 (m, 10 H, arom. H), 3.17 (d, J = 14.3 Hz, 1 H, 5-H), 2.91 (d, J = 19.0 Hz, 1 H, 13-H), 2.75 (d, J = 19.0 Hz, 1 H, 13-H), 2.66 (d, J = 14.3 Hz, 1 H, 5-H), 2.54 (br. t, J = 6.4 Hz, 2 H, CH_2), 2.23–1.71 (m, 4 H, $CH_2\times2$) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.0, 172.9 (2 C, C=O), 145.7, 142.5 (2 C, arom. C), 129.1, 128.6, 128.0, 127.4, 124.8, 124.6 (10 C, arom. *C*H), 111.9 (C-1), 85.2 (C-4), 53.5 (C-6), 37.1, 37.0, 34.3, 28.7, 16.9 (5 C, CH_2) ppm. IR (KBr): $\tilde{\nu}$ = 1794, 1719 (C=O) cm^{-1}. $C_{22}H_{20}O_5\cdot 1/5H_2O$ (367.99): calcd. C 71.80, H 5.59; found C 71.76, H 5.61.

8-Methyl-4,4,12-triphenyl-2,3,11-trioxa-8-aza-9,10-benzotricyclo[4.4.3.0^{1,6}]tridec-12-en-7-one (13): R_f = 0.38 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 174–175 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.85–7.78 (m, 2 H, arom. H), 7.47–7.12 (m, 15 H, arom. H), 7.00–6.97 (m, 2 H, arom. H), 5.29 (s, 1 H, 13-H), 3.61 (d, J = 13.9 Hz, 1 H, 5-H), 3.32 (s, 3 H, N–CH_3), 2.81 (d, J = 13.9 Hz, 1 H, 5-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 168.1 (C=O), 155.4 (C-12), 146.2, 143.5, 137.4 (3 C, arom. C), 132.4, 131.7, 130.0 (arom. *C*H), 129.09 (arom. C), 129.06, 128.3, 128.2, 128.1, 127.1, 125.5, 125.4, 125.2, 123.8 (arom. *C*H), 117.6 (arom. C), 114.5 (arom. *C*H), 108.7 (C-1), 99.3 (C-13), 85.6 (C-4), 54.2 (C-6), 37.7 (C-5), 29.7 (N–*C*H_3) ppm. IR (KBr): $\tilde{\nu}$ = 1666 (C=O) cm^{-1}. $C_{32}H_{25}NO_4$ (487.55): calcd. C 78.83, H 5.17, N 2.87; found C 78.83, H 5.20, N 2.85.

3-(2-Hydroperoxy-2,2-diphenylethyl)-1-methyl-3-(2-oxo-2-phenylethyl)-1*H*-quinoline-2,4-dione (14): R_f = 0.13 (chloroform). Colourless microcrystals (from ethyl acetate/hexane), m.p. 174–175 °C. ^1H NMR (300 MHz, $CDCl_3$) δ = 8.91 (br. s, 1 H, OO*H*), 7.85–7.83 (m, 2 H, arom. H), 7.59–6.90 (m, 17 H, arom. H), 4.24 (s, 2 H, CH_2), 3.58 (d, J = 14.5 Hz, 1 H, Bz–CH_2), 3.49 (d, J = 14.5 Hz, 1 H, Bz–CH_2), 3.26 (s, 3 H, N–CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$) δ = 197.6, 196.9, 174.5 (3 C, C=O), 142.8, 141.7 (3 C, arom. C), 135.4 (arom. *C*H), 135.2 (arom. C), 133.7, 130.8, 128.6, 128.4, 128.34, 128.28, 128.0, 127.6, 127.3, 127.2, 127.1, 125.8, 125.7, 125.5, 125.4, 123.6, 122.6 (arom. *C*H), 121.7 (arom. C), 114.6 (arom. *C*H), 86.5 ($Ph_2>C$), 55.0 (CH_2), 53.2 (C-3), 46.1 (Bz–CH_2), 29.9 (N–CH_3) ppm. IR (KBr): $\tilde{\nu}$ = 3500–3150 (OOH), 1682, 1636 (C=O) cm^{-1}. $C_{32}H_{27}NO_5$ (505.56): calcd. C 76.02, H 5.38, N 2.77; found C 76.04, H 5.26, N 2.83.

