Synthesis of enantioenriched tertiary boronic esters from secondary allylic carbamates. Application to the synthesis of C30 botryococcene.

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Supporting information: experimental procedures

General information

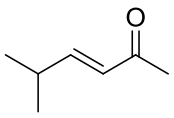
All reagents were sourced from commercial suppliers and were used without further purification unless stated otherwise. Where anhydrous conditions were necessary, standard syringe-septa techniques were used with oven dried glassware under a positive pressure of nitrogen. Anhydrous THF, CH_2Cl_2, toluene, hexane, acetonitrile and Et_2O were dried by passing through a modified Grubbs system of alumina columns, manufactured by Anhydrous Engineering. Triethylamine and *N*,*N*,*N*',*N*'-tetramethylethane-1,2-diamine (TMEDA) were distilled from CaH_2, and DMF was distilled from $MgSO_4$ under reduced pressure.[1] (−)-Sparteine was prepared according to the procedure of Beak and co-workers.[2] Anhydrous methanol was bought from Acros Organics. *s*-BuLi was periodically titrated with dimethoxybenzyl alcohol to ensure quality.[3] Petrol refers to the fraction of petroleum ether boiling at 40-60 °C. Where stated, degassed solvents were used. This refers to the action of cooling and placing under high vacuum for 1 min and then backfilling with nitrogen. This cycle was repeated ten times. During degassing Et_2O and THF were cooled to −78 °C (acetone/$CO_{2(S)}$), and H_2O_2/NaOH mixtures were cooled to 0 °C (ice/water). All below ambient temperatures stated are the temperatures of the cooling baths, unless stated otherwise.

Flash column chromatography was performed according to the procedures used by Still *et al*[4] using silica gel 60 (Fisher Scientific) and a suitable eluent. TLC was performed with aluminium backed silica TLC plates (Meck-Keiselgel 60 F_{254}) with a suitable solvent system and was visualised using UV fluorescence (254 & 366 nm) and/or developed with phosphomolybdic acid or potassium permanganate. Melting points were recorded on a Reichert apparatus and are uncorrected. Infra red spectra were recorded on a Perkin Elmer Spectrum 100 FTIR with an ATR accessory and frequencies are reported in wavenumbers (cm^{-1}). ^1H, ^{13}C and ^{11}B NMR spectra were recorded using Jeol Lambda 300, Jeol ECP (Eclipse) 400, Varian 400 and Varian 500 spectrometers at ambient temperature unless otherwise stated. Chemical shifts (δ) are quoted in parts per million (ppm) and coupling constants (*J*) are in hertz (Hz). Tetramethylsilane or residual solvent peaks were used as the internal reference for proton and carbon chemical shifts. HRMS CI and ESI were performed in the School of Chemistry, University of Bristol using VG Analytical Autospec and VG Analytical Quattro respectively and samples were submitted in MeOH. ESI HRMS was performed on a Thermo Fischer Orbitap XL with Nanomate injector at the EPSRC National Mass Spectrometry Service Centre, Swansea University. Elemental analysis was performed with a CHN Elemental Analyser. Microwave reactions were performed in a Biotage Initiator (300MW). Chiral HPLC was performed on a HP Agilent 1100 with a Chiralpak IA, IB or IC column eluting ^{i}PrOH/hexane at

ambient temperature, unless otherwise stated. Chiral GC was performed on Agilent 6890N and Agilent 7890A using Supelco α-cyclodextrin column (α-CD, 30 m × 0.25 mm × 0.25 μm), Supelco β-cyclodextrin column (β-CD, 30 m × 0.25 mm × 0.25 μm), Supelco γ-TFA cyclodextrin (γ-CD, 30 m × 0.25 mm × 0.12 μm) or Chiraldex β-Dimethyl cyclodextrin (β-DM, 30 m × 0.25 mm). GCMS was performed on an Agilent 6890+ with an Agilent JW Scientific DB-5ms column (15.0 m × 250 μm × 0.30 μm) and with an Agilent 5973 mass detector operating at 70 eV. The methods used for GCMS were: *M70* (70 °C for 3 min, increase to 200 °C at 25 °C/min, increase to 250 °C at 45 °C/min, hold for 3 min, increase to 300 °C at 45 °C/min and hold for 3 min); *M50* (50 °C for 3 min, increase to 150 °C at 5 °C/min, increase to 250 °C at 45 °C/min, hold for 3 min, increase to 300 °C at 45 °C/min and hold for 3 min); or *M30* (30 °C for 3 min, increase to 120 °C at 2 °C/min, increase to 250 °C at 45 °C/min, hold for 3 min, increase to 300 °C at 45 °C/min and hold for 3 min) while operating at a flow rate of 1 ml/min. Retentions times (T_R) are quoted in minutes. Optical rotation ($[\alpha]_D^T$) was measured on a Bellingham and Stanley Ltd. ADP220 polarimeter and is quoted in (° ml)(g dm)$^{-1}$.

Synthesis of racemic secondary allylic alcohols

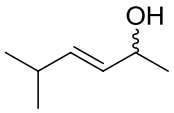
(*E*)-5-Methylhex-3-en-2-one



To a stirred solution of 2.5 M $NaOH_{(aq)}$ (25 ml) in acetone (68 ml) at 0 °C (salt/ice), isobutyraldehyde (34.5 ml, 0.38 mol) in acetone (68 ml) was added over 1.5 h at such a rate that the internal temperature did not rise above 8 °C. The reaction mixture was stirred at ambient temperature for 2.5 h, then 6 M $HCl_{(aq)}$ (10 ml) was added and the pH adjusted to 7 with 3 M NaOH (aprox. 2 ml). The reaction mixture was reduced in volume to approximately 50% *in vacuo* and the product extracted with Et_2O (5 × 50 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was distilled (55 – 70 °C at 2.2 – 3.2 mbar, Lit. b.p. 75 – 89 °C at 9.3 mbar)[5] to yield the corresponding β-hydroxy ketone (36.8 g, 74%) as a colourless liquid. δ_H (400 MHz, $CDCl_3$): 0.92 (3H, d, *J* 6.9, CH(C*H*$_3$)CH$_3$), 0.94 (3H, d, *J* 6.9, CH(C*H*$_3$)CH$_3$), 1.68 (1H, qqd, *J* 6.9, 6.9, 5.9, C*H*(CH$_3$)CH$_3$), 2.20 (3H, s, C(O)CH$_3$), 2.53 (1H, dd, *J* 17.6, 9.1, CH*H*), 2.32 (1H, dd, *J* 17.6, 2.7, C*H*H), 2.89 (1H, br. s, OH), 3.82 (1H, ddd, *J* 9.1, 5.9, 2.7, C*H*OH). To a mixture of Na_2SO_4 (20 g) and TsOH.H_2O (269 mg, 1.41 mmol), β-hydroxy ketone (36.8 g, 0.28 mol) in toluene (90 ml) was added and the mixture heated at 100 °C for 7 h. The reaction mixture was filtered and washed with

