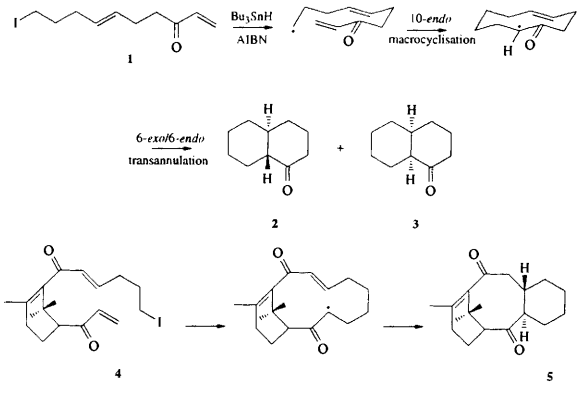
A cascade radical macrocyclisation–transannulation approach towards the construction of ring-fused tricycles and polycycles

Michael J. Begley,†[a] Gerald Pattenden,*[a] Allison Smithies,[a] David Tapolczay[b] and Daryl S. Walter[a]

[a] *Department of Chemistry, Nottingham University, Nottingham NG7 2RD, UK*
[b] *Glaxo Research and Development Ltd, Stevenage, Herts SG1 2NH, UK*

Treatment of the iodo trienone 6 with Bu_3SnH–AIBN results in the formation of the angular 5,7,5-ring-fused tricyclic ketone 20 by way of a novel sequential 13-*endo-trig* macrocyclisation followed by two successive 5-*exo-trig* transannulation processes, *viz* 7→8→18/19→20. The *cis-anti-trans* stereochemistry of 20 was established from an X-ray crystal structure determination of the corresponding 2,4-dinitrophenylhydrazone. By contrast, treatment of the iodo trienone 21 with Bu_3SnH–AIBN, under the same conditions, led to the substituted cyclopropane 33 (instead of the hoped-for tricyclic ketone 22), and only the product 38 of macrocyclisation (without further transannulation to the triquinane 24) was produced when the iodo trienone 23 was treated similarly.

In the immediately preceding paper we introduced and discussed the origins of a unified approach to the construction of polycyclic ring systems, based on cyclisations of polyene-based radical systems, pre-organised to cyclise either *via* a macrocyclisation–transannulation manifold or by sequential *endo*-cyclisations.[1] Furthermore, in the same publication we showed how the aforementioned protocol can be used as a useful stratagem in the synthesis of 5,6-, 6,6- and 5,7-fused bicycles, *e.g.* **1**→**2**/**3**. In other studies we have highlighted an application of this same macrocyclisation–transannulation approach to the 8,6-(BC)-ring system of the taxane ring system, *viz* **4**→**5** (Scheme 1).[2] In this paper we describe the extension of

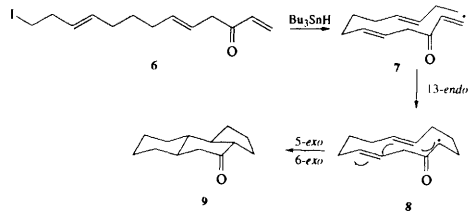


Scheme 1

our studies into the scope for macrocyclisation–transannulation processes in synthesis, with an investigation of the elaboration of tricyclic molecules from appropriate iodo triene precursors.[3–5] In the immediately following paper we show how serial *endo*-cyclisations initiated from *acyl* radical intermediates can be applied to the facile synthesis of linear and angular fused 6,6-systems, including steroid constructions.[6]

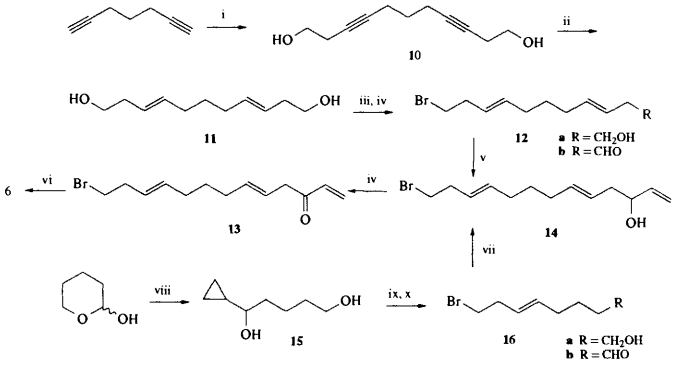
We began our investigations by first examining the radical macrocyclisation–transannulation sequence involving the iodo trienone **6**. This substrate was designed, based on earlier investigations,[1] to access the 6,6,5-tricycle **9** by way of a 13-*endo-trig* macrocyclisation, *i.e.* **7**→**8**, followed by two successive 5-*exo*, 6-*exo-trig* transannulations (see Scheme 2).

† Deceased 28 February 1994.



Scheme 2

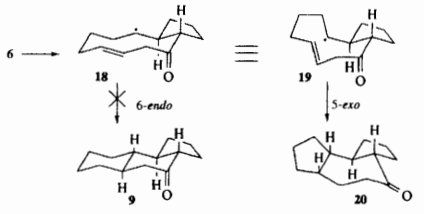
The iodo trienone **6** was synthesised by two routes and the details are summarised in Scheme 3. Thus, deprotonation of



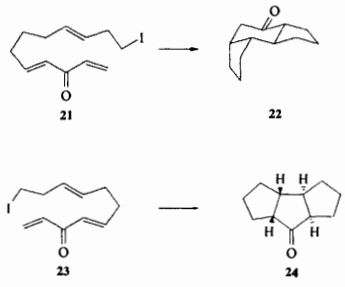
Scheme 3 *Reagents:* i, $NaNH_2$, ethylene oxide (37%); ii, $LiAlH_4$, THF (98%); iii, NBS, PPh_3 (46%); iv, Dess–Martin periodinane (96%); v, CH_2=CHMgCl (56%); vi, NaI, Me_2CO (94%); vii, Ph_3P=$CHCH_2CH(O^-)CH$=CH_2 **17** (75%); viii, cyclopropyl-MgBr (81%); ix, $ZnBr_2$, $ZnBr_2$ (65%); x, PCC (77%)

hepta-1,6-diyne followed by reaction of the resulting diyne dianion with ethylene oxide first led to the diyne diol **10** in 46% yield. Reduction of **10** with lithium aluminium hydride next gave the *E,E*-diene diol **11**, which was then converted into the corresponding bromo alcohol **12a** on treatment with *N*-bromosuccinimide and triphenylphosphine. The oxidation of the bromo alcohol **12a** to the aldehyde **12b** proceeded smoothly using periodinane, but other oxidising conditions, *e.g.* Swern and PCC, led to polymerisation or to products where the β,γ-double bond moved into conjugation with the carbonyl function. The aldehyde **12b** was next converted into the allylic alcohol **14** by treatment with vinylmagnesium chloride, which upon oxidation with periodinane provided the bromo trienone **13**. Finally, a Finkelstein reaction with **13**, using sodium iodide

in acetone, led to the *E,E*-iodo trienone **6**. A more satisfying route to the allylic alcohol intermediate **14**, *en route* to the iodo trienone **6**, started from the cyclopropylmethanol product **15** resulting from treatment of γ-valerolactol with cyclopropylmagnesium bromide. Thus, treatment of the diol **15** with $MgBr_2$–$ZnBr_2$ first gave the corresponding homoallylic bromide **16a**, which was next converted into the aldehyde **16b** following oxidation with pyridinium chlorochromate (PCC). A Wittig reaction between the aldehyde **16b** and the phosphonium ylide **17** produced *in situ* from methyltriphenylphosphonium ylide and butadiene monoepoxide,[7] then gave the *E,E*-trienol **14** in 71% yield. The trienol **14** prepared by this procedure was identical with the product produced earlier from the aldehyde **12b** and vinylmagnesium chloride.

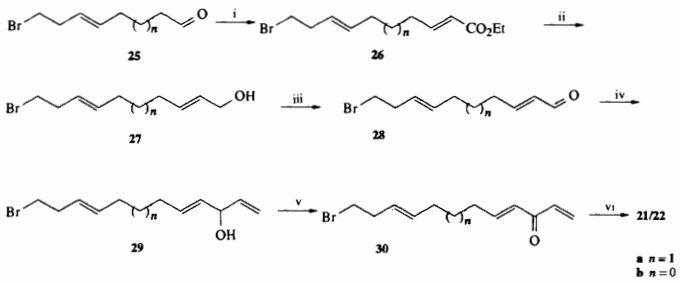


When a 3 mmol dm^{-3} solution of **6** in dry degassed benzene was heated under reflux in the presence of Bu_3SnH (1.1. equiv.) and a catalytic amount of AIBN for 0.5 h, work-up and chromatography led to the isolation of a single saturated ketone product in 55% yield. The saturated ketone product displayed ^1H NMR and ^{13}C NMR spectroscopic data which were consistent with the formation of a tricyclic ring system, but the data did not distinguish unambiguously between the 6,6,5- and the 5,7,5-ring fused tricycles, **9** and **20**, respectively. Accordingly, we prepared the crystalline 2,4-dinitrophenylhydrazone derivative of the product ketone, and determined its X-ray crystal structure. This determination established unambiguously that the tricycle produced from the cascade radical cyclisation of **6** was the *cis-anti-trans* 5,7,5-ring fused tricyclic ketone **20**.[3]



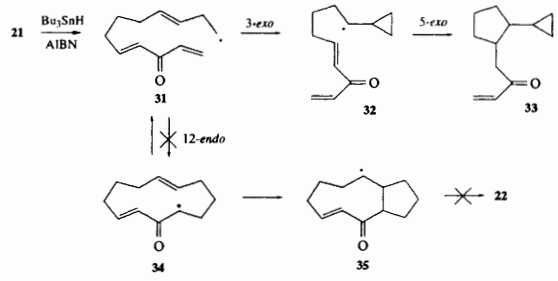
The tricycle **20** is produced from **6** *via* a sequential 13-*endo-trig* macrocyclisation, followed by two successive 5-*exo-trig* transannulation processes involving the radical intermediates **8** and **18**/**19**. We had expected that the iodo trienone **6** would undergo macrocyclisation–transannulation to give the 6,6,5-tricycle **9** rather than the 5,7,5-tricycle **20**. Accordingly, we carried out some MM2 studies to determine if we could learn something about this unexpected result. Before we discuss these studies however, it is instructive to summarise the outcome of the cyclisation studies we carried out with the related iodo trienones **21** and **23** with an eye to the synthesis of the corresponding 5,6,5- and 5,5,5-ring tricycles, **22** and **24** respectively.