Reactions with 3-Oxopropyl-Substituted Cyclic 1,3-Diones 15a–f: 1,1-Diphenylethene (**1a**) (45.1 mg, 0.25 mmol), a 3-oxopropyl-substituted cyclic 1,3-dione **15** (0.5 mmol), and glacial acetic acid (10 mL) were placed in a 50 mL flask, and manganese(III) acetate dihydrate (0.025–0.125 mmol) was added to the mixture. The mixture was stirred at room temperature in air until **1a** was completely consumed, followed by rapid quenching with water (80 mL). The resulting aqueous solution was treated by the workup described above.

1-Hydroxy-6-(3-oxo-3-phenylpropyl)-4,4-diphenyl-2,3-dioxabicyclo[4.3.0]nonan-7-one (16a): R_f = 0.31 (chloroform/methanol, 98:2, v/v). Colourless microcrystals (from ethyl acetate), m.p. 137 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.95–7.92 (m, 2 H, arom. H), 7.53–7.16 (m, 13 H, arom. H), 4.79 (br. s, 1 H, O*H*), 3.34 (d, J = 13.9 Hz, 1 H, 5-H), 3.18–3.05 (m, 2 H, Bz–CH_2CH_2), 2.40 (d, J = 13.9 Hz, 1 H, 5-H), 2.32–1.67 (m, 6 H, 8-H, 9-H, Bz–CH_2CH_2) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 215.4, 199.7 (2 C, C=O), 144.0, 140.0, 136.4 (3 C, arom. C), 133.2, 128.5, 128.3, 128.1, 127.7, 127.6, 127.3, 127.1, 125.3 (15 C, arom. *C*H), 106.4 (C-1), 85.1 (C-4), 50.7 (C-6), 35.2, 34.7, 31.7, 29.7, 28.2 (5 C, C-5, C-8, C-9, Bz–CH_2CH_2) ppm. IR (KBr): $\tilde{\nu}$ = 3600 –3100 (OH), 1738, 1686 (C=O) cm^{-1}. $C_{28}H_{26}O_5$ (442.50): calcd. C 76.00, H 5.92; found C 76.20, H 6.03.

1-Hydroxy-6-(3-oxo-3-phenylpropyl)-4,4-diphenyl-2,3-dioxabicyclo[4.4.0]decan-7-one (16b): R_f = 0.31 (chloroform/methanol, 98:2, v/v). Colourless prisms (from ethyl acetate), m.p. 137–138 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.93–7.90 (m, 2 H, arom. H), 7.54–7.13 (m, 13 H, arom. H), 4.22 (br. s, 1 H, O*H*), 3.60 (d, J = 13.6 Hz, 1 H, 5-H), 3.06–2.95 (m, 1 H, Bz–CH_2CH_2), 2.81–2.70 (m, 1 H, Bz–CH_2CH_2), 2.45 (d, J = 13.6 Hz, 1 H, 5-H), 2.34–2.11 (m, 4 H, 8-H, 10-H), 1.99–1.90 (m, 2 H, Bz–CH_2CH_2), 1.59–1.51 (m, 2 H, 9-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.5, 199.2 (2 C, C=O), 143.8, 141.2, 136.5 (3 C, arom. C), 133.1, 128.5, 128.3, 128.0, 127.2, 126.6, 125.7 (15 C, arom. *C*H), 101.5 (C-1), 85.3 (C-4), 53.3 (C-6), 36.6, 33.8, 32.1, 31.1, 29.6 (5 C, C-5, C-8, C-10, Bz–CH_2CH_2), 17.2 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 3600–3100 (OH), 1707, 1684 (C=O) cm^{-1}. $C_{29}H_{28}O_5\cdot 3/5H_2O$ (467.34): calcd. C 74.55, H 6.26; found C 74.78, H 6.55.

