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1,5-Stereocontrol in tin(IV) halide mediated reactions between *N*- and *S*-substituted pent-2-enylstannanes and aldehydes or imines

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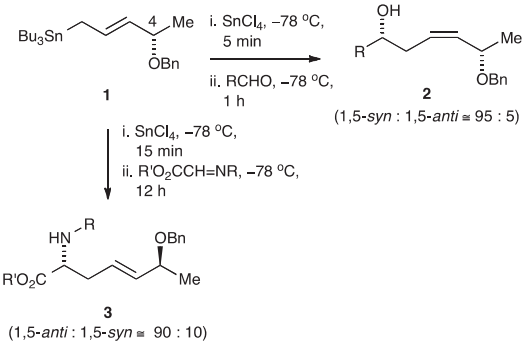
ABSTRACT

Following transmetalation of (4*S*)-4-(dibenzylamino)pent-2-enyl(tributyl)stannane with tin(IV) bromide, reactions of the resulting allyltin tribromide with aldehydes gave (3*Z*)-1,5-*syn*-5-(dibenzylamino)hex-3-en-1-ols with excellent, ca. 98:2, stereocontrol. (4*R*)-5-Benzylthio-4-methylpent-2-enyl(tributyl)stannane similarly reacted with aldehydes to give (3*Z*)-1,5-*anti*-6-benzylthio-5-methylhex-3-en-1-ols with 87:13 stereocontrol. Although the analogous reaction of (4*R*)-4-benzylthiopent-2-enyl(tributyl)stannane with benzaldehyde proceeded with some stereoselectivity, 80–90:20–10, in favour of the (3*Z*)-1,5-*syn*-diastereoisomer, the yield was low due to a competing Lewis acid catalysed 1,4-elimination. *N*-Acylamino- and *S*-acylthio-pent-2-enylstannanes reacted with aldehydes with variable *syn*/*anti*-stereoselectivities. Tin(IV) chloride promoted reactions of the 4-(dibenzylamino)pent-2-enylstannane with 1-alkoxycarbonylimines gave (*E*)-alk-4-enoates with a modest preference for the 2,6-*anti*-products, 2,6-*anti*/2,6-*syn*=75:25.

1. Introduction

Remote stereocontrol has been found for tin(IV) halide mediated reactions between alk-2-enylstannanes with an alkoxy substituent at the 4-, 5- or 6-position and aldehydes or imines.[1] For example, transmetalation of the (4*S*)-4-benzyloxypent-2-enyl(tributyl)stannane **1** using tin(IV) chloride generated an allyltin trichloride that reacted with aldehydes to give the (3*Z*)-1,5-*syn*-diastereoisomers **2**[2] and with 1-alkoxycarbonylimines to give the (4*E*)-2,6-*anti*-products **3**;[3] useful levels of remote stereocontrol were observed in both cases.



It was of interest to study the analogous reactions of pent-2-enylstannanes that had *N*- and *S*-containing substituents. We report here in full the results of this investigation.[4,5]

2. Results and discussion

2.1. 1,5-Stereocontrol in tin(IV) halide promoted reactions of *N*-substituted pent-2-enylstannanes and aldehydes

By analogy with the stannane **1**, the (4*S*)-4-(dibenzylamino) pent-2-enyl(tributyl)stannane **9** was selected for initial study and was prepared as outlined in Scheme 1. Oxidation of alcohol **4**[6] and condensation of the resulting aldehyde with triethyl phosphonoacetate gave ester **5**. Reduction gave alcohol **6** and thermolysis of the derived xanthate **7** gave the dithiocarbonate **8** as a mixture of epimers. These were reacted with tributyltin hydride to give the required stannane **9** mainly as its (*E*)-isomer.[7]

The NMR spectra of the (*R*)- and (*S*)-Mosher's derivatives of the 4-(dibenzylamino)pent-2-enol **6** were very similar and so the optical purity of this alcohol and hence of the pent-2-enylstannane **9** could not be checked at this stage. However, later functionalization of products prepared using this stannane confirmed that its enantiomeric excess was ca. 94%.[8]

Reactions of the stannane **9** with aldehydes were carried out using tin(IV) bromide to effect transmetalation. Better yields were obtained allowing 10 min for the transmetalation step with the reactions of the intermediate allyltin tribromide being carried out

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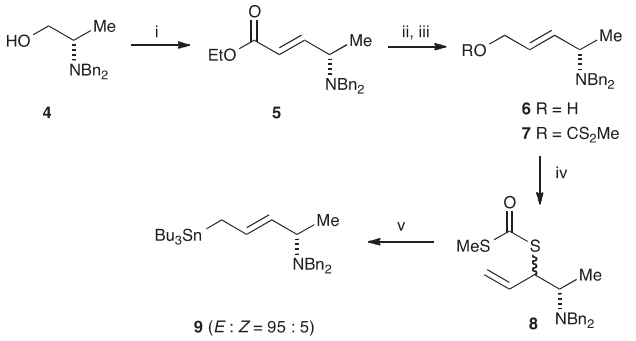
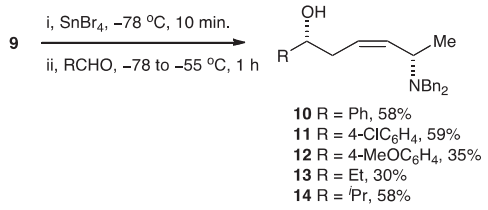


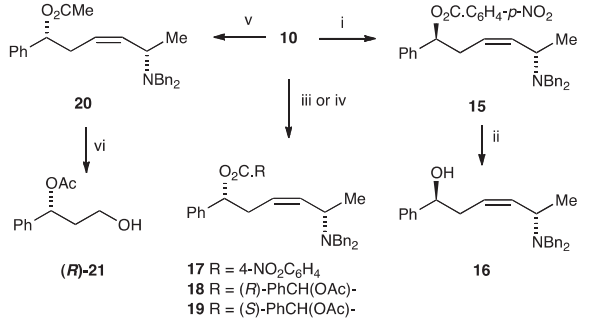
Scheme 1. Synthesis of the 4-(dibenzylamino)pent-2-enylstannane **9**. Reagents and conditions: (i) (a) DMSO, $(COCl)_2$, DCM, −55 °C, 15 min, Et_3N, 5 min; (b) KO^{t}Bu, $(EtO)_2P(O)CH_2CO_2Et$, THF, 0 °C, 1 h, add aldehyde, −78 °C, 20 min (82% from **4**); (ii) DIBAL–H, DCM, hexane, −78 °C, 40 min (83%); (iii) $NaN(SiMe_3)_2$, THF, 0 °C, 10 min, CS_2, rt, 3 h, MeI, rt, 2 h (85%); (iv) toluene, heat under reflux, 15 h (81%); (v) Bu_3SnH, AIBN (trace), benzene, heat under reflux, 3 h [79%; (*E*)/(*Z*)=95:5].

at −78 to −55 °C typically for 1 h. It was important to add base during the work-up and triethylamine followed by aqueous sodium bicarbonate were added to quench the reactions. Under these conditions, modest to reasonable yields were obtained for several aldehydes and excellent 1,5-stereoselectivities. Indeed the (3*Z*)-1,5-*syn*-alkenols **10**–**14** were the only products isolated together with minor side-products at the 1–2% level that were not characterized. Lower yields were obtained using tin(IV) chloride.



10 R = Ph, 58%
11 R = 4-ClC$_6$H$_4$, 59%
12 R = 4-MeOC$_6$H$_4$, 35%
13 R = Et, 30%
14 R = ^{i}Pr, 58%

The (3*Z*)-1,5-*syn*-product **10** from benzaldehyde was identified on the basis of the correlations outlined in Scheme 2. The (*Z*)-configuration of the double-bond followed from its vinylic ^{1}H NMR coupling constant of ca. 10.5 Hz. To show that the epimers at C(1) could be distinguished, the 1,5-*syn*-product **10** was converted into its 1,5-*anti*-epimer **16** via a Mitsunobu reaction[9] and saponification of the resulting *p*-nitrobenzoate **15**. The epimeric alcohols **10** and **16** could be distinguished by ^{1}H NMR and it appeared that just ca. 2% of the 1,5-*anti*-epimer **16** was present in the product mixture from the allylstannane reaction with benzaldehyde. The epimeric

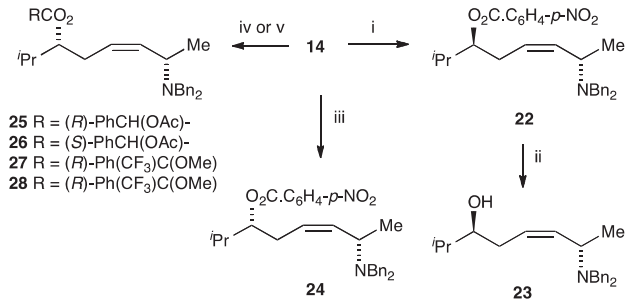


17 R = 4-NO$_2$C$_6$H$_4$
18 R = (*R*)-PhCH(OAc)-
19 R = (*S*)-PhCH(OAc)-

Scheme 2. Confirmation of the structure of (*Z*)-5-(dibenzylamino)-1-phenylhex-3-en-1-ol **10**. Reagents and conditions: (i) 4-$NO_2C_6H_4CO_2H$, DEAD, Ph_3P, −35 °C, 1.5 h (45%); (ii) aq NaOH, MeOH, rt, 50 min (63%); (iii) 4-$NO_2C_6H_4COCl$, Et_3N, DMAP, 0 °C, rt, 6 h (56%); (iv) (*R*)- or (*S*)-*O*-acetylmandelic acid, DCC, DMAP (cat.), DCM, rt, 18 h (**18**, 58%; **19**, 64%); (v) Ac_2O, Et_3N, DMAP (cat.), rt, 18 h (79%); (vi) O_3, DCM, ~78 °C, 40 min, then Me_2S, rt, followed by $NaBH_4$, MeOH, rt, 2 h (18%).

p-nitrobenzoates **15** and **17** could also be distinguished by NMR. The configuration of the alcohol **10** at C(1) was initially assigned on the basis of the relative chemical shifts of the corresponding (*R*)- and (*S*)-*O*-acetylmandelates **18** and **19**[10,11] and was confirmed by ozonolysis of its acetate **20**. This gave the (*R*)-enantiomer **21** of 3-acetoxy-3-phenylpropan-1-ol.[2] The structures of the products **11** and **12** from the other aromatic aldehydes were assigned by analogy.

Similar correlations were used to confirm the structure of the product **14** from the reaction between stannane **9** and 2-methylpropanal, see Scheme 3. The NOE enhancement of H-7 observed on irradiation of the 4-H_2 confirmed the (*Z*)-geometry of the alkenol. A Mitsunobu inversion followed by saponification converted alkenol **14** into its epimer **23**. The alcohols **14** and **23** were distinguished by ^{1}H NMR as were the corresponding 4-nitrobenzoates **22** and **24**. The configuration of the alcohol **14** at C(3) was established by comparison of the ^{1}H NMR spectra of the (*R*)- and (*S*)-*O*-acetylmandelates **25** and **26** and the (*R*)- and (*S*)-Mosher's derivatives **27** and **28**.[10,11] The Mosher's derivatives also indicated that the optical purity of the alcohol **14**, and hence of the stannane **9**, corresponded to an enantiomeric excess of ca. 94%. The structure of the product **13** from propanal was assigned by analogy.

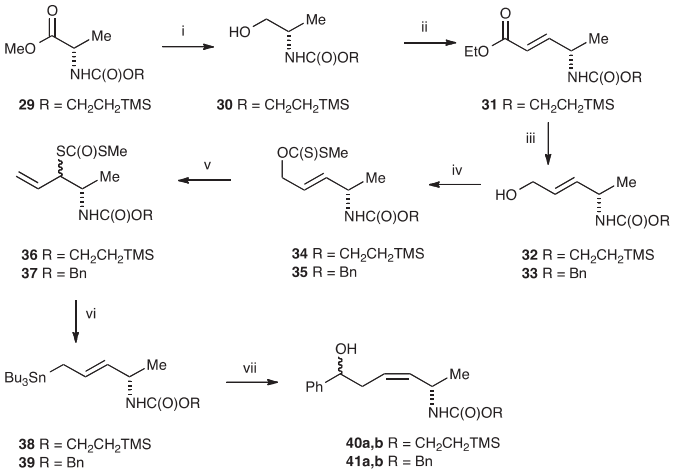


25 R = (*R*)-PhCH(OAc)-
26 R = (*S*)-PhCH(OAc)-
27 R = (*R*)-Ph(CF$_3$)C(OMe)
28 R = (*R*)-Ph(CF$_3$)C(OMe)

Scheme 3. Confirmation of the structure of (*Z*)-7-(dibenzyl)amino-2-methyloct-5-en-3-ol **14**. Reagents and conditions: (i) 4-$NO_2C_6H_4CO_2H$, DEAD, Ph_3P, toluene, −35 °C to rt, 90 min (31%); (ii) aq NaOH, MeOH, rt, 3 h (48%); (iii) 4-$NO_2C_6H_4COCl$, Et_3N, DMAP (cat.) DCM, rt, 6 h (58%); (iv) (*R*)- or (*S*)-*O*-acetylmandelic acid, DCC, DMAP (cat.), DCM, rt, 18 h (**25**, 44%; **26**, 76%); (v) (*S*)- or (*R*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoyl chloride, py, CCl_4, rt, 2 h (**27**, 78%; **28**, 49%).

Tin(IV) halide promoted reactions of 4-(dibenzylamino)pent-2-enyl(tributyl)stannane **9** with aldehydes would appear to proceed with useful 1,5-stereoselectivity in favour of the (3*Z*)-1,5-*syn*-alk-3-enols reminiscent of the stereoselectivity observed for the analogous reactions of the 4-benzyloxypent-2-enylstannane **1**.[2] To see whether varying the substituent on the nitrogen would affect the stereoselectivity of these reactions, the 4-(*N*-trimethylsilylethoxycarbonylamino)- and 4-(*N*-benzyloxycarbonylamino)-pent-2-enylstannanes **38** and **39** were synthesized and their reactions with benzaldehyde were investigated. The stannanes **38** and **39** were prepared from the corresponding alcohols **32** and **33** via the xanthates **34** and **35** and the dithiocarbonates **36** and **37**. Alcohol **32** was prepared from the protected alanine **29** by reduction to the alcohol **30**, oxidation with a phosphonate condensation to give the ester **31** followed by reduction, see Scheme 4.

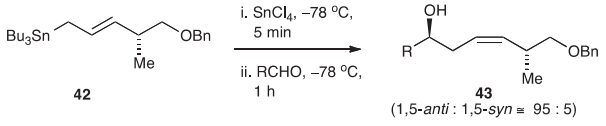
However, both stannanes **38** and **39** reacted with benzaldehyde, using either tin(IV) bromide or chloride to effect the transmetalation, to give 60:40 mixtures of the epimeric (3*Z*)-hex-3-enols **40a**,**b** and **41a**,**b**. The configurations of these products at C(1) were not established, but the minor epimer **40b** was converted into the major **40a** by a Mitsunobu esterification and saponification. The minor epimers were shown to be (*Z*)-alkenes by ^{1}H NMR. It would appear that tin(IV) halide promoted reactions of 4-acylaminopent-2-enylstannanes with aldehydes do not proceed with useful 1,5-stereocontrol.