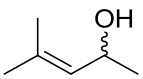
saturated $NaHCO_{3(aq)}$ (75 ml). The aqueous phase was extracted with Et_2O (3 × 75 ml), the combined organic phases were dried over $MgSO_4$ and the Et_2O gently removed *in vacuo* (leaving behind a solution of the product in toluene). The crude solution was purified by flash column chromatography eluting 20% Et_2O/pentane to yield the title compound (*E*)-5-methylhex-3-en-2-one (24.6 g, 77%, 58% over two steps) as a pale yellow liquid. $\boldsymbol{R_f}$ (20% EtOAc/petrol) 0.66. δ_H (400 MHz, $CDCl_3$): 1.07 (6H, d, *J* 6.9, $CH(CH_3)_2$), 2.24 (3H, s, $C(O)CH_3$), 2.47 (1H, sept.dd, *J* 6.9, 6.7, 1.5, $CH(CH_3)_2$), 6.02 (1H, dd, *J* 16.1, 1.5, CHC(O)), 6.76 (1H, dd, *J* 16.1, 6.7, *H*C=CHC(O)). δ_C (100 MHz, $CDCl_3$): 21.3 (CH_3), 26.8 (CH_3), 31.1 (CH), 128.5 (CH), 154.5 (CH), 199.0 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1257, 1626, 1674, 2964. Spectral data was in accordance with the literature.[5]

(*rac*,*E*)-5-Methylhex-3-en-2-ol



To a stirred solution of (*E*)-5-methylhex-3-en-2-one (14.5 g, 0.129 mol) and $CeCl_3.7H_2O$ (52.85 g, 0.142 mol) in anhydrous MeOH (210 ml) at 0 °C (ice/salt), was added $NaBH_4$ (5.37 g, 0.142 mol) in portions over 40 min at such a rate that the internal temperature did not rise above 7 °C (CAUTION: vigorous effervescence observed). After stirring for 1.5 h at 0 °C the reaction was quenched with the slow addition of saturated $NH_4Cl_{(aq)}$ (150 ml). After effervescence had ceased, the product was extracted with CH_2Cl_2 (4 × 50 ml), the combined organic phases were washed with brine, dried over $MgSO_4$, and the solvent removed gently *in vacuo* to yield approximately 20 ml of mixture of CH_2Cl_2 and the product. The residue was distilled (29 – 33 °C at 2.3 mbar, Lit. b.p. 57 – 60 °C at 19 mbar)[6] to give (*rac*,*E*)-5-methylhex-3-en-2-ol (10.29 g, 59%) as a colourless liquid that was deemed to be approximately 95% pure by GC. $\boldsymbol{R_f}$ (20% EtOAc/petrol) 0.38. δ_H (400 MHz, $CDCl_3$): 0.99 & 0.99* (6H, 2d, *J* 6.9, $CH(CH_3)_2$), 1.26 (3H, d, *J* 6.4, CH_3CH), 1.47 (1H, s, OH), 2.28 (1H, sept.dd, *J* 6.9, 6.6, 1.1, $CH(CH_3)_2$), 4.26 (1H, qd, *J* 6.4, 6.3, CHOH),[†] 5.46 (1H, ddd, *J* 15.4, 6.3, 1.1, CHCHOH), 5.61 (1H, ddd, *J* 15.4, 6.6, 1.0, CH=CHCHOH), **Signals were separated by less than 1 Hz*, [†]J^4 *coupling not observed due to broadness of signal*. δ_C (100 MHz, $CDCl_3$): 22.3 (CH_3), 23.4 (CH_3), 30.5 (CH), 69.0 (CH), 131.1 (CH), 138.0 (CH). $\boldsymbol{\nu_{max}}$ (neat): 969, 1056, 1365, 2869, 2961, 3331. Spectral data was in accordance with the literature.[7]

(*rac*)-4-Methylpent-3-en-2-ol

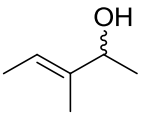


To a stirred solution of 4-methylpent-3-en-2-one (4.00 g, 40.1 mmol) in anhydrous MeOH (20 ml) at 0 °C (ice/salt, internal temperature), was added $NaBH_4$ (1.70 g, 44.8 mol) in portions over 30 min at such a rate that the internal temperature did not rise above 5 °C (CAUTION: vigorous effervescence observed). After stirring for 2 h at ambient temperature, approximately 50% of the solvent was carefully removed *in vacuo*. The reaction mixture was then cooled to 0 °C and saturated $NH_4Cl_{(aq)}$ (30 ml) was added slowly. After effervescence had ceased, the mixture was extracted with Et_2O (4 × 30 ml). The combined organic phases were washed with brine, dried over $MgSO_4$, and the solvent removed gently *in vacuo*. The residue was purified by flash column chromatography eluting 30% Et_2O/pentane to give (*rac*)-4-methylpent-3-en-2-ol (3.48 g, 85%, 4.77 g total containing 0.5 eq of Et_2O) as a colourless solution. $\boldsymbol{R_f}$ (30% Et_2O/pentane) 0.38. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.23 (3H, d, *J* 6.4, CHCH_3), 1.40 (1H, s, OH), 1.69 (3H, d, *J* 1.5, CCH_3), 1.71 (3H, d, *J* 1.5, CCH_3), 4.56 (1H, app. quint., *J* 6.4, C*H*CH_3), 5.20 (1H, dqq, *J* 8.6, 1.5, 1.5, =CH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 18.0 (CH_3), 23.6 (CH_3), 25.6 (CH_3), 64.8 (CH), 129.3 (CH), 134.1 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1043, 1066, 1376, 1447, 2928, 2969, 3336. Spectral data was in accordance with the literature.[8]

General procedure for 1,2-addition of an organometallic to *α,β*-unsaturated aldehydes (GP1)

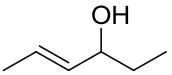
To a stirred solution of *α,β*-unsaturated aldehyde (1 mmol) in anhydrous Et_2O (1.5 ml) under a nitrogen atmosphere at −5 °C (ice/salt), a solution of the organometallic reagent (1.1 mmol) was added dropwise over 10 min. After stirring for 2 h at 0 °C the reaction was quenched with the slow addition of water (approx. 2 ml/mmol of organometallic reagent). The phases were separated and the aqueous phase extracted with Et_2O. The combined organic phases were washed with brine, dried with $MgSO_4$, and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 30% Et_2O/pentane to give pure allylic alcohols as colourless liquids. NOTE: compounds (*E*)-3-methylpent-3-en-2-ol and (*E*)-hex-4-en-3-ol are volatile enough to be lost during rotary evaporation. To minimise this, minimum vacuum (>800 mbar), 40 °C bath temperature and a 15 cm Vigreux column was used instead of a splash head during rotary evaporation.

(*rac*,*E*)-3-Methylpent-3-en-2-ol



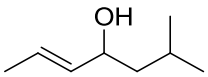
Following **GP1**, using tiglic aldehyde (2.60 ml, 26.7 mmol) and MeLi (1.6 M in Et_2O, 18.4 ml, 29.4 mmol) gave (*rac*,*E*)-3-methylpent-3-en-2-ol (2.49 g, 93%). $\boldsymbol{R_f}$ (30% EtOAc/petrol) 0.30. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.25 (3H, d, *J* 6.4, OCHC*H*$_3$), 1.40 (1H, br. s, OH), 1.61 (3H, dm, *J* 6.8, CH_3CHC), 1.63 (3H, qd, *J* 1.1, 1.1, CH_3C), 4.21 (1H, q, *J* 6.4, OCH), 5.49 (1H, qqd, *J* 6.8, 1.1, 1.1, CH_3C*H*C). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 11.0 (CH_3), 13.0 (CH_3), 21.5 (CH_3), 73.4 (CH), 119.2 (CH), 139.2 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 826, 1079, 1111, 1367, 1380, 1446, 1672, 2864, 2921, 2974, 3339. Spectral data was in accordance with the literature.[9]