6-[3-(4-Chlorophenyl)-3-oxopropyl]-1-hydroxy-4,4-diphenyl-2,3-dioxabicyclo[4.4.0]decan-7-one (16c): R_f = 0.11 (chloroform). Colourless microcrystals (from ethyl acetate/hexane), m.p. 158 °C. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.88–7.85 (m, 2 H, arom. H), 7.54–7.16 (m, 12 H, arom. H), 3.92 (br. s, 1 H, O*H*), 3.61 (d, J = 13.6 Hz, 1 H, 5-H), 3.00–2.92 (m, 1 H, 4-Cl-C_6H_4-CH_2CH_2), 2.81–2.73 (m, 1 H, 4-Cl-C_6H_4-CH_2CH_2), 2.44 (d, J = 13.6 Hz, 1 H, 5-H), 2.33–2.13 (m, 4 H, 8-H, 10-H), 2.04–1.91 (m, 2 H, 4-Cl-C_6H_4-CH_2CH_2), 1.65–1.55 (m, 2 H, 9-H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 208.6, 197.9 (2 C, C=O), 143.8, 141.1, 139.6, 134.9 (4 C, arom. C), 129.5, 128.9, 128.0, 127.4, 127.3, 126.8, 125.8 (14 C, arom. *C*H), 101.6 (C-1), 85.5 (C-4), 53.3 (C-6), 36.6, 34.0, 32.2, 31.2, 29.6 (5 C, C-5, C-8, C-10, 4-Cl-C_6H_4-CH_2CH_2), 17.2 (C-9) ppm. IR (KBr): $\tilde{\nu}$ = 3600–3150 (OH), 1707, 1686 (C=O) cm^{-1}. $C_{29}H_{27}ClO_5$ (490.97): calcd. C 70.94, H 5.54; found C 70.70, H 5.51.

Ethyl 3-(1-Hydroxy-7-oxo-4,4-diphenyl-2,3-dioxabicyclo[4.4.0]decan-6-yl)propionate (16d): R_f = 0.33 (chloroform/methanol, 98:2, v/v). Colourless oil. ^1H NMR (300 MHz, $CDCl_3$): δ = 7.51–7.13 (m, 10 H, arom. H), 4.07 (q, J = 7.1 Hz, 2 H, O–CH_2CH_3), 3.52 (d, J = 13.5 Hz, 1 H, 5-H), 2.37 (d, J = 13.5 Hz, 1 H, 5-H), 2.34–1.90 (m, 9 H, O*H*, $CH_2\times4$), 1.59–1.55 (m, 2 H, 9-H), 1.22 (t, J = 7.1 Hz, 3 H, O–CH_2CH_3) ppm. ^{13}C NMR (75 MHz, $CDCl_3$):

δ = 207.9, 173.1 (2 C, C=O), 143.8, 141.1 (2 C, arom. C), 128.2, 127.8, 127.23, 127.19, 126.6, 125.6 (10 C, arom. *C*H), 101.3 (C-1), 85.3 (C-4), 60.6 (O-*C*H_2CH$_3$), 53.1 (C-6), 36.5, 33.7, 31.1, 30.6, 28.2, 17.1 (6 C, *C*H_2), 14.1 (O–CH$_2$*C*H$_3$) ppm. IR (KBr): $\tilde{\nu}$ = 3600–3200 (OH), 1732, 1713 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{25}H_{29}O_6$ 425.1964 (M + 1); found 425.1933.

4a-Hydroxy-9-methyl-10a-(3-oxo-3-phenylpropyl)-2,2-diphenyl-1,4a,9,10a-tetrahydro-2*H*-9-aza-3,4-dioxaphenanthren-10-one (16e): R_f = 0.44 (chloroform/methanol, 98:2, v/v). Colourless microcrystals (from methanol), m.p. 161–164 °C. ^{1}H NMR (300 MHz, [D$_6$]-DMSO): δ = 7.86–6.97 (m, 19 H, arom. H), 3.75 (d, *J* = 13.4 Hz, 1 H, 1-H), 3.35 (br. s, 1 H, O*H*), 2.97–2.82 (m, 2 H, Bz–CH_2CH$_2$), 2.78 (d, *J* = 13.4 Hz, 1 H, 1-H), 2.67 (s, 3 H, N–CH_3), 2.02–1.92 (m, 1 H, Bz–CH$_2$CH_2), 1.83–1.74 (m, 1 H, Bz–CH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, [D$_6$]DMSO): δ = 198.9, 168.5 (2 C, C=O), 144.6, 141.8, 138.5, 136.4 (4 C, arom. C), 133.0, 130.9, 128.5, 128.1, 127.53, 127.45, 127.2, 126.6, 126.5, 125.9, 125.6, 122.6 (12 C, arom. *C*H), 122.3 (arom. C), 114.1 (arom. *C*H), 97.8 (C-4a), 84.5 (C-2), 46.5 (C-10a), 35.1 (C-1), 32.4 (Bz–*C*H$_2$CH$_2$), 29.3 (Bz–CH$_2$*C*H$_2$), 29.2 (N–*C*H$_3$) ppm. IR: $\tilde{\nu}$ = 3500–3000 (OH), 1686, 1651 (C=O) cm^{-1}. $C_{33}H_{29}NO_5 \cdot 2/5\,H_2O$ (526.80): calcd. C 75.26, H 5.66, N 2.66; found C 75.54, H 5.72, N 2.63.