The iodo trienones **21** and **23** were prepared using synthetic sequences similar to those used to synthesise the analogue **6** (see Scheme 4). To our surprise, when the iodo trienone **21** was treated with Bu_3SnH–AIBN (azoisobutyronitrile), instead of leading to the tricyclic ketone **22**, it gave a 3:1 mixture of diastereoisomers of the cyclopropylcyclopentane **33** (53%) in



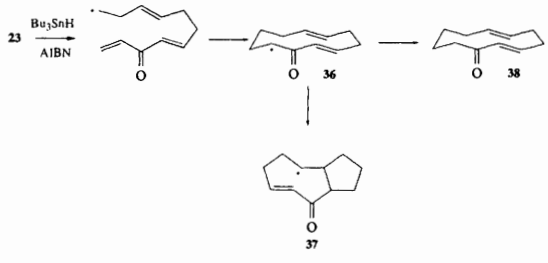
Scheme 4 *Reagents and conditions:* i, $EtO_2CCH{=}PPh_3$, CH_2Cl_2, 25 °C; ii, DIBAL, 0 °C; iii, PCC; iv, $CH_2{=}CHMgCl$; v, Dess–Martin periodinane; vi, NaI, Me_2CO

addition to recovered starting material (23%). The formation of **33** from **21** takes place by way of a 3-*exo-trig* cyclisation[8,9] leading to **32**, wherein the equilibria **31** ≡ **32** ≡ **34** are no doubt driven by a following, and rapid, 5-*exo-trig* cyclisation onto a reactive enone electrophore, *viz* **32**→**33** (Scheme 5). To add to



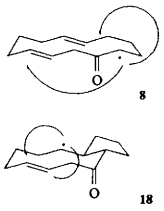
Scheme 5

our surprise with system **21**, when a solution of the related iodo trienone **23** in benzene was treated with Bu_3SnH–AIBN under the same conditions used in the conversion of **6** into **20**, the only product isolated, in a meagre 16% yield, was the macrocyclisation product cycloundeca-2,6-dienone **38** (Scheme 6).



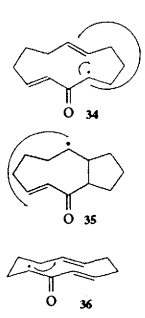
Scheme 6

In the accompanying paper[1] we described the outcome of MM2 calculations we had made in an attempt to rationalise the experimental results we observed in sequential radical macrocyclisation–transannulation reactions from iodo dienes leading to 5,5-, 5,6-, 6,6- and 5,7-ring fused carbocycles. Indeed, a reasonably satisfactory rationale of the experimental results was forthcoming from these calculations. Using the same MM2 modelling methodology described in the preceding paper, we have also been able to determine satisfactory qualitative rationalisations for the outcomes of the three attempted tricyclisations, *viz.* **6**→**20**; **21**→**22**; **23**→**24**, summarised in the present paper. Thus, calculations relating to the transition state energies for the two transannulations involved in the conversion of the iodo trienone **6** into the tricyclic ketone **9** showed favourable agreement (Fig. 1). The first 5-*exo-trig* transannulation, *i.e.* **8**→**18**, was found to have an energy of −25.4 kcal mol^{-1}, and the subsequent 6-*exo-trig* cyclisation leading to the 6,6,5-tricycle **9** was similarly favoured (−25.45 kcal mol^{-1}). However, the corresponding 5-*exo-trig* mode of cyclisation from **19** has a larger number of low energy



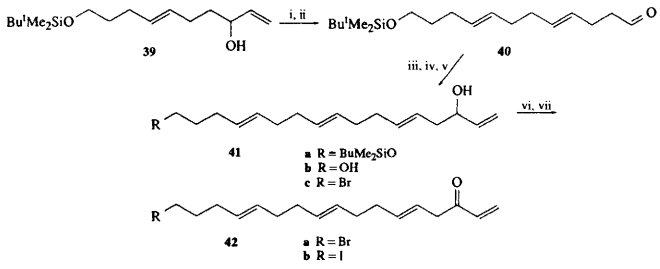
Transition state	Energy (kcal mol^{-1})
5-*exo*	-25.43
5-*endo*	2.90
5-*exo*	-25.78
5-*endo*	-25.45

Fig. 1 Transition state energies for the transannulation cyclisations **8**→**18**/**19**→**9**/**20**

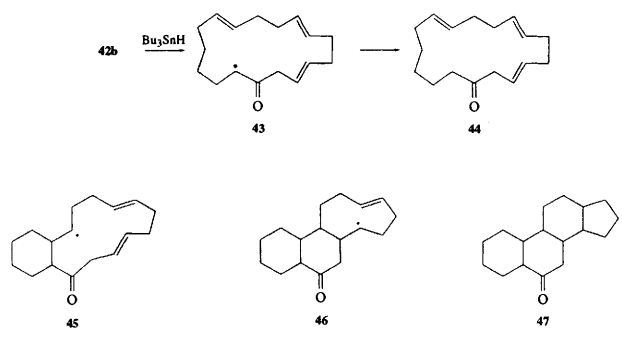


Transition state	Energy (kcal mol^{-1})
5-*exo*	-26.73
5-*endo*	0.63
5-*exo*	-5.89
5-*exo*	-15.91

Fig. 2 Transition state energies for the transannulation cyclisations **34**→**35**→**22** and **36**→**37**



Scheme 7 *Reagents and conditions:* i, CH_2=CHOEt, $Hg(OCOCF_3)_2$; ii, heat; iii, Ph_3P=$CHCH_2CH(O^-)CH$=CH_2; iv, TBAF; v, NBS, PPh_3; vi, Dess–Martin periodinane; vii, NaI, Me_2CO



conformations of similar energy (the lowest being −25.78 kcal mol^{-1}), and is consequently favoured statistically. Hence, as borne out experimentally, the iodo trienone **6** undergoes preferential macrocyclisation–transannulation to the 5,7,5-tricycle **20**.

The result obtained in the attempted macrocyclisation–transannulation of the iodo trienone **21** to **22** could also be understood in terms of similar MM2 calculations. Thus, the transition state energy of −26.73 kcal mol^{-1} in the first transannulation of this expected sequence, *i.e.* **34**→**35**, is of a favourable magnitude (Fig. 2). However, the second 5-*exo-trig* transannulation **35**→**22** has a considerable higher penalty (−5.89 kcal mol^{-1}). In view of the highly favoured 5-*exo-trig* cyclisation (−53.79 kcal mol^{-1}) from the alternative first-formed cyclopropylmethyl radical **32**, it is perhaps not surprising therefore that the iodo trienone **21** underwent cyclisation to **33** in preference to **22** in this study. By analogy, the relatively high energy (−15.92 kcal mol^{-1}) of the initial 5-*exo-trig* transannulation **36**→**37** in the attempted conversion of the iodo trienone **23** into the triquinone **24** probably also accounts for the isolation of only the macrocycle **38** in this reaction (Fig. 2).

Finally, in these particular studies we also examined the synthesis and the radical cyclisation chemistry of the all-*E*-iodo tetraenone **42b**, as a prelude to studying the synthesis of the steroid ring system according to the principles developed earlier. The all-*E*-iodo tetraenone **42b** was synthesised starting from the hydroxy diene **39** prepared in earlier work, and using reagents and reaction conditions already described in studies leading to the related iodo polyenones **6**, **21** and **23**. These details are summarised in Scheme 7. Treatment of **42b** with Bu_3SnH–AIBN resulted in a clean reaction but only the 17-ring product **44** of 17-*endo-trig* macrocyclisation was isolated. No evidence for the co-formation of polycyclic products resulting from subsequent radical transannulation reactions to **45**, **46** and **47** from the intermediate **43** could be accrued from this first, somewhat ambitious, attempt to effect a cascade tetracycle construction.

Having acquired an appreciation of the scope and some of the limitations of the approach to polycycle constructions based on the principles of radical mediated cascade macrocyclisation–transannulation reaction enunciated in this and the accompanying papers—together with an insight into the information that can be gleamed from molecular modelling—further detailed studies are now in progress building on these preliminary investigations, amongst a number of alternative carbo- and hetero-polycyclic constructions. The outcome of these studies will be published in due course.