(*rac*,*E*)-Hex-4-en-3-ol



Following **GP1**, using crotonaldehyde (2.71 ml, 32.7 mmol) and EtMgBr (1.0 M in THF, 36 ml, 36 mmol) gave (*rac*,*E*)-hex-4-en-3-ol (1.08 g, 30%). $\boldsymbol{R_f}$ (30% EtOAc/petrol) 0.32. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.91 (3H, t, *J* 7.3, CH_2C*H*$_3$), 1.47 (1H, s, OH), 1.49 (1H, qdd, *J* 7.3, 6.6, 6.6, CH*H*), 1.58 (1H, qdd, *J* 7.3, 6.6, 6.6, C*H*H), 1.71 (3H, ddd, *J* 6.4, 1.7, 0.7, C*H*$_3$CHCH), 3.96 (1H, app. q, *J* 6.8, *H*COH),* 5.48 (1H, ddq, *J* 15.4, 7.2, 1.7, CH_3CHC*H*), 5.67 (1H, dqd, *J* 15.2, 6.4, 0.9, CH_3C*H*CH). **J*^{4} & *J*^{5} *coupling not observed due to broadness of signal*. $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 9.7 (CH_3), 17.7 (CH_3), 30.1 (CH_2), 74.5 (CH), 126.9 (CH), 134.0 (CH). $\boldsymbol{\nu_{max}}$ (neat): 962, 1006, 1452, 1673, 2877, 2934, 2963. 3350. Spectral data was in accordance with the literature.[10]

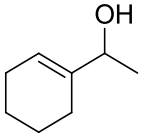
(*rac*,*E*)-6-Methylhept-2-en-4-ol



Following **GP1**, using crotonaldehyde (8.29 ml, 100 mmol) and *i*BuMgBr (1.33 M in Et_2O, 90 ml, 120 mmol) gave (*rac*,*E*)-6-methylhept-2-en-4-ol (9.69 g, 76%). *i*BuMgBr was prepared by the portion wise addition (approx. 20) of *i*BuBr (13.1 ml, 120 mmol) to a stirred mixture of magnesium turnings (2.92 g, 120 mmol) in anhydrous Et_2O (90 ml) at ambient temperature. $\boldsymbol{R_f}$ (20% Et_2O/pentane) 0.43. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.91 (3H, d, *J* 6.6, CH(CH_3)CH_3), 0.92 (3H, d, *J* 6.6, CH(C*H*$_3$)CH_3), 1.30 (1H, ddd, *J* 13.4, 7.3, 6.1, CH*H*), 1.39 (1H, d, *J* 3.3, OH), 1.50 (1H, ddd, *J* 13.4, 7.6, 6.6, C*H*H), 1.70 (1H, app. tsept., *J* 7.0, 6.6, C*H*(CH_3)$_2$), 1.70 (3H, ddd, *J* 6.4, 1.7, 0.6, C*H*$_3$CHCH), 4.11 (1H, app. qd, *J* 7.2, 3.3, C*H*OH),* 5.47 (1H, ddq, *J* 15.3, 7.3, 1.7, CH_3CHC*H*), 5.67 (1H, dqd, *J* 15.3, 6.4, 0.7, CH_3C*H*CH). **J*^{4} & *J*^{5} *coupling not observed due to broadness of signal*. $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 17.6 (CH_3), 22.5 (CH_3),

22.9 (CH), 24.5 (CH_3), 46.4 (CH_2), 71.3 (CH), 126.5 (CH), 134.7 (CH). ν_{max} (neat): 964, 1018, 1468, 1674, 2870, 2919, 2956, 3345. **GCMS** (*M30*): T_R 8.33; MS calc. for $[C_8H_{16}O]^{+\bullet}$ 128. Found: 128, 113, 110, 95, 86, 71 (basepeak). Spectral data was in accordance with the literature.[11]

(*rac*)-1-(Cyclohex-1-en-1-yl)ethanol



Following **GP1**, using cyclohex-1-enecarbaldehyde (2.50 ml, 22.7 mmol) and MeLi (1.6 M in Et_2O, 15 ml, 25 mmol) gave (*rac*)-1-(cyclohex-1-en-1-yl)ethanol (2.69 g, 94%). R_f (30% Et_2O/pentane) 0.38. δ_H (400 MHz, $CDCl_3$): 1.25 (3H, d, *J* 6.5, CH_3), 1.51 (1H, d, *J* 3.2, OH), 1.51-1.71 (4H, m, CH_2), 1.92-2.10 (4H, m, CH_2), 4.16 (1H, br. q, *J* 6.5, *H*COH), 5.64-5.68 (1H, m, =CH). δ_C (100 MHz, $CDCl_3$): 21.5 (CH_3), 22.55 (CH_2), 22.61 (CH_2), 23.6 (CH_2), 24.8 (CH_2), 72.1 (CH), 121.5 (CH), 141.2 (4° C). ν_{max} (neat): 1058, 1292, 1365, 1437, 2836, 2926, 2972, 3336. **GCMS** (*M50*): T_R 6.34; MS calc. for $[C_8H_{14}O]^{+\bullet}$ 126. Found: 126, 111, 108, 97, 93, 83, 79, 67 (basepeak), 55. Spectral data was in accordance with the literature.[12]

Synthesis of enantioenriched secondary allylic alcohols

General procedure for enzymatic kinetic resolution of secondary allylic alcohols (GP2)

To a stirred mixture of allylic alcohol and freshly activated crushed 4Å molecular sieves (50% wt. of alcohol) in pentane at ambient temperature, vinyl acetate or succinic anhydride and an enzyme was added. The reaction mixture was stirred until approximately 51-55% conversion to the acetate, as deemed by ^{1}H NMR or GC. The mixture was filtered through Celite and the filter cake washed with pentane (approx. 50% original reaction mixture volume). The solvent was gently removed *in vacuo* and the residue purified by flash column chromatography to yield pure alcohol and acetate.

General procedure for small scale benzoylation of alcohols for express analysis by chiral HPLC (GP3)

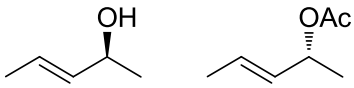
To a stirred solution of the alcohol (~10 mg), NEt_3 (~3 eq) and DMAP (~1 mg) in CH_2Cl_2 (0.5 ml), benzoyl chloride (~2 eq) was added. The resulting mixture was stirred overnight (~16 h) at ambient temperature. Water (1 ml) was added and the reaction stirred for 30 min. The phases were separated and the aqueous phase extracted with CH_2Cl_2 (3 × 1 ml). The combined organic phases were dried over $MgSO_4$ and the solvent removed *in vacuo*. The residue was purified by flash column chromatography using a Pasteur pipette containing ~5 cm of silica gel, collecting 0.5 ml fractions

while eluting 0-2% Et_2O/pentane. The solvent was removed from one of the clean fractions and then redissolved in an appropriate amount of HPLC grade hexane. The solution was analysed firstly by GCMS for identity and then chiral HPLC for *er* determination.