2-(2-Oxo-2-phenylethyl)-2-(3-oxo-3-phenylpropyl)cyclopentane-1,3-dione (17a): R_f = 0.47 (chloroform/methanol, 98:2, v/v). Colourless needles (from diethyl ether/hexane), m.p. 153–154 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.95–7.93 (m, 1 H, arom. H), 7.89–7.86 (br. d, *J* = 8.6 Hz, 1 H, arom. H), 7.60–7.41 (m, 6 H, arom. H), 3.78 (s, 2 H, Bz–CH_2), 3.11 (t, *J* = 7.3 Hz, 2 H, Bz–CH_2CH$_2$), 3.06–2.95 (m, 4 H, 4-H, 5-H), 2.06 (t, *J* = 7.3 Hz, 2 H, Bz–CH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 215.8 (2 C, C=O), 198.0, 197.3 (2 C, C=O), 136.3, 134.8 (2 C, arom. C), 134.0, 133.4, 128.7, 128.4, 128.0 (10 C, arom. *C*H), 55.1 (C-2), 45.6 (Bz–*C*H$_2$), 35.2 (2 C, C-4, C-5), 32.3 (Bz–*C*H$_2$CH$_2$), 26.6 (Bz–CH$_2$*C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 1720, 1684 (C=O) cm^{-1}. $C_{22}H_{20}O_4$ (348.39): calcd. C 75.84, H 5.79; found C 75.79, H 5.76.

3-(2-Oxo-2-phenylethyl)-3-(3-oxo-3-phenylpropyl)chroman-2,4-dione (17f): R_f = 0.56 (chloroform/methanol, 98:2, v/v). Colourless oil. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.97–7.26 (m, 14 H, arom. H), 4.23 (d, *J* = 17.8 Hz, 1 H, Bz–CH_2), 4.05 (d, *J* = 17.8 Hz, 1 H, Bz–CH_2), 3.19–3.00 (m, 2 H, Bz–CH_2CH$_2$), 2.50–2.32 (m, 2 H, Bz–CH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 197.2 (2 C, C=O), 193.0, 170.5 (2 C, C=O), 154.6 (C-6), 136.9 (arom. *C*H), 136.0 (arom. C), 134.9 (arom. *C*H), 133.9 (arom. C), 133.3, 128.5, 128.3, 127.8, 127.33, 127.28, 125.0 (arom. *C*H), 118.1 (arom. C), 117.6 (arom. *C*H), 56.0 (C-3), 45.7 (Bz–*C*H$_2$), 32.8 (Bz–*C*H$_2$CH$_2$), 30.7 (Bz–CH$_2$*C*H$_2$) ppm. IR (KBr): $\tilde{\nu}$ = 1767, 1686 (C=O) cm^{-1}. FAB HRMS (acetone/NBA): calcd. for $C_{26}H_{21}O_5$ 413.1386 (M + 1); found 413.1376.

Cyclization of 3-Oxopropyl-Substituted Bicyclic Endoperoxides 16 in the Presence of a Lewis Acid: The 3-oxopropyl-substituted bicyclic endoperoxides **16a**–**c** or **16e** (0.1 mmol) and dry solvent (2 mL) were placed in a 30 mL flask, and the Lewis acid was added to the mixture. The mixture was then stirred under the conditions described in Table 5. The resulting solution was quenched with water (10 mL) and the aqueous solution was extracted with chloroform (3 × 5 mL). The combined chloroform extracts were dried with anhydrous magnesium sulfate and concentrated to dryness. The obtained crude products were separated by TLC on silica gel with elution with chloroform, giving the corresponding propellanes **18a**–**c** or **19**. In some cases, the acid decomposition product **17b** was also produced. The obtained products were further purified by recrystallization from appropriate solvents.