Experimental

For general experimental details see preceding paper.[1]

Undeca-3,8-diyne-1,11-diol 10

Lithium (475 mg, 68 mmol) was added in small portions to stirred freshly distilled liquid ammonia (150 cm^3) in a flask fitted with a solid CO_2 condenser to give a blue solution. Iron(III) nitrate (200 mg, 0.5 mmol) was added in one portion to this, and the brown solution which developed was stirred under reflux for 30 min. Hepta-1,6-diyne (3 g, 33 mmol) was added dropwise over 5 min to the reaction mixture which was then stirred under reflux for 45 min. Ethylene oxide (approx. 6 g, 0.13 mol) was bubbled through the mixture over 30 min, after which it was stirred under reflux for 4 h. Water (50 cm^3) was added to the mixture which was then stirred for 16 h, during which time the residual ammonia evaporated. The resulting aqueous solution was acidified with dilute hydrochloric acid (100 cm^3) and then extracted with ether (4 × 100 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave a residue which was purified by column chromatography on silica using light petroleum–ether (1 : 1) as eluent to give (i) nona-3,8-diyn-1-ol (1.78 g, 40%) as a pale yellow oil (Found: C, 79.1; H, 9.2. $C_9H_{12}O$ requires C, 79.4; H, 8.9%); ν_{max}(film)/cm^{-1} 3928, 2938, 2844, 1454, 1433, 1045, 758 and 638; δ_H(250 MHz; $CDCl_3$) 1.71 (2 H, quin., *J* 7.0, $CH_2CH_2CH_2$), 1.91 (1 H, br s, OH), 1.97 (1 H, t, *J* 2.6, CCH), 2.31 (4 H, m, 2 × $CCCH_2$), 2.43 (2 H, m, $CCCH_2$) and 3.68 (2 H, t, *J* 5.8, CH_2OH); δ_C(67.8 MHz; $CDCl_3$) 17.3 (t), 17.6 (t), 22.9 (t), 27.5 (t), 61.1 (t), 68.7 (s), 77.2 (s), 80.9 (s) and 83.5 (d); *m*/*z* (EI) 136.0842 (M^+. $C_9H_{12}O$ requires 136.0888), 135 (13%), 121 (24%), 117 (33%), 105 (84%), 91 (93%) and 79 (100%); and (ii) the *diynediol* **10** (2.2 g, 37%), as a white crystalline solid, mp 102 °C (Found: C, 73.2; H, 9.1. $C_{11}H_{16}O_2$ requires C, 73.3; H, 9.0%); ν_{max}($CHCl_3$)/cm^{-1} 3576,

2943, 2842, 2360, 1346, 1002 and 909; δ_H(250 MHz; $CDCl_3$) 1.69 (2 H, quin., *J* 7.0, $CH_2CH_2CH_2$), 1.88 (2 H, br s, OH), 2.30 (4 H, m, 2 × $CCCH_2$), 2.44 (4 H, m, 2 × $CCCH_2CH_2OH$) and 3.69 (4 H, t, *J* 5.8, 2 × CH_2OH); δ_C(67.8 MHz; $CDCl_3$) 17.6 (2 × t), 22.8 (2 × t), 27.9 (t), 61.1 (2 × t), 77.1 (2 × s) and 81.0 (2 × s); *m/z* (EI) 179.1053 (M^+ − H. $C_{11}H_{15}O_2$ requires 179.1072), 161 (7%), 149 (53%), 135 (28%), 117 (31%), 105 (36%) and 91 (100%).

(*E*,*E*)-Undeca-3,8-diene-1,11-diol 11

A solution of undeca-3,8-diyne-1,11-diol (2 g, 11 mmol) in tetrahydrofuran (2 cm^3) was added cautiously dropwise over 5 min to a stirred solution of lithium aluminium hydride (8.3 g, 22 mmol) in tetrahydrofuran (200 cm^3) at 0 °C. The mixture was heated under reflux in an atmosphere of nitrogen for 20 h after which it was cooled and quenched by careful addition of saturated aqueous sodium sulfate. The mixture was acidified with dilute hydrochloric acid (100 cm^3) and then extracted with ether (4 × 100 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave a yellow oil, which was purified by column chromatography on silica using ether as eluent to give the *dienediol* **11** (2.0 g, 100%) as a colourless oil (Found: C, 71.5; H, 11.4. $C_{11}H_{20}O_2$ requires C, 71.7; H, 10.9%); ν_{max}(film)/cm^{-1} 3342, 2925, 1777, 1711, 1438, 1048, 968, 766 and 668; δ_H(250 MHz; $CDCl_3$) 1.45 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 1.65 (2 H, br s, OH), 2.03 (4 H, app q, *J* 7.0, 2 × CH_2CH=CH), 2.27 (4 H, app q, *J* 7.0, 2 × CH_2CH=CH), 3.63 (4 H, t, *J* 6.3, 2 × CH_2OH) and 5.34–5.61 (4 H, m, 2 × CH=CH); δ_C(67.8 MHz; $CDCl_3$) 29.3 (t), 32.3 (2 × t), 36.2 (2 × t), 62.3 (2 × t), 126.6 (2 × d) and 133.4 (2 × d); *m/z* (EI) 154.1334 (M^+ − CH_2O. $C_{10}H_{18}O$ requires 154.1358), 135 (7%), 125 (7%), 107 (24%), 98 (38%) and 81 (100%).

(*E*,*E*)-11-Bromoundeca-3,8-dien-1-ol 12a

Triphenylphosphine (4.1 g, 16 mmol) and then *N*-bromosuccinimide (2.79 g, 16 mmol) were added, each in one portion, to a stirred solution of undeca-3,8-diene-1,11-diol (1.8 g, 9.78 mmol) in dichloromethane (180 cm^3) at −30 °C. The solution was allowed to warm to room temperature and then stirred at this temperature for 36 h. Saturated aqueous sodium chloride (100 cm^3) was added to the reaction mixture after which the aqueous layer was separated and extracted with dichloromethane (4 × 100 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave a yellow oil which was purified by column chromatography on silica using light petroleum–ether (1 : 1) and then ether, to give (i) all-*E*-undeca-3,8-diene dibromide (0.654 g, 22%) as a colourless oil (Found: C, 42.9; H, 6.0; Br, 51.6. $C_{11}H_{18}Br_2$ requires C, 42.6; H, 5.9; Br, 51.5%); ν_{max}(film)/cm^{-1} 2960, 2926, 2853, 1435, 1265, 1207, 968 and 641; δ_H(250 MHz; $CDCl_3$) 1.44 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 2.02 (4 H, app q, *J* 7.0, 2 × CH_2CH=CH), 2.55 (4 H, app q, *J* 6.9, 2 × CH_2CH=CH), 3.38 (4 H, t, *J* 7.1, 2 × CH_2Br) and 5.34–5.59 (4 H, m, CH=CH); δ_C(67.8 MHz; $CDCl_3$) 28.7 (t), 31.8 (2 × t), 32.9 (2 × t), 36.0 (2 × t), 126.8 (2 × d) and 133.4 (2 × d); *m/z* (EI) 307.9806 (M^+. $C_{11}H_{18}Br_2$ requires 307.9775), 203 (5%), 201 (6%), 160 (51%) and 81 (100%); (ii) the *bromo alcohol* **12a** (1.08 g, 46%) as a pale yellow oil (Found: C, 53.5; H, 8.1. $C_{11}H_{19}BrO$ requires C, 53.5; H, 7.8%); ν_{max}(film)/cm^{-1} 3346, 2926, 2854, 1666, 1438, 1354, 1048 and 968; δ_H(250 MHz; $CDCl_3$) 1.45 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 1.61 (1 H, br s, OH), 2.04 (4 H, m, 2 × CH_2CH=CH), 2.27 (2 H, app q, *J* 6.8, CH_2CH=CH), 2.55 (2 H, app q, *J* 6.8, CH_2CH=CH), 3.38 (2 H, t, *J* 7.1, CH_2Br), 3.64 (2 H, br s, CH_2OH) and 5.34–5.59 (4 H, m, CH=CH); δ_C(67.8 MHz; $CDCl_3$) 28.9 (t), 31.8 (t), 31.9 (t), 32.9 (t), 35.9 (2 × t), 62.0 (t), 126.1 (d), 126.7 (d), 133.4 (d) and 133.6 (d); *m/z* (EI) 167.1388 (M^+ − HBr. $C_{11}H_{18}O$ requires 167.1435), 121 (16%), 98 (30%) and 81 (100%); and (iii) recovered diol (0.45 g, 25%).

(*E*,*E*)-11-Bromoundeca-3,8-dienal 12b

Periodinane (2.33 g, 6.19 mmol) was added in one portion to a stirred solution of 11-bromoundeca-3,8-dienol (1.0 g, 4.13 mmol) in dichloromethane (100 cm^3) at room temperature, and the solution was then stirred at room temperature under a nitrogen atmosphere for 4 h. The mixture was poured onto a stirred solution of sodium thiosulfate in saturated aqueous sodium hydrogencarbonate (10%; 50 cm^3), and then stirred vigourously for 20 min. The aqueous layer was separated and extracted with dichloromethane (4 × 50 cm^3) and the combined extracts were then dried and evaporated under reduced pressure to leave the *aldehyde* **12b** (0.95 g, 96%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 2924, 2854, 2721, 1726, 1690, 1439, 1266, 1208, 969, 739 and 641; δ_H(270 MHz; $CDCl_3$) 1.46 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 2.04 (4 H, m, 2 × CH_2CH=CH), 2.55 (2 H, app q, *J* 6.9, $BrCH_2CH_2CH$=CH), 3.17 (2 H, dd, *J* 6.4 and 1.5, $CHOCH_2CH$=CH), 3.38 (2 H, t, *J* 7.1, CH_2Br), 5.34–5.65 (4 H, m, CH=CH) and 9.67 (1 H, t, *J* 1.5, CHO); δ_C(100 MHz; $CDCl_3$) 28.7 (t), 31.9 (t), 32.1 (t), 33.0 (t), 36.1 (t), 47.4 (t), 119.6 (d), 127.1 (d), 133.4 (d), 136.5 (d) and 200.4 (d); *m/z* (EI) 159.9913 (M^+ − CH_2CH=$CHCH_2CHO$. C_6H_9Br requires 159.9888), 162 (18%), 121 (12%), 97 (15%), 79 (31%) and 67 (100%); the product was used without further purification.

(*E*,*E*)-13-Bromotrideca-1,5,10-trien-3-ol 14

(*a*) Vinylmagnesium chloride (1.7 mol dm^{-3} solution; 2.92 cm^3, 4.96 mmol) was added dropwise over 5 min to a stirred solution of the dienal **12b** (0.99 g, 4.1 mmol) in tetrahydrofuran (100 cm^3) at 0 °C. The solution was warmed to room temperature and stirred for 2 h, after which it was quenched by the addition of saturated aqueous ammonium chloride (50 cm^3). The aqueous layer was separated and extracted with ether (4 × 50 cm^3), and the combined extracts were then dried and evaporated under reduced pressure to leave a residue. This was purified by column chromatography on silica using light petroleum–ether (3 : 1) as eluent to give the *alcohol* **14** (0.625 g, 56% from bromo alcohol) as a colourless oil; ν_{max}(film)/cm^{-1} 3377, 2926, 2854, 1643, 1425, 1266, 1207, 1120, 968 and 922; δ_H(250 MHz; $CDCl_3$) 1.44 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 1.72 (1 H, br s, OH), 2.03 (4 H, m, 2 × CH_2CH=CH), 2.18–2.3 (2 H, m, CH_2CH=CH), 2.55 (2 H, app q, *J* 6.9, CH_2CH=CH), 3.37 (2 H, t, *J* 7.1, CH_2Br), 4.14 (1 H, m, CHOH), 5.13 (1 H, dd, *J* 10.4 and 1.4, CH=CH_2), 5.25 (1 H, dd, *J* 17.2 and 1.4, CH=CH_2), 5.35–5.59 (4 H, m, CH=CH) and 5.88 (1 H, ddd, *J* 17.2, 10.4 and 5.8, CH=CH_2); δ_C(100 MHz; $CDCl_3$) 28.9 (t), 31.9 (t), 32.0 (t), 32.9 (t), 36.0 (t), 40.5 (t), 72.1 (d), 114.6 (t), 125.5 (d), 126.8 (d), 133.5 (d), 134.4 (d) and 140.5 (d); *m/z* (EI) 216.0453 [M^+ − $CH(OH)CH$=CH_2. $C_{10}H_{17}Br$ requires 216.0514], 218 (3%), 189 (3%), 187 (3%), 160 (16%), 109 (11%), 95 (18%) and 57 (100%).