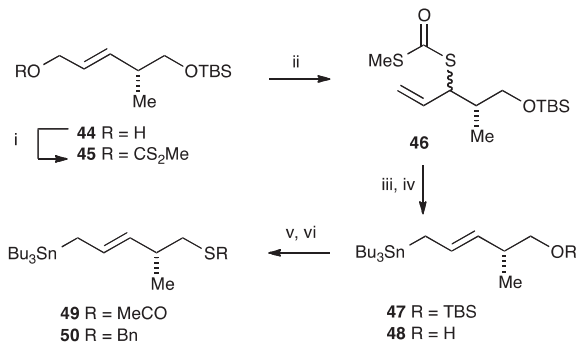
Scheme 4. Synthesis and reactions of stannanes **38** and **39**. Reagents and conditions: (i) (a) $NaBH_4$, LiCl, EtOH, THF, rt, 18 h (96%); (ii) DMSO, $(COCl)_2$, DCM, ~55 °C, 5 min, add **30**, −55 °C, 15 min, Et_3N, 5 min; (b) $(EtO)_2P(O)CH_2CO_2Et$, KO^{t}Bu, 0 °C, rt, 1 h, −78 °C, add aldehyde, 40 min (57%); (iii) DIBAL−H, hexane, −78 °C, 40 min (63%); (iv) ^{n}BuLi, THF, CS_2, rt, 3 h, add MeI, rt, 18 h (**34**, 99%; **35**, 82%); (v) toluene, heat under reflux, 18 h (**36**, 84%; **37**, 89%); (vi) Bu_3SnH, AIBN (cat.), benzene, heat under reflux 3 h (**38**, 76%; **39**, 86%); (vii) $SnBr_4$, −78 °C, 10 min, PhCHO, −55 °C, 12 h (**40**, 59%; **41**, 62%; 60:40 both cases).

2.2. 1,5-Stereocontrol in tin(IV) halide promoted reactions of *S*-substituted pent-2-enylstannanes and aldehydes

Transmetalation of the 5-benzyloxy-4-methylpent-2-enylstannane **42** generates an allyltin trichloride that reacts with aldehydes with useful 1,5-stereocontrol in favour of the (3*Z*)-1,5-*anti*-diastereoisomers **43**.[12] It was decided to prepare the analogous 5-benzylthiopent-2-enylstannane **50** and to study its reactions with aldehydes.

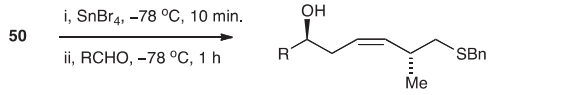


5-Benzylthio-4-methylpent-2-enyl(tributyl)stannane **50** was synthesized as outlined in Scheme 5. The xanthate **45**, prepared from the alcohol **44**,[13] was converted into the isomeric dithiocarbonate **46** by heating in toluene under reflux. Reaction of the dithiocarbonate with tributyltin hydride under free radical conditions then gave the pent-2-enylstannane **47** that was desilylated to give the 5-hydroxy-4-methylpent-2-enylstannnane **48**. This was converted into the thioester **49** under Mitsunobu conditions and hydrolysis of the thioester with in situ alkylation of the resulting thiol gave the 5-benzylthio-4-methylpent-2-enylstannane **50**.



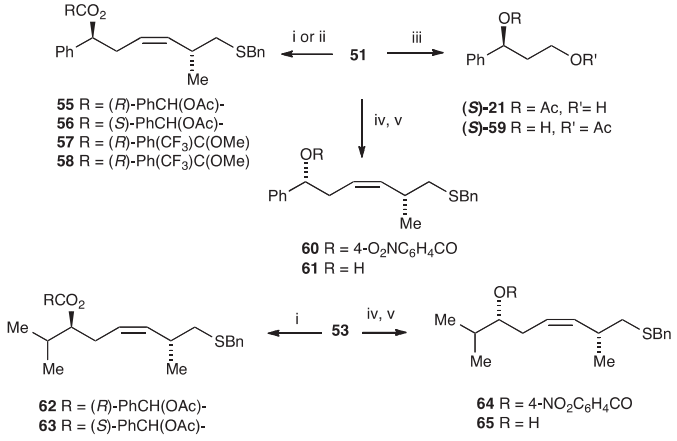
Scheme 5. Preparation of the 5-benzylthiopent-2-enylstannane **50**. Reagents and conditions: (i) BuLi, THF, 0 °C, 30 min, CS_2, rt, 3 h, MeI, rt, 18 h (76%); (ii) toluene, heat under reflux, 18 h (87%); (iii) Bu_3SnH, AIBN (cat.), benzene, heat under reflux, 3 h (73%); (iv) TBAF, THF, rt, 18 h (89%); (v) DIAD, Ph_3P, THF, 0 °C, 30 min, **48**, MeCOSH, THF, 0 °C−rt, 2 h (72%); (vi) KOH, EtOH, rt, 10 min, BnCl, rt, 1 h (98%).

Better results for the reactions of the *S*-substituted pentenylstannane **50** with aldehydes were obtained using tin(IV) bromide to effect transmetalation. Under the usual conditions reasonable to good yields were obtained of the (3*Z*)-6-benzylthio-5-methylhex-3-en-1-ols with a useful stereoselectivity in favour of the 1,5-*anti*-(*Z*)-diastereoisomers, typically 1,5-*anti*-(*Z*)/1,5-*syn*-(*Z*)=85:15. Minor amounts, ca. 5%, of an (*E*)-isomer were also formed. Using tin(IV) chloride to effect transmetalation, a lower yield, 49%, albeit with similar 1,5-stereoselectivity, 87:13, was observed for benzaldehyde.



51 R = Ph, 58%, 1,5-*anti* : 1,5-*syn* = 87 : 13
52 R = 4-$O_2NC_6H_4$, 66%, 1,5-*anti* : 1,5-*syn* = 89 : 11
53 R = ^{i}Pr, 71%, 1,5-*anti* : 1,5-*syn* = 87 : 13
54 R = Et, 54%, 1,5-*anti* : 1,5-*syn* = 82 : 18

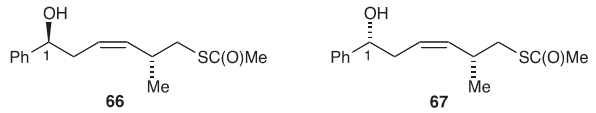
The ratios of the 1,5-*anti*/1,5-*syn*-products were estimated by ^{1}H NMR. The major product from the reaction with benzaldehyde was identified as the (3*Z*)-1,5-*anti*-isomer **51** on the basis of spectroscopic data and the correlations outlined in Scheme 6. The vinylic coupling constant of 10 Hz indicated the cis-geometry of its double-bond. The relative chemical shifts of the (*R*)- and (*S*)-*O*-acetylmandelates **55** and **56** were consistent with the 1,5-*anti*-configuration shown.[10,11] The acetate of the major product gave the (*S*)-enantiomer of 3-acetoxy-3-phenylpropan-1-ol (*S*)-**21** together with (*S*)-3-acetoxy-1-phenylpropan-1-ol (*S*)-**59**, the product of acetyl migration, on ozonolysis.[2,12] A Mitsunobu reaction followed by saponification of the ester **60** converted the major product **51** into the 1,5-*syn*-epimer **61** the ^{1}H NMR spectrum of which corresponded to that of the slightly less polar minor product. A second minor product, ca. 5%, was believed to be an (*E*)-isomer but its structure was not confirmed. The ^{1}H NMR spectra of the Mosher's derivatives **57** and **58** showed that the major product had an ee of ca. 80% and were consistent with the assigned configuration at C(1).[11]



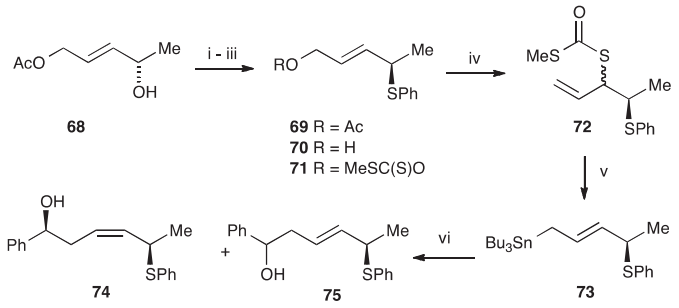
Scheme 6. Confirmation of the structures of the products **51** and **53** from reactions of the stannane **50**. Reagents and conditions: (i) (*R*)- or (*S*)-*O*-acetylmandelic acid, DCC, DMAP (cat.), DCM, rt, 18 h (**55**, 57%; **56**, 70%; **62**, 94%; **63**, 95%); (ii) (*S*)- or (*R*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoyl chloride, py, CCl_4, rt, 2 h (**57**, 68%; **58**, 64%); (iii) (a) Ac_2O, Et_3N, DMAP (cat.) (73%); (b) O_3, then Me_2S, followed by $NaBH_4$ (91%); (iv) 4-$NO_2C_6H_4CO_2H$, DEAD, Ph_3P (**60**, 77%; **64**, 42%); (ii) aq NaOH, MeOH (**61**, 45%; **65**, 91%).

The structure of the major product from the reaction of the stannane **50** with 2-methylpropanal was shown to correspond to the (5*Z*)-3,7-*anti*-isomer **53** by comparison of the ^{1}H NMR spectra of its (*R*)- and (*S*)-*O*-acetylmandelates **62** and **63**, which were consistent with the (*R*)-configuration at C(3).[10,11] The major product **53** was converted into its *syn*-epimer **65** via the inverted *p*-nitrobenzoate **64** showing that the two C(1)-epimers could be distinguished and that the *syn*-epimer **65** corresponded to a minor product from the reaction with the stannane **50**, see Scheme 6.

Although mixed results had been obtained for the tin(IV) halide mediated reactions between the *N*-acylaminopent-2-enyl stannanes **38** and **39** and benzaldehyde, it was decided to check the stereoselectivity of the analogous reaction of the *S*-acetylpent-2-enylstannane **49**. In the event good yields of two products were obtained but the ratio of the products was not reproducible varying from 90:10 to 66:34. The configurations of these products at C(1) were not established but the major product was shown to be a (3Z)-isomer, either **66** or **67** by ^{1}H NMR. The alkene geometry of the minor product was not confirmed.



To study the effect of a thio-ether substituent at C(4) in an alk-2-enylstannane, the 4-phenylthiopent-2-enyl(tributyl)-stannane **73** was prepared from the 5-acetoxypent-3-en-2-ol **68**[14] by substitution of the hydroxyl group with inversion using diphenyl disulfide and tributylphosphine[15] followed by conversion of the resulting acetoxyalkyl sulfide **69** into the xanthate **71** via the corresponding alcohol **70**. Thermolysis of the xanthate gave the dithiocarbonate **72** that was converted into the 4-phenylthiopent-2-enylstannane **73** by reaction with tributyltin hydride, see Scheme 7.



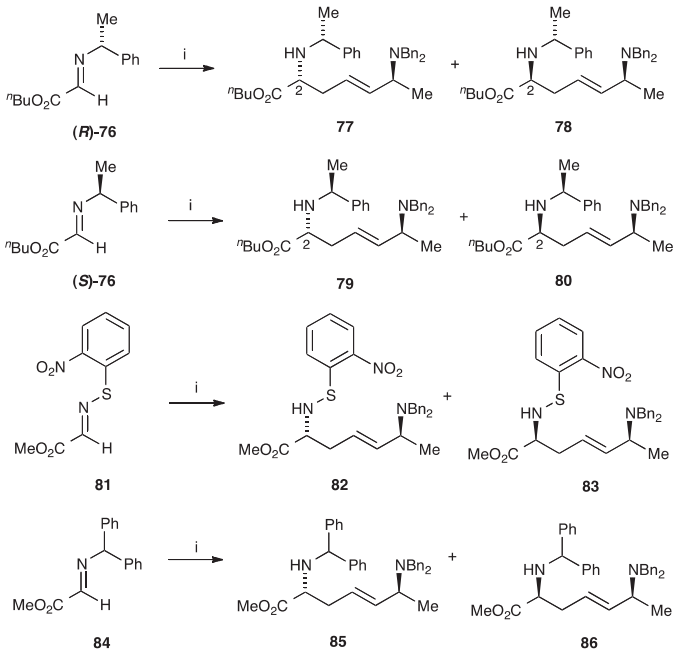
Scheme 7. Synthesis and chemistry of the 4-phenylthiopent-2-enylstannane **73**. Reagents and conditions: (i) Bu_3P, $(PhS)_2$, THF, rt, 18 h (86%); (ii) KOH, EtOH, rt, 2 h (81%); (iii) BuLi, THF, hexane, 0 °C, 30 min, CS_2, rt, 3 h, MeI, rt, 18 h (91%); (iv) toluene, heat under reflux, 18 h (79%); (v) Bu_3SnH, AIBN (cat.), benzene, heat under reflux, 1 h (46%); (vi) $SnBr_4$, DCM, −78 °C, 10 min, benzaldehyde, −78 °C, 1 h (40%; **74**/**75**=80: 20).

However, tin(IV) bromide promoted reactions of the 4-phenylthiopent-2-enylstannane **73** with benzaldehyde under the usual conditions tended to give low yields, typically 30–40%. Significant amounts, ca. 20% of the product, of a (3*E*)-5-phenyl-thiohex-3-en-1-ol **75** were isolated along with the major (3*Z*)-diastereoisomer **74**. Similar results were found using tin(IV) chloride. The 1,5-*syn*-configuration was assigned to the (3*Z*)-product **74** by analogy with the stereoselectivity of the analogous reactions of the 4-benzyloxy- and 4-(dibenzylamino)-pent-2-enylstannanes **1** and **9**. The configuration at C(1) of the (3*E*)-isomer was not established but its (*E*)-configuration was indicated by its vinylic coupling constant of 15 Hz.

2.3. 1,5-Stereocontrol in tin(IV) halide promoted reactions of *N*-substituted pent-2-enylstannanes and imines

The tin(IV) halide promoted reactions of alkoxyalk-2-enylstannanes with imines prepared from glyoxalates have been shown to proceed with useful stereoselectivity in favour of (*E*)-alk-4-enoates. The 2,6-*anti*-isomers **3** were obtained using the 4-benzyloxystannane **1**.[3] Based on this precedent, reactions of the 4-(dibenzylamino)pent-2-enylstannane **9** with 1-alkoxycarbonylimines were selected for study.

The tin(IV) chloride promoted reactions of the stannane **9** with both chiral and achiral 1-alkoxycarbonylimines[3] gave similar results. In all cases a ca. 3:1 mixture of two products identified as the (4*E*)-2,6-*anti*- and (4*E*)-2,6-*syn*-epimers were obtained, see Scheme 8.



Scheme 8. Reactions between the 4-(*N*,*N*-dibenzylamino)pent-2-enylstannane **9** and 1-alkoxycarbonylimines. Reagents and conditions: (i) **9**, $SnCl_4$, −78 °C, 15 min, add imine, −45 °C, 12 h (**77**/**78**, 60%, **77**/**78**=70:30; **79**/**80**, 63%, **79**/**80**=75:25; **82**/**83**, 60%, **82**/**83**=75:25; **85**/**86**, 62%, **85**/**86**=70:30).

