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Reactions with alkenes of η^2-7-oxotetracarbonylmanganese complexes derived from diterpenoids

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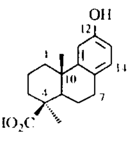
Abstract

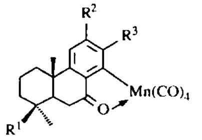
A number of activated 7-oxotetracarbonylmanganese(I) complexes derived from podocarpic acid (**1**) and from dehydroabietic acid have been coupled with alkenes to give C(14) functionalised derivatives in high yields. Some coupling reactions resulted in cyclization to C(7), forming 4*H*-acephenanthrylene derivatives in moderate yields. Several modes of activating these manganese complexes towards coupling reactions were investigated; these included oxidative decarbonylation at room temperature, thermal promotion, and palladium-mediation.

Introduction

Cyclomanganation has been used to activate specific sites in substituted arenes [1]. The η^1 C–Mn bond in orthomanganated aryl ketones can be transmetallated with either mercury(II) chloride [2] or palladium(II) chloride [3], making it possible subsequently to carry out Heck-type insertion reactions of substituted alkenes. Activation of aryltetracarbonylmanganese(I) complexes by oxidative decarbonylation with Me_3NO followed by coupling with alkenes or alkynes and cyclization to give indanols or indenols has also been communicated [4–6]. Here we report in full our work, which is directed at annulations of ring-C aromatic diterpenoids.



(1)



(4: $R^1 = CH_2OMe$, $R^2 = R^3 = H$
5: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Br$
7: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = CO_2Me$)

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Results and discussion

Simple tetracarbonylmanganese complexes such as that derived from acetophenone react with lithium tetrachloropalladate (1.0 molar equiv.) and subsequently couple with methyl propenoate at room temperature in methanol to form (*E*)-acrylate derivatives in good yield [3].

In the present work the diterpenoid-derived tetracarbonylmanganese complexes **2** and **3** [7] were treated with a palladium(II) salt and the subsequent coupling reactions with methyl propenoate investigated (Table 1). In the case of the 7-oxo complex **2**, coupling was observed at room temperature in methanol using lithium tetrachloropalladate and methyl propenoate, to give the saturated adduct **9** (3%) and the Heck-type insertion product **10** (50%), together with starting material **2** (8%) and the parent diterpenoid ligand **8** (11%). In contrast, the 12-methoxy-7-oxo complex **3** did not react with methyl propenoate at room temperature in the presence of either Li_2PdCl_4/MeOH or $Pd(OAc)_2(PPh_3)_2$/MeCN. When the latter reaction was repeated at reflux temperature coupling was observed in a combined yield of 59% [**13** and **14**], the saturated adduct **13** being the major component (50%). Reaction of **2** with Li_2PdCl_4/MeCN/propenenitrile using Pd^{II} in either catalytic or stoichiometric quantities at room temperature for 72 h afforded only mixtures of the starting complex **2** and the ketone **8** in varying amounts. In the Pd^{II}-mediated reactions reported previously [3] the palladium reagent was always used in stoichiometric quantities. Since catalytic processes involving this expensive metal are much more attractive, in the present work the complex **3** was reacted with methyl propenoate in the presence of 10 mol% of $Pd(OAc)_2(PPh_3)_2$, to give the saturated adduct **13** (86%) and the alkene insertion adduct **14** (10%). These results indicate that the optimum conditions for Pd^{II}-mediated coupling reactions of diterpenoid-derived tetracarbonylmanganese complexes require thermal activation but that stoichiometric use of Pd^{II} is unnecessary.

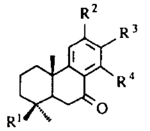
In all of the examples studied in the present work (Table 1) the alkene insertion product was exclusively the (*E*)-isomer (Scheme 1). Transmetallation of the tetracarbonylmanganese complex by lithium tetrachloropalladate is expected to give rise to cyclopalladated monomers (i), and possibly μ-chloro dimers, either of

Table 1

Products (%) from Pd-mediated coupling reactions of the tetracarbonyl complexes **2** and **3** with methyl propenoate

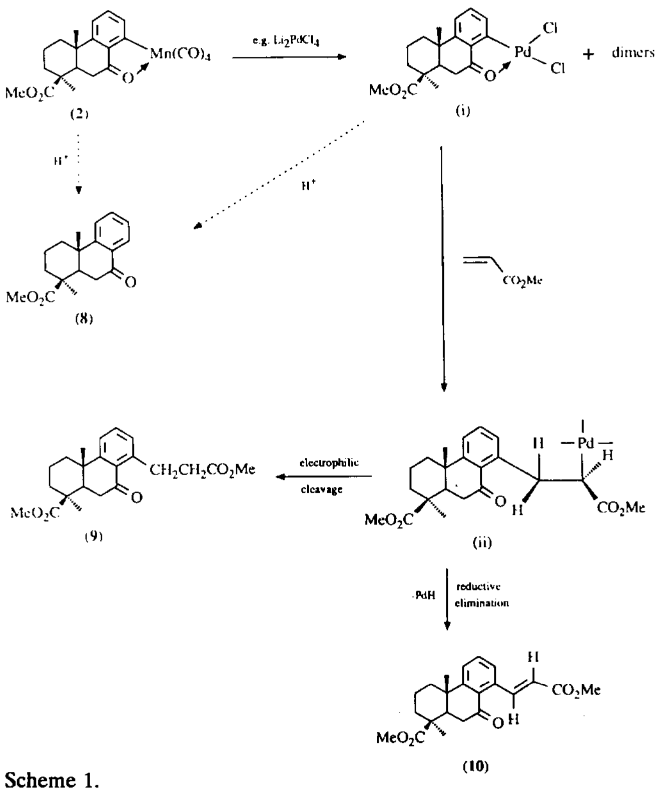
Complex 2	**2**	**8**	**9**	**10**
Li_2PdCl_4/MeOH/r.t./23 h [a]	8	11	3	50
Complex 3	**3**	**12**	**13**	**14**
Li_2PdCl_4/MeCN/Et_3N/r.t./21 h [b]	83	3	–	–
$Pd(OAc)_2(PPh_3)_2$/MeCN/r.t./47 h [a]	85	–	–	–
$Pd(OAc)_2(PPh_3)_2$/MeCN/NaO_2CCH_3/r.t./47 h [a]	91	–	–	–
$Pd(OAc)_2(PPh_3)_2$/MeCN/Et_3N/Δ 6.5 h [a]	–	13	50	9
$Pd(OAc)_2(PPh_3)_2$/MeCN/Et_3N/r.t./47 h [b]	90	–	–	–
$Pd(OAc)_2(PPh_3)_2$/MeCN/Et_3N/Δ/2 h [b]	–	3	86	10

[a] Pd used in stoichiometric amount (1.0 molar equiv.). [b] Pd used in catalytic amount (0.1 molar equiv.).



(11: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHCO_2Me$
13: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH_2CO_2Me$
14: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (E)CH{=}CHCO_2Me$
15: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (Z)CH{=}CHCO_2Me$
16: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = CH_2CH_2COMe$
17: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (E)CH{=}CHCOMe$
18: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHCOMe$
19: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = CH_2CH_2CHO$
20: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (E)CH{=}CHCHO$
21: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHCHO$
22: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = CH_2CH_2CN$
23: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (E)CH{=}CHCN$
24: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHCN$
25: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = CH_2CH_2OCOMe$
26: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (E)CH{=}CHOCOMe$
27: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHOCOMe$)

which react with methyl propenoate to form (ii). The most stable conformation for *syn* elimination of PdH from (ii) orients the bulky diterpenoid group *trans* to the ester carbonyl, leading exclusively to the (*E*)-isomer; cleavage of intermediate (ii) by H^+ gives rise to the saturated analogue **9**. When these reactions are performed in methanol, the solvent can act as the proton donor. However, when the reactions are performed in anhydrous acetonitrile there is no proton source of comparable



Scheme 1.

Table 2

Products (%) from coupling reactions between CH_2=CHX and chemically activated complexes

Complex 2	X = CO_2Me	**8**	11	**9**	59	**10**	22	**11**	–
	X = COMe	**8**	12	**16**	69	**17**	–	**18**	–
	X = CHO	**8**	4	**19**	32	**20**	–	**21**	–
	X = CN	**8**	8	**22**	39	**23**	4	**24**	2
	X = OCOMe	**8**	64	**25**	–	**26**	–	**27**	–
Complex 3	X = CO_2Me [a]	**12**	9	**13**	44	**14**	27	**15**	–
	X = CO_2Me	**12**	5	**13**	59	**14**	28	**15**	–
	X = CO_2Me [b]	**12**	3	**13**	64	**14**	18	**15**	–
	X = COMe [c]	**12**	11	**32**	51	**33**	–	**34**	–
	X = CHO	**12**	12	**35**	32	**36**	–	**37**	–
	X = CN	**12**	10	**38**	12	**39**	2	**40**	1
	X = OCOMe	**12**	56	**41**	–	**42**	–	**43**	–
Complex 4	X = CO_2Me	**28**	9	**29**	62	**30**	16	**31**	–
	X = CO_2Me [d]	**28**	6	**29**	53	**30**	9	**31**	8
Complex 5	X = CO_2Me	**44**	6	**45**	26	**46**	36	**47**	–

[a] In this reaction only 1.0 molar equiv. of methyl propenoate was used. [b] This reaction mixture was quenched with deuteriated acetic acid. [c] Also isolated was the cyclised product **56** (10%). [d] This reaction was performed in CD_3CN.

acidity, yet the saturated analogue **9** was still formed. The potential sources of the reducing hydrogen under these conditions will be discussed later. Similarly, protolytic cleavage of the tetracarbonylmanganese complex **2** or of the palladium derivative (i) can lead to the parent diterpenoid ketone **8**.

Palladium-catalyzed cross-coupling of aryl derivatives, including arylmercurials, with simple cyclic alkenes has been well documented [8–18]. Since transpalladation/vinylation of diterpenoid tetracarbonylmanganese complexes had been established using activated olefins it appeared that coupling with unactivated cycloalkenes should be feasible. In the event, however, reaction of the complex **3** with cyclohexene in the presence of palladium(II) acetate (2.5 mol%), tetrabutylammonium chloride, and potassium acetate in dimethylformamide [19–23] at room temperature for 23 h returned only **3** (23%) and the parent ketone **12** (32%).

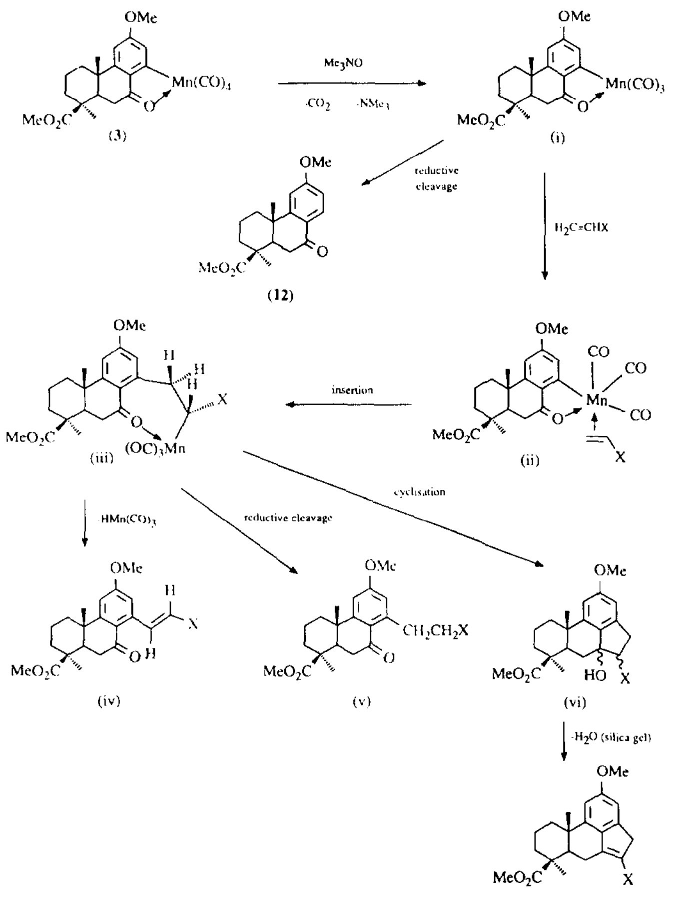
Liebeskind et al. [4] have reported the formation of 1-methyl-1*H*-inden-1-ols in high yields by conversion of (2-acetylphenyl)tetracarbonylmanganese into a reactive 16-electron species *via* oxidative decarbonylation with trimethylamine N-oxide in MeCN, followed by reaction with substituted alkynes. These workers did not, however, investigate any coupling reactions with substituted alkenes under these conditions. A number of 7-oxoditerpenoid-derived tetracarbonylmanganese complexes were therefore treated with trimethylamine N-oxide and then with a substituted olefin (Table 2). Of the five olefins used, methyl propenoate consistently gave the highest yields of coupled products. When two molar equivalents of this olefin were used, a typical product mixture consisted of 5–10% of the free diterpenoid ketone, 20–30% of the (*E*)-acrylate derivative, and 60–65% of its saturated analogue. When the quantity of olefin used was decreased to one molar equivalent the yield of the saturated analogue decreased by 10–15%.

Reaction of the activated complexes derived from **2** and **3** with 3-buten-2-one gave the saturated insertion products **16** and **32** in yields of 69 and 51%, respectively. In the case of the 12-methoxy-7-oxoditerpenoid complex **3**, the 4*H*-acephenanthrylene **56** (10%) was also isolated. The IR spectrum showed carbonyl maxima at 1723 (ester) and 1647 cm^{-1}, the latter being consistent with the presence of a highly conjugated ketone. The ^1H NMR spectrum showed a two-proton broadened singlet at 3.66 ppm which was assigned to $H(4)_2$. Furthermore, the resonance due to H(6ax) appeared as a doublet of doublets of triplets (*J* 17.6, 13.5, 3.9 Hz), the two large coupling constants being attributed to geminal splitting with H(6eq) and to diaxial vicinal splitting by H(6a), while the smallest splitting was characteristic of homoallylic coupling through to $H(4)_2$.

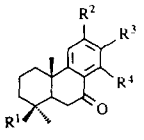
Coupling reactions of **2** and **3** with propenenitrile and with propenal gave much lower yields (45 and 15%, respectively), the saturated adduct being favoured in both cases. Reaction with acetoxyethene returned only the product of reductive cleavage of the C(14)–Mn bond. The alkene products isolated from these coupling reactions consisted exclusively of the (*E*)-isomer. However, a *trans* alkene can lead to a mixture of the (*E*)- and (*Z*)-isomers *via* photochemical excitation in the solid state. Such an isomerization was in fact observed for methyl (*E*)-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**10**), which was isolated in 22% yield from the reaction of activated **2** with methyl propenoate. ^1H NMR analysis immediately after isolation showed this compound to be pure, only two olefinic doublets being observed at 6.15 and 8.38 ppm (*J* 15.8 Hz). This crystalline solid was then left standing under argon exposed to daylight for 3 days; a mixture of the *trans* **10** and *cis* **11** isomers resulted. The less polar isomer (35%) showed the olefinic hydrogen resonances as doublets at 5.96 and 7.56 ppm (*J* 12.0 Hz) consistent with a (*Z*)-isomeric alkene. The (*E*)-isomer **10** was recovered in 56% yield. Although photochemically-induced isomerisation was not observed in all of the (*E*)-alkene adducts, it was observed most often in the coupled products from the 12-desmethoxy diterpenoids **2** and **4**, as well as in the analogous adducts derived from reaction of **2** and **3** with propenenitrile, from which a 2:1 (*E*:*Z*) ratio resulted.

The coupling products can arise as shown in Scheme 2. Oxidative decarbonylation of **3** gives the coordinatively unsaturated intermediate (i) and then the alkene complex (ii), which undergoes insertion into the Mn–C bond, forming (iii). Cyclization of this σ-alkyl complex affords a mixture of diastereoisomeric tricarbonylmanganese alkoxides which would decompose on workup, forming cyclopentanols (vi); elimination of water then gives the observed acephenanthrylene derivative (vii). Furthermore, *syn* elimination of $HMn(CO)_3$ from (iii) gives the (*E*)-alkene (iv). Alternatively, reductive cleavage of the C–Mn bond in intermediate (iii) gives rise to the saturated adduct (v) directly. Similar reaction of the activated tricarbonyl complex (i), presumably with a manganese hydride, leads to the formation of the free ketone **12**.

In an attempt to determine the source of putative reducing hydrogen, the complex **2** was treated with trimethylamine N-oxide and then methyl propenoate (2 molar equiv.); after 27 h at room temperature CD_3CO_2D was added (Table 2). The intention was to use the absence or presence of deuterium in the saturated adduct to establish whether a metal hydride generated *in situ* led to hydrogen transfer in the reductive cleavage, or whether demetallation occurred during workup. In the event, no deuterium incorporation was detected in either the saturated adduct **13** or in the parent ketone **12**. It was concluded, therefore, that



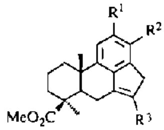
Scheme 2.