(*b*) A solution of butyllithium in hexane (1.6 mol dm^{-3}; 2.76 cm^3, 4.4 mmol) was added dropwise over 20 min to a stirred suspension of methyltriphenylphosphonium bromide (1.59 g, 4.4 mmol) in dry THF (10 cm^3) at 0 °C under nitrogen. Butadiene monoepoxide (393 mm^3, 4.88 mmol)‡ was added to the mixture which was then allowed to warm to room temperature, where it was stirred for a further 1 h. The mixture was cooled to −20 °C and after which butyllithium in hexane (2.7 cm^3, 4.4 mmol) was added dropwise over 10 min. The resulting solution of **17** was stirred at room temperature for 20 min, and then treated dropwise over 3 min with a solution of 8-bromooct-5-enal **16b**[1] (910 mg) in THF (0.5 cm^3). The mixture was stirred at room temperature overnight, and then quenched

‡ 1 mm^3 = 1 μl.

with water and poured onto ethyl acetate. The organic extracts were washed with saturated aqueous ammonium chloride, and then dried and evaporated under reduced pressure. The residue was purified by chromatography to give the bromo alcohol (0.86 g, 71%) (largely *E,E*-) as a colourless oil which showed spectroscopic data identical with those reported under (*a*).

(*E,E*)-13-Bromotrideca-1,5,10-trien-3-one 13

Periodinane (1.05 g, 2.78 mmol) was added in one portion to a stirred solution of the trienol **14** (0.5 g, 1.85 mmol) in dichloromethane (50 cm^3) at room temperature, after which the solution was stirred at room temperature under a nitrogen atmosphere for 6 h. The mixture was poured onto a stirred solution of sodium thiosulfate in saturated aqueous sodium hydrogen carbonate (10%; 25 cm^3) and then stirred vigorously for 20 min. The aqueous layer was separated and extracted with dichloromethane (4 × 25 cm^3), and the combined organic extracts were then dried and evaporated under reduced pressure to leave a yellow oil. This was purified by column chromatography on silica using light petroleum–dichloromethane (1:1) as eluent to give the *enone* **13** (369 mg, 75%) as a colourless oil; ν_{max}(film)/cm^{-1} 2925, 2853, 1701, 1686, 1615, 1438, 1400, 1255 and 967; δ_H(250 MHz; $CDCl_3$) 1.43 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 2.01 (4 H, m, 2 × CH_2CH=CH), 2.53 (2 H, app q, *J* 6.8, CH_2CH=CH), 3.28 (2 H, d, *J* 4.0, $COCH_2CH$=CH), 3.35 (2 H, t, *J* 7.1, CH_2Br), 5.34–5.55 (4 H, m, CH=CH), 5.82 (1 H, dd, *J* 10.0 and 1.6, CH=CH_2), 6.23 (1 H, dd, *J* 17.6 and 1.6, CH=CH_2) and 6.37 (1 H, dd, *J* 17.6 and 10.0, CH=CH_2); δ_C(67.8 MHz; $CDCl_3$) 28.5 (t), 31.7 (t), 31.8 (t), 32.8 (t), 35.8 (t), 43.6 (t), 121.9 (d), 126.7 (d), 128.4 (t), 133.2 (d), 134.6 (d), 135.7 (d) and 198.6 (s); *m/z* (EI) 270.0612 (M^+. $C_{13}H_{19}BrO$ requires 270.0619), 191 (2.5%), 122 (2.8%), 109 (3.8%) and 81 (16.3%).

(*E,E*)-13-Iodotrideca-1,5,10-trien-3-one 6

Sodium iodide (55.5 mg, 0.37 mmol) was added in one portion to a stirred solution of the trienone **13** (50 mg, 0.185 mmol) in acetone (30 cm^3) and the solution was then heated under reflux for 2 h. The mixture was cooled and evaporated under reduced pressure and the residue was dissolved in ether (30 cm^3). The solution was washed with aqueous sodium thiosulfate (10%; 30 cm^3) and then dried and evaporated under reduced pressure to leave the *iodide* **6** (55.4 mg, 94%); ν_{max}(film)/cm^{-1} 3017, 2927, 2854, 1681, 1618, 1216, 968 and 757; δ_H(270 MHz; $CDCl_3$) 1.45 (2 H, quin., *J* 7.4, $CH_2CH_2CH_2$), 1.96–2.17 (4 H, m, 2 × CH_2CH=CH), 2.54 (2 H, app q, *J* 6.8, CH_2CH=CH), 3.14 (2 H, t, *J* 7.3, CH_2I), 3.30 (2 H, d, *J* 4.0, $COCH_2CH$=CH), 5.32–5.62 (4 H, m, CH=CH), 5.84 (1 H, dd, *J* 10.0 and 1.6, CH_2=CH), 6.24 (1 H, dd, *J* 17.6 and 1.6, CH_2=CH) and 6.38 (1 H, dd, *J* 17.6 and 10.0, CH_2CH); δ_C(100 MHz; $CDCl_3$) 6.2 (t), 28.7 (t), 31.9 (t), 32.0 (t), 36.8 (t), 43.9 (t), 122.1 (d), 128.6 (t), 128.8 (d), 133.1 (d), 135.0 (d), 136.0 (d) and 198.9 (s); *m/z* (EI) 318.0466 (M^+. $C_{13}H_{19}IO$ requires 318.0481), 121 (13.5%), 81 (20.2%), 67 (26.1%) and 55 (100%). The product was used without further purification.

Dodecahydrodicyclopenta[*a,c*]cyclohepten-4-one 20

The trienone **6** (54 mg, 0.18 mmol) in benzene (1 cm^3) was added dropwise over 5 min to a stirred and refluxing solution of AIBN (10 mg) in degassed benzene (55 cm^3) under a nitrogen atmosphere. Tributyltin hydride (52.8 mm^3, 0.199 mmol) was added dropwise to the refluxing solution which was then heated under reflux for 2 h before being cooled to room temperature. Saturated aqueous potassium fluoride (40 cm^3) was added to the mixture which was then stirred vigorously for 18 h. The resulting mixture was partitioned between ether (50 cm^3) and water (50 cm^3). The aqueous layer was then separated and extracted with ether (4 × 20 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave a residue which was purified by column chromatography on silica using pentane–dichloromethane (2:1) as eluent to give the *cyclic ketone* (13 mg, 42%) as a colourless oil; ν_{max}(film)/cm^{-1} 2950, 2859, 1693, 1453, 1355, 1322, 1128, 968 and 907; δ_H(400 MHz; $CDCl_3$) 1.18–1.35 (4 H, m), 1.35–1.50 (1 H, m), 1.50–1.74 (7 H, m), 1.78–2.01 (4 H, m), 2.18–2.40 (2 H, m), 2.54–2.60 (1 H, ddd, *J* 14.6, 7.0 and 2.6) and 2.68–2.74 (1 H, dt, *J* 9.7 and 6.7); δ_C(100 MHz; $CDCl_3$) 24.9 (t), 25.3 (t), 25.9 (t), 27.4 (t), 33.0 (t), 33.9 (t), 34.8 (t), 41.9 (d), 44.0 (t), 45.9 (d), 48.8 (d), 56.5 (d) and 212.0 (s); *m/z* (EI) 192.1524 (M^+. $C_{13}H_{20}O$ requires 192.1514), 151 (37%), 123 (36%), 110 (27%) and 95 (100%). A small amount (~4%) of trideca-1,5,10-trien-3-one was also obtained, as a colourless oil; ν_{max}(film)/cm^{-1} 3005, 2924, 2853, 1718, 1681, 1617, 1402, 1383, 1249, 1182, 1070, 992 and 964; δ_H(400 MHz; $CDCl_3$) 0.96 (3 H, t, *J* 7.3, CH_3CH_2), 1.43 (2 H, app quin., *J* 7.4, $CH_2CH_2CH_2$), 1.99 (6 H, m, CH_2CH=CH), 3.30 (2 H, m, CH=$CHCH_2CO$), 5.41 (2 H, m, CH=CH), 5.55 (2 H, m, CH=CH), 5.84 (1 H, dd, *J* 10.0 and 1.8, CH=CH_2), 6.25 (1 H, dd, *J* 17.6 and 1.8 CH=CH_2) and 6.39 (1 H, dd, *J* 17.6 and 10.0, CH=CH_2); δ_C(100 MHz; $CDCl_3$) 14.1 (q), 25.7 (t), 29.2 (t), 32.0 (t), 32.1 (t), 43.9 (t), 121.9 (d), 128.6 (t), 128.9 (d), 132.5 (d), 135.2 (d), 136.0 (d) and 199.0 (s).

X-Ray crystal structure determination of the 2,4-dinitrophenylhydrazone derivative of the tricyclic ketone 20. The 2,4-DNP derivative crystallised from ethanol and had mp 184–186 °C. Monoclinic, a = 9.622(3), b = 14.658(2), c = 13.494(2) Å, β = 106.05(2)°, U = 1828.91 $Å^3$, Z = 4, space group $P2_1/a$. R = 0.0764, R_w = 0.0524 for 597 observed reflections measured with Cu-Kα radiation on an Enraf-Nonius CAD4 diffractometer. Atomic coordinates, bond lengths, bond angles, thermal parameters and observed and calculated structure factors have been deposited at the Cambridge Crystallographic Data Centre.