General procedure for small scale hydrolysis of acetates for express analysis of *er* (GP4)

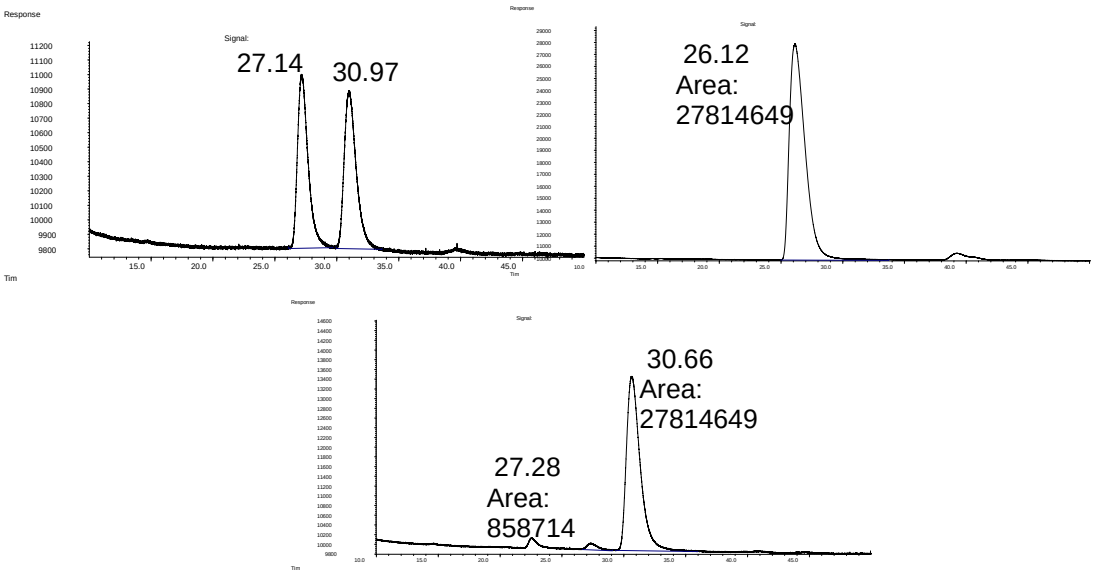
To a stirred solution of acetate (~20 mg) in methanol (0.5 ml), K_2CO_3 (~50 mg) was added. The resulting mixture was stirred overnight (~16 h) at ambient temperature. Water (1 ml) and CH_2Cl_2 (1 ml) was added and the phases separated. The aqueous phase was extracted with CH_2Cl_2 (3 × 1 ml). The combined organic phases were dried over $MgSO_4$ and the solvent carefully removed *in vacuo* to give approximately 1 ml of a solution containing the allylic alcohol. This could be directly analysed by chiral GC or HPLC after appropriate dilution or used in **GP3** after the solution was passed through a Pasteur pipette containing silica and washed down with CH_2Cl_2 (3 ml).

(*S*,*E*)-Pent-3-en-2-ol and (*R*,*E*)-pent-3-en-2-yl acetate

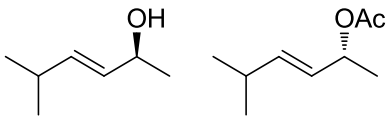


Following **GP2**, using (*rac*,*E*)-pent-3-en-2-ol (96:4 *E*/*Z*, 10.0 ml, 97.1 mmol), pentane (85 ml), vinyl acetate (44.8 ml, 485 mmol), 4Å molecular sieves (4 g) and Novozyme 435 (lipase acrylic resin from *Candida antarctica*, 10% wt, 860 mg), filtering the reaction at 54% conversion after 3 h, followed by flash column chromatography eluting 0%-50% Et_2O/pentane gave (*S*,*E*)-pent-3-en-2-ol (3.76 g, 45%, >99:1 *er*, 96:4 *E*/*Z*) as a colourless liquid and (*R*,*E*)-pent-3-en-2-yl acetate (4.6 g, 37%, 97:3 *er*, 96:4 *E*/*Z*,)[*] as a colourless liquid. NOTE: (*S*,*E*)-pent-3-en-2-ol is volatile enough to be lost during rotary evaporation. To minimise this, the removal of solvent prior to and after flash column chromatography was performed by slow distillation (atmospheric pressure, 40 °C) using a 15 cm Vigreux column. After the majority of the solvent had been removed in this way, the yield was determined by internal standard in ^{1}H NMR. The solvent was not fully removed from the product and thus the product was kept and used as a solution (1.54 M) in subsequent carbamoylation reactions without any detrimental effect on yield of that reaction. ***Alcohol characterisation***: R_f (30% Et_2O/pentane) 0.25. δ_H (400 MHz, $CDCl_3$): 1.25 (3H, d, *J* 6.2, OCHC*H*$_3$), 1.52 (1H, s, OH), 1.69 (3H, ddd, *J* 6.4, 1.3, 0.8, C*H*$_3$CHCH), 4.25 (1H, dq, *J* 6.6, 6.2, *H*COH),[†] 5.53 (1H, ddq, *J* 15.4, 6.6, 1.3, CH_3CHC*H*), 5.66 (1H, dqd, *J* 15.4, 6.4, 0.9, CH_3C*H*CH). [†]*J^4 & J^5 coupling not observed due to broadness of signal*. δ_C (100 MHz, $CDCl_3$): 17.5 (CH_3), 23.3 (CH_3), 68.9 (CH),

125.8 (CH), 135.4 (CH). ν_{max} (neat): 962, 1060, 1368, 1449, 1675, 2881, 2921, 2971, 3338. **Chiral GC** (γ-CD, 30 °C, 12.5 psi, 1.2 ml/min) T_R 26.10 min. $[\alpha]_D^T$ was found to be variable with time.[13, 14] Spectral data was in accordance with the literature.[15] ***Acetate Characterisation:*** R_f (5% Et_2O/pentane) 0.40. δ_H (400 MHz, $CDCl_3$): 1.30 (3H, d, *J* 6.2, OCHCH_3), 1.71 (3H, ddd, *J* 6.4, 1.7, 0.7, CH_3CHCH), 2.05 (3H, s, $COCH_3$), 5.32 (1H, dq, *J* 6.8, 6.2, HCO),[¥] 5.50 (1H, ddq, *J* 15.3, 6.8, 1.7, CH_3CHC*H*), 5.74 (1H, dqd, *J* 15.3, 6.4, 0.9, CH_3C*H*CH). [¥]*J*[4] *& J*[5] *coupling not observed due to broadness of signal.* δ_C (100 MHz, $CDCl_3$): 17.6 (CH_3), 20.3 (CH_3), 21.4 (CH_3), 71.1 (CH), 128.1 (CH), 130.7 (CH), 170.4 (4° C). ν_{max} (neat): 1040, 1237, 1370, 1734, 2859, 2936, 2981. **GCMS** (*M30*): T_R 4.25; MS calc. for $[C_7H_{12}O]^{+\bullet}$ 128. Found: 128, 113, 86 (basepeak), 71, 69, 67. [*]*er* determined by hydrolysis (**GP4**) to the *R*-alcohol which was analysed by **Chiral GC** (γ-CD, 30 °C, 12.5 psi, 1.2 ml/min) T_R 30.66 min (major), 27.28 min (minor). $[\alpha]_D^{24}$ +68.0 (*c* 1, CH_2Cl_2), Lit. −76.6 (*c* 0.99, CH_2Cl_2, >99:1 *er*, for *S*-acetate).[16] Spectral data was in accordance with the literature.[16]