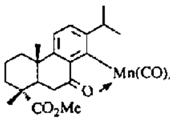
(**28**: $R^1 = CH_2OMe$, $R^2 = R^3 = R^4 = H$
29: $R^1 = CH_2OMe$, $R^2 = R^3 = H$, $R^4 = CH_2CH_2CO_2Me$
30: $R^1 = CH_2OMe$, $R^2 = R^3 = H$, $R^4 = (E)CH{=}CHCO_2Me$
31: $R^1 = CH_2OMe$, $R^2 = R^3 = H$, $R^4 = (Z)CH{=}CHCO_2Me$
32: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH_2COMe$
33: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (E)CH{=}CHCOMe$
34: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (Z)CH{=}CHCOMe$
35: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH_2CHO$
36: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (E)CH{=}CHCHO$
37: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (Z)CH{=}CHCHO$
38: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH_2CN$
39: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (E)CH{=}CHCN$
40: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (Z)CH{=}CHCN$
41: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH_2OCOMe$
42: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (E)CH{=}CHOCOMe$
43: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = (Z)CH{=}CHOCOMe$
44: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Br$, $R^4 = H$
45: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Br$, $R^4 = CH_2CH_2CO_2Me$
46: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Br$, $R^4 = (E)CH{=}CHCO_2Me$
47: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = Br$, $R^4 = (Z)CH{=}CHCO_2Me$
48: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH(Me)(CH_2CO_2Me)$
54: $R^1 = CO_2Me$, $R^2 = R^3 = H$, $R^4 = CH_2CH(COMe)(CO_2Me)$
55: $R^1 = CO_2Me$, $R^2 = OMe$, $R^3 = H$, $R^4 = CH_2CH(COMe)(CO_2M$

reductive cleavage occurs during the course of the reaction and not at the quenching stage. However, reaction of **4** with Me_3NO/methyl propenoate in deuteriated acetonitrile as solvent did not give any deuterium-labelled products. Since formation of the olefin insertion product (iv) (Scheme 2) generates one molar equivalent of $HMn(CO)_3$ this process can lead to one molar equivalent of the saturated analogue (v) and/or the ketone **12**. Clearly, however, this source of $HMn(CO)_3$ does not account for all of the reducing capability in the reaction medium, since with a single exception the yields of the reduced products far exceeded that of the alkene insertion product. Thus, reaction of the 13-bromo-12-methoxy-7-oxomanganese complex **5** with Me_3NO/methyl propenoate gave the alkene **46** (36%), together with the saturated analogue **45** (26%) and the parent ketone **44** (6%). The only remaining source of hydrogen able to lead, at least in part, to the reduced products was the excess of alkene. Transition metal complexes are known to be reduced by alkenes [24]. It is therefore possible that a redox reaction between a manganese(I) species and excess of alkene generates an alkyne and its complement, a manganese hydride.

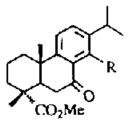
Reaction of the dehydroabietane complex **60** with Me_3NO/methyl propenoate at room temperature for 18 h afforded the ketone **61** (9%), the saturated adduct **62** (51%), the alkene insertion product **63** (7%), and the acephenanthrylene derivative **64** (12%). The ^1H NMR spectrum of the latter compound showed a two-proton triplet (J 1.3 Hz) at 3.63 ppm due to $H(4)_2$, the splitting again reflecting homoallylic coupling with $H(6)_2$. Since the coupled adducts obtained from **60** represent a combined yield of 70%, which compares favourably with the total yields of coupled products isolated from podocarpic acid derivatives (Table 2), the bulky isopropyl substituent at C(13) in **60** does not have a deleterious effect on the vinylation step.



(**56**: R^1 = OMe, R^2 = H, R^3 = COMe
57: R^1 = OMe, R^2 = COMe, R^3 = CO_2Me
58: R^1 = R^2 = H, R^3 = CO_2Me
59: R^1 = OMe, R^2 = H, R^3 = CO_2Me)

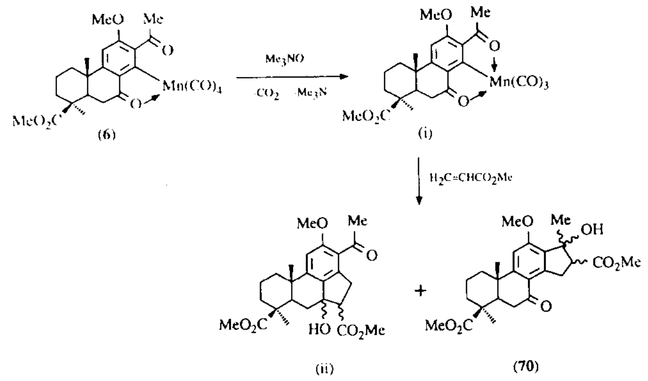


(**60**)

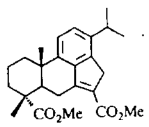


(**61**: R = H
62: R = $CH_2CH_2CO_2Me$
63: R = (E)CH=CHCO$_2$Me)

Coupling of the 13-acetyl-7-oxo complex **6** using Me_3NO/methyl propenoate presented an interesting dichotomy. This is because oxidative removal of a carbonyl ligand would form the tricarbonyl intermediate, which could be stabilised by internal ligation to the 13-acetyl group to regenerate an 18-electron complex (i) (Scheme 3) which might not be prone to undergo alkene coupling. Furthermore, if insertion of the olefin does occur, cyclization either to the 13-COMe or to C(7) can result. Examination of models of the potential tetracycles (ii) and **70** indicated that the C(13)–C(14) cyclized adduct **70** appeared to have less steric strain, and may therefore be the preferred indanol. In the event, treatment of **6** with Me_3NO in MeCN did not result in the distinctive colour change which had been observed with all of the other complexes, suggesting the formation of an intermediate of the



Scheme 3.



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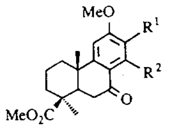
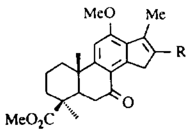
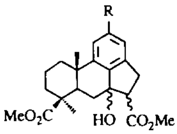


(65: R^1 = COMe, R^2 = H
66: R^1 = COMe, R^2 = $CH_2CH_2CO_2Me$
67: R^1 = COMe, R^2 = (*E*)CH=$CHCO_2Me$
68: R^1 = CO_2Me, R^2 = $CH_2CH_2CO_2Me$
69: R^1 = CO_2Me, R^2 = (*E*)CH=$CHCO_2Me$)

type (i); addition of methyl propenoate gave an inseparable mixture of the ketone **65** (6%) and the saturated addition product **66** (5%), the alkene **67** (15%), as well as the two C(13)–C(14) cyclopentaannulated products **70** (41%) and **71** (2%). The indene (**71**) had an accurate mass measurement for its molecular ion corresponding to $C_{23}H_{28}O_4$ and absorbed at 1725 (ester) and 1668 cm^{-1} (ketone) in the IR spectrum. In the ^{1}H NMR spectrum the 17-Me resonance occurred as a broadened triplet (*J* 1.6 Hz) at 2.30 ppm. The resonances owing to the indene methylene protons $H(15)_2$ were observed at 3.66 and 3.76 ppm as doublets of quartets (*J* 25.3, 2.0 Hz), while H(16) appeared as a quartet (*J* 1.6 Hz) at 6.14 ppm. Compound **71** corresponds to the product expected formally from the reaction of the complex **6** with ethene followed by loss of water. Apparently there is a demethoxycarbonylation reaction mediated by manganese after the olefin has inserted into the C–Mn bond. The cyclopentanols **70** were isolated in two fractions, the least polar of which consisted of a single diastereoisomer (9%) whereas the more polar fraction contained (^{1}H NMR) three diastereoisomers (1.0 : 1.2 : 1.5) (32%). Confirmation that cyclization had indeed occurred across 13-acetyl–C(14) came from the acid-catalysed elimination reaction of **70**, which gave the tetraene **72** (76%). In the ^{1}H NMR spectrum of **72** the 17-Me resonance occurred as a triplet (*J* 2.4 Hz) at 2.71 ppm, and the $H(15)_2$ resonances were observed at 3.97 and 4.09 ppm as doublets of quartets (*J* 25.3, 2.4 Hz). The presence of the latter homoallylic coupling to 17-Me is conclusive proof of the structure of **72** since analogous coupling would not be observed in the isomeric C(7)–C(14) tetraene **57**.



(71: R = H
72: R = CO$_2$Me)



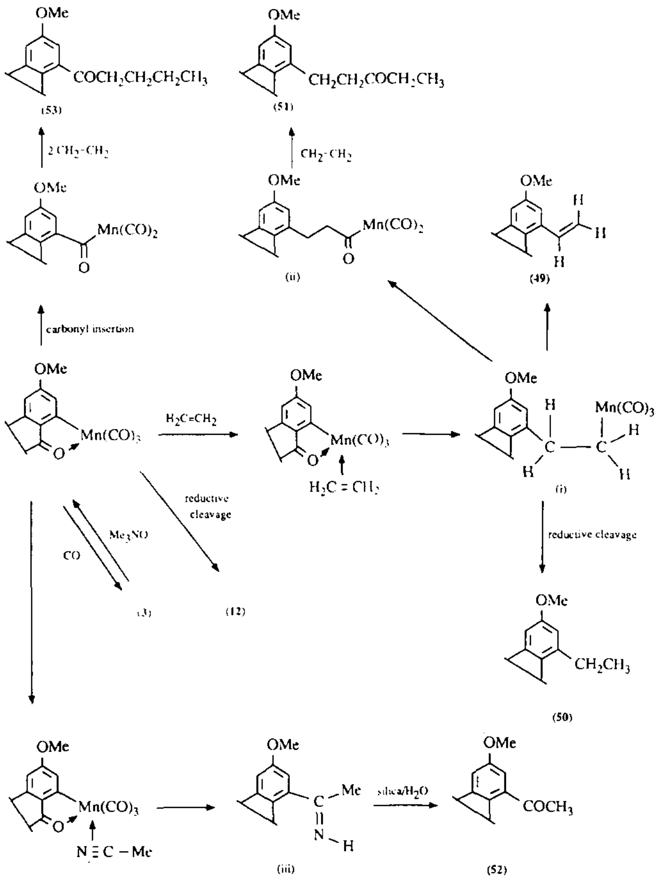
(73: R = H
74: R = OMe)

In contrast to the reaction of **6**, the 13-methoxycarbonyl-7-oxo complex **7** did not give any adducts cyclised to the 13-ester, yielding only the saturated adduct **68** (61%), and the alkene **69** (17%).

Reaction of the complex **3** with Me_3NO/methyl but-2-enoate gave the ketone **12** (80%) and a mixture (2 : 1) (11%) of the 3(*R*) and 3(*S*) diastereoisomers of the saturated adduct **48**. The presence of two methoxycarbonyl groups was evident in the ^{13}C NMR spectrum of **48** which showed resonances at *ca.* 173 and 177 ppm, assigned to the propanoate-CO_2Me and 4-CO_2Me, respectively. The presence of the terminal methyl group on the alkene clearly decreases the yield of coupled adducts, reflecting retardation of the insertion step. Only the parent ketone **12** was recovered when either cyclohexene or cyclohex-2-enone was used as the alkene. In general the yields of coupled adducts decreased as olefin substitution increased [$H_2C{=}CHX > RCH{=}CHX \sim CH_2{=}C(R)X \gg RCH{=}CHR$].

Coupling of ethene with manganese complexes activated either by transmetallation or chemically has not been reported by other workers. Reaction of complex **3** with Me_3NO and then with ethene (340 kPa) at room temperature afforded the starting complex (6%), the ketone **12** (23%), the saturated adduct **50** (21%), the insertion product **49** (2%), the 14-acetyl derivative **52** (3%), and the products **51** (9%) and **53** (3%) of insertion of CO and two molecules of ethene (Scheme 4). The re-formation and isolation of the tetracarbonylmanganese complex **3** is clearly a consequence of the reaction being carried out in a closed system so that re-ligation of CO is competitive to some degree with π-complexation of ethene. The 3-pentanone derivative **51** can form *via* intermediate (i), which also gives rise to the vinyl and ethyl derivatives **49** and **50**. This intermediate undergoes carbonyl insertion to form an acyl manganese species (ii) which then adds a further molecule of ethene; reductive cleavage affords **51**. Alternatively, if the initial tricarbonylmanganese complex undergoes carbonyl insertion followed by successive addition of two ethene molecules, reductive cleavage leads to **53**. The 14-acetyl derivative **52** could represent the product of carbonyl insertion followed by the incorporation of only one of the two ethene carbons. However, an alternative route could involve insertion of solvent acetonitrile into the C–Mn bond followed by reductive cleavage to form the imine (iii), which upon workup could hydrolyse to **52**. The latter explanation is favoured since in the thermally-promoted coupling reactions with methyl propenoate in acetonitrile (see below) similar products of apparent acetyl insertion were observed, and yet in these reactions methyl propenoate would have had to act as the donor of a methyl group, which is highly unlikely. Furthermore, the isolation of other coupled adducts containing an odd number of carbons in the C(14) side-chain whose origin was solely attributed to ethene insertion would have been expected; these were not observed.

Coupling of (2-acetylphenyl)tetracarbonylmanganese with diphenylacetylene in refluxing benzene to give 2,3-diphenyl-1-methylinden-1-ol (97%) has been re-



Scheme 4.

ported [25]. There is no report of the attempted coupling of tetracarbonylmanganese complexes with substituted olefins under thermal activation. Since all of the previous chemically activated coupling reactions had been performed in anhydrous acetonitrile, this solvent was chosen for the thermally activated reactions. Reaction of the 7-oxo complexes **2** and **7** with methyl propenoate in refluxing acetonitrile gave the products shown in Table 3.

Although complex **2** gave only a single diastereoisomer of the cyclopentanol **73**, it was obtained as an inseparable mixture (1 : 1 : 1) with the two diastereoisomers of

Table 3

Products from thermally promoted reactions of complexes **2** and **3** with methyl propenoate

solvent	complex	products (%)									
acetonitrile	**2**	**9**	36	**54**	24	**73**	14				
acetonitrile	**3**	**12**	27	**55**	50	**74**	10				
methanol	**3**	**3**	2	**12**	5	**13**	91				
heptane	**3**	**3**	15	**12**	15	**13**	13	**14**	30	**59**	9

the saturated adduct **54**, and its absolute stereochemistry could not be established. Treatment of a portion of this mixture with dilute aqueous HCl in methanol gave the 4*H*-acephenanthrylene derivative **58** and a mixture (24%) of the two diastereoisomers of **54**. A similar mixture containing at least three cyclized alcohols **74** in addition to the two diastereoisomers of **55** was obtained from complex **3**. Acid-catalysed dehydration gave separately the tetraene derivative **59** and a mixture (50%) of the two diastereoisomers of **55**. In the ^{1}H NMR spectra of **58** and **59** the expected homoallylic couplings between H(4) and H(6) were observed, providing conclusive proof for both structures. One of the diastereoisomeric alcohols **74** was obtained pure after repetitive PLC followed by recrystallization from hexanes/Et_2O. Its IR spectrum showed a sharp absorption band (OH) at 3503 cm^{-1} and carbonyl absorption maxima at 1733 and 1714 cm^{-1}. The ^{13}C NMR spectrum showed a quaternary carbon at 77.6 ppm due to C(5a), which is bonded to an hydroxyl group. The acetyl group in the adducts **54** and **55** was indicated by the presence of two three-proton singlets near 2.3 ppm in the ^{1}H NMR spectrum, and by resonances at *ca.* 30 and 204 ppm in the ^{13}C NMR spectrum. The formation from **2** and **3** of the diastereoisomeric mixtures of the acetoacetates **54** and **55** occurs presumably *via* insertion of acetonitrile into a coordinatively unsaturated intermediate formed subsequent to insertion of methyl propenoate into the C–Mn bond of the tricarbonylmanganese complex. The resultant imines would hydrolyse to the observed diastereoisomeric acetyl derivatives during workup.

Reaction of complex **3** with methyl propenoate in refluxing methanol gave the ketone **12** (5%) and the saturated adduct **13** (91%) (Table 3). The formation of **13** is clearly favoured under these conditions owing to the hydrogen (proton) donating ability of the solvent. Methanol can react with the unsaturated manganese intermediates to form manganese hydride species which form **13** upon reductive elimination. This conclusion is supported by the product distribution observed from the reaction of **3** with methyl propenoate in refluxing heptane; these aprotic conditions favour instead formation of the alkene **14** (30%). Also isolated were the ketone **12** (15%), the saturated adduct **13** (13%), and the acephenanthrylene **59** (9%).

Experimental

For general experimental details see refs. 26 and 27. High field ^{1}H NMR spectra were determined on a Bruker AM400 instrument operating at 9.2 Tesla. Multiplicities were determined from DEPT spectra.

General procedure for activation of tetracarbonylmanganese complexes with Me_3NO in acetonitrile followed by coupling with alkenes

A degassed solution of the yellow tetracarbonylmanganese complex (0.1–0.5 mmol) in dry acetonitrile (5–10 mL) was treated with anhydrous trimethylamine N-oxide (1.5 molar equiv.) under an argon atmosphere, giving an immediate colour change. After stirring for 5 min at room temperature, the deep orange or red solution was treated with the appropriate alkene (1.0–8.0 molar equiv.) and the mixture was stirred at room temperature for 6–54 h, over which period the colour faded. The mixture was then filtered through a small column of alumina or silica gel and the eluate concentrated *in vacuo*. The residue was purified by either PLC or flash chromatography (silica gel) using hexanes/Et$_2$O as eluent; products are reported in order of increasing polarity.