(*E,E*)-Ethyl 10-bromodeca-2,7-dienoate 26a

A solution of the enal **25a**[1] (340 mg, 1.66 mmol) and ethoxycarbonylmethylene(triphenyl)phosphorane (580 mg, 1.66 mmol) in dichloromethane (5 cm^3) was stirred at room temperature for 12 h, and then evaporated to dryness under reduced pressure. The residue was triturated with light petroleum (bp 60–80 °C), after which the light petroleum extracts were evaporated to leave a residue. Chromotography of this on silica, using dichloromethane–light petroleum (1:1) as eluent, gave the *dienoate* **26a** (0.43 g, 94%) as a colourless oil; ν_{max}(film)/cm^{-1} 2932, 1719, 1654, 1267, 1195, 1044 and 972; δ_H(250 MHz; $CDCl_3$) 1.20 (3 H, t, *J* 6.9, OCH_2CH_3), 1.46 (2 H, app quin., *J* 7.6, $CH_2CH_2CH_2$), 1.97 (2 H, m, allylic), 2.13 (2 H, m, allylic), 2.47 (2 H, m, allylic), 3.29 (2 H, t, *J* 6.9, CH_2Br), 4.10 (2 H, q, *J* 6.9, CH_2O), 5.38 (2 H, m, CH_2CH=$CHCH_2$), 5.74 (1 H, d, *J* 15.5, CH=$CHCO_2Et$) and 6.87 (1 H, dt, *J* 15.5 and 6.9, CH=$CHCO_2Et$); δ_C(67.8 MHz; $CDCl_3$) 166.5 (s), 148.8 (d), 132.7 (d), 127.2 (d), 121.3 (d), 60.0 (t), 35.7 (t), 32.7 (t), 31.6 (t), 31.3 (t), 27.3 (t) and 14.1 (q); *m/z* (EI) 195.1370 (M^+ − Br. $C_{12}H_{19}O_2$ requires 195.1385) 121 (100%), 114 (26%), 81 (73%), 67 (49%) and 55 (33%).

(*E,E*)-10-Bromodeca-2,7-dien-1-ol 27a

A solution of DIBAL in hexane (1 mol dm^{-3}; 4.1 cm^3, 4.06 mmol) was added dropwise over 10 min to a stirred solution of the dienoate **26a** (430 mg, 1.56 mmol) in dry hexane (5 cm^3) at 0 °C under nitrogen. The mixture was stirred at 0 °C for 15 min, after which it was quenched with hydrochloric acid (2 mol dm^{-3}; 1 cm^3). The separated hexane extract was washed with brine, dried and evaporated under reduced pressure. The residue was purified by chromatography on silica using ethyl acetate–light petroleum (bp 60–80 °C) (1:9) as eluent to give the *alcohol* **27a**

(0.37 g, 98%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 3343br, 2926, 2855, 1438 and 696; δ_H(250 MHz; $CDCl_3$) 1.44 (2 H, app quin., *J* 7.2, $CH_2CH_2CH_2$), 2.02 (4 H, m, allylic), 2.19 (1 H, br s, OH), 2.52 (2 H, m, allylic), 3.35 (2 H, t, *J* 7.1, CH_2Br), 4.05 (2 H, d, *J* 4.4, CH_2OH), 5.44 (2 H, m, vinylic) and 5.63 (2 H, m, vinylic); *m/z* (EI) 135.1188 [$M^+ - (Br + H_2O)$. $C_{10}H_{15}$ requires 135.1174] 162 (20%), 160 (17%), 95 (27%), 81 (100%), 79 (23%), 67 (73%), 55 (62%) and 41 (91%).

(*E*,*E*)-12-Bromododeca-1,4,9-trien-3-ol 29a

The alcohol was prepared from 10-bromodeca-2,7-dienal **28a** (produced from the corresponding carbinol **27a** by oxidation with PCC) and vinylmagnesium chloride, using the general procedure used in the synthesis of the trienol **14**. Chromatography gave the alcohol (50%) as a clear oil; ν_{max}(film)/cm^{-1} 3360br, 2926, 2855, 1668w and 968; δ_H(250 MHz; $CDCl_3$) 1.46 (2 H, app quin., *J* 7.3, $CH_2CH_2CH_2$), 2.04 (4 H, m, allylic), 2.54 (2 H, m, allylic), 3.36 (2 H, t, *J* 7.1, CH_2Br), 4.58 (1 H, m, CHOH), 5.09–5.58 (5 H, m, vinylic), 5.68 (1 H, dt, *J* 15.5 and 6.5, vinylic) and 5.89 (1 H, ddd, *J* 17.2, 10.4 and 5.8, CH_2=CH); δ_C(67.8 MHz; $CDCl_3$) 139.8 (d), 133.3 (d), 132.3 (d), 131.3 (d), 126.9 (d), 114.6 (t), 73.7 (d), 35.9 (t), 32.8 (t), 31.5 (t), 29.6 (t) and 28.5 (t); *m/z* (EI) 179.1807 (M^+ − Br. $C_{12}H_{19}O$ requires 179.1436) 123 (11%), 119 (11%), 111 (20%), 105 (13%), 97 (31%), 93 (100%), 77 (68%), 67 (57%), 57 (50%) and 41 (78%).

(*E*,*E*)-12-Bromododeca-1,4,9-trien-3-one 30a

The enone was prepared from the trienol **29a**, following oxidation with periodinane according to the procedure used in the synthesis of the trienone **13**. Chromatography on silica, using 5% ethyl acetate in light petroleum (bp 60–80 °C) as eluent gave the enone **30a** (84%) as a colourless oil; ν_{max}(film)/cm^{-1} 2931, 1666, 1632, 1611, 1403, 1217 and 969; δ_H(250 MHz; $CDCl_3$) 1.56 (2 H, app quin., *J* 7.3, $CH_2CH_2CH_2$), 2.05 (2 H, m, allylic), 2.26 (2 H, m, allylic), 2.54 (2 H, m, allylic), 3.37 (2 H, t, *J* 7.0, CH_2Br), 5.45 (2 H, m, CH_2CH=CHCH$_2$), 5.81 (1 H, dd, *J* 10.6 and 1.4, COCH=CHH), 6.23–6.39 (2 H, m, CH=CHCOCH=CHH), 6.60 (1 H, dd, *J* 17.4 and 10.5, COCH=CH_2) and 6.92 (1 H, dt, *J* 15.7 and 7.0, CH_2CH=CHCO); δ_C(67.8 MHz; $CDCl_3$) 190.0 (s), 148.9 (d), 135.2 (d), 133.1 (d), 128.6 (t), 128.6 (d), 127.8 (d), 36.2 (t), 33.2 (t), 32.3 (t), 32.1 (t) and 27.9 (t); *m/z* (EI) 177.1320 (M^+ − Br. $C_{12}H_{17}O$ requires 177.1279) 177 (7%), 159 (10%), 149 (9%), 131 (10%), 119 (10%), 107 (26%), 95 (21%), 81 (55%), 67 (42%) and 55 (100%).

(*E*,*E*)-12-Iodododeca-1,4,9-trien-3-one 21

The iodide was prepared from the corresponding bromide, in 75% yield, using the general procedure described for the synthesis of the trienone **6**. It showed ν_{max}(film)/cm^{-1} 2929, 1666, 1632, 1611, 1403, 1217 and 968; δ_H(250 MHz; $CDCl_3$) 1.57 (2 H, app quin., *J* 7.3, $CH_2CH_2CH_2$), 2.05 (2 H, m, allylic), 2.28 (2 H, m, allylic), 2.55 (2 H, m, allylic), 3.15 (2 H, t, *J* 7.1, CH_2I), 5.43 (2 H, m, CH_2CH=CHCH$_2$), 5.82 (1 H, dd, *J* 10.5 and 1.2, COCH=CHH), 6.33 (2 H, m, CH=CHCOCH=CHH), 6.61 (1 H, dd, *J* 17.4 and 10.6, COCH=CH_2) and 6.94 (1 H, dt, *J* 15.7 and 7.0, CH_2CH=CHCO); δ_C(67.8 MHz; $CDCl_3$) 189.7 (s), 148.6 (d), 134.9 (d), 132.4 (d), 129.3 (d), 128.3 (t), 128.3 (d), 36.5 (t), 32.0 (t), 31.8 (t), 27.5 (t) and 6.1 (t); *m/z* (EI) 177.1300 (M^+ − I. $C_{12}H_{17}O$ requires 177.1279) 177 (5%), 149 (6%), 133 (5%), 121 (10%), 107 (18%), 95 (14%), 81 (39%), 67 (31%) and 55 (100%).

1-(2-Cyclopropylcyclopentyl)but-3-en-2-one 33

Treatment of a solution of the trienone **21** (37 mg) in benzene (41 cm^3) with Bu_3SnH (35 mm^3, 0.13 mmol)–AIBN (2 mg), according to the procedure described for the synthesis of the dicyclopentacycloheptenone **20** gave the *bicycle* (51%), as a mixture of diastereoisomers showing ν_{max}(film)/cm^{-1} 2952, 1683, 1615, 1401, 1261, 1071 and 985; δ_H(270 MHz; $CDCl_3$) 0.30–0.60 (4 H, m, cyclopropyl CH_2), 0.80–2.20 (8 H, m, CH, CH_2), 2.37–2.62 (2 H, m, CHHCO), 2.83–3.01 (1 H, m, CHHCO), 5.82 (1 H, d, *J* 10.6, vinylic) and 6.19–6.45 (2 H, m, vinylic); δ_C(67.8 MHz; $CDCl_3$, major diastereoisomer) 211.0 (s), 136.9 (d), 127.5 (t), 47.5 (d), 41.4 (t), 38.6 (d), 31.3 (t), 30.7 (t), 22.8 (t), 12.0 (d), 5.0 (t) and 3.0 (t); *m/z* (EI) 135.08 [M^+ − (C_3H_5). $C_9H_{11}O$ requires 135.0810] 108 (66%), 95 (26%), 81 (36%), 73 (27%), 67 (47%) and 55 (100%).