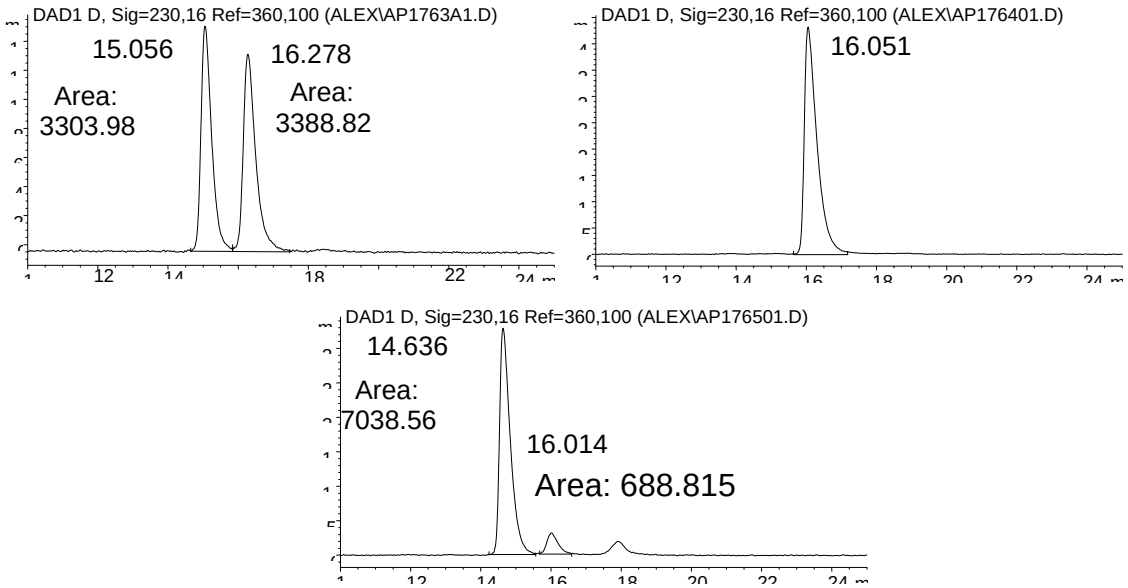


(*S*,*E*)-5-Methylhex-3-en-2-ol and (*R*,*E*)-5-methylhex-3-en-2-yl acetate

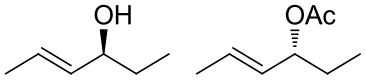


Following **GP2**, using (*rac*,*E*)-5-methylhex-3-en-2-ol (9.74 g, 85.3 mmol), pentane (75 ml), vinyl acetate (39.4 ml, 427 mmol), 4Å molecular sieves (5 g) and Novozyme 435 (lipase acrylic resin from *Candida antarctica*, 10% wt, 974 mg), filtering the reaction at 51% conversion after 5 h, followed by flash column chromatography eluting 0 - 100% CH_2Cl_2/pentane gave (*S*,*E*)-5-

methylhex-3-en-2-ol (3.85 g, 39%, >99:1 *er*)* as a colourless liquid and (*R,E*)-5-methylhex-3-en-2-yl acetate (5.33 g, 40%, 91:9 *er*)† as a colourless liquid. ***Alcohol characterisation***: $[\alpha]_D^{25}$ −10.5 (*c* 1.14, $CHCl_3$), contradiction to the literature: +81.6 (*c* 1.14, $CHCl_3$, 99:1 *er*).[6] **er* was determined by converting a small sample of *S*-alcohol (~10 mg) to the benzoate ester (**GP3**) which was analysed by **Chiral HPLC**: (IA, hexane, 0.7 ml/min) T_R 16.05 min. Spectroscopic data matched racemic alcohol. ***Acetate characterisation:*** $\boldsymbol{R_f}$ (CH_2Cl_2) 0.59. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.99 (6H, d, *J* 6.6, $CH(CH_3)_2$), 1.29 (3H, d, *J* 6.6, $CHCH_3$), 2.04 (3H, s, $OC(O)CH_3$), 2.28 (1H, dsept.d, *J* 6.9, 6.6, 1.5, $CH(CH_3)_2$), 5.32 (1H, dq, *J* 6.6, 6.6, CHO),¥ 5.41 (1H, ddd, *J* 15.4, 6.9, 1.5, $CHCHCH(CH_3)_2$), 5.66 (1H, ddd, *J* 15.4, 6.6, 1.0, $CHCHCH(CH_3)_2$). ¥*J^4 coupling not observed due to broadness of signal.* $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 20.4 (CH_3), 21.5 (CH_3), 22.0 (CH_3), 22.1 (CH_3), 30.6 (CH_3), 71.2 (CH), 126.5 (CH), 140.0 (CH), 170.3 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1040, 1236, 1734, 2871, 2961. $[\alpha]_D^{25}$ +50.8 (*c* 1.35, MeOH), Lit +76.9 (*c* 1.35, MeOH, 96:4 *er*).[6] †*er* determined by hydrolysis (**GP4**), and conversion to the benzoate ester (**GP3**) which was analysed by **Chiral HPLC**: (IA, hexane, 0.7 ml/min) T_R 14.64 min (major), 16.01 min (minor). Spectral data was in accordance with the literature.[7]

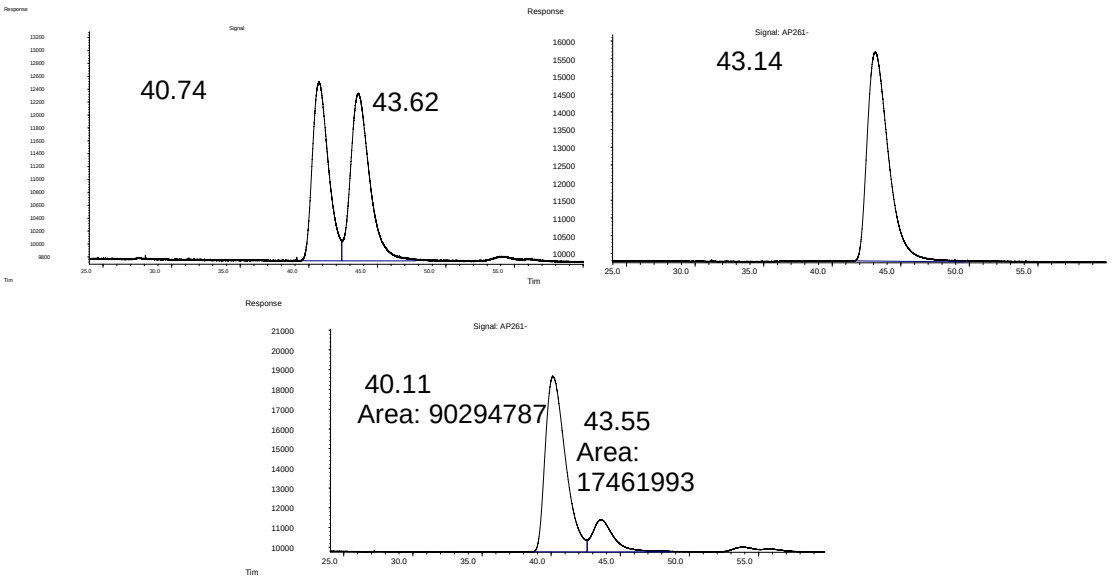


(*S,E*)-Hex-4-en-3-ol and (*R,E*)-hex-4-en-3-yl acetate

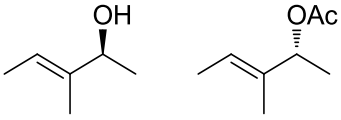


Following **GP2**, using (*rac,E*)-hex-4-en-3-ol (591 mg, 5.90 mmol), pentane (6 ml), vinyl acetate (0.60 ml, 6.49 mmol), 4Å molecular