The epimeric products from the (*R*)-imine (*R*)-**76** were separated and were shown to be (*E*)-alkenes by ^{1}H NMR. The chemical shifts of H(2) were used to establish the configurations of these products at C(2). The epimer with H(2) more shielded was assigned the 1,3-*like* configuration between C(2) and the imine derived stereogenic centre (major product **77**, 2-H, δ 3.12; minor product **78**, 2-H, δ 3.41).[3] The products from the (*S*)-imine (*S*)-**76** could not be separated but they too were assigned the configurations shown on the basis of the H(2) chemical shifts of the major and minor products in the reaction mixture (major product **79**, 2-H, δ 3.42; minor product **80**, 2-H, δ 3.12). The products from the achiral imines **81** and **84** could not be separated. ^{1}H NMR was used to estimate their ratio and to confirm their (*E*)-stereochemistry. Their configurations at C(1) were assigned by analogy with the structures assigned to the products formed using the chiral imines (*R*)- and (*S*)-**76**.

3. Summary and conclusions

This work has shown that amino and sulfur containing substituents can direct the stereoselectivity of tin(IV) halide mediated reactions of pent-2-enylstannanes. The regioselectivity of all of these reactions is consistent with transmetalation via an SE′

process to generate a pent-1-en-3-yltin trihalide that then reacts with the aldehyde to give the product of an overall *ipso* replacement of the tin.[1]

Under the low temperature conditions used the steroselectivity of the initial transmetalation is believed to be due to kinetic control.[16] For the tin(IV) mediated reactions of the stannane **9**, the selective formation of the (3*Z*)-1,5-*syn*-products **10**–**14** is consistent with participation of the allyltin tribromide **87**, in which the vinyl and methyl substituents are trans-disposed about the four-membered ring. Reaction with aldehydes via the chair-like six-membered transition structure **88**, in which the group next to tin adopts an axial position, then gives rise to the observed products, see Fig. 1.

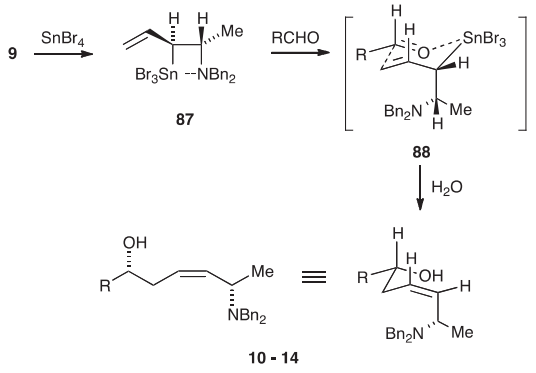


Fig. 1. Outline mechanism for the formation of the (3*Z*)-alkenols **10**–**14**.

The formation of the 1,5-*anti*-products **51**–**54** in the tin(IV) mediated reactions of the stannane **50** is consistent with participation of the allyltin tribromide **89** that reacts with aldehydes via the chair-like transition structure **90**, see Fig. 2.

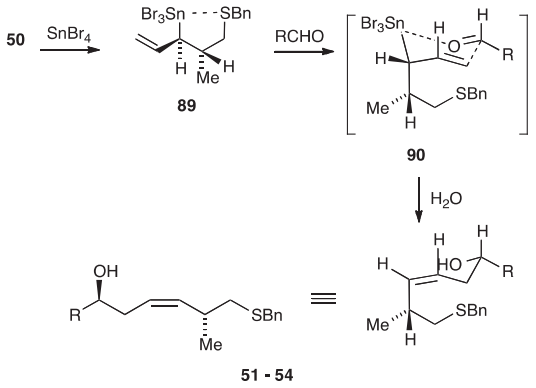
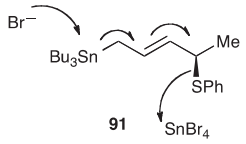


Fig. 2. Outline mechanism for the formation of the (3*Z*)-alkenols **51**–**54**.

Analogous allyltin trihalides have been postulated for the tin(IV) halide promoted reactions of the alkoxy-substituted stannanes **1** and **42** with aldehydes.[1,2,12] Chair-like transition structures analogous to **88** and **90**, in which the substituents next to tin are in axial positions, have been invoked for the uncatalysed reactions of 1-substituted but-2-enyl(tributyl)stannanes with aldehydes under high temperature conditions.[17]

(*Z*)-Alkene formation from 1-substituted allylstannanes is believed to be indicative of six-membered cyclic transition structures for the reactions of the intermediate allyltin trihalides with aldehydes.[16] These processes are believed to be highly stereoselective so that the 1,5-stereoselectivity in the (*Z*)-alkenol manifold is an accurate reflection of the configurations of the participating allyltin trihalides. The lower 1,5-stereoselectivity observed for the tin(IV) halide promoted reactions of the acylamino- and acetylthio-pentenylstannanes **38**, **39** and **49** with aldehydes means that either the acylated substituents are less effective at controlling the stereoselectivity of the initial transmetalation process, or that the resulting allyltin trihalides are more prone to epimerize at the stereogenic centre next to the tin.

The lower yield observed for the tin(IV) halide promoted reaction of the 4-phenylthiopent-2-enylstannane **73** with benzaldehyde may be due to a Lewis acid catalysed 1,4-elimination that competes with the transmetalation process, see structure **91**. The formation of a significant amount of (*E*)-alkenol **75** in this reaction may be due to participation of a competing process that proceeds via an open-chain transition structure.



It is not certain whether cyclic six-membered or open-chain transition structures are involved in the tin(IV) halide promoted reactions of 4-alkoxypent-2-enylstannanes with 1-alkoxycarbonylimines.[3] However, 1-substituted allyltin trihalides are known to epimerize on standing even at −78 °C and the reactions of the allyltin trichloride derived from the 4-(dibenzylamino)pent-2-enylstannane **9** with 1-alkoxycarbonylimines took 12 h at −45 °C to reach completion. It may be that the modest stereoselectivities observed for the reactions with imines are due to epimerization at C(3) of the intermediate allyltin trichloride under the reaction conditions. Nevertheless the consistent preference for formation of the 2,6-*anti*-epimer observed for both enantiomers of the chiral imine is of note.

Notwithstanding the modest stereoselectivities observed for the acylamino and acylthio substituted pentenylstannanes, and for the reactions with imines, the highly effective 1,5-stereocontrol observed for 4- and 5-alkoxy-pent-2-enylstannanes has now been found for tin(IV) halide promoted reactions of 4-alkylamino- and 5-alkylthio-pent-2-enylstannanes with aldehydes and this may be useful in synthesis.

4. Experimental

4.1. General

All non-aqueous reactions were performed under an atmosphere of dry nitrogen or argon at ambient temperature unless otherwise stated.

Proton nuclear magnetic resonance spectroscopy was performed on Varian Unity 500 (500 MHz), Bruker AC-300 or Varian XL 300 (300 MHz) and Varian Gemini 200 (200 MHz) spectrometers. Carbon nuclear magnetic resonance spectroscopy was performed on Bruker AC-300 or Varian XL 300 (75 MHz) and Varian Gemini 200 (50 MHz) spectrometers. Coupling constants in hertz are rounded to the nearest 0.5 Hz. Fluorine nuclear magnetic resonance spectroscopy was performed on a Varian Unity 500 (470 MHz) spectrometer. Infra-red spectroscopy was performed on a Perkin–Elmer 1710FT or an ATI Matteson Genesis FTIR spectrometer. All samples were run as evaporated discs (from chloroform) on sodium chloride plates. Absorption maxima were recorded in wavenumbers (cm^{-1}). Low-resolution electron impact (EI) and chemical ionisation (CI) mass spectroscopy were performed on a Kratos MS25 or a Fisons TRIO 2000 quadrupole mass spectrometer. High-resolution spectroscopy was performed on a Kratos Concept-1S mass spectrometer coupled to a Mach 3 data system. Compounds containing tin displayed characteristic peak clusters, only those associated to ^{120}Sn are

quoted. Optical rotations were recorded on an Optical Activity AA-100 polarimeter operating at 589 nm using either chloroform or methanol as a solvent at ambient temperature.

Analytical high performance liquid chromatography was performed on a Waters Z module, 10 cm×8 mm cartridge containing C18 5μ stationary phase (reverse phase chromatography). Detection was by ultraviolet (UV) absorption using a Perkin–Elmer IC-480 detector at 255 nm. Semi-preparative HPLC was carried out using a Gilson 303 pump (manometric module) attached to a Dynamax 83-211-C column 25 cm×10 mm containing C18 8μ stationary phase (reverse phase chromatography). Detection was by either UV absorption at 254 nm (Gilson 115 UV detector) or refractive index (RI) (Gilson 131 RI detector). Chromatography refers to flash column chromatography. The stationary phase was either silica (Merck, silica 60H, 40–63μ or aluminium oxide (Phase Separations, Act. Alumina UGI-100S)).

Petrol refers to the fraction of petroleum ether, which boils between 40 and 60 °C and was redistilled prior to use. Other solvents were dried by standard techniques. Brine refers to saturated aqueous sodium chloride. *n*-Butyllithium was obtained as a solution in hexanes and titrated against a solution of 2,5-dimethoxybenzyl alcohol in tetrahydrofuran prior to use.

(*R*)-5-*tert*-Butyldimethylsilyloxy-4-methylpent-2-enol **44**, $[\alpha]_D$ +6.1 (*c* 3.5, $CHCl_3$) [lit.[13] +10.7 (*c* 0.65, $CHCl_3$)] was prepared by reduction of the corresponding ethyl pent-2-enoate using DIBAL–H.[13]

4.2. Experimental procedures

*4.2.1. Ethyl (4S,2E)-4-(N,N-dibenzylamino)pent-2-enoate (**5**).* Dimethylsulfoxide (3.7 mL, 51.7 mmol) in DCM (15 mL) was added to oxalyl chloride (2.2 mL, 25.9 mmol) in DCM (40 mL) at −55 °C. After 5 min, alcohol **4** (6 g, 23.5 mmol) in DCM (30 mL) was added followed, after 15 min, by triethylamine (16.5 mL, 117.5 mmol). The solution was stirred for 5 min, then allowed to warm to room temperature. Water (50 mL) was added and the aqueous phase was extracted with DCM (50 mL). The organic phase was washed with brine (50 mL) and dried ($MgSO_4$). Removal of the solvent under reduced pressure gave the corresponding aldehyde. Chromatography (3:1 petrol/ether) of a small sample gave (*S*)-2-(*N*,*N*-dibenzylamino)propanal, $[\alpha]_D$ −24.5 (*c*, 5.2, $CHCl_3$); ν_{max}/cm^{-1} 3410, 3028, 2925, 1726, 1453, 1028, 747 and 699; δ_H (200 MHz, $CDCl_3$) 1.20 (3H, d, *J* 7.0, 3-H_3), 3.35 (1H, m, 2-H), 3.60 and 3.75 (each 2H, d, *J* 15.0, PhHC*H*), 7.20–7.50 (10H, m, ArH) and 9.80 (1H, s, CHO); *m*/*z* (CI, NH_3) 254 (M^++1, 100%) and 91 (59).

Potassium *tert*-butoxide (8.51 g, 76.14 mmol) was added to triethyl phosphonoacetate (17 mL, 84.6 mmol) in THF (250 mL) at 0 °C and solution stirred at room temperature for 1 h, before cooling to −78 °C. The *N*,*N*-(dibenzylamino)propanal (21.2 mmol) in THF (20 mL) was added dropwise and the solution stirred at −78 °C for 20 min. The solution was poured into a mixture of ether (100 mL) and aqueous saturated ammonium chloride (100 mL). The aqueous phase was extracted with ether (50 mL) and the organic extracts were washed with brine (50 mL) and dried ($MgSO_4$). Concentration reduced pressure and chromatography (10:1 petrol/ether) of the residue afforded the *title compound* **5** as a colourless oil (6.24 g, 82%), $[\alpha]_D$ −95 (*c* 0.7, $CHCl_3$); ν_{max}/cm^{-1} 2977, 1719, 1269, 1183 and 699; δ_H (300 MHz, $CDCl_3$) 1.25 (3H, d, *J* 7.0, 5-H_3), 1.32 (3H, t, *J* 7.0, CH_2CH_3), 3.48 (1H, m, 4-H), 3.57 and 3.65 (each 2H, d, *J* 15.0, PhHC*H*), 4.22 (2H, q, *J* 7.0, CH_2CH_3), 5.90 (1H, dd, *J* 16.0, l.5, 2-H), 7.05 (1H, dd, *J* 16.0, 6, 3-H) and 7.20–7.40 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 14.1, 14.3, 28.4, 53.8, 60.4, 121.9, 126.9, 128.3, 128.5, 139.9, 150.3 and 166.6; *m*/*z* (CI, NH_3) 324 (M^++1, 100%) and 91 (25).

*4.2.2. (4S,2E)-4-(N,N-Dibenzylamino)pent-2-en-1-ol (**6**).* Di-*iso*-butylaluminium hydride (29 mL, 1 M in hexane, 29 mmol) was added to the ester **5** (3.13 g, 9.7 mmol) in DCM (40 mL) and hexane (40 mL) at −78 °C. After 40 min, methanol (3 mL), saturated aqueous ammonium chloride (12 mL) and ether (40 mL) were added and the mixture was allowed to warm to room temperature. After filtration and extraction into ethyl acetate (150 mL), the organic extracts were washed with water (50 mL) and brine (50 mL), then dried ($MgSO_4$). After concentration under reduced pressure, chromatography (1:1 petrol/ether) of the residue afforded the *title compound* **6** as a colourless oil (2.26 g, 83%), $[\alpha]_D$ −52 (*c* 1.1, $CHCl_3$); ν_{max}/cm^{-1} 3332 (br), 3027, 2967, 1494, 1453, 977, 731 and 699; δ_H (300 MHz, $CDCl_3$) 1.20 (3H, d, *J* 6.5, 5-H_3), 3.35 (1H, m, 4-H), 3.57 and 3.65 (each 2H, d, *J* 14.0, PhHC*H*), 4.16 (2H, d, *J* 4.5, 1-H_2), 5.65–5.90 (2H, m, 2-H, 3-H) and 7.20–7.45 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 15.1, 53.7, 63.5, 77.2, 126.8, 128.2, 128.6, 130.3, 133.6 and 140.5; *m*/*z* (EI) 281 (M^+, 4%), 266 (60) and 91 (100); HRMS (CI, NH_3): M^+, found 281.1784. $C_{19}H_{23}ON$ requires 281.1780.