Reactions of tetracarbonyl(methyl 7-oxopodocarpa-8,11,13-trien-19-oate-C^{14};O^{7}) manganese (2)

(a) with methyl propenoate in MeCN. The complex **2** (0.27 g, 0.59 mmol) in MeCN (5 mL) was treated with Me$_3$NO (66 mg, 0.88 mmol) and then with methyl propenoate (0.11 mL, 1.17 mmol). 48 h workup and PLC afforded (i) methyl 7-oxopodocarpa-8,11,13-trien-19-oate (**8**) (18 mg, 11%); (ii) methyl 3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**9**) (0.13 g, 59%) which crystallized from Et$_2$O as needles, m.p. 86–87°C (Found: C, 71.2; H, 7.6. C$_{22}$H$_{28}$O$_5$ calcd.: C, 70.9; H, 7.2%). ν_{max} 1735, 1719 (ester CO), 1671 cm^{-1} (ketone CO). δ(H) (ppm) 1.11, s, H(20)$_3$; 1.13, txd, J 13.5, 4.0 Hz, H(3ax); 1.27, s, H(18)$_3$; 1.52, txd, J 13.4, 4.1 Hz, H(1ax); 1.71, dxp, J 14.3, 3.2 Hz, H(2eq); 2.02, qxt, J 13.9, 3.5 Hz, H(2ax); 2.03, dxd, J 14.3, 3.8 Hz, H(5); 2.31, bd, J 13.6 Hz, H(3eq); 2.35, bd, J 13.1 Hz, H(1eq); 2.60–2.74, m, 14-CH$_2$CH_2CO$_2$Me; 2.93, dxd, J 17.8, 3.8 Hz, H(6eq); 3.23–3.39, m, 14-CH_2CH$_2$CO$_2$Me; 3.27, dxd, J 17.8, 14.4 Hz, H(6ax); 3.67, s, 14-CH$_2$CH$_2$CO$_2$*Me*; 3.71, s, (19-OMe); 7.14, dxd, J 7.3, 1.2 Hz, H(11); 7.34, dxd, J 8.1, 1.2 Hz, H(13); 7.40, t, J 8.0 Hz, H(12). δ(C) (ppm) 19.7, C(2); 21.5, C(20); 27.7, C(18); 31.0, 14-CH$_2$*C*H$_2$CO$_2$Me; 35.3, C(6); 37.3, C(3); 39.0, C(1); 39.1, C(10), 14-*C*H$_2$CH$_2$CO$_2$Me; 43.8, C(4); 49.3, C(5); 51.4, 14-CH$_2$CH$_2$CO$_2$*Me*; 51.5, (19-OMe); 123.5, C(11); 129.3, C(8); 129.8, C(13); 132.8, C(12); 143.0, C(14); 155.8, C(9); 173.8, 14-CH$_2$CH$_2$*C*O$_2$Me; 176.9, C(19); 200.4, C(7). m/z 372 (40, M^+), 341 (8, M – OMe), 312 (100, M – HCO$_2$Me), 298 (13, M – HCO$_2$Me-Me), 265 (8), 237 (10), 197 (15); and (iii) methyl (E)-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**10**) (47 mg, 22%) which crystallized from hexanes/Et$_2$O as needles, m.p. 109.5–111°C (Found: C, 71.2; H, 7.0. C$_{22}$H$_{26}$O$_5$ calcd.: C, 71.3; H, 7.1%). ν_{max} 1718 (ester CO), 1674 (ketone CO), 1629, 1583, 1468, 1435 cm^{-1} (C=C). δ(H) (ppm) 1.12, s, H(20)$_3$; 1.15, txd, J 13.6, 4.0 Hz, H(3ax); 1.27, s, H(18)$_3$; 1.53, txd, J 13.3, 4.2 Hz, H(1ax); 1.73, dxp, J 14.3, 3.2 Hz, H(2eq); 2.03, qxt, J 13.9, 3.4 Hz, H(2ax); 2.06, dxd, J 14.3, 3.8 Hz, H(5); 2.31–2.40, m, H(1eq), H(3eq); 2.99, dxd, J 18.1, 3.8 Hz, H(6eq); 3.31, dxd, J 18.1, 14.4 Hz, H(6ax); 3.72, s, (19-OMe); 3.81, s, 14-CH=CHCO$_2$*Me*; 6.15, d, J 15.8 Hz, 14-CH=CHCO$_2$Me; 7.33, dxd, J 6.2, 2.3 Hz, H(13); 7.49–7.54, m, H(11), H(12); 8.38, d, J 15.8 Hz, 14-CH=CHCO$_2$Me. δ(C) (ppm) 19.6, C(2); 21.4, C(20); 27.7, C(18); 37.2, C(3); 38.3, C(6); 38.7, C(1); 38.9, C(10); 43.8, C(4); 49.3, C(5); 51.6, 14-CH=CHCO$_2$*Me*, (19-OMe); 119.3, 14-CH=*C*HCO$_2$Me; 126.1, 129.5, C(11), C(13); 129.5, C(8); 133.1, C(12); 137.1, C(14); 147.1, 14-*C*H=CHCO$_2$Me; 155.5, C(9); 167.2, 14-CH=CH*C*O$_2$Me; 176.8, C(19); 199.7, C(7). δ(C) (ppm) (C$_6$D$_6$) 0.74, txd, J 13.4, 4.0 Hz, H(3ax); 0.87, s, H(20)$_3$; 0.92, s, H(18)$_3$; 1.10, txd, J 13.4, 4.0 Hz, H(1ax); 1.45, dxp, J 14.3, 3.0 Hz, H(2eq); 1.50, dxd, J 14.3, 3.5 Hz, H(5); 1.91, bd, J 12.9 Hz, H(3eq); 2.00, qxt, J 13.9, 3.6 Hz, H(2ax); 2.21, bd, J 13.3 Hz, H(1eq); 2.87, dxd, J 17.9, 3.9 Hz, H(6eq); 3.20, dxd, J 17.9, 14.3 Hz, H(6ax); 3.22, s, (19-OMe); 3.49, s, 14-CH=CHCO$_2$*Me*; 6.35, d, J 15.8 Hz, 14-CH=CHCO$_2$Me; 7.04–7.09, 7.16–7.21, m, H(11), H(12), H(13); 8.99, d, J 15.8 Hz, 14-CH=CHCO$_2$Me. δ(C) (ppm) (C$_6$D$_6$) 20.0, C(2); 21.4, C(20); 27.5, C(18); 37.4, C(3); 38.7, C(1), C(6); 39.0, C(10); 43.8, C(4); 49.0, C(5); 51.0, 51.2, (19-OMe), 14-CH=CHCO$_2$*Me*; 120.1, 14-CH=*C*HCO$_2$Me; 126.2, 127.1, C(11), C(13); 132.9, C(12); 137.6, C(14); 147.5,

14-*C*H=CHCO$_2$Me; 155.5, C(9); 167.0, 14-CH=CH*C*O$_2$Me; 176.5, C(19); 198.7, C(7). C(8) was not detected. *m/z* 370 (1, *M*$^+$), 339 (1, *M* – OMe), 311 (100, *M* – CO$_2$Me), 251 (12), 195 (21).

Exposure of **10** (55 mg) under argon to sunlight for 3 days and PLC afforded (i) methyl (*Z*)-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**11**) (19 mg, 35%) as a clear oil (Kugelrohr, 180°C/0.05 mmHg) (Found: C, 71.2; H, 7.1. $C_{22}H_{26}O_5$ calcd.: C, 71.3; H, 7.1%). ν_{max} 1728, 1712 (ester CO), 1675 cm^{-1} (ketone CO). δ(H) (ppm) 1.13, txd, *J* 13.7, 4.3 Hz, H(3ax); 1.13, s, H(20)$_3$; 1.25, s, H(18)$_3$; 1.58, txd, *J* 13.4, 4.1 Hz, H(1ax); 1.71, dxp, *J* 14.3, 3.2 Hz, H(2eq);2.03, qxt, *J* 14.0, 3.6 Hz, H(2ax); 2.09, dxd, *J* 14.5, 3.4 Hz, H(5); 2.31, bd, *J* 13.5 Hz, H(3eq); 2.38, bd, *J* 12.9 Hz, H(1eq); 2.95, dxd, *J* 17.9, 3.4 Hz, H(6eq); 3.24, dxd, *J* 17.9, 14.5 Hz, H(6ax); 3.57, s, 14-CH=CHCO$_2$*Me*; 3.70, s, (19-OMe); 5.96, d, *J* 12.0 Hz, 14-CH=C*H*CO$_2$Me; 7.16, dxt, *J* 6.9, 1.0 Hz, H(13); 7.43–7.49, m, H(11), H(12); 7.56, d, *J* 12.0 Hz, 14-C*H*=CHCO$_2$Me, δ(C) (ppm) 19.6, C(2); 21.5, C(20); 27.8, C(18); 37.2, C(3); 38.3, C(6); 38.7, C(1); 38.9, C(10); 43.8, C(4); 49.4, C(5); 51.0, 14-CH=CHCO$_2$*Me*; 51.5, (19-OMe); 116.4, 14-CH=*C*HCO$_2$Me; 125.1, 128.4, C(11), C(13); 132.5, C(12); 137.8, C(14); 148.6, 14-*C*H=CHCO$_2$Me; 154.9, C(9); 166.6, 14-CH=CH*C*O$_2$Me; 176.9, C(19); 199.6, C(7). C(8) was not detected. *m/z* 370 (2, *M*$^+$), 339 (2, *M* – OMe), 311 (100, *M* – CO$_2$Me), 279 (3), 251 (12), 195 (19); and (ii) **5** (31 mg, 56%).

(b) with methyl propenoate and Li_2PdCl_4 *in MeOH.* A mixture of PdCl$_2$ (87 mg, 0.49 mmol) and LiCl (43 mg, 1.03 mmol) was stirred under argon in MeOH (10 mL) for 3 h, methyl propenoate (0.35 mL, 3.83 mmol) and a solution of **2** (0.22 g, 0.49 mmol) in MeOH (7 mL) were added, and the mixture was stirred for 23 h at room temperature, during which a dark precipitate formed. Workup and PLC gave (i) **2** (18 mg, 8%); (ii) **8** (16 mg, 11%); (iii) **9** (5 mg, 3%); and (iv) **10** (91 mg, 50%).

(c) with methyl propenoate in refluxing MeCN. A solution of **2** (0.22 g, 0.49 mmol) and methyl propenoate (0.09 mL, 0.97 mmol) in MeCN (5 mL) was heated to reflux for 8.5 h under argon. Workup and PLC gave (i) **4** (48 mg, 36%); and (ii) a mixture (1 : 1 : 1, ^{1}H NMR) (74 mg) of methyl 2*RS*-[14-methylene-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]-3-oxobutanoate (**54**) and a single diastereoisomer of dimethyl [6aR-(5ζ,5aζ,6aα,7β,10aβ)]-5a-hydroxy-7,10a-dimethyl-4,5,5b,6,6a,7,8,9,10,10a-decahydroacephenanthrylene-5,7-dicarboxylate (**73**) as an oily solid. **73**; δ(H) (ppm) 0.86, s, (7-Me); 1.13, s, (10a-Me); 3.64, s, (7-CO$_2$Me); 3.82, s, (5-CO$_2$Me); 7.07, 7.08, bd, *J* 7.8 Hz, H(1), H(3); 7.21, t, *J* 7.6 Hz, H(2). δ(C) (ppm) 19.7, C(9); 22.5, (10a-Me); 28.5, (7-Me); 33.4, 33.5, C(4), C(6); 37.5, C(8); 37.6, C(10); 38.3, C(10a); 43.9, C(7); 48.0, C(6a); 51.3, 51.9, 5-CO$_2$*Me*, 7-CO$_2$*Me*; 55.3, C(5); 78.0, C(5a); 122.2, C(1); 122.7, C(3); 129.5, C(2); 139.8, C(3b); 141.0, C(3a); 146.1, C(10b); 173.8, 5-*C*O$_2$Me; 178.3, 7-*C*O$_2$Me.

A portion of this mixture (65 mg) was treated with dilute aqueous HCl (2 drops) in methanol (3 mL) for 30 min at room temperature. Workup and PLC gave (i) dimethyl [6aR-(6aα,7β,10aβ)]-7,10a-dimethyl-6,6a,7,8,9,10,10a-octahydro-4*H*-acephenanthrylene-5,7-dicarboxylate (**58**) (13 mg, 20%) as a clear oil (Found: *M*$^+$, 354.1829. $C_{22}H_{26}O_4$ calcd.: *M*, 354.1831). ν_{max} 1714 (non-conj. ester CO), 1667 cm^{-1} (conj. ester CO). δ(H) (ppm) 1.03, s, (10a-Me); 1.11, txd, *J* 13.5, 4.0 Hz, H(8ax); 1.35, s, (7-Me); 1.51, txd, *J* 13.4, 4.1 Hz, H(10ax); 1.68, dxp, *J* 14.3, 3.8 Hz, H(9eq); 1.79, dxd, *J* 13.6, 3.4 Hz, H(6a); 2.03, qxt, *J* 13.9, 3.5 Hz, H(9ax); 2.32, bd, *J* 13.4 Hz, H(8eq); 2.39, bd, *J* 12.9 Hz, H(10eq); 3.23, dxdxt, *J* 18.5, 13.7, 4.3 Hz, H(6ax); 3.65–3.67, m, H(4)$_2$; 3.72, s, (7-CO$_2$Me); 3.81, bdxt, *J* 18.6, 3.4 Hz, H(6eq); 3.85, s, (5-CO$_2$Me); 7.19–7.23, m, H(3); 7.28–7.31, m, H(1), H(2).. δ(C) (ppm) 19.6, C(9); 21.8, (10a-Me); 24.6, C(4); 28.6, (7-Me); 37.3, C(10a); 37.6, C(6); 38.3, C(8); 38.6, C(10); 44.4, C(7); 51.2, 5-CO$_2$*Me*; 51.5, 7-CO$_2$*Me*; 51.6, C(6a); 121.1, C(1); 121.5, C(3); 125.1, C(5a); 128.6, C(2); 139.7, C(3b); 142.3, C(3a); 146.2, C(5); 153.6, C(10b); 166.3, 5-*C*O$_2$Me; 177.6, 7-*C*O$_2$Me. *m/z* 354 (64, M^+), 336 (5, $M - H_2O$), 322 (15, *M* − HOMe), 294 (100, *M* − HCO$_2$Me), 279 (67, 294 − Me), 235 (35), 179 (37), 165 (38); and (ii) a mixture (1:1) (24 mg, 37%) of epimers at C(2) of methyl 2*RS*-acetyl-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**54**) as a white solid, m.p. 87–95°C (Found: M^+, 414.2100. $C_{24}H_{30}O_6$ calcd.: *M* 414.2042). ν_{max} 1715 (ester CO), 1671 (ketone CO), 1460, 1440 cm^{-1} (C=C). δ(H) (ppm) 1.09, s, H(20)$_3$, H(20)$_3$′; 1.25, 1.26, s, H(18)$_3$, H(18)$_3$′; 2.30, 2.31, s, 14-CH$_2$CH(CO*Me*)(CO$_2$Me), 14-CH$_2$CH(CO*Me*)(CO$_2$Me)′; 3.65, 3.66, (19-OMe), (19-OMe′); 3.686, 3.692, s, 14-CH$_2$CH(COMe)(CO$_2$*Me*), 14-CH$_2$CH(COMe)(CO$_2$*Me*)′; 4.01–4.07, m, 14-CH$_2$C*H*(COMe)(CO$_2$Me), 14-CH$_2$C*H*(COMe)(CO$_2$Me)′; 7.15, txd, *J* 6.7, 2.2 Hz, H(12), H(12)′; 7.34–7.40, m, H(11), H(11)′, H(13), H(13)′. δ(C) (ppm) 19.7, C(2), C(2)′; 21.6, C(20), C(20)′; 27.8, C(18), C(18)′; 29.6, 14-CH$_2$CH(CO*Me*)(CO$_2$Me), 14-CH$_2$CH(CO*Me*)(CO$_2$Me)′; 34.2, 34.3, C(6), C(6)′; 37.2, 37.3, C(3), C(3)′; 39.0, C(1), C(1)′; 39.2, C(10), C(10′; 39.3, 14-*C*H$_2$CH(COMe)(CO$_2$Me), 14-*C*H$_2$CH(COMe)(CO$_2$Me)′; 43.8, C(4), C(4)′; 49.2, 49.5, C(5), C(5)′; 51.6, (19-OMe), (19-OMe′); 52.2, 14-CH$_2$CH(COMe)(CO$_2$*Me*), 14-CH$_2$CH(COMe)(CO$_2$*Me*)′; 60.1, 60.2, 14-CH$_2$*C*H(COMe)(CO$_2$Me), 14-CH$_2$*C*H(COMe)(CO$_2$Me)′; 124.1, 124.4, C(11), C(11)′; 129.0, 129.2, C(8), C(8)′; 131.0, 131.1, C(13), C(13)′; 133.0, C(12), C(12)′; 140.5, C(14), C(14)′; 156.1, C(9), C(9)′; 170.0, 14-CH$_2$CH(COMe)(*C*O$_2$Me), 14-CH$_2$CH(COMe)(*C*O$_2$Me)′; 176.5, C(19), C(19)′; 200.8, 200.9, C(7), C(7)′; 203.5, 14-CH$_2$CH(*C*OMe)(CO$_2$Me), 14-CH$_2$CH(*C*OMe)(CO$_2$Me)′. *m/z* 414 (11, M^+), 396 (12, $M - H_2O$), 382 (14, *M* − MeOH), 354 (64, *M* − HCO$_2$Me), 339 (74, 354 − Me), 311 (67), 298 (100), 279 (57), 223 (29), 183 (34), 43 (58).

(d) with 3-buten-2-one in MeCN. A solution of **2** (0.22 g, 0.49 mmol) in MeCN 6 mL) was treated with Me$_3$NO (55 mg, 0.73 mmol) and then 3-buten-2-one (0.12 mL, 1.46 mmol) at room temperature under argon. The mixture was stirred for 27 h, worked up, and purified by PLC to give (i) **8** (17 mg, 12%); and (ii) methyl 14-[4-(2-butanoyl)]-7-oxopodocarpa-8,11,13-trien-19-oate (**16**) (0.12 g, 69%) which crystallized from Et$_2$O as rods, m.p. 114–117°C (Found: C, 74.4; H, 8.0. $C_{22}H_{28}O_4$ calcd.: C, 74.1; H, 7.9%). ν_{max} 1715 (ester CO), 1709 (non-conj. ketone CO), 1672 cm^{-1} (conj. ketone CO). δ(H) (ppm) 1.07, s, H(20)$_3$; 1.10, txd, *J* 13.5, 4.0 Hz, H(3ax); 1.23, s, H(18)$_3$; 1.48, txd, *J* 13.3, 4.2 Hz, H(1ax); 1.67, dxp, *J* 14.3, 3.2 Hz, H(2eq); 1.992, dxd, *J* 14.3, 3.9 Hz, H(5); 1.994, qxd, *J* 13.9, 3.6 Hz, H(2ax); 2.14, s, 14-CH$_2$CH$_2$CO*Me*; 2.27, bd, *J* 13.6 Hz, H(3eq); 2.31, bd, *J* 13.3 Hz, H(1eq); 2.66–2.82, m, 14-CH$_2$C*H*$_2$COMe; 2.89, dxd, *J* 17.8, 3.8 Hz, H(6eq); 3.12–3.22, m, 14-C*H*$_2$CH$_2$COMe; 3.24, dxd, *J* 17.8, 14.3 Hz, H(6ax); 3.70, s, (19-OMe); 7.09, bd, *J* 7.3 Hz, H(11); 7.29, dxd, *J* 7.8, 1.0 Hz, H(13); 7.36, , *J* 7.7 Hz, H(12). δ(C) (ppm) 19.7, C(2); 21.5, C(20); 27.7, C(18); 29.7, 14-CH$_2$CH$_2$CO*Me*; 30.2, 14-CH$_2$*C*H$_2$COMe; 37.2, C(6); 39.0, 39.1, C(1), C(3); 39.1, C(10); 43.8, C(4); 45.1, 14-*C*H$_2$CH$_2$COMe; 49.3, C(5); 51.5, (19-OMe); 123.4, C(11); 129.2, C(8); 129.9, C(13); 132.9, C(12); 143.6, C(14); 155.8, C(9); 176.9, C(19); 200.5, C(7); 208.7, 14-CH$_2$CH$_2$*C*OMe. *m/z* 356 (46, M^+), 338 (4, $M - H_2O$), 313 (89, *M* − COMe),

298 (100, 313 − Me), 253 (49, 313 − $\mathrm{CO_2Me}$), 223 (22), 197 (63), 171 (17), 128 (17), 105 (26), 43 (44).