sieves (250 mg) and Novozyme 435 (lipase acrylic resin from *Candida antarctica*, 10% wt, 59 mg), filtering the reaction at 58% conversion after 13 h, followed by flash column chromatography eluting 2%-20% Et_2O/pentane gave (*S*,*E*)-hex-4-en-3-ol (199 mg, 34%, >99:1 *er*) as a colourless liquid and (*R*,*E*)-hex-4-en-3-yl acetate (435 mg, 52%, 84:16 *er*)[†] as a colourless liquid. ***Alcohol characterisation***: **Chiral GC** (*γ*-CD, 35 °C, 15 psi, 1.4 ml/min) T_R 43.14 min. $[\alpha]_D^{25}$ −2.9 (*c* 2.4, $CHCl_3$), Lit. −2.0 (c 0.93, $CHCl_3$, >99:1 *er*).[17] Spectroscopic data matched racemic alcohol. ***Acetate Characterisation***: $\boldsymbol{R_f}$ (20% Et_2O/pentane) 0.79. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.88 (3H, t, *J* 7.5, CH_2CH_3), 1.56 (1H, qdd, *J* 7.5, 6.6, 6.6, CH*H*), 1.64 (1H, qdd, *J* 7.5, 6.6, 6.6, C*H*H), 1.70 (3H, ddd, *J* 6.6, 1.7, 0.6, CH_3CHCH), 2.05 (3H, s, $COCH_3$), 5.11 (1H, app. q, *J* 6.8, CHO),* 5.40 (1H, ddq, *J* 15.2, 7.3, 1.7, CH_3CHCH), 5.72 (1H, dqd, *J* 15.2, 6.6, 0.9, CH_3CHCH). *J^4 & J^5 coupling not observed due to broadness of signal*. $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 9.5 (CH_3), 17.7 (CH_3), 21.3 (CH_3), 27.5 (CH_2), 76.2 (CH), 129.2 (CH), 129.4 (CH), 170.5 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 964, 1234, 1371, 1733, 2880, 2939, 2969. **GCMS** (*M30*): T_R 7.75; MS calc. for $[C_8H_{14}O_2]^{+\bullet}$ 142. Found: 142, 113, 100, 82, 71 (basepeak), 67, 55. [†]*er* determined by hydrolysis (**GP4**) to the *R*-alcohol which was analysed by **Chiral GC** (*γ*-CD, 35 °C, 15 psi, 1.4 ml/min) T_R 40.11 min (major), 43.55 min (minor). $[\alpha]_D^{25}$ +41.0 (*c* 2, $CHCl_3$), Lit. +47.6 (*c* 5.8, $CHCl_3$, 93:7 *er*).[17] Spectral data was in accordance with the literature.[18]

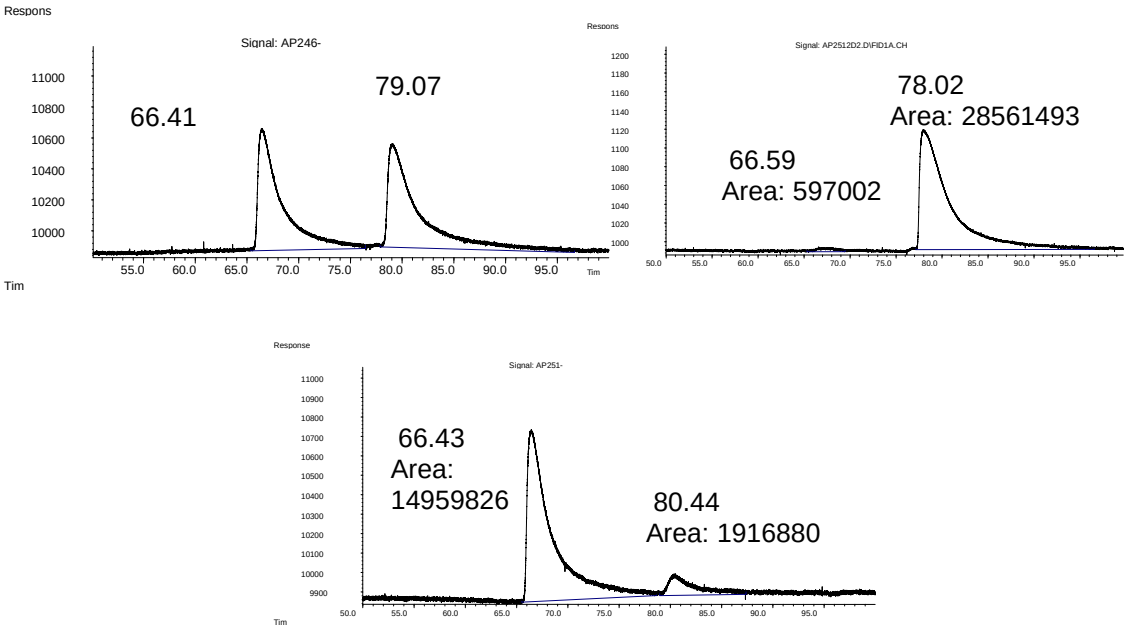


(*S*,*E*)-3-Methylpent-3-en-2-ol and (*R*,*E*)-3-methylpent-3-en-2-yl acetate

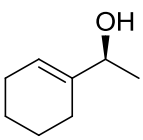


Following **GP2**, using (*rac*,*E*)-3-methylpent-3-en-2-ol (1.65 g, 16.5 mmol), pentane (16 ml), vinyl acetate (7.47 ml, 80.8 mmol), 4Å

molecular sieves (800 mg) and Amano AK (25% wt, 413 mg), filtering the reaction at 56% conversion after 7 h, followed by flash column chromatography eluting 10%-30% Et_2O/pentane gave (*S*,*E*)-3-methylpent-3-en-2-ol (528 mg, 32%, 98:2 *er*) as a colourless liquid and (*R*,*E*)-3-methylpent-3-en-2-yl acetate (1.17 g, 50%, 89:11 *er*)* as a colourless liquid. ***Alcohol characterisation***: **Chiral GC** (*β*-CD, 40 °C, 15.0 psi, 1.4 ml/min) T_R 78.02 min (major), 66.02 min (minor). $[\alpha]_D^{25}$ −18.3 (*c* 1.2, $CHCl_3$). Spectroscopic data matched racemic alcohol. ***Acetate Characterisation:*** $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.63. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.29 (3H, d, *J* 6.6, OCHCH_3), 1.59-1.69 (6H, m, CH_3), 2.04 (3H, s, $COCH_3$), 5.26 (1H, q, *J* 6.6, OCH), 5.33 (1H, app. qqd, 6.8, 1.1, 1.1, CH_3CHC). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 11.6 (CH_3), 13.0 (CH_3), 19.0 (CH_3), 21.4 (CH_3), 75.4 (CH), 121.5 (CH), 135.0 (4° C), 170.4 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1045, 1236, 1369, 1732, 2983, 2932. **GCMS** (*M30*): T_R 8.51; MS calc. for $[C_8H_{14}O_2]^{+\bullet}$ 142. Found: 142, 100, 85, 82, 67 (basepeak), 55. **er* determined by hydrolysis (**GP4**) to the *R*-alcohol which was analysed by **Chiral GC**: (*β*-CD, 40 °C, 15.0 psi, 1.4 ml/min) T_R 66.43 min (major), 80.44 min (minor). $[\alpha]_D^{25}$ +47.5 (*c* 2, CH_2Cl_2). Spectral data was in accordance with the literature.[19]