2-(2-Oxo-2-phenylethyl)-2-(3-oxo-3-phenylpropyl)cyclohexane-1,3-dione (17b): R_f = 0.49 (diethyl ether/hexane 8:2, v/v). Colourless microcrystals (from diethyl ether/hexane), m.p. 102 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.95–7.90 (m, 4 H, arom. H), 7.60–7.41 (m, 6 H, arom. H), 3.83 (s, 2 H, Bz–CH_2), 3.04 (t, *J* = 7.3 Hz, 2 H, Bz–CH_2CH$_2$), 2.90–2.76 (m, 4 H, 4-H, 6-H), 2.44–2.31 (m, 1 H, 5-H), 2.28–2.16 (m, 1 H, 5-H), 2.23 (t, *J* = 7.3 Hz, 2 H, Bz–CH$_2$CH_2) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 210.1 (2 C, C=O), 198.1, 197.7 (2 C, C=O), 136.4, 135.7 (2 C, arom. C), 133.6, 133.4, 128.7, 128.6, 128.3, 128.0 (10 C, arom. *C*H), 63.4 (C-2), 43.4, 38.0, 33.1, 29.1 (5 C, Bz–*C*H$_2$, C-4, C-6, Bz–*C*H$_2$CH$_2$), 17.6 (C-5) ppm. IR (KBr): $\tilde{\nu}$ = 1720, 1686 (C=O) cm^{-1}. $C_{23}H_{22}O_4$ (362.42): calcd. C 76.22, H 6.12; found C 76.20, H 5.98.

4,4,9-Triphenyl-2,3,10-trioxatricyclo[4.4.3.0^{1,6}]tridec-8-en-13-one (18a): R_f = 0.53 (chloroform). Colourless needles (from chloroform/diethyl ether), m.p. 201 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.73–7.69 (m, 2 H, arom. H), 7.56–7.52 (m, 2 H, arom. H), 7.44–7.13 (m, 11 H, arom. H), 5.34 (dd, *J* = 6.1, 2.6 Hz, 1 H, 8-H), 3.29 (d, *J* = 14.1 Hz, 1 H, 5-H), 2.49 (d, *J* = 14.1 Hz, 1 H, 5-H), 2.31–2.09 (m, 5 H, 7-H, 11-H, 12-H), 1.82–1.70 (m, 1 H, 11-H) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 213.9 (C=O), 150.9, 143.8, 139.7, 134.3 (4 C, arom. C, C-9), 128.6, 128.3, 128.2, 128.1, 128.0, 127.9, 127.8, 127.7, 127.3, 125.7, 125.6, 124.8 (15 C, arom. *C*H), 106.9 (C-1), 91.8 (C-8), 85.5 (C-4), 43.6 (C-6), 35.1, 34.2, 29.9, 28.8 (4 C, C-5, C-7, C-11, C-12) ppm. IR (KBr): $\tilde{\nu}$ = 1744 (C=O) cm^{-1}. $C_{28}H_{24}O_4$ (424.49): calcd. C 79.22, H 5.70; found C 79.12, H 5.62.

4,4,9-Triphenyl-2,3,10-trioxatricyclo[4.4.4.0^{1,6}]tetradec-8-en-14-one (18b): R_f = 0.76 (chloroform). Colourless microcrystals (from diethyl ether/hexane), m.p. 161–162 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.69–7.66 (m, 2 H, arom. H), 7.57–7.55 (m, 2 H, arom. H), 7.39–7.13 (m, 11 H, arom. H), 5.26 (dd, *J* = 5.3, 2.8 Hz, 1 H, 8-H), 3.44 (d, *J* = 13.8 Hz, 1 H, 5-H), 2.65 (d, *J* = 13.8 Hz, 1 H, 5-H), 2.43 (dd, *J* = 18.4, 2.8 Hz, 1 H, 7-H), 2.25–2.11, 1.93–1.84 (m, 4 H, 7-H, 11-H, 13-H), 1.78–1.64 (m, 2 H, 12-H) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 209.7 (C=O), 149.5, 143.3, 140.7, 134.5 (4 C, arom. C, C-9), 130.1, 128.6, 128.43, 128.37, 128.33, 128.27, 128.0, 127.9, 127.6, 127.1, 126.2, 124.7 (15 C, arom. *C*H), 102.6 (C-1), 91.7 (C-8), 85.6 (C-4), 46.4 (C-6), 35.7 (C-5), 35.3 (C-13), 32.29, 32.26, 32.2 (1 C, C-7), 29.4 (C-11), 16.4 (C-12) ppm. IR (KBr): $\tilde{\nu}$ = 1711 (C=O) cm^{-1}. $C_{29}H_{26}O_4$ (438.51): calcd. C 79.43, H 5.98; found C 79.35, H 5.85.