(e) with propenal in MeCN. A solution of **2** (0.20 g, 0.44 mmol) in MeCN (5 mL) was treated with $\mathrm{Me_3NO}$ (50 mg, 0.67 mmol) and then with propenal (0.06 mL, 0.89 mmol). The mixture was stirred for 20 h at room temperature. Workup followed by PLC gave (i) **8** (5 mg, 4%); (ii) 3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]propanal (**19**) (48 mg, 32%) as a clear oil (Found: M^+, 342.1821. $\mathrm{C_{21}H_{26}O_4}$ calcd.: M, 342.1831). $\nu_{\max}$ 2750 (aldehyde C–H), 1720 (ester and aldehyde CO), 1672 $\mathrm{cm^{-1}}$ (ketone CO). δ(H) (ppm) 1.09, s, $\mathrm{H(20)_3}$; 1.11, txd, J 13.6, 3.8 Hz, H(3ax); 1.25, s, $\mathrm{H(18)_3}$; 1.50, txd, J 13.3, 4.0 Hz, H(1ax); 1.69, dxp, J 14.3, 3.1 Hz, H(2eq); 2.00, qxt, J 13.9, 3.6 Hz, H(2ax); 2.01, dxd, J 14.3, 4.2 Hz, H(5); 2.27–2.35, m, H(1eq), H(3eq); 2.67–2.85, m, 14-$\mathrm{CH_2C}\mathit{H}_2\mathrm{CHO}$; 2.91, dxd, J 17.8, 3.7 Hz, H(6eq); 3.26, dxd, J 17.8, 14.3 Hz, H(6ax); 3.21–3.37, m, 14-$\mathrm{C}\mathit{H}_2\mathrm{CH_2CHO}$; 3.69, s, (19-OMe); 7.11, bd, J 7.4 Hz, H(11); 7.33, dxd, J 7.6, 1.0 Hz, H(13); 7.39, t, J 7.8 Hz, H(12); 9.82, t, J 1.5 Hz, 14-$\mathrm{CH_2CH_2C}\mathit{H}\mathrm{O}$. δ(C) (ppm) 19.7, C(2); 21.6, C(20); 27.8, C(18); 28.5, 14-$\mathrm{CH_2}\mathit{C}\mathrm{H_2CHO}$; 37.3, C(6); 39.0, 39.1, C(1), C(3); 39.1, C(10); 43.8, C(4); 45.3, 14-$\mathit{C}\mathrm{H_2CH_2CHO}$; 49.3, C(5); 51.5, (19-OMe); 123.6, C(11); 129.2, C(8); 129.9, C(13); 132.9, C(12); 143.0, C(14); 156.0, C(9); 176.9, C(19); 200.5, C(7); 202.3, 14-$\mathrm{CH_2CH_2}\mathit{C}\mathrm{HO}$. m/z 342 (1, M^+), 314 (4, M − CO), 298 (2, M − $\mathrm{H_2CCO}$), 239 (2), 83 (100), 47 (30); and (iii) a mixture (85 mg) of several components which could not be separated by repeated PLC.

(f) with propenenitrile in MeCN. A solution of **2** (0.25 g, 0.55 mmol) in MeCN (4 mL) was treated with $\mathrm{Me_3NO}$ (62 mg, 0.83 mmol) and then with propenenitrile (0.08 mL, 1.11 mmol). The mixture was stirred at room temperature for 6.5 h, worked up, and purified by PLC to give (i) **8** (13 mg, 8%); (ii) 3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]propanenitrile (**22**) (47 mg, 25%) as a clear oil (Kugelrohr, 160°C/0.5 mmHg) (Found: C, 74.5; H, 7.7; N, 4.1. $\mathrm{C_{21}H_{25}NO_3}$ calcd.: C, 74;3, H, 7.4; N, 4.1%). $\nu_{\max}$ 2245 (C≡N), 1720 (ester CO), 1673 $\mathrm{cm^{-1}}$ (ketone CO). δ(H) (ppm) 1.11, s, $\mathrm{H(20)_3}$; 1.14, txd, J 13.6, 4.1 Hz, H(3ax); 1.27, s, $\mathrm{H(18)_3}$; 1.53, txd, J 13.3, 4.1 Hz, H(1ax); 1.72, dxp, J 14.3, 3.2 Hz, H(2eq); 2.02, qxt, J 13.9, 3.6 Hz, H(2ax); 2.04, dxd, J 14.4, 3.7 Hz, H(5); 2.30–2.38, m, H(1eq), H(3eq); 2.77, dxd, J 7.1, 6.9 Hz, 14-$\mathrm{CH_2C}\mathit{H}_2\mathrm{CN}$; 2.94, dxd, J 17.9, 3.7 Hz, H(6eq); 3.29, dxd, J 17.9. 14.4 Hz, H(6ax); 3.21–3.34, m, 14-$\mathrm{C}\mathit{H}_2\mathrm{CH_2CN}$; 3.71, s, (19-OMe); 7.19, dxd, J 7.3, 1.3 Hz, H(11); 7.42, dxd, J 8.1, 1.3 Hz, H(13); 7.48, t, J 8.1 Hz, H(12). δ(C) (ppm) 18.6, 14-$\mathrm{CH_2}\mathit{C}\mathrm{H_2CN}$; 19.7, C(2); 21.6, C(20); 27.8, C(18); 31.8, 14-$\mathit{C}\mathrm{H_2CH_2CN}$; 37.3, C(6); 39.0, C(3); 39.1, C(1); 39.2, C(10); 43.8, C(4); 49.4, C(5); 51.6, (19-OMe); 119.9, 14-$\mathrm{CH_2CH_2}\mathit{C}\mathrm{N}$; 124.7, C(11); 129.2, C(8); 130.4, C(13); 133.3, C(12); 140.1, C(14); 156.3, C(9); 176.9, C(19); 200.9, C(7). m/z 339 (72, M^+), 324 (5, M − Me), 307 (14, M − MeOH), 279 (52, M − $\mathrm{HCO_2Me}$), 264 (100, 324 − $\mathrm{HCO_2Me}$), 246 (12), 224 (23), 198 (38), 169 (17), 128 (25); and (iii) a mixture (15 : 4 : 2) (35 mg, 19%) of **22**, (*E*)-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enenitrile (**23**) and (*Z*)-3-[14-(methyl 7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enenitrile (**24**). **23**; δ(H) (ppm) 5.60, d, J 16.4 Hz, 14-$\mathrm{CH{=}C}\mathit{H}\mathrm{CN}$; 8.20, d, J 16.4 Hz, 14-CH=CHCN. **24**; δ(H) (ppm) 5.51, d, J 11.6 Hz, 14-$\mathrm{CH{=}C}\mathit{H}\mathrm{CN}$; 7.89, d, J 11.6 Hz, 14-$\mathrm{C}\mathit{H}\mathrm{{=}CHCN}$.

(g) with propenenitrile and Li_2PdCl_4 in MeCN. Catalytic: Palladium chloride (3.7 mg, 20.8 μmol) and lithium chloride (1.7 mg, 41.6 μmol) were dissolved in dry acetonitrile (5 mL) by stirring under argon for 8 h forming a bright orange solution.

Propenenitrile (0.11 mL, 1.66 mmol) was added to this solution, followed by a solution of **2** (0.10 g, 0.21 mmol) in acetonitrile (2 mL). The yellow solution was stirred at room temperature for 72 h during which time a black precipitate formed. The mixture was then filtered through a plug of Celite and alumina and the solvent removed *in vacuo*. The yellow residue contained (^{1}H NMR) a mixture (1 : 4) of **2** and **8**.

Stoichiometric: Li_2PdCl_4 (0.42 mmol), propenenitrile (0.22 mL, 3.32 mmol), and **2** (0.20 g, 0.42 mmol) were stirred at room temperature in acetonitrile (15 mL) for 72 h, during which time a black precipitate formed. Workup gave a mixture (1 : 1) of **2** and **8**.

(h) With acetoxyethene in MeCN. A solution of **2** (0.15 g, 0.33 mmol) in MeCN (3 mL) was treated with Me_3NO (37 mg, 0.50 mmol) and then with acetoxyethene (0.06 mL, 0.66 mmol). The mixture was then stirred for 20 h at room temperature. Workup and PLC gave (i) **8** (61 mg, 64%); and (ii) a mixture (15 mg) of several unidentified components.

Reactions of tetracarbonyl(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate-C^{14},O^7)manganese (3)

(a) with methyl propenoate (2 molar equiv.) in MeCN. A solution of the manganese complex **3** (0.29 g, 0.60 mmol) was treated with Me_3NO (68 mg, 0.90 mmol) and then with methyl propenoate (0.11 ml, 1.20 mmol). After 22 h, workup and PLC gave (i) methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**12**) (9 mg, 5%); (ii) methyl 3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**13**) (0.14 g, 59%) as a clear oil (Kugelrohr, 165°C/0.2 mmHg) (Found: C, 68.9; H, 7.5. $C_{23}H_{30}O_6$ calcd.: C, 68.7; H, 7.5%). ν_{max} 1721 (ester CO), 1664 (ketone CO), 1593, 1566, 1557, 1536 cm^{-1} (C=C). δ(H) (ppm) 1.07, s, H(20)$_3$; 1.10, txd, *J* 13.7, 3.9 Hz, H(3ax); 1.24, s, H(18)$_3$; 1.50, txd, *J* 13.2, 3.9 Hz, H(1ax); 1.67–1.71, m, H(2eq); 2.00, dxd, *J* 14.3, 3.6 Hz, H(5); 1.98–2.07, m, H(2ax); 2.30, bd, *J* 13.2 Hz, H(1eq), H(3eq); 2.61–2.72, m, 14-$CH_2CH_2CO_2Me$ (*H* italic); 2.87, dxd, *J* 17.9, 3.6 Hz, H(6eq); 3.18, dxd, *J* 17.8, 14.4 Hz, H(6ax); 3.23–3.39, m, 14-$CH_2CH_2CO_2Me$; 3.66, 3.68, s, (19-OMe), 14-$CH_2CH_2CO_2Me$; 3.82, s, (12-OMe); 6.66, d, *J* 2.3 Hz, H(11); 6.80, d, *J* 2.3 Hz, H(13). δ(C) (ppm) 19.8, C(2); 21.5, C(20); 27.8, C(18); 31.7, 14-$CH_2CH_2CO_2Me$; 35.2, C(6); 37.3, C(3); 39.0, C(1); 39.1, 14-$CH_2CH_2CO_2Me$; 39.4, C(10); 43.9, C(4); 49.4, C(5); 51.49, 51.54, 14-$CH_2CH_2CO_2Me$, (19-OMe); 55.2, (12-OMe); 109.2, C(11); 114.9, C(13); 122.8, C(8); 146.3, C(14); 158.6, C(9); 162.5, C(12); 174.0, 14-$CH_2CH_2CO_2Me$; 177.0, C(19); 198.8, C(7). *m/z* 402 (82, M^+), 385 (13, M – OH), 342 (100, M – CO_2Me – H), 267 (11), 227 (20), 40 (79); and (iii) methyl (*E*)-3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**14**) (68 mg, 28%) which crystallized from hexanes/Et_2O as needles, m.p. 106–109°C (Found: C, 69.5; H, 7.0. $C_{23}H_{28}O_6$ calcd.: C, 70.0; H, 7.0%). ν_{max} 1718 (ester CO), 1663 cm^{-1} (ketone CO). δ(H) (ppm) 1.09, s, H(20)$_3$; 1.12, txd, *J* 13.5, 3.9 Hz, H(3ax); 1.25, s, H(18)$_3$; 1.52, txd, *J* 13.3, 4.1 Hz, H(1ax); 1.70, dxp, *J* 14.3, 3.1 Hz, H(2eq); 2.009, qxt, *J* 13.9, 3.7 Hz, H(2ax); 2.013, dxd, *J* 14.3, 3.4 Hz, H(5); 2.30, bd, *J* 13.7 Hz, H(1eq), H(3eq); 2.92, dxd, *J* 18.2, 3.7 Hz, H(6eq); 3.22, dxd, *J* 18.2, 14.3 Hz, H(6ax); 3.69, s, (19-OMe); 3.80, s, 14-$CH{=}CHCO_2Me$; 3.86, s, (12-OMe); 6.11, d, *J* 15.7 Hz, 14-$CH{=}CHCO_2Me$; 6.79, d, *J* 2.4 Hz, H(11); 6.93, d, *J* 2.4 Hz, H(13); 8.39, d, *J* 15.7 Hz, 14-$CH{=}CHCO_2Me$. δ(C) (ppm) 19.7, C(2); 21.4, C(20); 27.8, C(18); 37.3,

C(3); 38.2, C(6); 38.8, C(1); 39.1, C(10); 43.9, C(4); 49.4, C(5); 51.6, 51.7, 14-$CH{=}CHCO_2$*Me*, (19-OMe); 55.4, (12-OMe); 111.5, C(11); 112.1, C(13); 119.4, 14-CH=*C*HCO$_2$Me; 123.3, C(8); 140.1, C(14); 147.6, 14-*C*H=CHCO$_2$Me; 158.2, C(9); 162.8, C(12); 167.2, 14-CH=CH*C*O$_2$Me; 176.9, C(19); 198.3, C(7). m/z 400 (1, M^+), 369 (2, $M-$ OMe), 341 (100, $M-CO_2Me$), 309 (2), 281 (8), 225 (11).

(b) with methyl propenoate (1 molar equiv.) in MeCN. A solution of **3** (85 mg, 0.18 mmol) was treated with Me_3NO (20 mg, 0.26 mmol) and then methyl propenoate (0.02 ml, 0.18 mmol). After 30 h, workup and PLC gave (i) **12** (5 mg, 9%); (ii) **13** (31 mg, 44%); and (iii) **14** (19 mg, 27%).

(c) with methyl propenoate in MeCN and quenching with CD_3CO_2D. A solution of **3** (0.10 g, 0.21 mmol) was treated with Me_3NO (24 mg, 0.32 mmol) and then methyl propenoate (0.05 ml, 0.42 mmol). After 23 h at room temperature CD_3CO_2D (0.05 mL, 1.40 mmol) was added to the mixture which was stirred for a further 27 h. Workup and PLC gave (i) **12** (2 mg, 3%); (ii) **13** (53 mg, 64%); and (iii) **14** (15 mg, 18%).

(d) with methyl propenoate and Li_2PdCl_4 (0.1 molar equiv.) in MeCN. A mixture of $PdCl_2$ 3.3 mg, 0.02 mmol) and LiCl (1.7 mg, 0.02 mmol) was stirred under argon in MeCN (3 mL) for 3 h. Methyl propenoate (0.04 ml, 0.39 mmol) and a solution of **3** (90 mg, 0.19 mmol) were added and the mixture was stirred for 21 h at room temperature, during which time a dark precipitate formed. Workup and PLC gave (i) **3** (75 mg, 83%); and (ii) (2 mg, 3%).

(e) with methyl propenoate and $Pd(OAc)_2(PPh_3)_2$ in MeCN. Stoichiometric: A solution of **3** (95 mg, 0.20 mmol) in MeCN (2 mL) was added to a yellow solution prepared from $Pd(OAc)_2$ (44 mg, 0.20 mmol), PPh_3 (104 mg, 0.40 mmol), Et_3N (0.06 mL, 0.4 mmol), and methyl propenoate (0.04 mL, 0.4 mmol). The mixture was heated under reflux for 6.5 h under argon. Workup and PLC gave (i) **12** (8 mg, 13%); (ii) **13** (40 mg, 50%); and (ii) **14** (7 mg, 9%).

Catalytic: A solution of **3** (95 mg, 0.20 mmol) in MeCN (2 mL) was added to a yellow solution prepared from $Pd(OAc)_2$ (4.4 mg, 0.02 mmol), PPh_3 (10.4 mg, 0.04 mmol), Et_3N (0.06 mL, 0.4 mmol), and methyl propenoate (0.04 mL, 0.4 mmol). The mixture was heated under reflux for 2 h, then worked up and purified by PLC to give (i) **12** (2 mg, 3%); (ii) **13** (68 mg, 86%); and (iii) **14** (9 mg, 10%).