(*E*,*E*)-Ethyl 9-bromonona-2,6-dienoate 26b

The unsaturated ester was prepared from 7-bromohept-4-enal (400 mg)[1] and ethoxycarbonylmethylene(triphenyl)-phosphorane (730 mg), according to the procedure described for the synthesis of the analogue **26a**. Chromatography gave the *dienoate* (90%) as a colourless oil; ν_{max}(film)/cm^{-1} 2981, 1720, 1655 and 972; δ_H(250 MHz; $CDCl_3$) 1.25 (3 H, t, *J* 7.1, OCH_2CH_3), 2.17 (2 H, m, allylic), 2.24 (2 H, m, allylic), 2.51 (2 H, m, allylic), 3.33 (2 H, t, *J* 7.1, CH_2Br), 4.15 (2 H, q, *J* 7.2, OCH_2CH_3), 5.47 (2 H, m, CH_2CH=CHCH$_2$), 5.79 (1 H, dt, *J* 15.6 and 1.3, CH=CHCO$_2$Et) and 6.91 (1 H, dt, *J* 15.6 and 6.7, CH=CHCO$_2$Et); δ_C(67.8 MHz; $CDCl_3$) 166.4 (s), 148.1 (d), 131.8 (d), 127.7 (d), 121.6 (d), 60.0 (t), 35.7 (t), 32.5 (t), 31.7 (t), 30.7 (t) and 14.1 (q); *m/z* (EI) 260.0390 (M^+. $C_{11}H_{17}BrO_2$ requires 260.0412), 215 (17%), 181 (14%), 149 (14%), 135 (13%), 114 (83%), 107 (68%), 86 (87%), 81 (11%), 67 (100%), 55 (13%) and 41 (91%).

(*E*,*E*)-9-Bromonona-2,6-dien-1-ol 27b

The alcohol was prepared from the corresponding ester by reduction with DIBAL, according to the procedure described for the synthesis of the dienol **27a**. Chromatography, using dichloromethane as eluent gave the *alcohol* (68%) as a clear oil; ν_{max}(film)/cm^{-1} 3334br, 2922, 1436, 1265, 1208, 1089 and 969; δ_H(250 MHz; $CDCl_3$) 2.07 (4 H, m, allylic), 2.49 (2 H, m, allylic), 3.32 (2 H, t, *J* 7.0, CH_2Br), 4.00 (2 H, d, *J* 4.2, CH_2OH) and 5.30–5.63 (4 H, m, vinylic); δ_C(67.8 MHz; $CDCl_3$) 132.6 (d), 131.8 (d), 129.3 (d), 126.9 (d), 63.1 (t), 35.7 (t), 32.7 (t), 31.8 (t) and 31.7 (t); *m/z* (EI) 121.1027 [$M^+ - (Br + H_2O)$. C_9H_{13} requires 121.1017] 187 (12%), 121 (15%), 93 (34%), 79 (50%) and 67 (100%).

(*E*,*E*)-11-Bromoundeca-1,4,8-trien-3-ol 29b

The title trienol was prepared from the dienol **27b**, according to the procedures described for the synthesis of the trienol **29a**. Chromatography, using ethyl acetate–light petroleum (bp 60–80 °C) (1:4) as eluent gave the *bromo alcohol* (85% overall) as a colourless oil; ν_{max}(film)/cm^{-1} 3361br, 2924, 2848, 1435, 1265 and 969; δ_H(250 MHz; $CDCl_3$) 2.08 (4 H, m, allylic), 2.50 (2 H, m, allylic), 2.58 (1 H, br s, OH), 3.32 (2 H, t, *J* 7.1, CH_2Br), 4.53 (1 H, app t, *J* 5.7, CHOH), 5.07 (1 H, dt, *J* 10.4 and 1.4, CH=CHH), 5.19 (1 H, dt, *J* 17.2 and 1.5, CH=CHH), 5.31–5.55 (3 H, m, vinylic), 5.64 (1 H, m, vinylic) and 5.84 (1 H, ddd, *J* 17.2, 10.3 and 5.7, CH=CHH); δ_C(67.8 MHz; $CDCl_3$) 139.7 (d), 132.6 (d), 131.4 (2 × d), 127.0 (d), 114.4 (t), 73.4 (d), 35.7 (t), 32.7 (t), 31.8 (t) and 31.7 (t); *m/z* (EI) 226.0376 ($M^+ - H_2O$. $C_{11}H_{15}Br$ requires 226.0357) 226 (6%), 174 (10%), 119 (20%), 105 (30%), 83 (73%), 67 (81%) and 55 (100%).

(*E*,*E*)-11-Iodoundeca-1,4,8-trien-3-one 23

Oxidation of the trienol **29b**, using periodinane, according to the procedure described for the preparation of the trienone **13** first gave the trienone **30a** (92%) as a colourless oil;

ν_{max}(film)/cm^{-1} 2928, 1666, 1632, 1611, 1403, 1216 and 970; δ_H(250 MHz; $CDCl_3$) 2.10–2.25 (2 H, m, allylic), 2.25–2.40 (2 H, m, allylic), 2.52 (2 H, app q, *J* 7, CH_2CH_2Br), 3.33 (2 H, t, *J* 7.0, CH_2Br), 5.46 (2 H, m, $BrCH_2CH_2CH{=}CH$), 5.78 (1 H, dd *J* 10.6 and 1.4, COCH=CH*H*), 6.24 (1 H, dd, *J* 17.4 and 1.4, COCH=C*H*H), 6.34 (1 H, d, *J* 15.8, COC*H*=$CHCH_2$), 6.58 (1 H, dd, *J* 14.4 and 10.5, COC*H*=CH_2) and 6.89 (1 H, dt, *J* 15.7 and 6.6, COCH=C*H*CH_2); δ_C(67.8 MHz; $CDCl_3$) 189.9 (s), 148.1 (d), 135.1 (d), 132.1 (d), 128.8 (d), 128.7 (t), 128.2 (d), 36.1 (t), 33.0 (t), 32.6 (t) and 31.2 (t); *m*/*z* (EI) 163.1078 (M^+ − Br. $C_{11}H_{15}O$ requires 163.1123) 163 (17%), 96 (55%), 67 (100%) and 55 (46%). Treatment of the bromide with sodium iodide in acetone, according to the procedure described for the preparation of the trienone **6**, then gave the corresponding *iodide* **23** (83%); ν_{max}(film)/cm^{-1} 1665, 1632, 1614, 1403 and 969; δ_H(250 MHz; $CDCl_3$) 2.10–2.25 (2 H, m, allylic), 2.25–2.40 (2 H, m, allylic), 2.52 (2 H, app q, *J* 7, CH_2CH_2I), 3.11 (2 H, t, *J* 7.1, CH_2I), 5.43 (2 H, m, $ICH_2CH_2CH{=}CH$), 5.79 (1 H, dd, *J* 10.6 and 1.2, COCH=CH*H*), 6.25 (1 H, dd, *J* 17.4 and 1.3, COCH=C*H*H), 6.35 (1 H, d, *J* 15.8, COC*H*=$CHCH_2$), 6.58 (1 H, dd, *J* 17.4 and 10.6, COC*H*=CH_2) and 6.90 (1 H, dt, *J* 15.7 and 6.6, COCH=C*H*CH_2); δ_C(67.8 MHz; $CDCl_3$) 189.5 (s), 147.7 (d), 134.7 (d), 131.4 (d), 129.6 (d), 128.4 (d), 128.3 (d), 36.3 (t), 32.3 (t), 32.2 (t), 30.8 (t) and 5.8 (t); *m*/*z* (EI) 163.0865 (M^+ − I. $C_{11}H_{15}O$ requires 163.1123) 163 (15%), 107 (14%), 96 (20%), 79 (15%), 67 (87%) and 55 (100%).

(*E*,*E*)-Cycloundeca-2,6-dienone 38

Treatment of a solution of the trienone **23** (67 mg) in benzene (77 cm^3) with Bu_3SnH (67 mm^3, 0.25 mmol)–AIBN (4 mg), according to the procedure described for the synthesis of dicyclopentacycloheptene **20**, gave the *dienone* **38** (6 mg, 16%) as a colourless oil; ν_{max}(film)/cm^{-1} 2927, 2854, 1692, 1630, 1260, 1023 and 798; δ_C(67.8 MHz; $CDCl_3$) 202.8 (s), 144.5 (d), 136.7 (d), 134.0 (d), 128.4 (d), 45.1 (t), 32.9 (t), 32.4 (t), 32.1 (t), 26.6 (t) and 23.7 (t); *m*/*z* (EI) 164.1195 (M^+. $C_{11}H_{16}O$ requires 164.1201) 164 (10%), 120 (15%), 107 (15%), 98 (25%), 79 (39%) and 68 (100%). A considerable amount of unchanged starting material (~80%) was recovered.