*4.2.3. S-Methyl-O-[(4S,2E)-4-(N,N-Dibenzylamino)pent-3-en-1-yl] dithiocarbonate (**7**).* Sodium bis(trimethylsilyl)amide (8.7 mL, 1 M in THF, 8.7 mmol) was added dropwise to the pent-2-enol **6** (2.45 g, 8.7 mmol) in THF (150 mL) at 0 °C. The mixture was stirred at this temperature for 10 min, carbon disulphide (2.1 mL, 34.9 mmol) was added and the mixture stirred at room temperature for 3 h. Iodomethane (2.2 mL, 34.9 mmol) was then added and the stirring continued for 2 h. Aqueous saturated ammonium chloride (20 mL) was added and the mixture extracted with DCM (200 mL). The organic extracts were washed with brine (50 mL), dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (8:1 petrol/ether) of the residue afforded the *title compound* **7** as a pale yellow oil (2.75 g, 85%), $[\alpha]_D$ −43 (*c* 1.6, $CHCl_3$); ν_{max}/cm^{-1} 3401, 2927, 1216, 1059 and 699; δ_H (200 MHz, $CDCl_3$) 1.20 (3H, d, *J* 7.5, 5-H_3), 2.55 (3H, s, SCH_3), 3.35–3.65 (5H, m, 2×$PhCH_2$, 4-H), 5.10 (2H, d, *J* 7.5, 1-H_2), 5.55–6.05 (2H, m, 2-H, 3-H) and 7.20–7.50 (10H, m, ArH); *m*/*z* (CI, NH_3) 372 (M^++1, 21%), 106 (74) and 91 (l00); HRMS (CI, NH_3): MH^+, found 372.1459. $C_{21}H_{26}NOS_2$ requires 372.1456.

*4.2.4. S-Methyl-S-[(4S)-4-(N,N-Dibenzylamino)pent-1-en-3-yl]dithiocarbonate (**8**).* The xanthate **7** (2.75 g, 7.4 mmol) was heated in anhydrous degassed toluene (100 mL) under reflux for 15 h. After concentration under reduced pressure, chromatography (8:1 petrol/ether) of the residue afforded the *title compound* **8** as a white solid (2.23 g, 81%), a 2:1 mixture of epimers (^1H NMR), mp=108–111 °C (DCM, acetone). Found: C, 67.5; H, 7.3; N, 4.2. $C_{21}H_{25}ONS_2$ requires C, 67.9; H, 6.75; N, 3.75%. $[\alpha]_D$ −90 (*c* 1.0, $CHCl_3$); ν_{max}/cm^{-1} 3400, 2927, 1722, 1643, 1453, 863 and 747; δ_H (300 MHz, $CDCl_3$) major epimer 1.10 (3H, d, *J* 6.5, 5-H_3), 2.40 (3H, s, SCH_3), 2.85–3.00 (1H, m, 4-H), 3.35 and 3.85 (each 2H, d, *J* 14, 2×PhHC*H*), 4.40 (1H, t, *J* 10.0, 3-H), 5.10 (1H, d, *J* 10.0, 1-H), 5.31 (1H, d, *J* 15.0, 1-H), 5.60 (1H, m, 2-H) and 7.20–7.50 (10H, m, ArH); *m*/*z* (CI, NH_3) 372 (M^++1, 100%), 266 (45), 224 (60), 106 (59) and 91 (60); HRMS (CI, NH_3): MH^+, found 372.1442. $C_{21}H_{26}NOS_2$ requires 372.1456.

*4.2.5. (4S,2E)-4-(N,N-Dibenzylamino)pent-2-enyl(tributyl)stannane (**9**).* Tributyltin hydride (1.1 mL, 3.77 mmol) and AIBN (5 mg) were added to an anhydrous degassed solution of the dithiocarbonate **8** (1.12 g, 3.02 mmol) in benzene (50 mL) and the solution was heated under reflux for 3 h. After concentration under reduced pressure, chromatography (petrol, 1% triethylamine followed by 100:2:1 petrol/ether/triethylamine) of the residue gave the *title compound* **9** as a colourless oil (1.22 g, 79%), ca. a 95:5 mixture of (*E*)- and (*Z*)-isomers (^1H NMR), $[\alpha]_D$ −36.5 (*c* 0.8, $CHCl_3$); ν_{max}/cm^{-1} 2958, 2926, 1643, 1603, 1454, 1073, 1029, 965, 744 and 698; δ_H (300 MHz, $CDCl_3$) (*E*)-isomer 0.85–0.95 (15H, m, 3×CH_2, 3×CH_3), 1.15 (3H, d, *J* 7.5, 5-H_3), 1.25–1.60 (12H, m, 6×CH_2), 1.75 (2H, d, *J* 8, 1-H_2), 3.20 (1H, qn, *J* 7.0, 4-H), 3.45 and 3.65 (each 2H, d, *J* 14.0, 2×PhHC*H*), 5.30 (1H, dd, *J* 15.0, 7.0, 3-H), 5.60 (1H, dt, *J* 15, 8.5, 4-H) and 7.20–7.45 (15H, m,

ArH); δ_C (75 MHz, $CDCl_3$) 9.2, 13.8, 14.3, 17.2, 27.4, 29.1, 53.5, 55.0, 125.9, 126.5, 128.0, 1285, 131.5 and 141.1; *m/z* (EI) 498 (M^+-57, 2%), 430 (4), 291 (14), 224 (48) and 91 (100); HRMS (CI, NH_3): $M-C_4H_9^+$, found 498.2185. $C_{27}H_{40}N^{120}Sn$ requires 498.2183.

*4.2.6. (1R,5S,3Z)-5-(N,N-Dibenzylamino)-1-phenylhex-3-en-1-ol (**10**).* Tin(IV) bromide (168 μL, 1.027 M in DCM, 0.173 mmol) was added to the stannane **9** (96 mg, 0.173 mmol) in DCM (2 mL) at −55 °C. After 10 min, benzaldehyde (59 μL, 2.95 M in DCM, 0.173 mmol, cooled to −55 °C) was added and the mixture was stirred at −55 °C for 1 h. Triethylamine (103 μL, 0.692 mmol) was added followed by saturated aqueous sodium hydrogen carbonate (2 mL) and the mixture was allowed to warm to room temperature. The mixture was partitioned between water (30 mL) and DCM (30 mL) and the aqueous phase was extracted with DCM (20 mL). The organic extracts were washed with brine (20 mL), dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (6:1 petrol/ether+1% triethylamine) of the residue afforded the *title compound* **10** as a colourless oil (35 mg, 55%), the minor product **16** being detected at the 2% level (^{1}H NMR) $[\alpha]_D$ +98 (*c* 2.9, $CHCl_3$); ν_{max}/cm^{-1} 3400 (br), 3027, 1603, 1494, 1453, 1109, 1029, 745 and 699; δ_H (300 MHz, C_6D_6) major isomer **10** 1.00 (3H, d, *J* 7.0, 6-H_3), 2.15–2.40 (2H, m, 2-H_2), 3.55 (2H, d, *J* 13.0, 2×PhHC*H*), 3.57–3.70 (3H, m, 2×PhHC*H*, 5-H), 4.53 (1H, dd, *J* 8.5, 5.0, 1-H), 5.50 (1H, dd, *J* 10.0, 9.0, 4-H), 5.60 (1H, dt, *J* 10.0, 7, 3-H) and 7.10–7.60 (10H, m, ArH); minor isomer **16** 1.08 (d, *J* 7, 6-H_3); δ_C (75 MHz, $CDCl_3$) 15.6, 38.0, 49.9, 53.8, 73.6, 125.9, 126.8, 127.3, 128.0, 128.2, 128.4, 129.0, 134.1, 139.9 and 144.4; *m/z* (CI, NH_3) 372 (M^++1, 100%); HRMS (CI, NH_3): MH^+, found 372.2325. $C_{26}H_{30}NO$ requires 372.2327.

4-Nitrobenzoyl chloride (18 mg, 0.095 mmol) was added to the pentenol **10** (16 mg, 0.043 mmol), triethylamine (13 μL, 0.086 mmol) and DMAP (5 mg) in DCM (0.5 mL) at 0 °C and the mixture was stirred for 6 h at room temperature. After concentration under reduced pressure, chromatography (10:1 petrol/ether) of the residue afforded the 4-nitrobenzoate **17** as a colourless oil (12.5 mg, 56%); δ_H (300 MHz, $CDCl_3$) 1.05 (3H, d, *J* 6.5, 6-H_3), 2.50–2.75 (2H, m, 2-H_2), 3.45 (2H, d, *J* 14.0, 2×PhHC*H*), 3.47 (1H, m, 5-H), 3.70 (2H, d, *J* 14.0, 2×PhHC*H*), 5.55 (2H, m, 3-H, 4-H), 5.95 (1H, t, *J* 7.0, 1-H), 7.20–8.35 (19H, m, ArH); *m/z* (CI, NH_3) 521 (M^++1, 5%), 491 (20), 196 (100) and 106 (91).

*4.2.7. (1R,5S,3Z)-5-(N,N-Dibenzylamino)-1-(4-chlorophenyl)hex-3-en-1-ol (**11**).* Tin(IV) bromide (158 μL, 1.027 M in DCM, 0.162 mmol) was added to the stannane **9** (90 mg, 0.162 mmol) in DCM (2 mL) at −78 °C. After 10 min, 4-chlorobenzaldehyde (76 μL, 3.2 M in DCM, 0.243 mmol, cooled to −78 °C) was added and the mixture stirred at −78 °C for 1 h. Triethylamine (95 μL, 0.648 mmol) was added followed by saturated aqueous sodium hydrogen carbonate (2 mL). The mixture was allowed to warm to ambient temperature and the aqueous phase extracted with DCM. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (4:1 petrol/ether, 1% triethylamine) of the residue gave the *title compound* **11** as a colourless oil (27 mg, 59%), no minor product was evident (^{1}H NMR), $[\alpha]_D$ +48 (*c* 3.2, MeOH); ν_{max}/cm^{-1} 3395 (br), 2967, 1492, 1453, 1091, 1071, 1014, 745 and 699; δ_H (300 MHz, $CDCl_3$) 1.15 (3H, d, *J* 7.0, 6-H_3), 2.25 (2H, m, 2-H_2), 3.35 (1H, br s, OH), 3.58 (1H, m, 5-H), 3.60 and 3.70 (each 2H, d, *J* 14.0, PhHC*H*), 4.63 (1H, m, 1-H), 5.68 (2H, m, 3-H, 4-H) and 7.15–7.50 (14H, m, ArH); δ_C (75 MHz, $CDCl_3$) 14.8, 38.2, 49.5, 53.8, 72.7, 127.0, 127.3, 128.0, 128.3, 128.4, 129.2, 132.9, 134.8, 139.5 and 143.0; *m/z* (CI, NH_3) 406 (M^++1, 100%); HRMS (CI, NH_3): MH^+, found 406.1945. $C_{26}H_{29}{}^{35}ClNO$ requires 406.1938.

*4.2.8. (1R,5S,3Z)-5-(N,N-Dibenzylamino)-1-(4-methoxyphenyl)hex-3-en-1-ol (**12**).* Following the procedure outlined for alkenol **11**, stannane **9** (94 mg, 0.169 mmol), tin(IV) bromide (165 μL, 1.027 M in DCM, 0.169 mmol) and 4-methoxybenzaldehyde (86 μL, 2.88 M in DCM, 0.254 mmol) after chromatography (2:1 petrol/ether, 1% triethylamine) gave the *title compound* **12** as a colourless oil (24 mg, 35%), a minor product was detected at the 2% level (^{1}H NMR), $[\alpha]_D$ +31 (*c* 2.9, $CHCl_3$); ν_{max}/cm^{-1} 3395 (br), 3027, 2963, 1611, 1512, 1454, 1364, 1303, 1247, 1031, 745 and 699; δ_H (300 MHz, $CDCl_3$) major product **12** 1.15 (3H, d, *J* 7, 6-H_3), 2.30 (2H, m, 2-H_2), 2.85 (1H, br s, OH), 3.60 (1H, m, 5-H), 3.65 (3H, s, OCH_3), 3.88 (4H, s, 2×PhCH_2), 4.62 (1H, dd, *J* 8.0, 5.0, 1-H), 5.65 (2H, m, 3-H, 4-H) and 6.90–7.45 (14H, m, ArH); minor poduct 1.18 (d, *J* 7.0, 6-H_3); δ_C (75 MHz, $CDCl_3$) 15.7, 38.0, 49.8, 53.8, 55.3, 73.2, 113.7, 126.9, 127.2, 128.2, 128.5, 129.0, 133.9, 136.6, 139.9 and 158.9; *m/z* (CI, NH_3) 402 (M^++1, 19%) and 198 (100); HRMS (CI, NH_3): MH^+, found 402.2435. $C_{27}H_{32}NO_2$ requires 402.2433.

*4.2.9. (3R,7S,5Z)-7-(N,N-Dibenzylamino)oct-5-en-3-ol (**13**).* Following the procedure outlined for alkenol **11**, stannane **9** (84 mg, 0.151 mmol), tin(IV) bromide (147 μL, 1.027 M in DCM, 0.151 mmol), and propanal (44 μL, 3.47 M in DCM, 0.151 mmol) after chromatography (4:1 petrol/ether, 1% triethylamine) gave the *title compound* **13** as a colourless oil (14 mg, 30%), $[\alpha]_D$ +29 (*c* 1.2, $CHCl_3$); ν_{max}/cm^{-1} 3372 (br), 3027, 2964, 1603, 1494, 1454, 1365, 1137, 1073, 1029, 746 and 699; δ_H (300 MHz, $CDCl_3$) 0.95 (3H, t, *J* 7.0,1-H_3), 1.24 (3H, d, *J* 7.0, 8-H_3), 1.45 (2H, m, 2-H_2), 2.00 (2H, m, 4-H_2), 3.35 (6H, m, 3-H, 2×PhCH_2, 7-H), 5.65 (2H, m, 5-H, 6-H) and 7.20–7.50 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 10.0, 15.3, 15.8, 30.2, 35.3, 53.8, 65.9, 72.6, 126.9, 127.4, 128.2, 129.1 and 139.9; *m/z* (EI) 323 (M^+, 6%) and 91 (100); HRMS (CI, NH_3): M^+, found 323.2233. $C_{22}H_{29}NO$ requires 323.2249.

*4.2.10. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-ol (**14**).* Following the procedure outlined for alkenol **11**, stannane **9** (120 mg, 0.216 mmol), tin(IV) bromide (207 μL, 1.044 M in DCM, 0.216 mmol) and 2-methylpropanal (65 μL, 3.31 M in DCM, 0.216 mmol) after chromatography (4:1 petrol/ether, 1% triethylamine) gave the *title compound* **14** as a colourless oil (42 mg, 58%), $[\alpha]_D$ +46 (*c* 1.5, $CHCl_3$); ν_{max}/cm^{-1} 3413 (br), 3027, 2962, 1603, 1494, 1453, 1366, 1139, 1029, 744 and 699; δ_H (300 MHz, $CDCl_3$) 0.89 and 0.92 (each 3H, t, *J* 6.0, 1-H_3 or 2-CH_3), 1.20 (3H, d, *J* 7.0, 8-H_3), 1.65 (1H, m, 2-H), 2.00 (2H, m, 4-H_2), 2.25 (1H, br s, OH), 3.35 (1H, m, 3-H), 3.63 (5H, m, 2×PhCH_2, 7-H), 5.65 (2H, m, 5-H, 6-H) and 7.20–7.50 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 16.1, 17.6, 18.6, 32.6, 33.6, 49.8, 53.8, 76.2, 126.8, 128.2, 129.0, 129.2, 133.3 and 140.0; *m/z* (CI, NH_3) 338 (M^++1, 68%) and 106 (100); HRMS (CI, NH_3): MH^+, found 338.2485. $C_{23}H_{32}NO$ requires 338.2484.