(f) with methyl propenoate in refluxing MeCN. A solution of **3** (0.25 g, 0.52 mmol) and methyl propenoate (0.1 mL, 1.11 mmol) in MeCN (5 mL) was heated under reflux for 12 h under argon. Filtration through alumina followed by concentration *in vacuo* afforded a dark brown oil which was dissolved in MeOH (10 mL) and treated with dilute aqueous HCl (3 drops) at room temperature for 30 min. Workup and PLC afforded (i) dimethyl [6a*R*-(6aα,7β,10aβ)]-2-methoxy-7,10a-dimethyl-6,6a,7,8,9,10,10a-octahydro-4*H*-acephenanthrylene-5,7-dicarboxylate (**59**) (19 mg, 10%) as a pale orange solid, m.p. 122–127°C (Found: M^+, 384.1933. $C_{23}H_{28}O_5$ calcd.: M, 384.1937). ν_{max} 1721 (non-conj. ester CO), 1695 (conj. ester CO), 1625, 1600, 1583, 1455, 1437 cm^{-1} (C=C). δ(H) (ppm) 1.02, s, (10a-Me); 1.10, txd, J 13.5, 3.9 Hz, H(8ax); 1.34, s, (7-Me); 1.51, txd, J 13.5, 4.1 Hz, H(10ax); 1.67, dxp, J 14.3, 3.2 Hz, H(9eq); 1.77, dxd, J 13.5, 3.3 Hz, H(6a); 2.02, qxt, J 13.9, 3.4 Hz, H(9ax); 2.26–2.34, m, H(8eq), H(10eq); 3.20, dxdxt, J 18.4, 13.8, 4.2 Hz, H(6ax); 3.62, d, J 3.9 Hz, $(H4)_2$; 3.71, s, (7-CO_2Me); 3.77, bdxt, J 18.4, 1.9 Hz, H(6eq); 3.830, 3.834, s, (2-OMe), (5-CO_2Me); 6.76, d, J 1.9 Hz, H(1); 6.88, d, J 1.9 Hz, H(3). δ(C) (ppm) 19.6, C(9); 21.6, (10a-Me); 24.6, C(4); 28.6, (7-Me); 37.4,

C(10a); 37.5, C(6); 38.2, C(8); 38.6, C(10); 44.5, C(7); 51.0, 5-CO_2*Me*; 51.5, 7-CO_2*Me*; 51.7, C(6a); 55.6, (2-OMe); 107.2, C(1); 108.1, C(3); 122.8, C(5a); 133.2, C(3b); 144.4, C(3a); 147.2, C(5); 153.8, C(10b); 161.4, C(2); 166.3, 5-*C*O_2Me; 177.6, 7-*C*O_2Me. *m/z* 384 (100, M^+), 369 (12, $M-$ Me), 353 (10, $M-$ OMe), 341 (13), 325 (14, $M-$ CO_2Me), 284 (32), 265 (20), 209 (18), 165 (12), 94 (18), 57 (20); (ii) **9** (56 mg, 27%); and (iii) an epimeric mixture (1 : 1) (0.12 g, 50%) of methyl (2*RS*)-acetyl-3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**55**) as a clear oil (Found: $M^{+\cdot}$, 444.2139. $C_{25}H_{32}O_7$ calcd.: M, 444.2148). ν_{max} 1720 (ester and non-conj. ketone (CO), 1667 (conj. ketone CO), 1590, 1575, 1460 cm^{-1} (C=C). δ(H) (ppm) 1.08, s, $H(20)_3$, $H(20)_3'$; 1.24, 1.25, s, $H(18)_3$, $H(18)_3'$; 2.31, 2.33, s, 14-CH_2CH(CO*Me*)(CO_2Me), 14-CH_2CH(CO*Me*)(CO_2Me)$'$; 3.662, 3.665, (19-OMe), (19-OMe$'$); 3.68, 3.69, s, 14-CH_2CH(COMe)(CO_2*Me*), 14-CH_2CH(COMe)(CO_2*Me*)$'$; 3.80, 3.81, s, (12-OMe), (12-OMe$'$); 3.99–4.05, m, 14-CH_2C*H*(COMe)(CO_2Me), 14-CH_2C*H*(COMe)(CO_2Me)$'$; 6.69, 6.71, d, *J* 2.4 Hz, H(13), H(13)$'$; 6.80–6.81, m, H(11), H(11)$'$. δ(C) (ppm) 19.7, C(2), C(2)$'$; 21.5, C(20), C(20)$'$; 27.8, C(18), C(18)$'$; 29.7, 14-CH_2CH(CO*Me*)(CO_2Me), 14-CH_2CH(CO*Me*)(CO_2Me)$'$; 34.7, 34.8, C(6), C(6)$'$; 37.2, 37.3, C(3), C(3)$'$; 38.8, 39.1, 14-*C*H_2CH(COMe)(CO_2Me), 14-*C*H_2CH(COMe)(CO_2Me)$'$; 39.0, C(1), C(1)$'$; 39.3, 39.5, C(10), C(10)$'$; 43.80, 43.83, C(4), C(4)$'$; 49.2, 49.4, C(5), C(5)$'$; 51.6, (19-OMe), (19-OMe$'$); 52.2, 14-CH_2CH(COMe)(CO_2*Me*), 14-CH_2CH (COMe)(CO_2*Me*)$'$; 52.3, (12-OMe), (12-OMe); 59.9, 60.0, 14-CH_2*C*H(COMe) (CO_2Me), 14-CH_2*C*H(COMe)(CO_2Me)$'$; 109.8, 109.9, C(11), C(11)$'$; 116.0, 116.1, C(13), C(13)$'$; 122.4, 122.6, C(8), C(8)$'$; 143.70, 143.73, C(14), C(14)$'$; 158.8, C(9), C(9)$'$; 162.4, C(12), C(12)$'$; 169.87, 169.93, 14-CH_2CH(COMe)(*C*O_2Me), 14-CH_2CH(COMe)(*C*O_2Me)$'$; 177.0, C(19), C(19)$'$; 199.1, 199.2, C(7), C(7)$'$; 203.6, 14-CH_2CH(*C*OMe)(CO_2Me), 14-CH_2CH(*C*OMe)(CO_2Me)$'$. *m/z* 444 (5, M^+), 401 (4, $M-$ COMe), 384 (18, $M-$ HCO_2Me), 369 (8, 384 − Me), 343 (14), 309 (9), 258 (9), 83 (100).

When this reaction (0.13 g, 0.26 mmol) was repeated without hydrolytic workup, PLC gave (i) **13** (33 mg, 32%); and (ii) a mixture (1 : 1 : 1) (70 mg) of **55** and cyclised alcohols, from which after PLC a single diastereoisomer of dimethyl [6a*R*-(5ζ,5aζ,6aα,7β,10aβ)]-5a-hydroxy-2-methoxy-7,10a-dimethyl-4,5,5b,6,6a,7,8,9,10,10a-decahydroacephenanthrylene-5,7-dicarboxylate (**74**) (7 mg, 7%) crystallized from hexanes/Et$_2$O as rods, m.p. 176–180°C (Found: $M^{+\cdot}$, 402.2071. $C_{23}H_{30}O_6$ calcd.: M, 402.2042). ν_{max} 3505 (OH), 1733, 1714 cm^{-1} (ester CO). δ(H) (ppm) 0.86, 1.31, s, (7-Me), (10a-Me); 1.20, txd, *J* 13.3, 4.0 Hz, H(8ax); 1.55, txd, *J* 13.4, 4.5 Hz, H(10ax); 1.65, bd, *J* 14.3 Hz, H(9eq); 1.96, qxt, *J* 14.0, 3.8 Hz, H(9ax); 1.98, dxd, *J* 13.6, 12.4 Hz, H(6ax); 2.19, bd, *J* 12.7 Hz, H(10eq); 2.33, bd, *J* 12.3 Hz, H(8eq); 2.39, dxd, *J* 12.3, 1.4 Hz, H(6a); 2.59, dxd, *J* 13.8, 1.2 Hz, H(6eq); 2.83, s, (5a-OH); 2.97, dxd, *J* 15.1, 7.4 Hz, H(4); 3.05, dxd, *J* 9.7, 7.4 Hz, H(5); 3.50, dxd, *J* 15.1, 9.7 Hz, H(4); 3.65, s, (7-CO_2Me); 3.77, 3.82, s, (2-OMe), (5-CO_2Me); 6.59, d, *J* 1.8 Hz, H(1); 6.66, d, *J* 1.8 Hz, H(3). δ(C) (ppm) 19.7, C(9); 22.4, (10a-Me); 28.6, (7-Me); 33.4, 33.7, C(4), C(6); 37.5, C(8); 37.6, C(10); 38.6, C(10a); 43.9, C(7); 48.2, C(6a); 51.3, 51.9, 5-CO_2*Me*, 7-CO_2*Me*; 55.5, (2-OMe); 55.8, C(5); 77.6, C(5a); 108.1, 108.5, C(1), C(3); 132.6, C(3b); 142.5, C(3a); 147.3, C(10b); 161.3, C(2); 173.6, 5-*C*O_2Me; 178.2, 7-*C*O_2Me. *m/z* 402 (69, M^+), 384 (100, $M-H_2O$), 370 (5, $M-$ MeOH), 342 (64, $M-$ HCO_2Me), 325 (30), 309 (42), 265 (4), 258 (43), 197 (24), 155 (17), 125 (26), 69 (29).

(g) with methyl propenoate in refluxing MeOH. A solution of **3** (0.13 g, 0.27 mmol) and methyl propenoate (0.05 mL, 0.54 mmol) in anhydrous MeOH (5 mL) was heated under reflux for 5 h under argon. Workup and PLC gave (i) **3** (3 mg, 2%); (ii) **12** (2 mg, 5%); and (iii) **13** (98 mg, 91%).

(h) with methyl propenoate in refluxing heptane. A solution of **3** (0.10 g, 0.21 mmol) and methyl propenoate (0.04 mL, 0.42 mmol) in anhydrous heptane (4 mL) was heated under reflux for 6 h under argon. Workup and PLC gave (i) **3** (15 mg, 15%); (ii) **59** (7 mg, 9%); (iii) **12** (10 mg, 15%); (iv) **13** (11 mg, 13%); and (v) **14** (25 mg, 30%).

(i) with 3-buten-2-one in MeCN. A solution of **3** (0.18 g, 0.36 mmol) in MeCN (4 mL) was treated with Me_3NO (41 mg, 0.55 mmol) and then 3-buten-2-one (0.09 mL, 1.1 mmol). After 27 h at room temperature, workup and PLC gave (i) **12** (12 mg, 11%); (ii) methyl 14-[4-(2-butanoyl)]-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**32**) (71 mg, 51%) which crystallized from hexanes/Et_2O as prisms, m.p. 115–116°C (Found: C, 71.4; H, 7.8. $C_{23}H_{30}O_5$ calcd.: C, 71.5; H, 7.8%). ν_{max} 1726 (ester CO), 1713 (non-conj. ketone CO), 1659 (conj. ketone CO), 1590, 1565 cm^{-1} (C=C). δ(H) (ppm) 1.07, s, $H(20)_3$; 1.10, txd, *J* 13.7, 4.1 Hz, H(3ax); 1.24, s, $H(18)_3$; 1.50, txd, *J* 13.3, 4.0 Hz, H(1ax); 1.69, dxp, *J* 14.3, 3.3 Hz, H(2eq); 1.98, dxd, *J* 14.3, 3.8 Hz, H(5); 2.00, qxt, *J* 13.9, 3.5 Hz, H(2ax); 2.17, s, 14-$CH_2CH_2CO\mathit{Me}$; 2.28, bd, *J* 13.3 Hz, H(1eq), H(3eq); 2.68–2.82, m, 14-$CH_2C\mathit{H}_2COMe$; 2.87, dxd, *J* 17.9, 3.7 Hz, H(6eq); 3.19, dxd, *J* 17.9, 14.3 Hz, H(6ax); 3.16–3.28, m, 14-$C\mathit{H}_2CH_2COMe$; 3.68, s, (19-OMe); 3.82, s, (12-OMe); 6.65, d, *J* 2.5 Hz, H(11); 7.21, d, *J* 2.5 Hz, H(13). δ(C) (ppm) 19.8, C(2); 21.5, C(20); 27.8, C(18); 29.8, 14-$CH_2CH_2CO\mathit{Me}$; 30.9, 14-$CH_2\mathit{C}H_2COMe$; 37.3, C(6); 39.0, 39.1, C(1), C(3); 39.4, C(10); 43.9, C(4); 45.0, 14-$\mathit{C}H_2CH_2COMe$; 49.4, C(5); 51.5, (19-OMe); 55.2, (12-OMe); 109.2, C(11); 114.9, C(13); 122.8, C(8); 147.0, C(14); 158.7, C(9); 162.5, C(12); 177.0, C(19); 198.9, C(7); 208.9, 14-$CH_2CH_2\mathit{C}OMe$. *m/z* 386 (23, M^+), 368 (6, $M - H_2O$), 343 (100, M − COMe), 328 (15, 343 − Me), 283 (15), 227 (17); and (iii) methyl [6a*R*-(6aα,7β,10aβ)]-5-acetyl-2-methoxy-7,10a-methyl-6,6a,7,8,9,10,10a-octahydro-4*H*-acephenanthrylene-7-carboxylate (**56**) (13 mg, 10%) which crystallized from Et_2O as needles, m.p. 175–178°C (Found: C, 74.7; H, 7.5. $C_{23}H_{28}O_4$ calcd.: C, 75.0; H, 7.7%). ν_{max} 1723 (ester CO), 1647 (ketone CO), 1636, 1603, 1550 cm^{-1} (C=C). δ(H) (ppm) 1.03, s, (10a-Me); 1.11, txd, *J* 13.6, 3.9 Hz, H(8ax); 1.35, s, (7-Me); 1.52, txd, *J* 13.5, 4.0 Hz, H(10ax); 1.66–1.70, m, H(9eq); 1.81, dxd, *J* 12.9, 3.4 Hz, H(6a); 2.02, qxt, *J* 13.9, 3.4 Hz, H(9ax); 2.31–2.35, m, H(8eq), H(10eq); 2.47, s, (5-COMe); 3.31, dxdxt, *J* 17.6, 13.5, 3.9 Hz, H(6ax); 3.66, bs, $H(4)_2$; 3.65–3.75, m, H(6eq); 3.72, s, (7-CO_2Me); 3.84, s, (2-OMe); 6.77, d, *J* 1.9 Hz, H(1); 6.89, d, *J* 1.9 Hz, H(3). δ(C) (ppm) 19.6, C(9); 21.6, (10a-Me); 25.5, C(4); 28.6, (7-Me); 29.9, 5-$CO\mathit{Me}$; 37.3, C(10a); 37.4, C(6); 38.1, C(8); 38.8, C(10); 44.4, C(7); 51.6, 7-$CO_2\mathit{Me}$; 51.8, C(6a); 55.6, (2-OMe); 107.1, C(1); 108.3, C(3); 133.1, C(3b); 133.4, C(5a); 144.5, C(3a); 148.0, C(5); 152.3, C(10b); 161.8, C(2); 177.4, 7-$\mathit{C}O_2Me$; 195.4, 5-$\mathit{C}OMe$. *m/z* 368 (85, M^+), 353 (9, M − Me), 325 (6, M − COMe), 309 (16, $M - CO_2Me$), 293 (27), 265 (76), 253 (14), 242 (100), 209 (34).

(j) with propenal in MeCN. A solution of **3** (0.20 g, 0.42 mmol) in MeCN (5 mL) was treated with Me_3NO (47 mg, 0.62 mmol) and then with propenal (0.06 mL, 0.83 mmol). The solution was stirred for 20 h and then worked up in the usual manner. PLC gave (i) **12** (16 mg, 12%); (ii) 3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanal (**36**) (50 mg, 32%) as a clear oil (Kugelrohr,

180°C/0.2 mmHg) (Found: C, 71.0; H, 7.6. $C_{22}H_{28}O_5$ calcd.: C, 71.0; H, 7.6%) (Found: $M^{+\cdot}$, 372.1940. $C_{22}H_{28}O_5$ calcd.: M, 372.1937). ν_{max} 2735 (aldehyde C-H), 1719 (CHO), 1663 cm^{-1} (ketone CO). δ(H) (ppm) 1.08, s, $H(20)_3$; 1.10, txd, J 13.6, 4.0 Hz, H(3ax); 1.24, s, $H(18)_3$; 1.51, txd, J 13.3, 4.0 Hz, H(1ax); 1.69, dxp, J 14.3, 3.2 Hz, H(2eq); 1.98, dxd, J 14.3, 3.7 Hz, H(5); 2.00, qxt, J 13.9, 3.6 Hz, H(2ax); 2.28, bd, J 13.3 Hz, H(1eq), H(3eq); 2.70–2.83, m, 14-$\mathrm{CH_2C}\mathit{H}_2\mathrm{CHO}$; 2.87, dxd, J 17.9, 3.7 Hz, H(6eq); 3.19, dxd, J 17.9, 14.4 Hz, H(6ax); 3.24–3.37, m, 14-$\mathrm{C}\mathit{H}_2\mathrm{CH_2CHO}$; 3.68, s, (19-OMe); 3.83, s, (12-OMe); 6.64, d, J 2.5 Hz, H(11); 6.87, d, J 2.5 Hz, H(13); 9.82, t, J 1.5 Hz, 14-$\mathrm{CH_2CH_2C}\mathit{HO}$. δ(C) (ppm) 19.7, C(2); 21.5, C(20); 27.8, C(18); 29.1, 14-$\mathrm{CH_2}\mathit{C}\mathrm{H_2CHO}$; 37.3, C(6); 38.97, 39.04, C(1), C(3); 39.4, C(10); 43.8, C(4); 45.1, 14-$\mathit{C}\mathrm{H_2CH_2CHO}$; 49.4, C(5); 51.6, (19-OMe); 55.2, (12-OMe); 109.1, C(11); 115.0, C(13); 122.8, C(8); 146.3, C(14); 158.8, C(9); 162.5, C(12); 177.0, C(19); 198.9, C(7); 202.4, 14-$\mathrm{CH_2CH_2}\mathit{C}\mathrm{HO}$. m/z 372 (8, M^+), 344 (100, M – CO), 355 (4, M – OH), 327 (30), 283 (14), 227 (27), 201 (10), 41 (18); and (iii) a mixture (40 mg) of unidentified products.