(*E*,*E*)-12-*tert*-Butyldimethylsiloxydodeca-4,8-dienal 40

Mercuric trifluoroacetate (273.5 mg, 0.64 mmol) was added in one portion to a stirred solution of 10-*tert*-butyldimethylsiloxydeca-1,6-dien-3-ol (3.65 g, 13 mmol)[1] in ethyl vinyl ether (100 cm^3), after which the solution was heated under reflux for 24 h. The solution was allowed to cool to room temperature and the solvent was then removed under reduced pressure to leave a brown oil. This was purified by column chromatography on silica using light petroleum–dichloromethane (10:1) as eluent to give (*E*)-10-*tert*-butyldimethylsiloxy-3-vinyloxydeca-1,6-diene (12.18 g, 36%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 2930, 2857, 1634, 1614, 1256, 1194, 1102, 837 and 759; δ_H(270 MHz; $CDCl_3$) 0.05 (6 H, s, 2 × CH_3), 0.90 [9 H, s, $C(CH_3)_3$], 1.52–1.81 (4 H, m, 2 × CH_2), 2.0–2.08 (4 H, m, 2 × $CH_2CH{=}CH$), 3.60 (2 H, t, *J* 6.5, CH_2O), 4.0 (1 H, dd, *J* 6.6 and 1.5, OCH=CH_2), 4.15 (1 H, app q, *J* 6.6, CHO), 4.30 (1 H, dd, *J* 14.1 and 1.5, OCH=CH_2), 5.20 (1 H, dt, *J* 10.7 and 1.2, CHCH=CH_2), 5.21 (1 H, dt, *J* 17.2 and 1.2, CHCH=CH_2), 5.42 (2 H, m, CH=C*H*), 5.74 (1 H, dt, *J* 17.2, 10.7 and 6.7, CHC*H*=CH_2) and 6.32 (1 H, dd, *J* 14.1 and 6.6, OC*H*=CH_2); δ_C(67.8 MHz; $CDCl_3$) −4.8 (2 × q), 18.8 (s), 26.4 (3 × q), 28.5 (t), 29.3 (t), 32.1 (t), 35.2 (t), 63.0 (t), 80.5 (d), 89.1 (t), 117.1 (t), 129.8 (d), 131.2 (d), 138.3 (d) and 151.2 (d); *m*/*z* (EI) 253.1669 [M^+ − $C(CH_3)_3$.$C_{14}H_{25}O_2Si$ requires 253.1624], 209 (9%), 171 (3%), 155 (3%), 135 (14%) and 81 (100%).

A solution of the above diene (2.87 g, 9.2 mmol) in benzene (2 cm^3) was heated in a sealed tube at 120 °C for 13 h. The solution was allowed to cool to room temperature, after which it was evaporated under reduced pressure to leave a yellow oil. This was purified by column chromatography on silica using light petroleum–dichloromethane (7:1) as eluent to give the *aldehyde* **40** (2.5 g, 87%) as a colourless oil (Found: C, 69.5; H, 11.6. $C_{18}H_{34}O_2Si$ requires C, 69.6; H, 11.0%); ν_{max}(film)/cm^{-1} 2856, 2717, 1728, 1472, 1256, 1103, 968, 836 and 758; δ_H(250 MHz; $CDCl_3$) 0.03 (6 H, s, 2 × CH_3), 0.88 [9 H, s, $C(CH_3)_3$], 1.55 (2 H, quin., $CH_2CH_2CH_2$), 2.02 (6 H, m, 3 × CH_2), 2.32 (2 H, app q, *J* 6.7, $CH_2CH{=}CH$), 2.48 (2 H, t, *J* 7.0, CH_2CHO), 3.59 (2 H, t, *J* 6.5, CH_2O), 5.38–5.44 (4 H, m, CH=CH) and 9.74 (1 H, s, CHO); δ_C(67.8 MHz; $CDCl_3$) −5.4 (2 × q), 18.3 (s), 25.1 (t), 25.9 (3 × q), 28.7 (t), 32.5 (t), 32.6 (t), 32.8 (t), 43.4 (t), 62.5 (t), 127.9 (d), 129.7 (d), 130.2 (d), 131.3 (d) and 202.1 (d); *m*/*z* (EI) 253.1669 [M^+ − $C(CH_3)_3$. $C_{14}H_{25}O_2Si$ requires 253.1624], 209 (9%), 171 (3%), 155 (3%), 135 (14%), 81 (100%).

(all-*E*)-17-*tert*-Butyldimethylsiloxyheptadeca-1,5,9,13-tetraen-3-ol 41a

Butyllithium (1.6 mol dm^{-3} solution; 1.94 cm^3, 3.09 mmol) was added dropwise over 5 min to a stirred suspension of methyl(triphenyl)phosphonium bromide (1.109 g, 3.09 mmol) in tetrahydrofuran (8 cm^3) at 0 °C under a nitrogen atmosphere, and the resulting solution was then stirred at 0 °C for 20 min. Butadiene monoepoxide (275 mm^3, 3.40 mmol) was added dropwise over 5 min to the solution which was then stirred at room temperature for 1 h. After this, the solution was cooled to −20 °C, and then treated dropwise with butyllithium (1.6 mol dm^{-3} solution; 1.94 cm^3, 3.09 mmol) over 5 min; it was then stirred at −20 °C for 20 min. A solution of the dienal **40** (960 mg, 3.09 mmol) in tetrahydrofuran (2 cm^3) was added over 10 min to the red solution which was then stirred at room temperature for 18 h under a nitrogen atmosphere. After this the solution was quenched by the addition of ether (10 cm^3) and water (5 cm^3), and the aqueous layer was then separated and extracted with ether (4 × 10 cm^3). The combined extracts were dried and evaporated under reduced pressure and the residue was purified by column chromatography on silica using light petroleum–dichloromethane (1:2) as eluent to give the *allylic alcohol* **41a** (650 mg, 56%) as a colourless oil; ν_{max}(film)/cm^{-1} 3405, 2929, 2856, 1644, 1472, 1438, 1256, 1102, 967, 836 and 776; δ_H(250 MHz; $CDCl_3$) 0.05 (6 H, s, 2 × CH_3), 0.89 [9 H, s, $C(CH_3)_3$], 1.56 (2 H, app quin., $CH_2CH_2CH_2$), 1.88 (1 H, br s, OH), 2.0–2.13 (10 H, m, 5 × $CH{=}CHCH_2$), 2.13–2.33 (2 H, m, $CH{=}CHCH_2CHOH$), 3.60 (2 H, t, *J* 6.5, CH_2O), 4.12 (1 H, m, C*H*OH), 5.11 (1 H, dt, *J* 10.5 and 1.5, CH=CH_2), 5.24 (1 H, dt, *J* 17.2 and 1.5, CH=CH_2), 5.30–5.60 (6 H, m, CH=CH) and 5.88 (1 H, ddd, *J* 17.2, 10.5 and 5.7, C*H*=CH_2). Signals observed for the major *E* isomer: δ_C(67.8 MHz; $CDCl_3$) −5.3 (2 × q), 18.3 (s), 25.9 (3 × q), 28.7 (t), 32.4 (t), 32.6 (4 × t), 40.5 (t), 62.5 (t), 71.8 (d), 114.5 (t), 125.3 (d), 129.7 (d), 130.0 (2 × d), 130.3 (d), 134.3 (d) and 140.3 (d); *m*/*z* (CI) 379.3032 (MH^+. $C_{23}H_{43}O_2Si$ requires 379.3032), 361, 247 and 229 (100%).

(all-*E*)-Heptadeca-4,8,12,16-tetraen-1,15-diol 41b

Tetrabutylammonium fluoride (1.1 mol dm^{-3} solution; 1.72 cm^3, 1.89 mmol) was added dropwise over 10 min to a stirred solution of the tetraenol **41a** (650 mg, 1.73 mmol) in tetrahydrofuran (50 cm^3) at 0 °C, after which the solution was allowed to warm to room temperature. After the solution had been stirred at room temperature for 6 h, it was diluted with water (50 cm^3) and ether (50 cm^3). The separated aqueous layer was extracted with ether (4 × 50 cm^3), and the combined organic layers were dried and evaporated under reduced pressure to leave a yellow oil. This was purified by column chromatography on silica using light petroleum–ether (1:1) as eluent to give the *diol* (366 mg, 81%) as a colourless oil; ν_{max}(film)/cm^{-1} 3382, 2921, 1644, 1434, 1052, 968 and 758; δ_H(250 MHz; $CDCl_3$) 1.62 (2 H, m, $CH_2CH_2CH_2OH$), 2.04 (10

H, m, CH_2CH=CH), 2.26 (2 H, m, CH=CHCH_2CHOH), 3.63 (2 H, t, J 6.5, CH_2OH), 4.10 (1 H, m, C*H*OH), 5.11 (1 H, dt, J 10.4 and 1.3, CH=CH_2), 5.23 (1 H, dt, J 17.2 and 1.3, CH=CH_2), 5.41 (6 H, m, CH=CH), 5.86 (1 H, ddd, J 17.2, 10.4 and 5.7, C*H*=CH_2). Signals observed for the major (*E*) isomer: δ_C(67.8 MHz; $CDCl_3$) 28.8 (t), 32.3 (t), 32.3 (d), 32.4 (t), 32.5 (d), 32.5 (t), 40.4 (t), 62.2 (t), 71.8 (d), 114.4 (t), 125.3 (d), 129.7 (d), 129.8 (d), 130.2 (d), 130.3 (d), 134.1 (d) and 140.3 (d).

(all-*E*)-17-Bromoheptadeca-1,5,9,13-tetraen-3-ol 41c

N-Bromosuccinimide (273 mg, 1.5 mmol) and triphenylphosphine (436 mg, 1.7 mmol) were added each in one portion to a stirred solution of the diol **41b** (366 mg, 1.4 mmol) in dichloromethane (30 cm^3) at −30 °C under a nitrogen atmosphere. The solution was allowed to warm to room temperature after which it was stirred at room temperature for 6 h. It was then evaporated under reduced pressure to leave a semi-solid residue which was purified by column chromatography on silica using dichloromethane as eluent to give the bromo alcohol (312 mg, 69%) as a colourless oil; ν_{max}(film)/cm^{-1} 3385, 2927, 1726, 1644, 1435, 1248, 1102, 1045 and 968; δ_H(250 MHz; $CDCl_3$) 1.70 (1 H, br s, OH), 1.92 (2 H, app quin., J 6.8, $BrCH_2CH_2$), 1.96–2.20 (10 H, m, CH=CHCH_2), 2.23–2.35 (2 H, m, CH=CHCH_2CHOH), 3.41 (2 H, t, J 6.8, CH_2Br), 4.13 (1 H, m, C*H*OH), 5.13 (1 H, dd, J 10.4 and 1.4, CH=CH_2), 5.26 (1 H, dd, J 17.1 and 1.4, CH=CH_2), 5.32–5.60 (6 H, m, CH=CH) and 5.88 (1 H, ddd, J 17.1, 10.4 and 5.3, C*H*=CH_2). Signals observed for the major *E* isomer: δ_C(67.8 MHz; $CDCl_3$) 30.8 (t), 32.3 (t), 32.4 (t), 32.5 (t), 32.5 (t), 32.6 (t), 33.3 (t), 40.5 (t), 71.8 (d), 114.6 (t), 125.3 (d), 128.3 (d), 129.9 (d), 130.2 (d), 131.5 (d), 134.5 (d) and 140.3 (d); m/z (CI) 344.1589 ($M + NH_4^+$. $C_{17}H_{31}BrNO$ requires 344.1589), 326, 309 and 279.