*4.2.11. (1S,5S,3Z)-5-(N,N-Dibenzylamino)-1-phenylhex-3-en-1-yl 4-nitrobenzoate (**15**).* DEAD (23 μL, 0.142 mmol) was added to the pentenol **10** (35 mg, 0.094 mmol), triphenylphosphine (37 mg, 0.142 mmol) and 4-nitrobenzoic acid (24 mg, 0.142 mmol) in toluene (2 mL) at −35 °C. The orange-red colour disappeared immediately and the reaction mixture was stirred for 1.5 h allowing the solution to warm to room temperature. The mixture was partitioned between ether (15 mL) and water (15 mL) and the aqueous phase was extracted with ether (15 mL). The organic extracts were washed with brine (20 mL), dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (50:1 petrol/ether) of the residue afforded the *title compound* **15** as a colourless oil (20 mg, 41%), $[\alpha]_D$ +57 (*c* 1.8, $CHCl_3$); ν_{max}/cm^{-1} 3028, 2967, 1726, 1605, 1529, 1494, 1454, 1343, 1272, 1075, 1015 and 699; δ_H (300 MHz, $CDCl_3$) 1.10 (3H, d, *J* 7.0, 6-H_3), 2.45–2.80 (2H, m, 2-H_2), 3.50 (2H, d, *J* 14.0, 2×PhHC*H*), 3.62 (1H, qn, *J* 7.0, 5-H), 3.70 (2H, d, *J* 14.0, 2×PhHC*H*), 5.60 (2H, m, 3-H, 4-H), 6.00 (1H, dd, *J* 8.5, 5.0, 1-H) and 7.20–8.35 (19H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.3, 34.7, 50.3, 53.7, 77.2, 123.5, 126.1, 126.5, 126.7, 128.2, 128.3, 128.6 (2), 130.7, 134.1, 135.7, 139.6, 140.5, 150.6 and 163.8; *m/z* (CI, NH_3) 491 (10%) and 196 (100).

*4.2.12. (1S,5S,3Z)-5-(N,N-Dibenzylamino)-1-phenylhex-3-en-1-ol (**16**).* Nitrobenzoate ester **15** (20 mg, 0.038 mmol) was added to

sodium hydroxide (14 mg, 0.56 mmol) in methanol (2 mL) and the solution stirred at room temperature for 50 min. DCM (10 mL) was added and the aqueous phase was extracted with DCM (20 mL). The organic extracts were washed using brine (20 mL) and dried ($MgSO_4$). After concentration under reduced pressure, chromatography (6:1 petrol/ether) afforded the *title compound* **16** as a colourless oil (8 mg, 57%), $[\alpha]_D$ −37 (*c* 0.6, $CHCl_3$); ν_{max}/cm^{-1} 3400 (br), 3027, 2925, 1603, 1494, 1453, 1365, 1029, 745 and 699; δ_H (300 MHz, $CDCl_3$) 1.20 (3H, d, *J* 6.5, 6-H_3), 2.30 (2H, t, *J* 6.5, 2-H_2), 2.80 (1H, br s, OH), 3.55 (1H, m, 5-H), 3.60 and 3.65 (each 2H, d, *J* 14.0, 2×PhHC*H*), 4.70 (1H, t, *J* 6.5, 5-H), 5.50–5.75 (2H, m, 3-H, 4-H) and 7.20–7.50 (15H, m, ArH); δ_C (75 MHz, $CDCl_3$) 16.2, 37.2, 50.0, 53.8, 73.3, 125.9, 126.8, 127.3, 127.4, 128.2 (2), 128.9, 134.3, 140.0 and 144.1; *m*/*z* (CI, NH_3) 372 (M^++1, 45 %), 198 (77) and 91 (86); HRMS (CI, NH_3): MH^+, found 372.2329. $C_{26}H_{30}NO$ requires 372.2327.

*4.2.13. (1R,5S,3Z)-1-[(R)-2-Acetoxy-2-phenylacetoxy]-5-(N,N-dibenzylamino)-1-phenylhex-3-ene (**18**).* Dicyclohexylcarbodiimide (25 mg, 0.121 mmol) was added to a solution of (*R*)-2-acetoxy-2-phenylacetic acid (24 mg, 0.121 mmol), 4-*N*,*N*-dimethylaminopyridine (5 mg) and the alcohol **10** (30 mg, 0.081 mmol) in DCM (2 mL) and the solution stirred for 18 h at ambient temperature. After concentration under reduced pressure, hexane (5 mL) was added and the mixture filtered. The filtrate was washed with aqueous hydrogen chloride (1 M) and saturated aqueous sodium hydrogen carbonate then dried ($MgSO_4$). After concentration under reduced pressure, chromatography of the residue (4:1 petrol/ether) afforded the *title compound* **18** as a colourless oil (26 mg, 58%), $[\alpha]_D$ +7.1 (*c* 1.6, $CHCl_3$); ν_{max}/cm^{-1} 2929, 1744, 1d, *J* 7, 6-H_3), 2.22 (3496, 1455, 1373, 1232, 1208, 1175, 1057, 750 and 699; δ_H (300 MHz, $CDCl_3$) 1.00 (3H, H, s, O_2CCH_3), 2.40 (2H, m, 2-H_2), 3.37 (1H, m, 5-H), 3.45 and 3.73 (each 2H, d, *J* 14.0, 2×PhHC*H*), 5.55 (2H, m, 3-H and 4-H), 5.70 (1H, t, *J* 7.0, 1-H), 6.05 (1H, s, O_2CCH) and 6.75–7.50 (20H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.7, 20.8, 34.5, 50.3, 53.6, 74.5, 77.2, 125.9, 126.2, 126.7, 127.8, 128.0, 128.1, 128.6, 128.7, 129.2, 133.2, 133.6, 139.1, 140.6, 167.9 and 170.3; *m*/*z* (CI, NH_3) 548 (M^++1, 52%) and 106 (100); HRMS (CI, NH_3): MH^+, found 548.2794. $C_{36}H_{38}NO_4$ requires 548.2801.

*4.2.14. (1R,5S,3Z)-1-[(S)-2-Acetoxy-2-phenylacetoxy]-5-(N,N-dibenzylamino)-1-phenylhex-3-ene (**19**).* Following the procedure outlined for ester **18**, alcohol **10** (30 mg, 0.081 mmol) and (*S*)-2-acetoxy-2-phenylacetic acid, after chromatography (4:1 petrol/ether) gave the *title compound* **19** as a colourless oil (29 mg, 64%), $[\alpha]_D$ +74 (*c* 2.8, $CHCl_3$); ν_{max}/cm^{-1} 3031, 1744, 1495, 1454, 1372, 1231, 1208, 1175, 1057, 749 and 699; δ_H (300 MHz, $CDCl_3$) 0.95 (3H, d, *J* 7.0, 6-H_3), 2.20 (3H, s, O_2CCH_3), 2.35 (2H, m, 2-H_2), 3.30 (1H, m, 5-H), 3.32 and 3.65 (each 2H, d, *J* 14.0, PhHC*H*), 5.25 (1H, dt, *J* 10.0, 7, 3-H), 5.40 (1H, t, *J* 10.0, 4-H), 5.70 (1H, t, *J* 7.0, 1-H), 6.05 (1H, s, O_2CCH), 7.10–7.50 (20H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.5, 20.8, 34.3, 50.2, 53.6, 74.6, 125.9, 126.4, 126.7, 127.9, 128.1, 128.3, 128.6, 128.8, 129.3, 133.0, 134.0, 139.1, 140.5, 168.2 and 170.2; *m*/*z* (CI, NH_3) 548 (M^++1, 58%) and 106 (100) HRMS (CI, NH_3): MH^+, found 548.2800. $C_{36}H_{38}NO_4$ requires 548.2801.

*4.2.15. (lR,5S,3Z)-1-Acetoxy-5-(N,N-dibenzylamino)-1-phenylhex-3-ene (**20**).* Triethylamine (166 μL, 1.12 mmol), DMAP (2 mg) and acetic anhydride (56 μL, 0.659 mmol) were added to the pentenol **10** (83 mg, 0.224 mmol) in DCM (3 mL) and the mixture was stirred at room temperature for 18 h. Water (5 mL) was added and the aqueous phase extracted with DCM (10 mL). The organic extracts were washed with brine (l0 mL), dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (3:1, petrol/ether) of the residue afforded the *title compound* **20** as a colourless oil (78 mg, 85%), $[\alpha]_D$ +51 (*c* 1.3, $CHCl_3$); ν_{max}/cm^{-1} 2964, 2927, 1739, 1529, 1494, 1453, 1371, 1236, 1027 and 699; δ_H (200 MHz, $CDCl_3$) 1.05 (3H, d, *J* 7.0, 6-H_3), 2.10 (3H, s, O_2CCH_3), 2.30–2.65 (2H, m, 2-H_2), 3.55 (1H, m, 5-H), 3.57 and 3.75 (each 2H, d, *J* 14.0, 2×PhHC*H*), 5.55 (2H, m, 3-H, 4-H), 5.75 (1H, t, *J* 6.5, 1-H) and 7.15–7.45 (I5H, m, ArH); *m*/*z* (CI, NH_3) 414 (M^++1, 16%) and 121 (100); HRMS (CI, NH_3): MH^+, found 414.2438. $C_{28}H_{32}NO_2$ requires 414.2433.

Ozone was bubbled through a solution of acetate **20** (86 mg, 0.2 mmol) in DCM (10 mL) over a period of 40 min at −78 °C and the solution was then purged with oxygen for 10 min. Methyl sulphide (146 μL, 2.0 mmol) was added and the mixture warmed to ambient temperature. After concentration under reduced pressure the residue was dissolved in DCM (5 mL). Sodium borohydride (32 mg, 0.8 mmol) in methanol (5 mL) was added and the solution stirred for 2 h. Water (3 mL) was added and the aqueous phase extracted with DCM. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography of the residue (3:1 petrol/ether) afforded (*R*)-3-acetoxy-3-phenylpropan-1-ol [(*R*)-**21**] as a colourless oil (7 mg, 18%), $[\alpha]_D$ +78 (*c* 0.7, $CHCl_3$) [lit.[2] +79.2 (*c* 1, $CHCl_3$)].

*4.2.16. (3S,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-yl 4-nitrobenzoate (**22**).* Diethyl azodicarboxylate (55 μL, 0.34 mmol) was added to the alcohol **14** (42 mg, 0.113 mmol), triphenylphosphine (89 mg, 0.340 mmol) and 4-nitrobenzoic acid (58 mg, 0.340 mmol) in toluene (2 mL) at −35 °C. The orange-red colour disappeared immediately and the reaction mixture was stirred for 90 min allowing the solution to warm to ambient temperature. The mixture was partitioned between ether and water and the aqueous phase extracted with ether. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (80:1 petrol/ether) of the residue gave the *title compound* **22** as a colourless oil (19 mg, 31%), $[\alpha]_D$ +49 (*c* 0.7, $CHCl_3$); ν_{max}/cm^{-1} 2965, 1722, 1606, 1528, 1274, 1102, 720 and 699; δ_H (300 MHz, $CDCl_3$) 0.91 and 0.93 (each 3H, d, *J* 7.0, CH_3), 1.05 (3H, d, *J* 7.0, 8-H_3), 1.90 (1H, m, 2-H), 2.25 (2H, m, 4-H_2), 3.45 (2H, d, *J* 14.0, 2×PhHC*H*), 3.60 (1H, m, 7-H), 3.70 (2H, d, *J* 14.0, 2×PhHC*H*), 5.00 (1H, dt, *J* 9.0, 7.0, 3-H), 5.55 (2H, m, 5-H, 6-H), 7.20–7.45 (10H, m, ArH) and 8.13 and 8.30 (each 2H, d, *J* 8.5, ArH); δ_C (75 MHz, $CDCl_3$) 17.7, 18.6, 29.7, 29.9, 31.7, 50.0, 53.7, 123.5, 126.7, 127.1, 128.2, 128.5, 130.6, 133.0, 140.6, 150.5 and 164.2; *m*/*z* (CI, NH_3) 487 (M^++1, 100%) and 457 (80); HRMS (CI, NH_3): MH^+, found 487.2593. $C_{30}H_{35}N_2O_4$ requires 487.2597.

*4.2.17. (3S,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-ol (**23**).* Nitrobenzoate **22** (9 mg, 0.019 mmol) was added to sodium hydroxide (1% w/v in MeOH, 1 mL) and the solution stirred at ambient temperature for 3 h. DCM and water were added and the aqueous phase was extracted with DCM. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography (6:1 petrol/ether) of the residue afforded the *title compound* **23** as a colourless oil (3 mg, 48%); ν_{max}/cm^{-1} 3415 (br), 2956, 1494, 1453, 1028, 745 and 699; δ_H (200 MHz, $CDCl_3$) 0.81 and 0.87 (each 3H, d, *J* 6.0, 1-H_3 or 2-CH_3), 1.20 (3H, d, *J* 7.0, 8-H_3), 1.55 (1H, m, 2-H), 1.70 (1H, br s, OH), 2.00 (2H, m, 4-H_2), 3.30 (1H, m, 3-H), 3.45 (2H, d, *J* 14.0, 2×PhHC*H*), 3.55 (1H, m, 7-H), 3.70 (2H, d, *J* 14.0, 2×PhHC*H*), 5.65 (2H, m, 5-H, 6-H) and 7.20–7.45 (10H, m, ArH); *m*/*z* (CI, NH_3) 338 (M^++1, 75%) and 106 (100); HRMS (CI, NH_3): MH^+, found 338.2487. $C_{23}H_{32}NO$ requires 338.2484.

*4.2.18. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-yl 4-nitrobenzoate (**24**).* 4-Nitrobenzoyl chloride (46 mg, 0.242 mmol) was added to the alcohol **14** (31 mg, 0.110 mmol), triethylamine (33 μL, 0.220 mmol) and DMAP (5 mg) in DCM (1 mL) at 0 °C. The mixture was stirred for 6 h at ambient temperature and then concentrated under reduced pressure. Chromatography (10:1 petrol/ether) of the residue gave the *title compound* **24** as a colourless oil (26 mg, 58%), $[\alpha]_D$ +23 (*c* 2.7, $CHCl_3$); ν_{max}/cm^{-1} 3027, 2966, 1723,

1607, 1529, 1494, 1454, 1348, 1274, 1118, 1102, 746, 720 and 699; δ_H (300 MHz, $CDCl_3$) 0.89 and 0.91 (each 3H, d, *J* 7.0, CH_3), 1.20 (3H, d, *J* 7.0, 8-H_3), 1.95 (1H, m, 2-H), 2.30 (2H, m, 4-H_2), 3.45 (2H, d, *J* 14.0, 2×PhHC*H*), 3.60 (1H, qn, *J* 7.0, 7-H), 3.73 (2H, d, *J* 14.0, 2×PhHC*H*), 5.03 (1H, dt, *J* 8.5. 5.0, 3-H), 5.60 (2H, m, 5-H, 6-H), 7.20–7.40 (10H, m, ArH) and 8.23 and 8.33 (each 2H, d, *J* 8.5, ArH); δ_C (75 MHz, $CDCl_3$) 17.5, 17.9, 18.7, 29.7, 31.4, 50.6, 53.8, 80.2, 123.6, 126.7, 128.1, 128.6, 130.7, 133.0, 136.0, 140.5, 150.5 and 164.4; *m*/*z* (CI, NH_3) 486 (M^+, 100%); HRMS (CI, NH_3): M^+, found 486.2516. $C_{30}H_{34}N_2O_4$ requires 486.2519.