(k) with propenenitrile in MeCN. A solution of **3** (0.14 g, 0.29 mmol) in MeCN (2 mL) was treated with Me_3NO (33 mg, 0.44 mmol) and then with propenenitrile (0.04 mL, 0.58 mmol). After 31 h at room temperature, workup and PLC gave (i) **12** (8 mg, 10%); (ii) a mixture (40:7:3) (16 mg, 15%) of 3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanenitrile (**38**), (*E*)-3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enenitrile (**39**) and (*Z*)-3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enenitrile (**40**). ν_{max} 2251, 2225 ($C \equiv N$), 1725, 1717 (ester CO), 1667, 1652 cm^{-1} (ketone CO). m/z 369 (100), 342 (19), 309 (21), 294 (46), 266 (18), 228 (30), 201 (11), 174 (9), 148 (11), 115 (11), 83 (15), 41 (25). **38**; (Found: $M^{+\cdot}$, 369.1937. $C_{22}H_{27}NO_4$ calcd.: M, 369.1940). δ(H) (ppm) 1.10, s, $H(20)_3$; 1.15, txd, J 13.6, 4.0 Hz, H(3ax); 1.27, s, $H(18)_3$; 1.53, txd, J 13.3, 4.1 Hz, H(1ax); 1.72, dxp, J 14.3, 3.6 Hz, H(2eq); 1.96–2.06, m, H(2ax); 2.00, dxd, J 14.3, 3.7 Hz, H(5); 2.31, bd, J 13.3 Hz, H(1eq), H(3eq); 2.77, dxd, J 6.9, 6.9 Hz, 14-$\mathrm{CH_2C}\mathit{H}_2\mathrm{CN}$; 2.89, dxd, J 17.9, 3.7 Hz, H(6eq); 3.21, dxd, J 17.9, 14.3 Hz, H(6ax); 3.19–3.34, m, 14-$\mathrm{C}\mathit{H}_2\mathrm{CH_2CN}$; 3.70, s, (19-OMe); 3.87, s, (12-OMe); 6.70, d, J 2.5 Hz, H(11); 6.88, d, J 2.5 Hz, H(13). δ(C) (ppm) 18.5, 14-$\mathrm{CH_2}\mathit{C}\mathrm{H_2CN}$; 19.7, C(2); 21.5, C(20); 27.8, C(18); 32.4, 14-$\mathit{C}\mathrm{H_2CH_2CN}$; 37.3, C(6); 38.9, 39.0, C(1), C(3); 39.4, C(10); 43.9, C(4); 49.4, C(5); 51.6, (19-OMe); 55.4, (12-OMe); 110.1, C(11); 115.7, C(13); 119.9, 14-$\mathrm{CH_2CH_2}\mathit{C}\mathrm{N}$; 122.6, C(8); 143.3, C(14); 159.0, C(9); 162.7, C(12); 177.0, C(19); 199.2, C(7). **39**; δ(H) (ppm) 5.58, d, J 16.4 Hz, 14-$\mathrm{CH{=}C}\mathit{H}\mathrm{CN}$; 6.72, d, J 2.3 Hz, H(11); 6.98, d, J 2.3 Hz, H(13); 8.23, d, J 16.4 Hz, 14-$\mathrm{C}\mathit{H}\mathrm{{=}CHCN}$. **40**; δ(H) (ppm) 5.51, d, J 11.6 Hz, 14-$\mathrm{CH{=}C}\mathit{H}\mathrm{CN}$; 7.00, d, J 2.2 Hz, H(11); 7.03, d, J 2.2 Hz, H(13); 7.92, d, J 11.6 Hz, 14-$\mathrm{C}\mathit{H}\mathrm{{=}CHCN}$; and (iii) a mixture (16 mg) from which no products could be identified.

(l) with acetoxyethene in MeCN. A solution of **3** (0.15 g, 0.31 mmol) in MeCN (3 mL) was treated with Me_3NO (35 mg, 0.47 mmol) and then with acetoxyethene (0.06 mL, 0.62 mmol). The mixture was then stirred for 20 h at room temperature. Workup and PLC gave (i) **12** (55 mg, 56%); and (ii) a mixture (21 mg) of unidentified products.

(m) with methyl but-2-enoate in MeCN. A solution of **3** (0.20 g, 0.42 mmol) in MeCN (3 mL) was treated with Me_3NO (47 mg) and then with methyl but-2-enoate (0.09 mL, 0.83 mmol). After 19.5 h at room temperature, workup and PLC

gave (i) **12** (104 mg, 80%); and (ii) a mixture (2:1) (19 mg, 11%) of epimers of methyl (3*RS*)-methyl-3-[14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**48**) as a clear oil (Found: $M^{+\cdot}$, 416.2165. $C_{24}H_{32}O_6$ calcd.: *M*, 416.2199). ν_{max} 1728 (ester CO), 1668 (ketone CO), 1597, 1569, 1462, 1437 cm^{-1} (C=C). *m/z* 416 (20, M^+), 357 (21, *M* − CO$_2$Me), 342 (21, 357-Me), 316 (52, *M*-CH(Me)CH$_2$CO$_2$Me), 241 (43), 59 (100). Major epimer; δ(H) (ppm) 1.07, s, H(20)$_3$; 1.07–1.16, m, H(3ax); 1.25, s, H(18)$_3$; 1.32, d, *J* 6.8 Hz, 14-CH(*Me*)CH$_2$CO$_2$Me; 1.53, txd, *J* 13.3, 3.7 Hz, H(1ax); 1.68–1.73, m, H(2eq); 1.96–2.07, m, H(2ax), H(5); 2.28, bd, *J* 13.5 Hz, H(1eq), H(3eq); 2.46, dxd, *J* 15.1, 8.5 Hz, 14-CH(Me)C*H*$_2$CO$_2$Me; 2.64, dxd, *J* 15.1, 6.2 Hz, 14-CH(Me)C*H*$_2$CO$_2$Me; 2.90, dxd, *J* 18.1, 4.3 Hz, H(6eq); 3.23, dxd, *J* 18.0, 14.1 Hz H(6ax); 3.61, s, 14-CH(Me)CH$_2$CO$_2$*Me*; 3.69, s, (19-OMe); 3.83, s, (12-OMe); 4.40–4.53, m, 14-C*H*(Me)CH$_2$CO$_2$Me; 6.73–6.85, m, H(11), H(13). δ(C) (ppm) 19.8, C(2); 21.47, 21.52, C(20), 14-CH(*Me*)CH$_2$CO$_2$Me; 27.8, C(18); 31.7, 14-*C*H(Me)CH$_2$CO$_2$Me; 37.4, C(3); 39.1, C(1); 39.2, C(6); 39.5, C(10); 42.6, 14-CH(Me)*C*H$_2$CO$_2$Me; 44.0, C(4); 49.3, C(5); 51.5, 14-CH(Me)CH$_2$CO$_2$*Me*, (19-OMe); 55.1, (12-OMe); 107.8, C(11); 110.8, C(13); 123.3, C(8); 151.4, C(14); 158.2, C(9); 162.5, C(12); 172.9, 14-CH(Me)CH$_2$*C*O$_2$Me; 177.0, C(19); 199.4, C(7). Minor epimer, δ(H) (ppm) 1.07, s, H(20)$_3$; 1.07–1.16, m, H(3ax); 1.25, s, H(18)$_3$; 1.27, d, *J* 6.9 Hz, 14-CH(*Me*)CH$_2$CO$_2$Me; 1.53, txd, *J* 13.3, 3.7 Hz, H(1ax); 1.68–1.73, m, H(2eq); 1.96–2.07, m, H(2ax), H(5); 2.28, bd, *J* 13.5 Hz, H(1eq), H(3eq); 2.40, dxd, *J* 14.9, 9.2 Hz, 14-CH(Me)C*H*$_2$CO$_2$Me; 2.79, dxd, *J* 15.0, 5.0 Hz, 14-CH(Me)C*H*$_2$CO$_2$Me; 2.89, dxd, *J* 18.1, 4.3 Hz, H(6eq); 3.24, dxd, *J* 18.1, 14.1 Hz, H(6ax); 3.66, s, 14-CH(Me)CH$_2$CO$_2$*Me*; 3.68, s, (19-OMe); 3.84, s, (12-OMe); 4.40–4.53, m, 14-C*H*(Me)CH$_2$CO$_2$Me; 6.73–6.85, m, H(11), H(13). δ(C) (ppm) 19.8, C(2); 21.47, 21.52, 14-CH(*Me*)CH$_2$CO$_2$Me, C(20); 28.0, C(18); 31.8, 14-*C*H(Me)CH$_2$CO$_2$Me; 37.4, C(3); 39.10, C(1); 39.14, C(6); 39.5, C(10); 42.6, 14-CH(Me)*C*H$_2$CO$_2$Me; 44.0, C(4); 49.3, C(5); 51.4, 14-CH(Me)CH$_2$CO$_2$*Me*, (19-OMe); 55.1, (12-OMe); 107.9, C(11); 110.8, C(13); 123.1, C(8); 151.5, C(14); 158.3, C(9); 162.6, C(12); 173.0, 14-CH(Me)CH$_2$*C*O$_2$Me; 177.0, C(19); 199.4, C(7).

(n) with ethene in MeCN. A solution of **3** (0.90 g, 1.87 mmol) in MeCN (35 mL) was treated with Me$_3$NO (210 mg, 2.80 mmol) to give a deep red solution. After stirring under argon for 5 min the solution was saturated with ethene, and then stirred under ethene (340 kPa) for 22 h. Workup gave a red-orange oil (0.65 g), a portion (0.17 g) of which was purified by PLC to give (i) 14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)ethene (**49**) (4 mg, 2%) as a clear oil (Found: $M^{+\cdot}$, 342.1816. $C_{21}H_{26}O_4$ calcd.: *M*, 342.1831). ν_{max} 1725 (ester CO), 1669 (ketone CO), 1590, 1564, 1464 cm^{-1} (C=C). δ(H) (ppm) 1.09, s, H(20)$_3$; 1.12, txd, *J* 13.5, 3.9 Hz, H(3ax); 1.25, s, H(18)$_3$; 1.54, txd, *J* 13.3, 4.0 Hz, H(1ax); 1.71, dxp, *J* 14.3, 3.1 Hz, H(2eq); 2.02, dxd, *J* 14.2, 3.8 Hz, H(5); 2.03, qxt, *J* 13.9, 3.6 Hz, H(2ax); 2.30, bd, *J* 13.9 Hz, H(1eq), H(3eq); 2.91, dxd, *J* 18.1, 3.8 Hz, H(6eq); 3.21, dxd, *J* 18.1, 14.4 Hz, H(6ax); 3.70, s, (19-OMe); 3.87, s, (12-OMe); 5.30, d, *J* 10.7 Hz, 14-CH=C*H*$_2$ *cis*; 5.49, d, *J* 17.3 Hz, 14-CH=C*H*$_2$ *trans*; 6.81–6.86, m, H(11), H(13); 7.54, dxd, *J* 17.3, 10.8 Hz, 14-C*H*=CH$_2$. *m/z* 342 (77, M^+), 341 (100, *M* − H), 316 (14, *M* − HC≡CH), 281 (7), 241 (13), 182 (17), 149 (30), 122 (24), 57 (20); (ii) **12** (23%); (iii) methyl 12-methoxy-7-oxo-14-[1-(3-pentanoyl)podocarpa-8,11,13-trien-19-oate (**51**) (17 mg, 9%) as a clear oil (Found: $M^{+\cdot}$, 400.2243. $C_{24}H_{32}O_5$ calcd.: *M*, 400.2250). ν_{max} 1723 (ester CO and non-conj. ketone CO), 1668 cm^{-1} (conj.

ketone CO). δ(H) (ppm) 1.05, t, J 7.3 Hz, 14-$CH_2CH_2COCH_2\mathit{Me}$; 1.08, s, H(20)$_3$; 1.11, txd, J 13.6, 4.0 Hz, H(3ax); 1.25, s, H(18)$_3$; 1.51, txd, J 13.5, 4.1 Hz, H(1ax); 1.69, dxp, J 14.3, 3.2 Hz, H(2eq); 1.98, dxd, J 14.3, 3.7 Hz, H(5); 2.01, qxt, J 13.9, 3.6 Hz, H(2ax); 2.28, bd, J 13.3 Hz, H(1eq), H(3eq); 2.46, q, J 7.3 Hz, 14-$CH_2CH_2COC\mathit{H}_2Me$; 2.66–2.82, m, 14-$CH_2C\mathit{H}_2COCH_2Me$; 2.87, dxd, J 17.9, 3.7 Hz, H(6eq); 3.20, dxd, J 17.9, 14.3 Hz, H(6ax); 3.17–3.29, m, 14-$C\mathit{H}_2CH_2COCH_2Me$; 3.69, s, (19-OMe); 3.82, s, (12-OMe); 6.65, d, J 2.5 Hz, H(11); 6.79, d, J 2.5 Hz, H(13). δ(C) (ppm) 7.8, 14-$CH_2CH_2COCH_2\mathit{Me}$; 19.8, C(2); 21.5, C(20); 27.8, C(18); 31.0, 14-$CH_2\mathit{C}H_2COCH_2Me$; 35.8, 14-$CH_2CH_2CO\mathit{C}H_2Me$; 37.3, C(6); 39.0, C(3); 39.1, C(1); 39.4, C(10); 43.7, 14-$\mathit{C}H_2CH_2COCH_2Me$; 43.9, C(4); 49.4, C(5); 51.5, (19-OMe); 55.2, (12-OMe); 109.2, C(11); 114.9, C(13); 122.9, C(8); 147.2, C(14); 158.7, C(9); 162.5, C(12); 177.0, C(19); 198.9, C(7); 211.5, 14-$CH_2CH_2\mathit{C}OCH_2Me$. m/z 400 (18, M^+), 382 (6, $M-H_2O$), 343 (100, $M-COCH_2Me$), 328 (15, 343 − Me), 283 (20), 227 (19); (iv) methyl 14-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**52**) (5 mg, 3%) as a clear oil (Found: $M^{+\cdot}$, 358.1801. $C_{21}H_{26}O_5$ calcd.: M, 358.1780). ν_{max} 1724 (ester CO), 1703, 1668 cm^{-1} (ketone CO). δ(H) (ppm) 1.08, s, H(20)$_3$; 1.14, txd, J 13.6, 4.0 Hz, H(3ax); 1.26, s, H(18)$_3$; 1.53, txd, J 13.2, 3.7 Hz, H(1ax); 1.72, dxp, J 14.3, 3.1 Hz, H(2eq); 2.02, qxt, J 13.9, 3.7 Hz, H(2ax); 2.06, dxd, J 14.5, 3.4 Hz, H(5); 2.32, bd, J 13.3 Hz, H(1eq), H(3eq); 2.45, s, (14-COMe); 2.94, dxd, J 18.2, 3.4 Hz, H(6eq); 3.07, dxd, J 18.2, 14.4 Hz, H(6ax); 3.70, s, (19-OMe); 3.85, s, (12-OMe); 6.56, d, J 2.5 Hz, H(11); 6.90, d, J 2.5 Hz, H(13). m/z 358 (34, M^+), 343 (100, $M-Me$), 283 (96, M-HCO_2Me), 227 (78), 43 (46); (v) a mixture (1 : 1 : 2 : 3) (12 mg) of 4 components, the major one of which was assigned as methyl 14-[1-(1-pentanoyl)]-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**53**) (5 mg, 3%) (Found: $M^{+\cdot}$, 400.2266. $C_{24}H_{32}O_5$ calcd.: M, 400.2250). ν_{max} 1723 (ester CO), 1667 cm^{-1} (ketone CO). δ(H) (ppm) 1.08, s, H(20)$_3$; 1.25, s, H(18)$_3$; 3.69, s, (19-OMe); 3.83, s, (12-OMe); 6.64, d, J 2.5 Hz, H(11); 6.79, d, J 2.5 Hz, H(13). m/z 400 (9, M^+), 343 (58, $M-CH_2CH_2CH_2Me$), 283 (25), 227 (32), 216 (100); (vi) a mixture of 5 components including at least 2 lactones. ν_{max} 1756 (lactone CO, v br), 1724 (ester CO), 1667 cm^{-1} (ketone CO); (vii) **7** (12 mg, 6%); and (viii) 14-(methyl 12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)ethane (**50**) (35 mg, 21%) as a yellow oil (Found: $M^{+\cdot}$, 344.1991. $C_{21}H_{28}O_4$ calcd.: M, 344.1988). ν_{max} 1725 (ester CO), 1668 (ketone CO), 1594, 1463 cm^{-1} (C=C). δ(H) (ppm) 1.09, s, H(20)$_3$; 1.11, txd, J 13.6, 4.1 Hz, H(3ax); 1.22, bxt, J 7.4 Hz, 14-$CH_2\mathit{Me}$; 1.25, s, H(18)$_3$; 1.53, txd, J 13.1, 3.4 Hz, H(1ax); 1.66–1.72, m, H(2eq); 1.98–2.08, m, H(2ax), H(5); 2.29, bd, J 13.4 Hz, H(1eq), H(3eq); 2.87, dxd, J 17.7, 3.5 Hz, H(6eq); 2.99–3.14, m, 14-$C\mathit{H}_2Me$; 3.19, dxd, J 17.7, 14.3 Hz, H(6ax); 3.69, s, (19-OMe); 3.84, s, (12-OMe); 6.65, d, J 2.4 Hz, H(11); 6.78, d, J 2.4 Hz, H(13). δ(C) (ppm) 15.5, 14-$CH_2\mathit{Me}$; 19.8, C(2); 21.5 C(20); 27.9, C(18); 29.2, 14-$\mathit{C}H_2Me$; 37.4, C(6); 39.2, C(1), C(3); 39.4, C(10); 43.9, C(4); 49.4, C(5); 51.5, (19-OMe); 55.1, (12-OMe); 108.2, C(11); 113.8, C(13); 122.9, C(8); 150.4, C(14); 158.5, C(9); 162.5, C(12); 177.1, C(19); 198.9, C(7). m/z 344 (100, M^+), 327 (59, $M-Me$-2H), 269 (26, $M-HCO_2Me-Me$), 241 (18), 203 (38), 150 (20), 57 (32), 41 (38).