(all-*E*)-17-Bromoheptadeca-1,5,9,13-tetraen-3-one 42a

Periodinane (658 mg, 1.6 mmol) was added in one portion to a stirred solution of the tetraenol **41c** in dichloromethane (12 cm^3) at room temperature, and the solution was then stirred at room temperature under a nitrogen atmosphere for 3 h. After this the mixture was poured onto a stirred solution of sodium thiosulfate in saturated aqueous sodium hydrogen carbonate (10%; 20 cm^3) and then stirred vigorously for 15 min. The aqueous layer was separated and extracted with dichloromethane (4 × 25 cm^3) and the combined organic extracts were then dried and evaporated under reduced pressure to leave a white semi-solid. This was purified by column chromatiography on silica using pentane–dichloromethane (1 : 1) as eluent to give the *enone* (286 mg, 100%) as a colourless oil; ν_{max}(film)/cm^{-1} 2984, 2938, 1711, 1681, 1432, 1240, 1092 and 909; δ_H(250 MHz; $CDCl_3$) 1.90 (2 H, app quin., J 6.9, $BrCH_2CH_2$), 1.96–2.21 (10 H, m, CH=CHCH_2), 3.33 (2 H, dd, J 14.3 and 5.3, CH=CHCH_2CO), 3.40 (2 H, t, J 6.7, CH_2Br), 5.35–5.55 (4 H, m, CH=CH), 5.55–5.61 (2 H, m, C*H*=C*H*CH_2CO), 5.84 (1 H, dt, J 10.0 and 1.7, CH=CH_2), 6.24 (1 H, dd, J 17.6 and 1.7, CH=CH_2) and 6.39 (1 H, dd, J 17.6 and 10.0, C*H*=CH_2). Signals observed for the major *E* isomer: δ_C(67.8 MHz; $CDCl_3$) 29.8 (t), 30.9 (t), 32.3 (t), 32.5 (t), 32.6 (t), 32.7 (t), 33.4 (t), 43.9 (t), 122.1 (d), 128.3 (d), 128.6 (t), 129.9 (d), 130.2 (d), 131.6 (d), 134.7 (d), 136.0 (d) and 199.9 (s); m/z (CI) 342.1432 ($M + NH_4^+$. $C_{17}H_{29}BrNO$ requires 342.1433), 325 (MH^+), 309, 279, 255 and 201.

(all-*E*)-17-Iodoheptadeca-1,5,9,13-tetraen-3-one 42b

Sodium iodide (248 mg, 1.65 mmol) was added in one portion to a stirred solution of the tetraenone **42b** (270 mg, 0.83 mmol) in acetone (12 cm^3) at room temperature, and the solution was then heated under reflux for 2 h in a nitrogen atmosphere. It was cooled and evaporated under reduced pressure to leave a residue which was redissolved in ether (12 cm^3). The solution was washed with aqueous sodium thiosulphate (10%; 25 cm^3), and the aqueous layer was separated and extracted with ether (3 × 25 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave the *iodide* **42b** (259 mg, 84%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 3414, 3018, 2927, 2851, 1682, 1616, 1441, 1404, 1216, 1097, 969 and 757; δ_H(250 MHz; $CDCl_3$) 1.84 (2 H, app quin., J 6.9, $ICH_2CH_2CH_2$), 1.90–2.15 (10 H, m, CH_2CH=CH), 3.15 (2 H, t, J 6.9, CH_2I), 3.30 (2 H, dd, J 15.2 and 5.5, CH=CHCH_2CO), 5.25–5.48 (4 H, m, CH=CH), 5.48–5.58 (2 H, m, C*H*=C*H*CH_2O), 5.81 (1 H, dd, J 10.0 and 1.5, CH=CH_2), 6.22 (1 H, dt, J 17.6 and 1.5, CH=CH_2) and 6.34 (1 H, dd, J 17.6 and 10.0, C*H*=CH_2). Signals observed for the major *E* isomer: δ_C(67.8 MHz; $CDCl_3$) 6.5 (t), 32.0 (t), 32.3 (t), 32.3 (t), 32.4 (t), 32.8 (t), 32.8 (t), 43.6 (t), 121.8 (d), 127.8 (d), 128.3 (t), 129.5 (d), 129.9 (d), 131.3 (d), 134.3 (d), 135.7 (d) and 198.5 (s); m/z (FAB) 373 ($M^+ + H$, 1%). The product was used without further purification.

(all-*E*)-Cycloheptadeca-3,7,11-trienone 44

A solution of tetraenone **42b** (100 mg, 0.269 mmol) in benzene (1 cm^3) was added dropwise over 5 min to a stirred solution of AIBN (10 mg) in degassed benzene (70 cm^3) under reflux in a nitrogen atmosphere. Tributyltin hydride (78 mm^3, 0.296 mmol) was added dropwise over 10 min to the refluxing solution and heating under reflux continued for 2 h. The mixture was then cooled to room temperature.

Saturated aqueous potassium fluoride (20 cm^3) was added to the mixture which was then stirred vigorously for 18 h. It was then partitioned between ether (30 cm^3) and water (30 cm^3), and the aqueous layer was separated and extracted with ether (3 × 20 cm^3). The combined extracts were dried and evaporated under reduced pressure to leave a residue which was purified by column chromatography on silica using pentane–dichloromethane (2:1) as eluent to give the *cyclic ketone* (27 mg, 42%) as a colourless oil; ν_{max}(film)/cm^{-1} 2924, 2852, 1715, 1437, 1358, 1284, 1215, 1095 and 967; δ_H(250 MHz; $CDCl_3$) 1.17–1.43 (4 H, m), 1.53–1.69 (2 H, m), 1.95–2.17 (10 H, m, CH=CHCH_2), 2.44 (2 H, app q, J 6.7, CH_2CH_2CO), 3.11 (2 H, 2 × d, J 7.9, CH=CHCH_2CO) and 5.29–5.65 (6 H, m, CH=CH); δ_C(67.8 MHz; $CDCl_3$) 23.2 (t), 27.3 (t), 27.9 (t), 31.3 (t), 31.5 (t), 31.6 (t), 31.9 (t), 32.6 (t), 41.2 (t), 47.2 (t), 122.8 (d), 129.6 (d), 130.3 (2 × d), 130.5 (d), 135.0 (d) and 210.2 (s); m/z (EI) 246.1980 (M^+. $C_{17}H_{26}O$ requires 246.1984), 189 (4%), 161 (5%), 149 (9%) and 137 (20%).

Acknowledgements

We thank Fisons Pharmaceuticals for a Research Scholarship (to A. J. S.) and Glaxo Group Research Ltd, for a Research Fellowship (to D. S. W.). We also thank Drs J. Dixon (Fisons Pharmaceuticals) and R. F. Newton (Glaxo Group Research Ltd) for their interest.

References

1 G. Pattenden, A. J. Smithies and D. S. Walter, *J. Chem. Soc., Perkin Trans. 1*, 1995, preceding paper.
2 S. A. Hitchcock and G. Pattenden, *Tetrahedron Lett.*, 1992, **33**, 4843 (corrigendum *Tetrahedron Lett.*, 1992, **33**, 7448).
3 For preliminary publication see: M. J. Begley, G. Pattenden, A. J. Smithies and D. S. Walter, *Tetrahedron Lett.*, 1994, **35**, 2417.
4 For some summary of earlier work see: G. Pattenden, 'Polycycle Constructions by Transition Metal Catalysed and Radical Mediated Processes' in *Organometallic Reagents in Organic Synthesis*, Academic Press, eds. J. H. Bateson and M. B. Mitchell, 1993.
5 For an example of a radical-mediated transannular strategy towards diterpenoid ring systems see: A. G. Myers and K. R. Condroski, *J. Am. Chem. Soc.*, 1993, **115**, 7926; *J. Am. Chem. Soc.*, 1995, **117**,

3057. For examples of transannular cyclisations of cyclooctenyl radicals leading to polyquinane synthesis see: L. A. Paquette, J. A. Colapret and D. R. Andrews, *J. Org. Chem.*, 1985, **50**, 201; J. D. Winkler and V. Sridar, *J. Am. Chem. Soc.*, 1986, **108**, 1708; J. D. Winkler and V. Sridar, *Tetrahedron Lett.*, 1988, **29**, 6219.
6 C. Ligong, G. B. Gill and G. Pattenden, *J. Chem. Soc., Perkin Trans. 1*, 1995, following paper.
7 E. J. Enholm, H. Satici and G. Prasad, *J. Org. Chem.*, 1990, **55**, 324.
8 For other examples see: A. J. L. Beckwith and K. U. Ingold, in *Rearrangements in Ground and Excited States.* vol 1, ed. P. de Mayo, Academic Press Inc., New York, 1980; L. K. Montgomery and J. W. Matt, *J. Am. Chem. Soc.*, 1967, **89**, 3050; L. K. Montgomery, J. W. Matt and J. R. Webster, *J. Am. Chem. Soc.*, 1967, **89**, 923; Z. Cekovi and R. Saicic, *Tetrahedron Lett.*, 1990, **31**, 6085.
9 For recent examples of 3-*exo trig* cyclisations see: R. C. Denis and D. Gravel, *Tetrahedron Lett.*, 1994, **35**, 4531; W-W. Weng and T-Y. Luh, *J. Org. Chem.*, 1993, **58**, 5574; W. Zhang and P. Dowd, *Tetrahedron Lett.* 1992, **33**, 7307; M. Journet and M. Melacria, *J. Org. Chem.*, 1994, **59**, 718.

Paper 5/03364K
Received 14*th June* 1995
Accepted 2*nd August* 1995