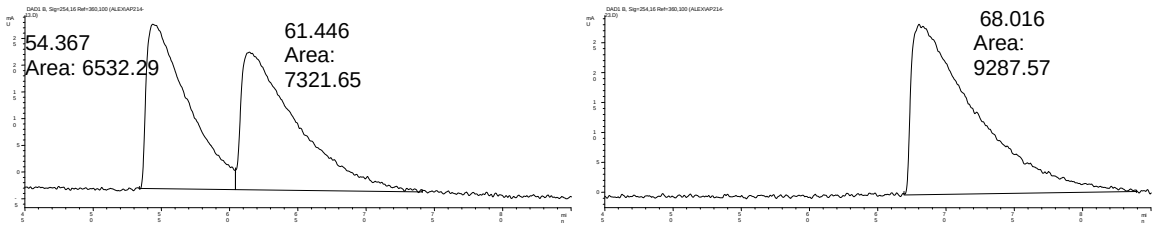


(*S*)-1-(Cyclohex-1-en-1-yl)ethanol



Following the procedure of Jacquet *et al*;[12] to a stirred mixture of (*rac*)-1-(cyclohex-1-en-1-yl)ethanol (1.54 g, 12.2 mmol) and succinic anhydride (3.66 g, 36.6 mmol) in Et_2O (50 ml) at ambient temperature, PS-Amano lipase (488 mg) was added. The

mixture was stirred for 3.5 days at which point 51% conversion was reached. The mixture was filtered through Celite and the filter cake washed with Et_2O (50 ml). The filtrate was washed with sat. $NaHCO_3$ (2 × 30 ml) and the aqueous phases extracted with Et_2O (2 × 30 ml). The combined organic phases were washed with water (100 ml), brine, and dried over $MgSO_4$. The solvent was removed *in vacuo* and the residue purified by flash column chromatography eluting 30% Et_2O/pentane to give (*S*)-1-(cyclohex-1-en-1-yl)ethanol (1.09 g, 48%, >99:1 *er*)* as a colourless liquid. $[\alpha]_D^{25}$ −6.3 (*c* 2.4, $CHCl_3$), Lit. −6.5 (*c* 1, $CHCl_3$, >99:1 *er*).[12] **er* was determined by converting a small sample of *S*-alcohol (~10 mg) to the *p*-nitrobenzoate ester (**GP3**) and analysed by **Chiral HPLC**: (IB, 0.1% IPA/hexane, 0.7 ml/min, 5 °C) T_R 68.02 min. Spectroscopic data matched racemic alcohol.

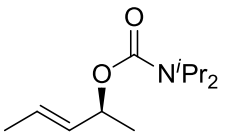


Synthesis of enantioenriched secondary allylic carbamates

General procedure for carbamoylation of allylic alcohols (GP5)

To a stirred suspension of NaH (60% dispersion in mineral oil, 1.5 mmol) in anhydrous THF (1.5 ml) at ambient temperature under an atmosphere of nitrogen, the allylic alcohol (1.0 mmol) was added dropwise. The mixture was stirred for 30 min, and diisopropylcarbamoyl chloride (1.3 mmol) and DMAP (~5% wt of alcohol) were added in one portion. The mixture was stirred at reflux overnight. The reaction mixture was quenched by the slow addition of 2 M $NaOH_{(aq)}$ at ambient temperature and stirred for 30 min. The mixture was extracted with Et_2O (3 × 10 ml) and the combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 10% Et_2O/pentane to yield pure carbamates.

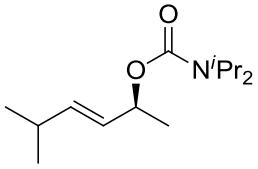
(*S*,*E*)-Pent-3-en-2-yl diisopropylcarbamate 1a



Following **GP5**, using (*S*,*E*)-pent-3-en-2-ol (1.54 M, 8.77 ml, 13.5 mmol, >99:1 *er*, 96:4 *E*/*Z*) gave *S*-**1a** (2.81 g, 97%) as a colourless oil. R_f (10% Et_2O/pentane)

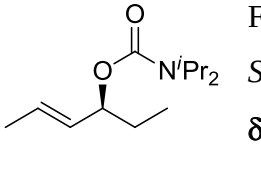
0.31. δ_H (400 MHz, $CDCl_3$): 1.19 & 1.21 (12H, 2br. s, CH(C*H*$_3$)$_2$), 1.30 (3H, d, *J* 6.6, OCHC*H*$_3$), 1.69 (3H, ddd, *J* 6.4, 1.4, 0.8, C*H*$_3$CHCHCHO) 3.74 & 4.06 (2H, 2br. s, C*H*(CH$_3$)$_2$), 5.26 (1H, br. dq, *J* 6.6, 6.6, OCH),* 5.51 (1H, ddq, *J* 15.4, 6.6, 1.3, CHC*H*CHO), 5.69 (1H, dqd, *J* 15.4, 6.4, 0.9, C*H*CHCHO). **J*^{4} *& J*^{5} *coupling not observed due to broadness of signal.* δ_C (100 MHz, $CDCl_3$): 17.7 (CH_3), 20.8 (CH_3), 21.1 (br. s, CH_3), 45.7 (br. CH), 71.1 (CH), 126.7 (CH), 131.9 (CH), 155.3 (4° C). **Elemental analysis**: calc. for $C_{12}H_{23}NO_2$: C, 67.57; H, 10.87; N, 6.57; Found: C, 67.83; H, 10.94; N, 6.29. ν_{max} (neat): 1042, 1285, 1432, 1686, 2934, 2970. **HRMS** (CI) calc. for $[C_{12}H_{23}NO_2 + H]^+$ 214.1807. Found 214.1811. **LRMS** (CI) calc. for $[C_{12}H_{23}NO_2 + H]^+$ 214.2. Found 214.2, 146.1, 69.1 (basepeak). $[\alpha]_D^{22}$ +11.6 (*c* 1.2, $CHCl_3$), Lit. +10.8 (*c* 1.9, $CHCl_3$, 92:8).[20] Spectral data was in accordance with the literature.[21]

(*S*,*E*)-5-Methylhex-3-en-2-yl diisopropylcarbamate 1b



Following **GP5**, using (*S*,*E*)-5-methylhex-3-en-2-ol (3.65 g, 31.9 mmol, >99:1 *er*) gave *S*-**1b** (6.0 g, 78%) as a colourless oil. R_f (10% Et_2O/pentane) 0.40. δ_H (400 MHz, $CDCl_3$): 0.98 (6H, d, *J* 6.9, CHCH(C*H*$_3$)$_2$), 1.19 & 1.21 (12H, 2br. s, NCH(C*H*$_3$)$_2$), 1.31 (3H, d, *J* 6.6, CHC*H*$_3$), 2.28 (1H, dsept.d, *J* 6.9, 6.6, 1.5, CHC*H*(CH$_3$)$_2$), 3.83 & 3.93 (2H, 2br. s, NC*H*(CH$_3$)$_2$), 5.28 (1H, dq, *J* 6.6, 6.6, OCH),* 5.44 (1H, ddd, *J* 15.7, 6.6, 1.5, C*H*CHCH(CH$_3$)$_2$), 5.65 (1H, ddd, *J* 15.7, 6.6, 1.0, CHC*H*CH(CH$_3$)$_2$). **J*^{4} *coupling not observed due to broadness of signal.* δ_C (100 MHz, $CDCl_3$): 20.8 (CH_3), 21.1 (br. s, CH_3), 22.1 (CH_3), 22.2 (CH_3), 30.6 (CH), 45.7 (br. s, CH), 71.1 (CH), 127.5 (CH), 139.0 (CH), 155.3 (4° C). ν_{max} (neat): 1043, 1284, 1433, 1688, 2928, 2967. **HRMS** (CI) calc. for $[C_{14}H_{27}NO_2 + H]^+$ 242.2120. Found 242.2110. **LRMS** (CI) calc. for $[C_{14}H_{27}NO_2 + H]^+$ 242.2. Found 242.2, 198.2, 146.1 (basepeak), 97.1. $[\alpha]_D^{25}$ +4 (*c* 1, $CHCl_3$).