Reaction of tetracarbonyl(19-methoxy-7-oxopodocarpa-8,11,13-triene-C^{14},O^7)manganese (4) with methyl propenoate

A solution of **4** (0.22 g, 0.50 mmol) in MeCN (10 mL) was treated with Me_3NO (45 mg, 0.60 mmol) and then with methyl propenoate (0.09 mL, 1.0 mmol). After

16 h at room temperature, workup and PLC gave (i) 19-methoxy-7-oxopodocarpa-8,11,13-triene (**28**) (12 mg, 9%); (ii) methyl 3-[14-(19-methoxy-7-oxopodocarpa-8,11,13-triene)]propanoate (**29**) (0.11 g, 62%) which crystallized from Et_2O as globular crystals, m.p. 105–107.5°C (Found: C, 73.8; H, 8.2. $C_{22}H_{30}O_4$ calcd.: C, 73.7; H, 8.4%). ν_{max} 1736 (ester CO), 1671 (ketone CO), 1103 cm^{-1} (C–O–C). δ(H) (ppm) 1.02, s, H(18)$_3$; 1.05, txd, *J* 13.2, 4.4 Hz, H(3ax); 1.22, s, H(20)$_3$; 1.59, txd, *J* 12.9, 4.1 Hz, H(1ax); 1.65–1.71, m, H(2eq); 1.74, qxt, *J* 13.6, 2.8 Hz, H(2ax); 1.87–1.93, m, H(3eq); 1.91, dxd, *J* 10.7, 8.2 Hz, H(5); 2.32, m, H(1eq); 2.59, dxdxd, *J* 15.9, 9.1, 6.6 Hz, 14-CH$_2$C*H*$_2$CO$_2$Me; 2.71–2.80, m, H(6ax), H(6eq), 14-CH$_2$C*H*$_2$CO$_2$Me; 3.16–3.32, m, 14-CH$_2$CH$_2$CO$_2$Me; 3.34, s, (19-OMe); 3.38, 3.52, d, *J* 9.1 Hz, H(19)$_2$; 3.67, s, 14-C*H*$_2$CH$_2$CO$_2$*Me*; 7.14, dxd, *J* 7.4, 0.6 Hz, H(11); 7.29, dxd, *J* 7.8, 1.1 Hz, H(13); 7.39, t, *J* 7.8 Hz, H(12). δ(C) (ppm) 18.8, C(2); 23.9, C(20); 26.9, C(18); 30.6, 14-CH$_2$*C*H$_2$CO$_2$Me; 35.4, C(6); 36.0, C(3); 37.5, C(10); 37.7, C(1); 38.4, C(4); 38.7, 14-*C*H$_2$CH$_2$CO$_2$Me; 48.4, C(5); 51.4, 14-CH$_2$CH$_2$CO$_2$*Me*; 59.4, (19-OMe); 75.8, C(19); 122.1, C(11); 129.5, C(13); 129.8, C(8); 132.7, C(12); 142.8, C(14); 157.2, C(9); 173.8, 14-CH$_2$CH$_2$*C*O$_2$Me; 201.0, C(7). *m/z* 358 (61, M^+), 327 (11, *M* – OMe), 298 (100, *M* – HCO$_2$Me), 284 (15, *M*-CO$_2$Me-Me), 231 (11), 199 (28), 183 (18), 171 (30), 45 (31); and (iii) methyl (E)-3-[14-(19-methoxy-7-oxopodocarpa-8,11,13-triene)]prop-2-enoate (**30**) (28 mg, 16%) as a clear oil (Kugelrohr, 150°C/0.07 mmHg) (Found: C, 73.9; H, 8.0. $C_{22}H_{28}O_4$ calcd.: C, 74.1; H, 7.9%). ν_{max} 1718 (ester CO), 1673 (ketone CO), 1635 (C=C), 1102 cm^{-1} (C–O–C). δ(H) (ppm) 1.03, s, H(18)$_3$; 1.06, txd, *J* 13.3, 4.4 Hz, H(3ax); 1.23, s, H(20)$_3$; 1.60, txd, *J* 12.8, 4.1 Hz, H(1ax); 1.67–1.82, m, H(2)$_2$; 1.90, bd, *J* 13.6 Hz, H(3eq); 1.95, dxd, *J* 10.6, 8.1 Hz, H(5); 2.35, bd, *J* 11.5 Hz, H(1eq); 2.75–2.85, m, H(6)$_2$; 3.34, s, (19-OMe); 3.39, 3.51, d, *J* 9.2 Hz, H(19)$_2$; 3.81, s, 14-CH=CHCO$_2$*Me*; 6.18, d, *J* 15.8 Hz, 14-CH=C*H*CO$_2$Me; 7.35, dxd, *J* 7.4, 0.6 Hz, H(13); 7.44, dxd, *J* 7.9, 1.2 Hz, H(11); 7.50, t, *J* 7.9 Hz, H(12); 8.30, d, *J* 15.8 Hz, 14-C*H*=CHCO$_2$Me. δ(C) (ppm) 18.8, C(2); 23.8, C(20); 27.0, C(18); 36.1, C(3); 37.1, C(6); 37.5, C(10); 38.4, C(4); 38.5, C(1); 48.6, C(5); 51.7, 14-CH=CHCO$_2$*Me*; 59.4, (19-OMe); 75.9, C(19); 119.6, 14-CH=*C*HCO$_2$Me; 125.0, 126.7, C(11), C(13); 130.1, C(8); 133.1, C(12); 136.9, C(14); 146.6, 14-*C*H=CHCO$_2$Me; 157.0, C(9); 167.2, 14-CH=CH*C*O$_2$Me; 200.3, C(7). *m/z* 356 (1, M^+), 325 (4, *M* – MeOH), 297 (100, *M* – CO$_2$Me), 235 (14), 195 (15), 167 (15), 69 (11), 45 (19).

Repetition of the reaction in CD_3CN gave (i) **28** (5 mg, 6%); (ii) **29** (41 mg, 53%); and (iii) a mixture (55 : 45) (13 mg, 17%) of **30** and methyl (*Z*)-3-[14-(19-methoxy-7-oxopodocarpa-8,11,13-triene)]prop-2-enoate (**31**) as a clear oil. **31**; δ(H) (ppm) 1.02, s, H(18)$_3$; 1.27, s, H(20)$_3$; 3.33, s, (19-OMe); 3.58, s, 14-CH=CHCO$_2$*Me*; 5.96, d, *J* 12.0 Hz, 14-CH=C*H*CO$_2$Me; 7.54, d, *J* 12.0 Hz, 14-C*H*=CHCO$_2$Me.

Reaction of tetracarbonyl(methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate-C^{14},O^{7})manganese (5) with methyl propenoate

A yellow solution of **5** (90 mg, 0.16 mmol) in MeCN (4 mL) was treated with Me_3NO (18 mg, 0.24 mmol); there was no appreciable colour change. Methyl propenoate (0.03 mL, 0.32 mmol) was added immediately giving a deep burgundy colour. The solution was stirred for 24.5 h, during which time the colour faded. Workup and PLC gave (i) methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**44**) (4 mg, 6%); (ii) methyl 3-[14-(methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**45**) (20 mg, 26%) as a clear oil

(Kugelrohr, 170°C/0.1 mmHg) (Found: C, 57.6; H, 6.3. $\mathrm{C_{23}H_{29}BrO_6}$ calcd.: C, 57.4; H, 6.1%). ν_{max} 1729 (ester CO), 1672 $\mathrm{cm^{-1}}$ (ketone CO). δ(H) (ppm) 1.09, s, $\mathrm{H(20)_3}$; 1.12, txd, *J* 13.6, 4.0 Hz, H(3ax); 1.25, s, $\mathrm{H(18)_3}$; 1.55, txd, *J* 13.2, 3.8 Hz, H(1ax); 1.72, dxp, *J* 14.3, 3.1 Hz, H(2eq); 1.99, dxd, *J* 14.1, 4.1 Hz, H(5); 2.03, qxt, *J* 13.9, 3.5 Hz, H(2ax); 2.30, bd, *J* 13.2 Hz, H(1eq), H(3eq); 2.59–2.76, m, $\mathrm{14\text{-}CH_2CH_2CO_2Me}$; 2.90, dxd, *J* 18.0, 4.1 Hz, H(6eq); 3.25, dxd, *J* 18.0, 14.1 Hz, H(6ax); 3.45–3.51, m, $\mathrm{14\text{-}C}\mathit{H}_2\mathrm{CH_2CO_2Me}$; 3.70, s, (19-OMe); 3.72, s, $\mathrm{14\text{-}CH_2CH_2CO_2}\mathit{Me}$; 3.94, s, (12-OMe); 6.82, s, H(11). δ(C) (ppm) 19.7, C(2); 21.4, C(20); 27.7, C(18); 30.1, $\mathrm{14\text{-}CH_2}\mathit{C}\mathrm{H_2CO_2Me}$; 33.0, C(6); 37.3, C(3); 38.9, C(1); 39.1, $\mathrm{14\text{-}}\mathit{C}\mathrm{H_2CH_2CO_2Me}$; 39.5 C(10); 43.9, C(4); 49.2, C(5); 51.58, 51.62, $\mathrm{14\text{-}CH_2CH_2CO_2}\mathit{Me}$, (19-OMe); 56.3, (12-OMe); 105.8, C(11); 115.5, C(13); 125.5, C(8); 143.4, C(14); 156.9, C(9); 158.7, C(12); 173.6, $\mathrm{14\text{-}CH_2CH_2}\mathit{C}\mathrm{O_2Me}$; 176.9, C(19); 198.4, C(7). *m/z* 482/480 (18/19, M^+), 451/449 (6/6, *M* − OMe), 422/420 (31/32, $M - \mathrm{HCO_2Me}$), 401 (100, *M* − Br), 369 (11, 401 − MeOH); and (iii) methyl (*E*)-3-[14-(methyl 13-bromo-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**46**) (28 mg, 36%) which crystallized from hexanes/$\mathrm{Et_2O}$ as needles, m.p. 144–147°C (Found: C, 57.7; H 6.0. $\mathrm{C_{23}H_{27}BrO_6}$ calcd.: C, 57.6, H, 5.7%). ν_{max} 1723 (ester CO), 1674 $\mathrm{cm^{-1}}$ (ketone CO). δ(H) (ppm) 1.12, s, $\mathrm{H(20)_3}$; 1.13, txd, *J* 13.9, 4.1 Hz, H(3ax); 1.25, s, $\mathrm{H(18)_3}$; 1.55, txd, *J* 13.3, 3.9 Hz, H(1ax); 1.73, dxp, *J* 14.4, 3.3 Hz, H(2eq); 2.02, dxd, *J* 14.4, 3.7 Hz, H(5); 2.03, qxt, *J* 13.8, 3.5 Hz, H(2ax); 2.28–2.33, m, H(1eq), H(3eq); 2.90, dxd, *J* 18.2, 3.9 Hz, H(6eq); 3.19, dxd, *J* 18.1, 14.4 Hz, H(6ax); 3.69, s, (19-OMe); 3.81, s, $\mathrm{14\text{-}CH{=}CH}\mathit{C}\mathrm{O_2}\mathit{Me}$; 3.96, s, (12-OMe); 5.81, d, *J* 16.2 Hz $\mathrm{14\text{-}CH{=}C}\mathit{H}\mathrm{CO_2Me}$; 6.89, s, H(11); 7.95, d, *J* 16.2 Hz, $\mathrm{14\text{-}C}\mathit{H}\mathrm{{=}CHCO_2Me}$. δ(C) (ppm) 19.6, C(2); 21.3, C(20); 27.8, C(18); 37.2, C(3); 38.0, C(6); 38.8, C(1); 39.4, C(10); 43.8, C(4); 49.3, C(5); 51.7, $\mathrm{14\text{-}CH{=}CHCO_2}\mathit{Me}$, (19-OMe); 56.5, (12-OMe); 107.0, C(11); 112.3, C(13); 122.0, $\mathrm{14\text{-}CH{=}}\mathit{C}\mathrm{HCO_2Me}$; 124.8, C(8); 140.1, C(14); 146.3, $\mathrm{14\text{-}}\mathit{C}\mathrm{H{=}CHCO_2Me}$; 156.7, C(9); 159.4, C(12); 166.7, $\mathrm{14\text{-}CH{=}CH}\mathit{C}\mathrm{O_2Me}$; 176.8, C(19); 196.8, C(7). *m/z* 480/478 (3/3, M^+), 421/419 (100/98, $M - \mathrm{CO_2Me}$), 305/303 (14/12), 129 (10).

Reaction of tetracarbonyl(methyl 13-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate-C^{14},O^{7})manganese (6) with methyl propenoate in MeCN

A solution of **6** (0.18 g, 0.34 mmol) in MeCN (5 mL) was treated with $\mathrm{Me_3NO}$ (41 mg, 0.54 mmol) (without appreciable colour change) and the mixture stirred for 5 min. Methyl propenoate (0.07 mL, 0.73 mmol) was added, and stirring continued for 24 h. Workup and PLC gave (i) methyl 12-methoxy-4α,17-dimethyl-7-oxo-18-nor-5α-androsta-8,11,13,16-tetraene-4β-carboxylate (**71**) (2.5 mg, 2%) as a clear oil (Found: $M^{+\cdot}$, 368.1989. $\mathrm{C_{23}H_{28}O_4}$ calcd.: *M*, 368.1988). ν_{max} 1725 (ester CO), 1668 (ketone CO), 1614, 1568, 1465 $\mathrm{cm^{-1}}$ (C=C). δ(H) (ppm) 1.07–1.15, m, H(3ax); 1.14, s, $\mathrm{H(19)_3}$; 1.29, s, (4-Me); 1.56–1.60, m, H(1ax); 1.67–1.73, m, H(2eq); 2.07, dxd, *J* 14.4, 3.4 Hz, H(5); 2.10–2.25, m, H(2ax); 2.30, bt, *J* 1.6 Hz, (17-Me); 2.29–2.41, m, H(1eq), H(3eq); 2.94, dxd, *J* 17.8, 3.2 Hz, H(6eq); 3.19, dxd, *J* 17.8, 14.4 Hz, H(6ax); 3.66, 3.76, dxq, *J* 25.3, 2.0 Hz, $\mathrm{H(15)_2}$; 3.70, s, $\mathrm{(4\text{-}CO_2Me)}$; 3.91, s, (12-OMe); 6.14, q, *J* 1.6 Hz, H(16); 6.82, s, H(11). *m/z* 368 (100, M^+), 293 (34, $M - \mathrm{CO_2Me}$), 241 (24), 175 (20), 43 (55); (ii) a mixture (15 mg) of (a) methyl 13-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate (**65**) (6%) and methyl 3-[14-(methyl 13-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]propanoate (**66**) (5%) (Found: $M^{+\cdot}$, 444.2137. $\mathrm{C_{25}H_{32}O_7}$ calcd.: *M*, 444.2148). δ(H) (ppm) 1.10, s, H(20)$_3$; 1.25, s, H(18)$_3$; 2.47, s, (13-COMe); 3.68, 3.69, s, 14-CH$_2$CH$_2$CO$_2$*Me*, (19-OMe); 3.86, s, (12-OMe); 6.83, s, H(11). δ(C) (ppm) 19.8, C(2); 21.5, C(20); 27.5, C(18); 27.8, 14-CH$_2$*C*H$_2$CO$_2$Me; 32.5, 13-CO*Me*; 35.1, C(6); 37.4, C(1), C(3); 39.1, 14-*C*H$_2$CH$_2$CO$_2$Me; 39.2, C(10); 43.9, C(4); 49.2, C(5); 51.5, 51.7, 14-CH$_2$CH$_2$CO$_2$*Me*, (19-OMe); 55.5, (12-OMe); 105.2, C(11); 123.5, C(13); 132.3, C(8); 140.7, C(14); 158.6, C(9); 159.2, C(12); 173.5, 14-CH$_2$CH$_2$*C*O$_2$Me; 176.9, C(19); 198.6, C(7); 205.0, 13-*C*OMe; (iii) methyl (*E*)-3-[14-(methyl 13-acetyl-12-methoxy-7-oxopodocarpa-8,11,13-trien-19-oate)]prop-2-enoate (**67**) (23 mg, 15%) which crystallized from hexanes/Et$_2$O as rods, m.p. 139–141°C (Found: C, 68.1; H, 6.8. C$_{25}$H$_{30}$O$_7$ calcd.: C, 67.9; H, 6.8%). ν_{max} 1723 (ester CO), 1670 (ketone CO), 1637, 1579, 1556 cm^{-1} (C=C). δ(H) (ppm) 1.12, s, H(20)$_3$; 1.13, txd, *J* 13.6, 3.9 Hz, H(3ax); 1.24, s, H(18)$_3$; 1.54, txd, *J* 13.2, 4.1 Hz, H(1ax); 1.71–1.75, m, H(2eq); 2.01, dxd, *J* 14.4, 3.5 Hz, H(5); 2.03, qxt, *J* 14.0, 3.5 Hz, H(2ax); 2.30–2.34, m, H(1eq), H(3eq); 2.34, s, (13-COMe); 2.91, dxd, *J* 18.1, 3.5 Hz, H(6eq); 3.18, dxd, *J* 18.1, 14.4 Hz, H(6ax); 3.69, s, (19-OMe); 3.76, s, 14-CH=CHCO$_2$*Me*; 3.88, s, (12-OMe); 5.74, d, *J* 16.1 Hz, 14-CH=C*H*CO$_2$Me; 6.92, s, H(11); 8.13, d, *J* 16.1 Hz, 14-C*H*=CHCO$_2$Me. δ(C) (ppm) 19.6, C(2); 21.3, C(20); 27.8, C(18); 32.7, 13-CO*Me*; 37.2, C(3); 38.1, C(6); 38.8, C(1); 39.5, C(10); 43.8, C(4); 49.4, C(5); 51.7, 14-CH=CHCO$_2$*Me*, (19-OMe); 55.9, (12-OMe); 106.8, C(11); 121.2, 14-CH=*C*HCO$_2$Me; 122.9, C(13); 131.0, C(8); 136.0, C(14); 145.5, 14-*C*H=CHCO$_2$Me; 158.6, C(9); 159.0, C(12); 166.5, 14-CH=CH*C*O$_2$Me; 176.8, C(19); 197.6, C(7); 203.1, 13-*C*OMe. m/z 442 (2, M^+), 383 (100, $M-$ CO$_2$Me), 323 (7), 267 (8); (iv) a single diastereoisomer tentatively assigned as dimethyl 17α-hydroxy-12-methoxy-4α,17β-dimethyl-7-oxo-18-nor-5α-androsta-8,11,13-triene-4β,16α-dicarboxylate (**70**) (14 mg, 9%) which crystallized from Et$_2$O as globular crystals, m.p. 127–131°C. ν_{max} 3423 (OH), 1740, 1722 (ester CO), 1671 cm^{-1} (ketone CO). δ(H) (ppm) 1.10, s, H(19)$_3$; 1.13, txd, *J* 13.7, 3.9 Hz, H(3ax); 1.25, s, (4-Me); 1.54, txd, *J* 13.3, 4.0 Hz, H(1ax); 1.71, dxp, *J* 14.2, 3.1 Hz, H(2eq); 1.78, s, (17-Me); 2.02, qxt, *J* 14.0, 3.4 Hz, H(2ax); 2.03, dxd, *J* 14.4, 3.3 Hz, H(5); 2.28–2.32, m, H(1eq), H(3eq); 2.89, dxd, *J* 17.9, 3.4 Hz, H(6eq); 3.14, dxd, *J* 17.9, 14.4 Hz, H(6ax); 3.17–3.24, m, H(15)$_2$; 3.60, s, (17-OH); 3.60–3.64, m, H(16); 3.69, s, (4-CO$_2$Me); 3.73, s, (16-CO$_2$Me); 3.91, s, (12-OMe); 6.77, s, H(11). δ(C) (ppm) 19.7, C(2); 21.5, C(19); 27.7, (4-Me); 27.9, (17-Me); 35.6, C(15); 37.3, C(3); 38.2, C(1); 39.0, C(6); 39.3, C(10); 43.9, C(4); 49.8, C(5); 51.5, 4-CO$_2$*Me*; 51.8, 16-CO$_2$*Me*; 54.9, C(16); 55.3, (12-OMe); 81.6, C(17); 105.6, C(11); 121.1, C(8); 132.1, C(13); 145.9, C(14); 158.7, C(9); 159.8, C(12); 173.9, 16-*C*O$_2$Me; 177.1, 4-*C*O$_2$Me; 198.5, C(7). m/z 444 (1, M^+), 426 (100, $M-$ H$_2$O), 394 (72, $M-$ MeOH), 367 (33, 426 − CO$_2$Me), 334 (30), 279 (18); and (v) a mixture (1 : 1.2 : 1.5) (49 mg, 32%) of the other 3 diastereoisomers of dimethyl 17ζ-hydroxy-12-methoxy-4α,17ζ-dimethyl-7-oxo-18-nor-5α-androsta-8,11,13-triene-4β,16ζ-dicarboxylate (**70**) (Found: $M^{+\cdot}$, 444.2136. C$_{25}$H$_{32}$O$_7$ calcd.: *M*, 444.2148). ν_{max} 3493 (OH), 1728 (ester CO), 1667 (ketone CO), 1590, 1440 cm^{-1} (C=C). δ(H) (ppm) 1.09 (6H), 1.10 (3H), s, H(19)$_3$; 1.24 (9H), s, (4-Me); 1.43, 1.47, 1.80 (3H each), s, (17-Me); 3.676 (3H), 3.680 (6H), s, (4-CO$_2$Me); 3.736, 3.738, 3.78 (3H each), s, (16-CO$_2$Me); 3.897 (3H), 3.925 (6H), s, (12-OMe); 6.77, s, (4H), H(11), m/z 444 (8, M^+), 426 (100, $M-$ H$_2$O), 394 (52, 426 − MeOH), 367 (27), 334 (14), 279 (9) 225 (7).