*4.2.19. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-3-[(R)-2-acetoxy-2-phenylacetoxy]-2-methyloct-5-ene (**25**).* Following the procedure outlined for ester **18**, alcohol **14** (21 mg, 0.062 mmol) and (*R*)-2-acetoxy-2-phenylacetic acid, after chromatography (4:1 petrol/ether), gave the *title compound* **25** as a colourless oil (14 mg, 44%), $[\alpha]_D$ −35 (*c* 1.6, $CHCl_3$); ν_{max}/cm^{-1} 2965, 1743, 1498, 1457, 1373, 1234, 1211, 1179, 1057, 753 and 699; δ_H (500 MHz, $CDCl_3$) 0.50 (6H, d, *J* 6.0, 1-H_3, 2-CH_3), 1.15 (3H, d, *J* 7.0, 8-H_3), 1.55 (1H, m, 2-H), 2.10 (2H, m, 4-H_2), 2.19 (3H, s, O_2CCH_3), 3.40 (2H, d, *J* 11.0, 2×PhHC*H*), 3.50 (1H, m, 7-H), 3.70 (2H, d, *J* 11.0, 2×PhHC*H*), 4.70 (1H, m, 3-H), 5.50 (2H, m, 5-H, 6-H), 5.95 (1H, s, O_2CCH) and 7.10–7.50 (15H, m, ArH); δ_C (75 MHz, $CDCl_3$) 16.8, 18.3, 20.9, 29.7, 31.3, 50.4, 53.6, 74.7, 79.8, 126.5, 127.0, 127.6, 128.0, 128.5, 129.0, 132.0, 134.1, 140.6, 168.4 and 169.9; *m*/*z* (CI, NH_3) 514 (M^++1, 100%); HRMS (CI, NH_3): MH^+, found 514.2945. $C_{33}H_{40}NO_4$ requires 514.2957.

*4.2.20. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-3-[(S)-2-acetoxy-2-phenylacetoxy]-2-methyloct-5-ene (**26**).* Following the procedure outlined for ester **18**, alcohol **14** (19 mg, 0.051 mmol) and (*S*)-2-acetoxy-2-phenylacetic acid, after chromatography (4:1 petrol/ether), gave the *title compound* **26** as a colourless oil (22 mg, 76%), $[\alpha]_D$ +57 (*c* 2.2, $CHCl_3$); ν_{max}/cm^{-1} 2965, 1743, 1498, 1457, 1373, 1234, 1180, 1055, 1003, 753 and 700; δ_H (500 MHz, $CDCl_3$) 0.75 and 0.77 (each 3H, d, *J* 7.0, CH_3), 1.09 (3H, d, *J* 7.0, 8-H_3), 1.70 (1H, oct, *J* 7.0, 2-H), 1.92 (2H, t, *J* 7.0, 4-H_2), 2.18 (3H, s, O_2CCH_3), 3.20 (2H, d, *J* 14.0, 2×PhHC*H*), 3.35 (1H, m, 7-H), 3.60 (2H, d, *J* 14.0, 2×PhHC*H*), 4.70 (1H, q, *J* 7.0, 3-H), 5.05 (1H, dt, *J* 10.5, 7.0, 5-H), 5.20 (1H, t, *J* 10.5, 6-H), 5.88 (1H, s, O_2CCH) and 7.10–7.50 (15H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.4, 18.1, 18.4, 20.8, 29.3, 31.5, 50.1, 53.5, 74.8, 80.0, 126.5, 126.8, 127.8, 128.0, 128.4, 128.5, 129.1, 131.7, 133.8, 140.4, 168.5 and 170.1; *m*/*z* (CI, NH_3) 514 (M^++1, 100%); HRMS (CI, NH_3): MH^+, found 514.2936. $C_{33}H_{40}NO_4$ requires 514.2957.

*4.2.21. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-yl (R)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoate (**27**).* Alcohol **14** (28 mg, 0.083 mmol) in carbon tetrachloride (0.5 μL) was added to (*S*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoyl chloride (32 mg, 0.125 mmol) in pyridine (0.5 μL) and the solution stirred for 2 h at ambient temperature. 3-(*N*,*N*-Dimethylamino)propylamine (0.5 μL) was added and, after 10 min, the solution was partitioned between ether and water. The aqueous phase was extracted with ether and the organic extracts were washed with dilute aqueous aqueous hydrogen chloride (1 M), saturated aqueous sodium hydrogen carbonate and brine, then dried ($MgSO_4$). Concentration under reduced pressure afforded the *title compound* **27** as a pale yellow oil (36 mg, 78%), $[\alpha]_D$ +43 (*c* 2.5, $CHCl_3$); ν_{max}/cm^{-1} 2968, 1743, 1494, 1453, 1370, 1260, 1168, 1123, 1079, 1020, 996, 837 and 700; δ_H (300 MHz, $CDCl_3$) 0.73 and 0.83 (each 3H, d, *J* 7.0, CH_3), 1.17 (3H, d, *J* 7.0, 8-H_3), 1.85 (1H, m, 2-H), 2.10 (2H, m, 4-H_2), 3.30 (2H, d, *J* 14.0, 2×PhHC*H*), 3.45 (1H, dq, *J* 11.5, 7.0, 7-H), 3.55 (3H, s, OCH_3), 3.68 (2H, d, *J* 14.0, 2×PhHC*H*), 4.90 (1H, dt, *J* 9.0 6.0, 3-H), 5.35 (1H, dt, *J* 11.0, 6.0, 5-H), 5.45 (1H, dd, *J* 11.0, 9.0, 6-H) and 7.15–7.60 (15H, m, ArH); δ_F (470 MHz, $CDCl_3$) −72.75 (major) and −72.70 (trace); *m*/*z* (EI) 553 (M^+, 3%), 539 (60) and 189 (100); HRMS (CI, NH_3): M^+, found 553.2812. $C_{33}H_{38}F_3NO_3$ requires 553.2804.

*4.2.22. (3R,7S,5Z)-7-(N,N-Dibenzylamino)-2-methyloct-5-en-3-yl [(S)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoate (**28**).* Following the procedure outlined for ester **27**, alcohol **14** (26 mg, 0.077 mmol) and (*R*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoyl chloride gave the *title compound* **28** as a colourless oil (21 mg, 49%); δ_H (200 MHz, $CDCl_3$) 0.69 and 0.71 (each 3H, d, *J* 7.0, CH_3), 1.20 (3H, d, *J* 7.0, 8-H_3), 1.75 (1H, m, 2-H), 2.15 (2H, m, 4-H_2), 3.40 (2H, d, *J* 14.0, 2×PhHC*H*), 3.50 (1H, m, 7-H), 3.55 (3H, s, OCH_3), 3.70 (2H, d, *J* 14.0, 2×PhHC*H*), 4.95 (1H, dt, *J* 9.0, 6.0, 3-H), 5.55 (2H, m, 5-H, 6-H) and 7.15–7.60 (15H, m, ArH); δ_F (470 MHz, $CDCl_3$) −72.70 (major), −72.75.

*4.2.23. S-Methyl-O-[(4R)-5-(tert-butyldimethylsilyloxy)-4-methyl pent-2-en-1-yl]dithiocarbonate (**45**).* *n*-Butyllithium (25 mL, 1.6 M solution in hexanes, 39.5 mmol) was added dropwise to the alcohol **44** (7.56 g, 32.9 mmol) in THF (200 mL) at 0 °C. The solution was stirred for 30 min, then carbon disulphide (8.25 mL, 131.6 mmol) was added and the mixture was stirred at ambient temperature for 3 h. Iodomethane (8.25 mL, 131.6 mmol) was added and the mixture was stirred for 18 h. Saturated aqueous ammonium chloride was added and the aqueous phase was extracted with ether. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced pressure. Chromatography of the residue (20:1 petrol/ether) gave the *title compound* **45** as a yellow oil (8.02 g, 76%), an 80:20 mixture of (*E*)- and (*Z*)-isomers (^1H NMR), $[\alpha]_D$ −8.1 (*c* 2.3, $CHCl_3$); ν_{max}/cm^{-1} 2956, 2847, 1471, 1387, 1255, 1063, 838 and 777; δ_H (300 MHz, $CDCl_3$) 0.08 (6H, s, 2×CH_3Si), 0.90–1.05 [12H, m, 4-CH_3, (CH_3)$_3$CSi], 2.40 (0.8H, m, 4-H), 2.60 (3H, s, SCH_3), 2.70 (0.2H, m, 4-H), 3.40–3.60 (2H, m, 5-H_2), 5.05 (2H, d, *J* 6.5, 1-H_2) and 5.60–5.90 (2H, m, 2-H, 3-H); *m*/*z* (CI, NH_3) 338 (M^++18, 100%) and 321 (M^++1, 9); HRMS (CI, NH_3): MNH_4^+, found 338.1648. $C_{14}H_{32}NO_2S_2Si$ requires 338.1643.

*4.2.24. S-Methyl-S′-[(4S)-5-tert-butyldimethylsilyloxy-4-methyl-pent-1-en-3-yl]dithiocarbonate (**46**).* The xanthate **45** (8.02 g, 25.1 mmol) in degassed toluene (100 mL) was heated under reflux for 18 h. After concentration under reduced pressure, chromatography (50:1 petrol/ether) gave the *title compounds* **46** as a colourless oil (6.97 g, 87%), $[\alpha]_D$ +3.9 (*c* 2.1, $CHCl_3$); ν_{max}/cm^{-1} 2956, 1649, 1470, 1256, 1104, 870, 776 and 666; δ_H (300 MHz, $CDCl_3$) 0.05 (6H, s, 2×CH_3Si), 0.95 [12H, m, 4-CH_3, (CH_3)$_3$CSi], 2.02 (1H, m, 4-H), 2.20 (3H, s, SCH_3), 3.55 (2H, m, 5-H_2), 4.45 (1H, m, 3-H), 5.20 (2H, m, 1-H_2) and 5.85 (1H, m, 2-H); *m*/*z* (CI, NH_3) 338 (M^++18, 100%) and 321 (M^++1, 65); HRMS (CI, NH_3): MH^+, found 321.1377. $C_{14}H_{29}O_2S_2Si$ requires 321.1378.

*4.2.25. (4R)-5-tert-Butyldimethylsilyloxy-4-methylpent-2-enyl(tributyl)stannane (**47**).* Tri-*n*-butyltin hydride (10.95 mL, 32.7 mmol) was added to the dithiocarbonate **46** (6.97 g, 21.8 mmol) and AIBN (350 mg) in degassed benzene (120 mL) and the solution was heated under reflux for 3 h. After concentration under reduced pressure, chromatography (petrol, 0.5% triethylamine) of the residue gave the *title compound* **47** as a colourless oil (7.96 g, 73%), $[\alpha]_D$ −4.6 (*c* 2.3, $CHCl_3$); ν_{max}/cm^{-1} 2957, 1523, 1377, 1254, 1085, 1006, 835, 775 and 667; δ_H (300 MHz, $CDCl_3$) 0.05 (6H, s, 2×CH_3Si), 0.85–1.05 [27H, m, (CH_3)$_3$CSi, 4-CH_3, 3×CH_2, 3×CH_3], 1.15–1.75 (14H, m, 1-H_2, 6×CH_2), 2.28 (1H, m, 4-H), 3.30 and 3.52 (each 1H, m, 5-H) and 5.15 and 5.62 (each 1H, m, 2-H or 3-H); *m*/*z* (EI) 447 (M^+−57, 15%) and 177 (100); HRMS (CI, NH_3): M−$C_4H_9^+$, found 447.2102. $C_{20}H_{43}OSi^{120}Sn$ requires 447.2105.

*4.2.26. (4R)-5-Hydroxy-4-methylpent-2-enyl(tributyl)stannane (**48**).* Tetrabutylammonium fluoride (31.7 mL, 1 M in THF, 31.7 mmol) was added to the stannane **47** (7.96 g, 15.8 mmol) and

the solution was stirred for 18 h. After concentration under reduced pressure, chromatography (gradient: petrol to 5:1 petrol/ether+1% triethylamine) of the residue gave the *title compound* **48** as a colourless oil (5.48 g, 89%), an 80:20 mixture of (*E*)- and (*Z*)-isomers (^{1}H NMR), $[\alpha]_D$ +7.1 (*c* 1.9, $CHCl_3$); ν_{max}/cm^{-1} 3345 (br), 2957, 2923, 1655, 1460, 1376, 1035, 962 and 868; δ_H (300 MHz, $CDCl_3$) 0.85–0.95 (15H, m, 3×CH_2, 3×CH_3), 1.00 (3H, d, *J* 7.0, 4-CH_3), 1.20–1.95 (14H, m, CH_2Sn, 6×CH_2), 2.30 (1H, qn, *J* 7.0, 4-H), 3.30–3.55 (2H, m, 5-H_2), 4.85 (0.2H, t, *J* 10.0, 3-H), 5.05 (0.8H, dd, *J* 15.0, 8, 3-H) and 5.70 (1H, m, 2-H); *m/z* (EI) 333 (M^+−57, 39%) and 235 (100); HRMS (CI, NH_3): M−$C_4H_9^+$, found 333.1241. $C_{14}H_{29}O^{120}Sn$ requires 333.1240.

*4.2.27. (4R)-5-Acetylthio-4-methylpent-2-enyl(tributyl)stannane (**49**).* Di-*iso*-propyl azodicarboxylate (3 mL, 15.4 mmol) was added to triphenylphosphine (4.03 g, 15.4 mmol) in THF (20 mL) at 0 °C and the mixture stirred for 30 min. The hydroxyalkylstannane **48** (2 g, 5.14 mmol) and thioacetic acid (1.1 mL, 15.4 mmol) in THF (30 mL) were added and the mixture stirred at 0 °C for 1 h, then at ambient temperature for 1 h. After concentration under reduced pressure, chromatography (petrol, 1% triethylamine) of the residue gave the *title compound* **49** as a colourless oil (1.66 g, 72%), an 80:20 mixture of (*E*) and (*Z*)-isomers (^{1}H NMR), $[\alpha]_D$ +9.6 (*c* 4.1, $CHCl_3$); ν_{max}/cm^{-1} 2957, 2925, 2871, 1696, 1457, 1376, 1353, 1136, 960 and 875; δ_H (300 MHz, $CDCl_3$) 0.85–0.95 (15H, m, 3×CH_2CH_3), 1.05 (3H, d, *J* 7.0, 4-CH_3), 1.30–1.65 (12H, m, 3×CH_2CH_2), 1.70 (2H, d, *J* 8.0, 1-H_2), 2.35 (4H, m, 4-H, CH_3CO), 2.85 (2H, m, 5-H_2), 4.90 (0.2H, dd, *J* 10.5, 9.5, 3-H), 5.10 (0.8H, dd, *J* 15.0, 7.5, 3-H) and 5.60 (1H, m, 4-H); δ_C (75 MHz, $CDCl_3$) (*E*)-isomer 9.2, 13.7, 14.2, 20.3, 27.4, 29.2, 30.6, 36.4, 36.9, 128.9, 129.7 and 196.0; *m/z* (EI) 448 (M^+, 3%), 391 (M^+−57, 51) and 179 (100); HRMS (CI, NH_3): M−$C_4H_9^+$, found 391.1112. $C_{16}H_{31}OS^{120}Sn$ requires 391.1118.