9-(4-Chlorophenyl)-4,4-diphenyl-2,3,10-trioxatricyclo[4.4.4.0^{1,6}]-tetradec-8-en-14-one (18c): R_f = 0.53 (chloroform). Colourless needles (from diethyl ether/hexane), m.p. 170 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.60–7.54 (m, 4 H, arom. H), 7.34–7.14 (m, 10 H, arom. H), 5.24 (dd, *J* = 5.1, 2.6 Hz, 1 H, 8-H), 3.69 (d, *J* = 13.8 Hz, 1 H, 5-H), 2.62 (d, *J* = 13.8 Hz, 1 H, 5-H), 2.41 (dd, *J* = 18.4, 2.6 Hz, 1 H, 7-H), 2.24–1.84, 1.93–1.84 (m, 5 H, 7-H, 11-H, 13-H), 1.76–1.60 (m, 2 H, 12-H) ppm. ^{13}C NMR (75 MHz, CDCl$_3$): δ = 209.5 (C=O), 148.6, 143.2, 140.6, 134.2, 132.9 (5 C, arom. C, C-9), 132.4, 130.1, 128.4, 128.3, 128.0, 127.9, 127.6, 127.1, 126.1, 126.0 (14 C, arom. *C*H), 102.7 (C-1), 92.2 (C-8), 85.6 (C-4), 46.3 (C-6), 35.7 (C-5), 35.3 (C-13), 32.1 (C-7), 29.4 (C-11), 16.3 (C-12) ppm. IR (KBr): $\tilde{\nu}$ = 1709 (C=O) cm^{-1}. $C_{29}H_{25}ClO_4$ (472.96): calcd. C 73.64, H 5.33; found C 73.60, H 5.38.

8-Methyl-3,12,12-triphenyl-2,11-dioxa-8-aza-9,10-benzotricyclo-[4.4.3.0^{1,6}]tridec-3-en-7-one (19):[15] R_f = 0.31 (chloroform). Colourless prisms (from diethyl ether/hexane), m.p. 209 °C. ^{1}H NMR (300 MHz, CDCl$_3$): δ = 7.77–7.01 (m, 19 H, arom. H), 5.21 (dd, *J* = 5.3, 2.4 Hz, 1 H, 4-H), 3.78 (d, *J* = 12.5 Hz, 1 H, 13-H), 3.14 (d, *J* = 12.5 Hz, 1 H, 13-H), 3.07 (s, 3 H, N–CH_3), 2.56 (dd, *J* = 18.5, 5.3 Hz, 1 H, 5-H), 2.15 (dd, *J* = 18.5, 2.4 Hz, 1 H, 5-H) ppm. ^{13}C

NMR (75 MHz, $CDCl_3$): δ = 170.6 (C=O), 147.8, 147.6, 145.4, 138.2, 134.3 (5 C, arom. C, C-3), 130.6, 128.5, 128.1, 128.0, 127.9, 127.6, 126.6, 125.8, 125.3, 124.1, 123.4 (arom. *C*H), 122.5 (arom. C), 114.6 (arom. *C*H), 102.7 (C-1), 92.9, 92.8 (1 C, C-4), 88.5 (C-12), 50.0 (C-6), 45.2 (C-13), 29.7 (N–*C*H_3), 26.3 (C-5) ppm. IR (KBr): $\tilde{\nu}$ = 1672 (C=O) cm^{-1}. $C_{33}H_{27}NO_3$ (485.57): calcd. C 81.63, H 5.60, N 2.88; found C 81.64, H 5.73, N 2.92.

Supporting Information (see also the footnote on the first page of this article): ^{1}H NMR, ^{13}C NMR, DEPT, and IR spectra of trioxaazapropellanes **4ab**, **4ah** (9 pages), and the equilibrium mixture **5aa**, **5eb**, **5ei**, and **5fi** (16 pages).

Acknowledgments

This research was supported by the Japanese Society for the Promotion of Science (Grants-in-Aid for Scientific Research (C), No. 15550039 and No. 19550046). We gratefully acknowledge Professor Teruo Shinmyozu, Institute for Materials Chemistry and Engineering, Kyushu University, Japan, for the measurement of the high-resolution FAB mass spectrum.

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Received: December 30, 2007
Published Online: March 25, 2008