The mixture of diastereoisomers of **70** (40 mg, 90 μmol) was treated with dilute aqueous HCl in methanol (10 mL) for 1.5 h at 60°C to give dimethyl 12-methoxy-

4α,17-dimethyl-7-oxo-18-nor-5α-androsta-8,11,13,16-tetraene-4β,16-dicarboxylate (**72**) (29 mg, 76%) which crystallized from MeOH as needles, m.p. 254–255°C (Found: C, 70.1; H, 6.7. $C_{25}H_{30}O_6$ calcd.: C, 70.4; H, 7.1%). ν_{max} 1720 (non-conj. ester CO), 1708 (conj. ester CO), 1689 (ketone CO), 1664, 1603, 1570 cm^{-1} (C=C). δ(H) (ppm) 1.14, txd, *J* 13.6, 3.9 Hz, H(3ax); 1.15, s, H(19)$_3$; 1.28, s, (4-Me); 1.58, txd, *J* 13.3, 3.9 Hz, H(1ax); 1.73, dxp, *J* 14.3, 3.1 Hz, H(2eq): 2.06, qxt, *J* 14.0, 3.6 Hz, H(2ax); 2.07, dxd, *J* 14.4, 3.3 Hz, H(5); 2.30–2.38, m, H(1eq), H(3eq); 2.71, t, *J* 2.4 Hz, (17-Me); 2.95, dxd, *J* 17.8, 3.3 Hz, H(6eq); 3.19, dxd, *J* 17.8, 14.4 Hz, H(6ax); 3.71, s, (4-CO$_2$Me); 3.81, 3.94, s, (12-OMe), (16-CO$_2$Me); 3.97, 4.09, dxq, *J* 25.3, 2.4 Hz, H(15)$_2$; 6.84, s, H(11). δ(C) (ppm) 15.2, (17-Me); 19.7, C(2); 21.5, C(19); 28.0, (4-Me); 37.4, C(3); 38.3, C(1); 39.1, C(6); 39.4, C(10); 42.2, C(15); 44.0, C(4); 50.1, C(5); 51.0, 16-CO$_2$*Me*; 51.6, 4-CO$_2$*Me*; 55.3, (12-OMe); 105.1, C(11); 120.5, C(8); 129.7, C(13); 132.3, C(16); 148.1, C(14); 150.8, C(17); 157.5, C(9); 159.9, C(12); 166.3, 16-*C*O$_2$Me; 177.1, 4-*C*O$_2$Me; 198.0, C(7). *m/z* 426 (100, M^+), 395 (58, M – OMe), 367 (13, M – CO$_2$Me), 352 (12, 367 – Me), 334 (30), 278 (20), 69 (38).

Reaction of tetracarbonyl(dimethyl 12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate-C^{14},O^7)manganese (7) with methyl propenoate in MeCN

A solution of **7** (0.18 g, 0.33 mmol) in MeCN (3 mL) was treated with Me$_3$NO (30 mg, 0.37 mmol) and then with methyl propenoate (0.06 mL, 0.60 mmol). After 24 h at room temperature, workup and PLC gave (i) methyl 3-[14-(dimethyl 12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate)]propanoate (**68**) (93 mg, 61%) which crystallized from hexanes/Et$_2$O as needles, m.p. 121–123°C (Found: C, 65.1; H, 6.8. $C_{25}H_{32}O_8$ calcd.: C, 65.2; H, 7.0%). ν_{max} 1740, 1730 (non-conj. ester CO), 1717 (conj. ester CO), 1668 cm^{-1} (ketone CO). δ(H) (ppm) 1.06, s, H(20)$_3$; 1.08, txd, *J* 13.7, 3.6 Hz, H(3ax); 1.21, s, H(18)$_3$; 1.50, txd, *J* 13.2, 3.9 Hz, H(1ax); 1.68, dxp, *J* 14.3, 2.8 Hz, H(2eq); 1.94, dxd, *J* 14.4, 3.8 Hz, H(5); 1.99, qxt, *J* 13.8, 3.3 Hz, H(2ax); 2.24–2.28, m, H(1eq), H(3eq); 2.53–2.69, m, 14-CH$_2$C*H*$_2$CO$_2$Me; 2.85, dxd, *J* 17.9, 3.8 Hz, H(6eq); 3.05–3.18, m, 14-C*H*$_2$CO$_2$ Me; 3.16, dxd, *J* 17.9, 14.2 Hz, H(6ax); 3.65, 3.66, s, 14-CH$_2$CH$_2$CO$_2$*Me*, (19-OMe); 3.83, 3.86, s, (12-OMe), (13-CO$_2$Me); 6.81, s, H(11). δ(C) (ppm) 19.6, C(2); 21.4, C(20); 27.7, C(18); 28.1, 14-CH$_2$*C*H$_2$CO$_2$Me; 34.6, 14-*C*H$_2$CH$_2$CO$_2$Me; 37.1, C(3); 38.9, 39.0, C(1), C(6); 39.7, C(10); 43.8, C(4); 49.1, C(5); 51.4, (19-OMe); 51.5, 52.4, 13-CO$_2$*Me*, 14-CH$_2$CH$_2$CO$_2$*Me*; 55.6, (12-OMe); 105.3, C(11); 123.0, 124.8, C(8), C(13); 141.8, C(14); 158.8, C(9); 159.5, C(12); 167.8, 13-*C*O$_2$Me; 173.4, 14-CH$_2$CH$_2$*C*O$_2$Me; 176.7, C(19); 198.2, C(7). *m/z* 460 (34, M^+), 445 (60, M – Me), 429 (23, M – OMe), 400 (100, M – HCO$_2$Me), 386 (98, 445 – CO$_2$Me), 371 (65, 386 – Me), 341 (15), 311 (17) 91 (73); and (ii) methyl (*E*)-3-[14-(dimethyl 12-methoxy-7-oxo-19-norpodocarpa-8,11,13-triene-4β,13-dicarboxylate)]prop-2-enoate (**69**) (26 mg, 17%) which crystallized from hexanes/Et$_2$O as prisms, m.p. 168–172°C (Found: C, 65.2; H, 6.7. $C_{25}H_{30}O_8$ calcd.: C, 65.5; H, 6.6%). ν_{max} 1719 (ester CO), 1674 cm^{-1} (ketone CO). δ(H) (ppm) 1.12, s, H(20)$_3$; 1.16, txd, *J* 13.3, 3.9 Hz, H(3ax); 1.25, s, H(18)$_3$; 1.54, txd, *J* 13.2, 4.0 Hz, H(1ax) 1.71–1.74, m, H(2eq); 2.00, dxd, *J* 14.4, 3.6 Hz, H(5); 2.03, qxt, *J* 13.9, 3.3 Hz, H(2ax); 2.29–2.34, m, H(1eq), H(3eq); 2.91, dxd, *J* 18.1, 3.5 Hz, H(6eq); 3.17, dxd, *J* 18.0, 14.4 Hz, H(6ax); 3.69, s, (19-OMe); 3.77, s, 14-CH=CHCO$_2$*Me*; 3.79, 3.90, s, (12-OMe), (13-CO$_2$Me); 5.84, d, *J* 16.1 Hz, 14-CH=C*H*CO$_2$Me; 6.93, s, H(11); 8.12, d, *J* 16.1

Hz, 14-C*H*=CHCO$_2$Me. δ(C) (ppm) 19.6, C(2); 21.4, C(20); 27.8, C(18); 37.2, C(3); 38.1, C(6); 38.9, C(1); 39.6, C(10); 43.8, C(4); 49.4, C(5); 51.6, (19-OMe); 51.7, 13-CO$_2$*Me*; 52.5, 14-CH=CHCO$_2$*Me*; 56.0, (12-OMe); 106.8, C(11); 119.8, 14-CH=*C*HCO$_2$Me; 122.8, 123.3, C(8), C(13); 137.4, C(14); 146.0, 14-*C*H=CHCO$_2$Me; 159.0, C(9); 159.5, C(12); 166.6, 14-CH=CH*C*O$_2$Me; 167.0, 13-*C*O$_2$Me; 176.7, C(19); 197.3, C(7). *m/z* 458 (2, M^+), 427 (3, M – OMe), 399 (100, M – CO$_2$Me), 339 (6), 283 (10), 129 (10), 60 (32).

*Reaction of tetracarbonyl(methyl 7-oxoabieta-8,11,13-trien-18-oate-C^{14},O^7)manganese (**60**) with methyl propenoate in MeCN*

A solution of **60** (0.15 g, 0.29 mmol) in MeCN (3 mL) was treated with Me$_3$NO (33 mg, 0.59 mmol) and then methyl prop-2-enoate (0.05 mL, 0.59 mmol). After 18 h, workup and PLC gave (i) methyl 7-oxoabieta-8,11,13-trien-18-oate (**61**) (9 mg, 9%); (ii) dimethyl [6a*R*-(6aα,7α,10aβ)-7,10a-dimethyl-3-(1-methylethyl)-6,6a,7,8,9,10,10a-octahydro-4*H*-acephenanthrylene-5,7-dicarboxylate (**64**) (13.5 mg, 12%) which crystallized from hexanes/Et$_2$O as needles, m.p. 181–184°C (Found: C, 76.0; H, 8.0. C$_{25}$H$_{32}$O$_4$ calcd.: C, 75.7; H, 8.1%). ν_{max} 1721 (non-conj. ester CO), 1693 (conj. ester CO), 1621, 1595 cm^{-1} (C=C). δ(H) (ppm) 1.19, s, (10a-Me); 1.28, 1.29, d, *J* 6.6 Hz, 3-CH*Me*$_2$; 1.40, s, (7-Me); 1.63–1.80, m, 5H; 2.36, bd, *J* 11.7 Hz, 1H; 2.46, dxd, *J* 13.3, 3.3 Hz, 1H; 2.77, qxt, *J* 13.4, 4.0 Hz, H(9ax); 3.02, dxt, *J* 18.0, 1.4 Hz, 1H; 3.09, sept, *J* 6.9 Hz, 3-C*H*Me$_2$; 3.63, t, *J* 1.9 Hz, H(4)$_2$; 3.67, s, (7-CO$_2$Me); 3.82, s, (5-CO$_2$Me); 7.14, d, *J* 8.0 Hz, H(1); 7.20, d, *J* 8.0 Hz, H(2). δ(C) (ppm) 16.5, (7-Me); 18.1, C(9); 22.7, 23.0, 3-CH*Me*$_2$; 23.8, (10a-Me); 25.8, C(4); 31.0, 3-*C*HMe$_2$; 36.1, C(8); 36.3, C(10a); 37.2, C(10); 37.5, C(6); 45.5, C(6a); 47.3, C(7); 51.5, 5-CO$_2$*Me*; 52.1, 7-CO$_2$*Me*; 120.6, C(1); 125.3, C(2); 125.6, C(3b); 139.6, 139.7, 141.7, C(3), C(3a), C(5a); 144.8, C(5); 153.1, C(10b); 166.2, 5-*C*O$_2$Me; 178.5, 7-*C*O$_2$Me. *m/z* 396 (75, M^+), 381 (5, M – Me), 364 (15, M – MeOH), 349 (14, 364 – Me), 336 (24, M – HCO$_2$Me), 321 (100, 336 – Me), 305 (8), 289 (32), 261 (10), 238 (16), 179 (15), 69 (45), 43 (50); (iii) methyl 3-[14-(methyl 7-oxoabieta-8,11,13-trien-18-oate)]propanoate (**62**) as a clear oil (62 mg, 51%) (Kugelrohr, 160°C/0.05 mmHg) (Found: C, 72.2; H, 8.5. C$_{25}$H$_{34}$O$_5$ calcd.: C, 72.4; H, 8.3%). ν_{max} 1728 (ester CO), 1673 cm^{-1} (ketone CO). δ(H) (ppm) 1.16, s, H(20)$_3$; 1.17, 1.25, H(16)$_3$, H(17)$_3$; 1.32, s, H(19)$_3$; 1.62–1.84, m, 5H; 2.27, bd, *J* 12.1 Hz, 1H; 2.36–2.44, m, 2H; 2.55–2.70, m, 14-CH$_2$C*H*$_2$CO$_2$Me; 2.91, dxdxd, *J* 15.6, 11.9, 5.4 Hz, 1H; 3.07–3.19, m, 14-C*H*$_2$CH$_2$CO$_2$Me; 3.21, sept, *J* 6.8 Hz, H(15); 3.61, s, 14-CH$_2$CH$_2$CO$_2$*Me*; 3.68, s, (18-OMe); 7.24, d, *J* 8.4 Hz, H(11); 7.42, d, *J* 8.4 Hz, H(12). δ(C) (ppm) 16.5, C(19); 18.1, C(2); 23.3, 23.5, 24.6, C(16), C(17), C(20); 25.0, 14-CH$_2$*C*H$_2$CO$_2$Me; 27.8, C(15); 35.4, C(3); 36.6, C(6); 37.5, C(1); 39.1, 14-*C*H$_2$CH$_2$CO$_2$Me; 42.4, C(5); 46.1, C(4); 51.5, 14-CH$_2$CH$_2$CO$_2$*Me*; 52.1, (18-OMe); 121.5, C(11); 130.1, C(12); 131.4, C(8); 138.4, C(14); 146.1, C(13); 153.5, C(9); 173.8, 14-CH$_2$CH$_2$*C*O$_2$Me; 177.8, C(18); 200.7, C(7). C(10) was not observed. *m/z* 414 (65, M^+), 396 (23, M – H$_2$O), 382 (50, M – MeOH), 354 (93, M – HCO$_2$Me), 340 (95, 354 – CO$_2$Me), 327 (100), 321 (63), 279 (36), 197 (29); and (iv) methyl (*E*)-3-[14-(methyl 7-oxoabieta-8,11,13-trien-18-oate)]prop-2-enoate (**63**) (8 mg, 7%) as a clear oil (Kugelrohr, 180°C/0.05 mmHg) (Found: C, 73.1; H, 7.7. C$_{25}$H$_{32}$O$_5$ calcd.: C, 72.8; H, 7.8%). ν_{max} 1719 (ester CO), 1675 (ketone CO), 1637 cm^{-1} (C=C). δ(H) (ppm) 1.12, 1.19, d, *J* 6.8 Hz, H(16)$_3$, H(17)$_3$; 1.22, s, H(20)$_3$; 1.33, s, H(19)$_3$; 1.64–1.81, m, 5H; 2.31–2.40, m, 2H; 2.60–2.71, m, 2H; 3.24, sept, *J* 6.9 Hz, H(15); 3.65, s, (18-OMe); 3.81, s, 14-CH=CHCO$_2$*Me*; 5.69, d, *J* 16.2 Hz, 14-CH=C*H*CO$_2$Me; 7.36, d, *J* 8.4 Hz, H(11); 7.50, d, *J* 8.4 Hz, H(12); 8.12, d, *J* 16.2 Hz, 14-C*H*=CHCO$_2$Me. *m/z* 412 (1, M^+), 353 (100).

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