*4.2.28. (4R)-5-Benzylthio-4-methylpent-2-enyl(tributyl)stannane (**50**).* Potassium hydroxide (362 μL, 10% w/v in EtOH, 0.64 mmol) was added to the stannane **49** (219 mg, 0.49 mmol) in ethanol (8 mL) and the solution stirred for 10 min. Benzyl chloride (139 μL, 1.23 mmol) was added and the solution stirred for 1 h. Ether and water were added and the aqueous phase extracted with ether. The organic extracts were washed with brine, dried ($MgSO_4$) and concentrated under reduced presure. Chromatography (petrol, 1% triethylamine) of the residue gave the *title compound* **50** as a colourless oil (238 mg, 98%), as an 80:20 mixture of (*E*)- and (*Z*)-isomers (^{1}H NMR), $[\alpha]_D$ −5.6 (*c* 2.5, $CHCl_3$); ν_{max}/cm^{-1} 2957, 2924, 1457, 1073 and 962; δ_H (300 MHz, $CDCl_3$) 0.85–0.95 (15H, m, 3×CH_2, 3×CH_3), 1.05 (3H, d, *J* 7.0, 4-CH_3), 1.30–1.60 (12H, m, 6×CH_2), 1.73 (1.6H, d, *J* 7.0, 1-H_2), 1.82 (0.4H, d, *J* 7.0, 1-H_2), 2.25–2.50 (2H, m, 5-H_2), 3.70 (1.6H, s, $PhCH_2$), 3.77 (0.4H, s, $PhCH_2$), 4.90 (0.2H, dd, *J* 10.5, 9.5, 3-H), 5.10 (0.8H, dd, *J* 15.0, 8.0, 3-H), 5.55 (1H, m, 2-H) and 7.30 (5H, m, ArH); δ_C (75 MHz, $CDCl_3$) 9.2, 13.8, 14.2, 20.3, 27.4, 29.2, 36.7, 36.8, 39.4, 126.8, 128.4, 128.8, 128.9, 129.7 and 138.8; *m/z* (EI) 439 (M^+−57, 2%) and 91 (100); HRMS (CI, NH_3): M−$C_4H_9^+$, found 439.1498. $C_{21}H_{35}S^{120}Sn$ requires 439.1481.

*4.2.29. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-phenylhex-3-en-1-ol (**51**).* Tin(IV) bromide (150 μL, 1.027 M in DCM, 0.154 mmol) was added to the stannane **50** (76 mg, 0.154 mmol) in DCM (2 mL) at −78 °C. After 10 min, benzaldehyde (52 μL, 2.95 M in DCM, 0.154 mmol, cooled to −78 °C) was added and the mixture stirred at −78 °C for 1 h. Saturated aqueous sodium hydrogen carbonate (2 mL) was added and the mixture allowed to warm to ambient temperature. The aqueous phase was extracted with DCM and the organic extracts were washed with brine and dried ($MgSO_4$). After concentration under reduced pressure chromatography (3:1 petrol/ether, 1% triethylamine) of the residue gave the *title commpound* **51** as a colourless oil (28 mg, 58%), a 78:12:10 mixture of diastereoisomers (^{1}H NMR), $[\alpha]_D$ −10 (*c* 2.8, $CHCl_3$); ν_{max}/cm^{-1} 3409 (br), 3028, 2958, 1602, 1494, 1453, 1049, 760 and 701; δ_H (500 MHz, $CDCl_3$) major isomer **51** 0.90 (3H, d, *J* 7.0, 5-CH_3), 2.20–2.65 (6H, m, 6-CH_2, 5-H, 2-H_2, OH), 3.66 (2H, s, $PhCH_2$), 4.70 (1H, dd, *J* 8.0 and 4.5, 1-H), 5.28 (1H, t, *J* 10.5, 4-H), 5.42 (1H, m, 3-H) and 7.20–7.40 (10H, m, ArH); minor isomers 0.97 and 1.03 (each d, *J* 7, 5-CH_3), 3.67 and 3.68 (each s, $PhCH_2$), 4.65 (dd, *J* 9.0, 4.0, 1-H) and 4.73 (t, *J* 5.5, 1-H); δ_C (75 MHz, $CDCl_3$) major isomer **51** 20.7, 32.2, 36.6, 38.2, 38.6, 73.3, 125.1, 125.7, 126.9, 127.3, 128.2, 128.4, 128.8, 137.6 and 144.0; *m/z* (CI, NH_3) 330 (M^++18, 100%), 295 (M^+−17, 70); HRMS (CI, NH_3): MNH_4^+, found 330.1895. $C_{20}H_{28}NOS$ requires 330.1891.

Following the procedures outlined for the alkenol **10**, acetylation of the hexenol **51** (73%) and ozonolysis of the acetate (71 mg, 0.192 mmol) gave, after chromatography (5:2 petrol/ether), (*S*)-3-acetoxy-3-phenylpropan-1-ol (*S*)-**21** as a colourless oil, $[\alpha]_D$ −42 (*c* 1.9, $CHCl_3$) and (*S*)-3-acetoxy-1-phenylpropan-1-ol **60**, $[\alpha]_D$ −12 (*c* 1.5, $CHCl_3$) (lit.[12] for the (*R*)-enantiomer +15 (*c* 0.49, $CHCl_3$) (34 mg, combined yield, 91%)) both with spectroscopic data identical to those obtained previously.

*4.2.30. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-(4-nitrophenyl)hex-3-en-1-ol (**52**).* Following the procedure outlined for the synthesis of alkenol **51**, stannane **50** (80 mg, 0.16 mmol), tin(IV) bromide (146 μL, 1.1 M in DCM, 0.16 mmol) and *p*-nitrobenzaldehyde (0.244 μL, 0.66 M in DCM, 0.16 mmol) after chromatography (4:1 petrol/ether, 1% triethylamine) gave the *title compound* **52** as a colourless oil (38 mg, 66%), an 82:10:8 mixture of diastereoisomers (^{1}H NMR), $[\alpha]_D$ −14 (*c* 3.7, $CHCl_3$); ν_{max}/cm^{-1} 3429 (br), 2958, 1603, 1520, 1453, 1346, 1068 and 855; δ_H (500 MHz, $CDCl_3$) major isomer **52** 0.90 (3H, d, *J* 8.5, 5-CH_3), 2.25–2.60 (5H, m, 2-H_2, 6-H_2, 5-H), 2.72 (1H, br s, OH), 3.68 and 3.72 (each 1H, d, *J* 13.0, PhHC*H*), 4.80 (1H, dd, *J* 8.5, 4.0, 1-H), 5.32 (1H, t, *J* 10.0, 4-H), 5.40 (1H, dt, *J* 9.5, 6.0, 3-H), 7.20–7.30 (5H, m, ArH) and 7.52 and 8.17 (each 2H, d, *J* 9.0, ArH); minor isomers 0.94 and 1.05 (each d, *J* 7.0, 5-CH_3), 3.6 (s, $PhCH_2$), 4.73 (dd, *J* 8.5, 4.0, 1-H), 4.86 (dd, *J* 6.5, 5.5, 1-H); δ_C (75 MHz, $CDCl_3$) major isomer **52** 20.6, 32.1, 36.8, 38.1, 38.3, 72.4, 123.2, 124.1, 126.2, 126.7, 128.2, 128.5, 138.4 and 151.2; *m/z* (EI) 357 (M^+, 13%), 340 (M^+−17, 41) and 91 (100); HRMS (CI, NH_3): M^+, found 357.1398. $C_{20}H_{23}NO_3S$ requires 357.1399.

*4.2.31. (3S,7R,5Z)-8-Benzylthio-2,7-dimethyloct-5-en-3-ol (**53**).* Following the procedure outlined for the synthesis of alkenol **51**, stannane **50** (202 mg, 0.408 mmol), tin(IV) bromide (0.37 μL, 1.1 M in DCM, 0.408 mmol) and 2-methypropanal (38 μL, 0.408 mmol) after chromatography (20:1 petrol/ether, 0.5% triethylamine) gave the *title compound* **53** as a colourless oil (80 mg, 71%), an 87:13 mixture of two diastereoisomers (^{1}H NMR), $[\alpha]_D$ +15 (*c* 3.2, $CHCl_3$); ν_{max}/cm^{-1} 3443 (br), 2958, 1494, 1453, 1238, 1030, 870 and 700; δ_H (500 MHz, $CDCl_3$) major isomer **53** 0.925 and 0.935 (each 3H, d, *J* 7.0, CH_3), 0.96 (3H, d, *J* 7.0, 7-CH_3), 1.70 (1H, oct, *J* 6.5, 2-H), 2.08 (1H, br s, OH), 2.15 (2H, m, 8-H_2), 2.30 (1H, dd, *J* 13.0, 9.0, 4-H), 2.38 (1H, dd, *J* 13.0, 5.0, 4-H), 2.65 (1H, m, 7-H), 3.37 (1H, dt, *J* 8.5, 5.0, 3-H), 3.67 and 3.70 (each 1H, d, *J* 14.0, PhHC*H*), 5.28 (1H, t, *J* 10.5, 6-H), 5.40 (1H, m, 5-H) and 7.20–7.30 (5H, m, ArH); minor isomer **61** 0.99 (d, *J* 7.0, 7-CH_3); δ_C (75 MHz, $CDCl_3$) major isomer **53** 17.6, 18.8, 20.9, 32.1, 32.6, 33.4, 36.9, 38.6, 76.1, 126.4, 126.9, 128.5, 129.0, 137.3 and 138.4; minor isomer **61** 17.8, 18.9, 20.8, 33.2, 38.8, 76.2, 125.4, 137.5 and 138.5; *m/z* (CI, NH_3) 296 (M^++18, 100%), 279 (M^++1, 15) and 261 (M^+−17, 14); HRMS (CI, NH_3): MH^+, found 279.1778. $C_{17}H_{27}OS$ requires 279.1783. Repeated chromatography achieved a partial separation of the two diastereoisomers.

*4.2.32. (3S,7R,5Z)-8-Benzylthio-7-methyloct-5-en-3-ol (**54**).* Following the procedure outlined for the synthesis of alkenol **51**, stannane **50** (99 mg, 0.20 mmol), tin(IV) bromide (181 μL, 1.1 M in DCM, 0.20 mmol) and propanal (15 μL, 0.20 mmol) after chromatography (4:1 petrol/ether, 1% triethylamine) gave the *title compound* **54** as a colourless oil (29 mg, 54%), an 82:18 mixture of

diastereoisomers (^{1}H NMR), $[\alpha]_D$ +6.0 (*c* 1.9, $CHCl_3$); ν_{max}/cm^{-1} 3422 (br), 2960, 1494, 1453, 1238, 1071, 1027, 972 and 700; δ_H (500 MHz, $CDCl_3$) major isomer **54** 0.95 (3H, t, *J* 8.0, 1-H_3), 0.97 (3H, d, *J* 7.0, 7-CH_3), 1.50 (1H, m, 2-H_2), 1.94 (1H, br s, OH), 2.15 (2H, m, 8-H_2), 2.35 (2H, m, 4-H_2), 2.65 (1H, m, 7-H), 3.53 (1H, m, 3-H), 3.68 and 3.685 (each 1H, d, *J* 14.0, PhHC*H*), 5.28 (1H, t, *J* 10.5, 6-H), 5.40 (1H, dt, *J* 10.5, 8.0, 5-H) and 7.20–7.30 (5H, m, ArH); minor isomer 0.94 (t, *J* 8, 1-H_3) and 0.99 (d, *J* 7.0, 7-CH_3); δ_C (75 MHz, $CDCl_3$) 10.1, 20.8, 29.9, 32.1, 35.4, 36.9, 38.7, 72.7, 125.9, 127.0, 128.5, 129.0, 137.4 and 138.5; *m*/*z* (CI, NH_3) 282 (M^++18, 100%), 265 (M^++1, 14), 247 (M^+−17, 12); HRMS (CI, NH_3): MNH_4^+, found 282.1910. $C_{16}H_{28}NOS$ requires 282.1892.

*4.2.33. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-[(R)-2-acetoxy-2-phenylacetoxy]-1-phenylhex-3-ene (**55**).* Following the procedure outlined for the synthesis of ester **18**, alcohol **51** (19 mg, 0.061 mmol) and (*R*)-2-acetoxy-2-phenylacetic acid after chromatography (5:1 petrol/ether) gave the *title compound* **55** as a colourless oil (20 mg, 68%), $[\alpha]_D$ −66 (*c* 1.6, $CHCl_3$); ν_{max}/cm^{-1} 2959, 1745, 1495, 1454, 1372, 1232, 1208, 1175, 1056 and 699; δ_H (300 MHz, $CDCl_3$) 0.80 (3H, d, *J* 7.0, 5-CH_3), 2.22 (3H, s, CH_3CO_2), 2.15–2.60 (5H, m, 5-H, 6-H_2, 2-H_2), 3.65 (2H, s, $PhCH_2$), 5.05 (2H, m, 3-H, 4-H), 5.75 (1H, t, *J* 7.0, 1-H), 6.05 (1H, s, O_2CCH) and 7.15–7.50 (15H, m, ArH); δ_C (75 MHz, $CDCl_3$) 20.0, 20.8, 32.0, 34.2, 36.9, 38.5, 74.6, 123.0, 126.5, 126.9, 127.4, 128.6, 128.7, 129.0, 129.3, 133.9, 137.2, 139.2, 168.1, 170.2 and 213.9; *m*/*z* (CI, NH_3) 506 (M^++18, 100%); HRMS (CI, NH_3): MNH_4^+, found 506.2374. $C_{30}H_{36}NO_4S$ requires 506.2365.

*4.2.34. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-[(S)-2-acetoxy-2-phenylacetoxy]-1-phenylhex-3-ene (**56**).* Following the procedure outlined for the synthesis of ester **18**, alcohol **51** (23 mg, 0.074 mmol) and (*S*)-2-acetoxy-2-phenylacetic acid after chromatography (4:1 petrol/ether) gave the *title compound* **56** as a colourless oil (23 mg, 64%), $[\alpha]_D$ +16 (*c* 2.3, $CHCl_3$); ν_{max}/cm^{-1} 2959, 1744, 1495, 1454, 1372, 1232, 1208, 1175, 1056 and 699; δ_H (300 MHz, $CDCl_3$) 0.85 (3H, d, *J* 7.0, 5-CH_3), 2.21 (3H, s, CH_3CO_2), 2.20–2.70 (5H, m, 6-CH_2, 2-CH_2, 5-H), 3.73 (2H, s, $PhCH_2$), 5.25 (2H, m, 3-H, 4-H), 5.75 (1H, t, *J* 7.0, 1-H), 6.05 (1H, s, O_2CCH) and 7.00–7.50 (15H, m, ArH); *m*/*z* (CI, NH_3) 506 (M^++18, 48%) and 295 (100); HRMS (CI, NH_3): MNH_4^+, found 506.2375. $C_{30}H_{36}NO_4S$ requires 506.2365.

*4.2.35. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-phenylhex-3-en-1-yl (R)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoate (**57**).* *N*,*N*-Dimethylformamide (5 μL) was added to (*R*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoic acid (37 mg, 0.16 mmol) and oxalyl chloride (139 μL, 0.80 mmol) in hexane (1 mL) and the solution was stirred for 1 h. Filtration and concentration of the filtrate under reduced pressure afforded the crude acid chloride as a colourless oil. This acid chloride (0.16 mmol) in DCM (0.5 mL) was added to the alcohol **51** (25 mg, 0.08 mmol), triethylamine (47 μL, 0.32 mmol) and DMAP (2 mg) in DCM (0.5 mL) and the solution was stirred for 3.5 h. Ether was added and the solution washed with water and brine, then dried ($MgSO_4$). Concentration under reduced pressure and chromatography (20:1 petrol/ether) of the residue gave the *title compound* **57** as a colourless oil (24 mg, 57%) together with minor isomers, ratio 72:14:14 (^{1}H and ^{19}F NMR), $[\alpha]_D$ +7.3 (*c* 2.7, $CHCl_3$); ν_{max}/cm^{-1} 2956, 1748, 1495, 1453, 1271, 1170, 1123, 1081, 1018, 763 and 699; δ_H (500 MHz, $CDCl_3$) major isomer **57** 0.79 (3H, d, *J* 7.0, 5-CH_3), 2.28 (2H, d, *J* 5.0, 6-H_2), 2.40–2.70 (3H, m, 2-H_2, 5-H), 3.43 (3H, s, OCH_3), 3.64 (2H, s, $PhCH_2$), 5.10–5.30 (2H, m, 3-H, 4-H), 5.87 (1H, t, *J* 5.5, 1-H) and 7.15–7.40 (15H, m, ArH); δ_F (470 MHz, $CDCl_3$) −73.17 (major isomer **57**), −72.93 (minor), −72.88 (minor); *m*/*z* (CI, NH_3) 546 (M^++18, 34%), 295 (95) and 205 (100); HRMS (CI, NH_3): MNH_4^+, found 546.2303. $C_{30}H_{35}F_3NO_3S$ requires 546.2290.

*4.2.36. (1S,5R,3Z)-6-Benzylthio-5-methyl-1-phenylhex-3-en-1-yl (S)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoate (**58**).* Following the procedure outlined for the synthesis of ester **57**, the alcohol **51** (17 mg, 0.054 mmol) and (*S*)-2-methoxy-2-phenyl-3,3,3-trifluoropropanoic acid (35 mg, 0.15 mmol) after chromatography (30:1 petrol/ether) gave the *title compound* **58** as a colourless oil (20 mg, 70%) together with minor isomers, ratio 72:14:14 (^{1}H and ^{19}F NMR), $[\alpha]_D$ −50 (*c* 2.4, $CHCl_3$); ν_{max}/cm^{-1} 2956, 1748, 1495, 1453, 1271, 1170, 1122, 1081, 1018, 762 and 699; δ_H (500 MHz, $CDCl_3$) 0.77 (3H, d, *J* 7.0, 5-CH_3), 2.22 (2H, d, *J* 5.0, 6-H_2), 2.40–2.70 (3H, m, 2-H_2, 5-H), 3.43 (3H, s, OCH_3), 3.64 (2H, s, $PhCH_2$), 5.15 (2H, m, 3-H, 4-H), 5.93 (1H, t, *J* 5.5, 1-H) and 7.15–7.40 (15H, m, ArH); δ_F (470 MHz, $CDCl_3$) −72.93 (major), −73.17; *m*/*z* (CI, NH_3) 546 (M^++18, 22%) and 295 (100); HRMS (CI, NH_3): MNH_4^+, found 546.2295. $C_{30}H_{35}F_3NO_3S$ requires 546.2290.

*4.2.37. (1R,5R,3Z)-6-Benzylthio-5-methyl-1-phenylhex-3-en-1-yl 4-nitrobenzoate (**60**).* Following the procedure outlined for ester **22**, the alcohol **51** (36 mg, 0.115 mmol) after chromatography (10:1 petrol/ether) gave the *title compound* **60** as a colourless oil (41 mg, 77%), $[\alpha]_D$ −2.0 (*c* 1.9, $CHCl_3$); ν_{max}/cm^{-1} 2961, 1724, 1606, 1528, 1344, 1273, 1103, 720 and 700; δ_H (300 MHz, $CDCl_3$) 0.97 (3H, d, *J* 7.0, 5-CH_3), 2.32 (2H, m, 6-H_2), 2.55–2.90 (3H, m, 5-H, 2-H_2), 3.70 (2H, s, $PhCH_2$), 5.35 (2H, m, 3-H, 4-H), 6.07 (1H, dd, *J* 7.0, 6.0, 1-H), 7.15–7.45 (10H, m, ArH) and 8.25–8.35 (4H, m, ArH); δ_C (75 MHz, $CDCl_3$) 20.5, 32.3, 34.7, 37.1, 38.7, 123.4, 123.6, 126.5, 127.0, 128.4, 128.5, 128.7, 128.8, 130.8, 135.8, 137.6, 138.5, 139.5, 150.6 and 163.9; *m*/*z* (CI, NH_3) 479 (M^++18, 15%) and 117 (100).

*4.2.38. (1R,5R,3Z)-6-Benzylthio-5-methyl-1-phenylhex-3-en-1-ol (**61**).* Following the procedure outlined for the synthesis of alcohol **23**, the *p*-nitrobenzoate **60** (23 mg, 0.05 mmol) after chromatography (3:1 petrol/ether) gave the *title compound* **61** as a colourless oil (7 mg, 45%) a 75:13:12 mixture of **61**, **51** and an (*E*)-isomer (^{1}H NMR), $[\alpha]_D$ +10.5 (*c* 0.7, $CHCl_3$); ν_{max}/cm^{-1} 3428 (br), 3027, 2919, 1493, 1452, 1048, 758 and 700; δ_H (500 MHz, $CDCl_3$) major isomer **61** 0.96 (3H, d, *J* 7.0, 5-CH_3), 1.80 (1H, br s, OH), 2.25–2.65 (5H, m, 6-H_2, 5-H, 2-H_2,), 3.66 (2H, s, $PhCH_2$), 4.73 (1H, t, *J* 6.0, 1-H), 5.30 (1H, t, *J* 10.0, 4-H), 5.36 (1H, dt, *J* 10.5, 9.0, 3-H) and 7.20–7.35 (10H, m, ArH); *m*/*z* (CI, NH_3) 330 (M^++18, 100%); HRMS (CI, NH_3): MNH_4^+, found 330.1892. $C_{20}H_{28}NOS$ requires 330.1891.

*4.2.39. (3S,7R,5Z)-8-Benzylthio-2,7-dimethyl-3-[(R)-2-acetoxy-2-phenylacetoxy]hex-5-ene (**62**).* Following the procedure outlined for the synthesis of ester **18**, the alcohol **53** (24 mg, 0.087 mmol) and (*R*)-2-acetoxy-2-phenylacetic acid after chromatography (20:1 petrol/ether) gave the *title compound* **62** as a colourless oil (37 mg, 94%), $[\alpha]_D$ −65 (*c* 3.5, $CHCl_3$); ν_{max}/cm^{-1} 2963, 1745, 1454, 1372, 1234, 1180, 1055 and 699; δ_H (500 MHz, $CDCl_3$) major isomer 0.85 (9H, d, *J* 7.0, 3×CH_3), 1.60–2.65 (6H, m, 7-H, 2-H, 4-H_2, 8-H_2), 2.17 (3H, s, CH_3CO_2), 3.64 (2H, s, $PhCH_2$), 4.73 (1H, m, 3-H), 4.90 (1H, dt, *J* 10.5, 7.0, 5-H), 5.00 (1H, t, *J* 10.5, 6-H), 5.86 (1H, s, O_2CCH) and 7.20–7.50 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.2, 18.7, 20.2, 20.7, 29.1, 31.0, 32.0, 36.9, 38.7, 74.8, 79.9, 123.8, 126.9, 127.7, 128.5, 128.7, 128.9, 129.2, 133.9, 136.5, 138.6, 168.7 and 170.3; *m*/*z* (CI, NH_3) 472 (M^++18, 100%), 455 (M^++1, 5); HRMS (CI, NH_3): MNH_4^+, found 472.2527. $C_{27}H_{38}NO_4S$ requires 472.2522.

*4.2.40. (3S,7R,5Z)-8-Benzylthio-2,7-dimethyl-3-[(S)-2-acetoxy-2-phenylacetoxy]hex-5-ene (**63**).* Following the procedure outlined for the synthesis of ester **18**, the alcohol **53** (20 mg, 0.072 mmol) and (*S*)-2-acetoxy-2-phenylacetic acid, after chromatography (20:1 petrol/ether), gave the *title compound* **63** as a colourless oil (31 mg, 95%), $[\alpha]_D$ +33 (*c* 3.1, $CHCl_3$); ν_{max}/cm^{-1} 2964, 1745, 1495, 1454, 1372, 1233, 1212, 1180, 1056 and 699; δ_H (500 MHz, $CDCl_3$) 0.60 and 0.63 (each 3H, d, *J* 7.0, CH_3), 0.98 (3H, d, *J* 7.0, 7-CH_3), 1.70 (1H, oct, *J* 5.0, 2-H), 2.17 (3H, s, O_2CCH_3), 2.28 (2H, t, *J* 7.5, 8-CH_2), 2.33 (1H, dd, *J* 13.0, 7.0, 4-H) 2.40 (1H, dd, *J* 15.0, 7.0, 4-H), 2.60 (1H, m, 7-H), 3.68 (2H, s, $PhCH_2$), 4.73 (1H, q, *J* 4.0, 3-H), 5.25 (2H, m, 5-H, 6-H), 5.90

(1H, s, O_2CCH) and 7.20–7.50 (10H, m, ArH); δ_C (75 MHz, $CDCl_3$) 16.6, 18.6, 20.4, 20.8, 29.5, 30.7, 32.2, 37.0, 38.8, 74.7, 79.7, 123.8, 126.9, 127.7, 128.5, 128.7, 128.9, 129.1, 134.3, 136.8, 138.7, 168.6 and 170.2; *m/z* (CI, NH_3) 472 (M^++18, 100%) and 455 (M^++1, 5); HRMS (CI, NH_3): MNH_4^+, found 472.2525. $C_{27}H_{38}NO_4S$ requires 472.2522.

*4.2.41. (3R,7R,5Z)-8-Benzylthio-2,7-dimethyloct-5-en-3-ol (**65**).* Following the procedure outlined for the synthesis of ester **22**, the alcohol **53** (29 mg, 0.106 mmol) after chromatography (15:1 petrol/ether) gave the 4-nitrobenzoate **64** as a colourless oil (19 mg, 42%), $[\alpha]_D$ −20 (*c* 2.0, $CHCl_3$); ν_{max}/cm^{-1} 2965, 1721, 1528, 1275 and 720; δ_H (200 MHz, $CDCl_3$) 0.90 (3H, d, *J* 6.5, 7-CH_3), 0.99 and 1.01 (each 3H, d, *J* 6.5, CH_3), 2.00 (1H, m, 2-H), 2.30–2.70 (5H, m, 4-H_2, 8-H_2, 7-H), 3.70 (2H, s, $PhCH_2$), 5.05 (1H, m, 3-H), 5.30 (2H, m, 5-H, 6-H), 7.25 (5H, m, ArH) and 8.20 (4H, m, ArH); *m/z* (CI, NH_3) 445 (M^++18, 45%) and 194 (100).

Following the procedure outlined for the synthesis of alcohol **23**, the 4-nitrobenzoate **64** (17 mg, 0.04 mmol) after chromatography (4:1 petrol/ether) gave the *title compound* **65** as a colourless oil (10 mg, 91%), $[\alpha]_D$ −8.8 (*c* 1.5, $CHCl_3$); ν_{max}/cm^{-1} 3422 (br), 2958, 1453, 1237, 1030, 870 and 700; δ_H (500 MHz, $CDCl_3$) 0.91 and 0.93 (each 3H, d, *J* 7.0, CH_3), 0.99 (3H, d, *J* 7.0, 7-CH_3), 1.58 (1H, br s, OH), 1.67 (1H, oct, *J* 6.5, 2-H), 2.15 (2H, m, 8-H_2), 2.35 (2H, m, 4-H_2), 2.65 (1H, m, 7-H), 3.34 (1H, m, 3-H), 3.68 (2H, s, $PhCH_2$), 5.30 (1H, t, *J* 10.0, 6-H), 5.40 (1H, dt, *J* 10.5, 7.0, 5-H) and 7.20–7.30 (5H, m, ArH); δ_C (75 MHz, $CDCl_3$) 17.8, 18.9, 20.7, 32.1, 32.6, 33.2, 37.0, 38.8, 76.2, 125.7, 126.9, 128.5, 128.9, 137.5 and 138.5; *m/z* (CI, NH_3) 296 (M^++18, 100%), 279 (M^++1, 15) and 261 (M^+−17, 14); HRMS (CI, NH_3): MH^+, found 279.1776. $C_{17}H_{27}OS$ requires 279.1783.

*4.2.42. 6-Hydroxy-2-methyl-6-phenylhex-3-en-1-yl thioacetates (**66**) and (**67**).* Following the procedure outlined for the synthesis of alkenol **51**, stannane **49** (97 mg, 0.217 mmol), tin(IV) bromide (197 μL, 1.1 M in DCM, 0.217 mmol) and benzaldehyde (94 μL, 2.3 M in DCM, 0.217 mmol) after chromatography (3:1 petrol/ether, 1% triethylamine) gave a mixture of the *title compounds* **66** and **67** as a colourless oil (51 mg, 89%), ratio 90:10 (^1H NMR), $[\alpha]_D$ −17 (*c* 2.0, $CHCl_3$); ν_{max}/cm^{-1} 3442 (br), 2962, 1691, 1453, 1135, 1049, 957 and 701; δ_H (500 MHz, $CDCl_3$) major isomer 0.92 (3H, d, *J* 7.0, 2-CH_3), 2.20 (1H, s, OH), 2.32 (3H, s, CH_3CO), 2.43 and 2.55 (each 1H, m, 1-H), 2.64 (1H, m, 2-H), 2.76 (1H, dd, *J* 13.0, 7.5, 5-H), 2.83 (1H, dd, *J* 13.0, 6.5, 5-H), 4.69 (1H, dd, *J* 7.5, 5.0, 6-H), 5.28 (1H, t, *J* 10.5, 3-H), 5.41 (1H, m, 4-H) and 7.20–7.35 (5H, m, ArH); minor isomer 1.025 (d, *J* 7.0, 2-CH_3), 2.30 (s, CH_3CO), 2.89 (dd, *J* 13.0, 6.5, 5-H), 4.65 (dd, *J* 7.5, 5.0, 6-H); δ_C (75 MHz, $CDCl_3$) major isomer 20.2, 30.7, 32.2, 35.9, 37.9, 73.9, 125.7, 125.9, 127.5, 128.4, 136.8, 144.1 and 196.0; *m/z* (CI, NH_3), 282 (M^++18, 100%), 264 (M^+, 22) and 247 (M^+−17, 78); HRMS (CI, NH_3): MNH_4^+, found 282.1535. $C_{15}H_{24}NO_2S$ requires 282.1528.

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Supplementary data

Full experimental procedures and characterization of the products in Schemes 4, 7 and 8. Supplementary data associated with this article can be found in the online version, at doi:10.1016/j.tet.2012.05.032.

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