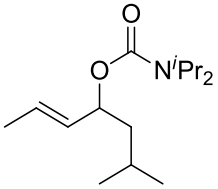
(*S*,*E*)-Hex-4-en-3-yl diisopropylcarbamate 1c



Following **GP5**, using (*S*,*E*)-hex-4-en-3-ol (169 mg, 1.69 mmol, >99:1 *er*) gave *S*-**1c** (250 mg, 65%) as a colourless oil. R_f (10% Et_2O/pentane) 0.37. δ_H (400 MHz, $CDCl_3$): 0.90 (3H, t, *J* 7.5, CH_2CH_3), 1.20 & 1.22 (12H, 2br. s, CH(C*H*$_3$)$_2$), 1.59 (1H, dqd, *J* 13.6, 7.5, 6.4, CH*H*), 1.68 (1H, dqd, *J* 13.6, 7.5, 6.4, C*H*H), 1.70 (3H, ddd, *J* 6.5, 1.7, 0.6, C*H*$_3$CH), 3.76 & 4.07 (2H, 2br. s, C*H*(CH$_3$)$_2$), 5.08 (1H, ddd, *J* 7.2, 6.4, 6.4,

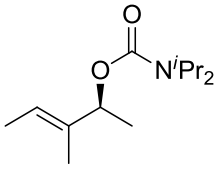
OCH),* 5.43 (1H, ddq, *J* 15.3, 7.2, 1.7, CH_3CHCH), 5.69 (1H, dqd, *J* 15.3, 6.4, 0.9, $CHCHCHO$). *J^4 & J^5 coupling not observed due to broadness of signal*. δ_C (100 MHz, $CDCl_3$): 9.7 (CH_3), 17.8 (CH_3), 20.9 (br. s, CH_3), 27.9 (CH_2), 45.7 (br. s, CH), 76.3 (CH), 127.8 (CH), 130.4 (CH), 155.4 (4° C). ν_{max} (neat): 1047, 1285, 1431, 1688, 2879, 2936, 2968. **HRMS** (ESI) calc. for $[C_{13}H_{25}O_2N + Na]^+$ 250.1778. Found 250.1776. **GCMS** (*M70*): T_R 6.01; MS calc. for $[C_{13}H_{25}O_2N]^{+\bullet}$ 227. Found: 227, 168, 154, 146, 130, 128, 102, 86, 83 (basepeak), 70, 67, 55. $[\alpha]_D^{24}$ +18.0 (*c* 2, $CHCl_3$).

(*E*)-6-Methylhept-2-en-4-yl diisopropylcarbamate 1d



Following **GP5**, using (*rac*,*E*)-6-methylhept-2-en-4-ol (385 mg, 3.00 mmol) gave *rac*-**1d** (644 mg, 84%) as a colourless oil. R_f (10% Et_2O/pentane) 0.38. δ_H (400 MHz, $CDCl_3$): 0.91 (3H, d, *J* 6.5, $CH_2CH(CH_3)_2$), 0.93 (3H, d, *J* 6.5, $CH_2CH(CH_3)_2$), 1.20 & 1.21 (12H, 2br. s, $NCH(CH_3)_2$), 1.38 (1H, ddd, *J* 6.5, 6.5, 6.5, OCHCH*H*), 1.56-1.69 (2H, m, OCHC*H*H & $CH_2CH(CH_3)_2$), 1.70 (3H, ddd, *J* 6.5, 1.6, 0.6, CH_3CHCH), 3.75 & 4.07 (2H, 2br. s, $NCH(CH_3)_2$), 5.22 (1H, br. app. q, *J* 7.3, OCH), 5.42 (1H, ddq, *J* 15.3, 7.5, 1.6, CH_3CHCH), 5.71 (1H, dqd, *J* 15.3, 6.5, 0.9, CH_3CHCH). δ_C (100 MHz, $CDCl_3$): 17.8 (CH_3), 21.1 (br. s, CH_3), 22.6 (CH_3), 22.7 (CH_3), 24.6 (CH), 44.1 (CH_2), 45.7 (br. s, CH), 73.7 (CH), 127.7 (CH), 131.0 (CH), 155.4 (4° C). ν_{max} (neat): 1048, 1291, 1432, 1688, 2872, 2935, 2960. **Elemental analysis**: calc. for $C_{15}H_{29}NO_2$: C, 70.54; H, 11.45; N, 5.48; Found: C, 70.28; H, 11.46; N, 5.96. **GCMS** (*M70*): T_R 6.57; MS calc. for $[C_{15}H_{29}NO_2]^{+\bullet}$ 255. Found: 255, 196, 154, 128, 111, 95, 86, 69 (basepeak), 55.

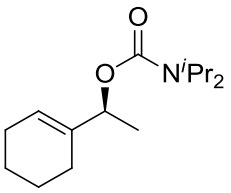
(*S*,*E*)-3-Methylpent-3-en-2-yl diisopropylcarbamate 1e



Following **GP5**, using (*S*,*E*)-3-methylpent-3-en-2-ol (401 mg, 4.00 mmol, 98:2 *er*) gave *S*-**1e** (793 mg, 87%) as a colourless oil. R_f (10% Et_2O/pentane) 0.30. δ_H (400 MHz, $CDCl_3$): 1.20 & 1.21 (12H, 2br. s, $CH(CH_3)_2$), 1.31 (3H, d, *J* 6.6, $OCHCH_3$), 1.61 (3H, br. d, *J* 6.6, CH_3CH=C),* 1.65 (3H, dq, *J* 1.1, 1.1, CH_3C), 3.72 & 4.12 (2H, 2br. s, $CH(CH_3)_2$), 5.22 (1H, br. q, *J* 6.6, OCH), 5.53 (1H, ddq, *J* 6.6, 1.1, 1.1, CH_3CH=C).. δ_C (100 MHz, $CDCl_3$): 11.8 (CH_3), 13.1 (CH_3), 19.5 (CH_3), 21.2 (br. s, CH_3), 45.7 (br. s, CH), 75.8 (CH), 120.6 (CH), 135.8 (4° C), 155.3 (4° C). ν_{max} (neat): 1045, 1283, 1433, 1687, 2874, 2933, 2972. **HRMS** (ESI) calc. for $[C_{13}H_{25}O_2N + Na]^+$ 250.1778. Found 250.1783. **GCMS**

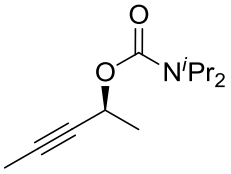
(*M70*): T_R 6.13; MS calc. for $[C_{13}H_{25}O_2N]^{+\bullet}$ 227. Found: 227, 168, 146, 128, 102, 86, 83 (basepeak), 70, 67, 55. $[\alpha]_D^{25}$ +9.0 (*c* 2, $CHCl_3$).

(*S*)-1-(Cyclohex-1-en-1-yl)ethyl diisopropylcarbamate 1f



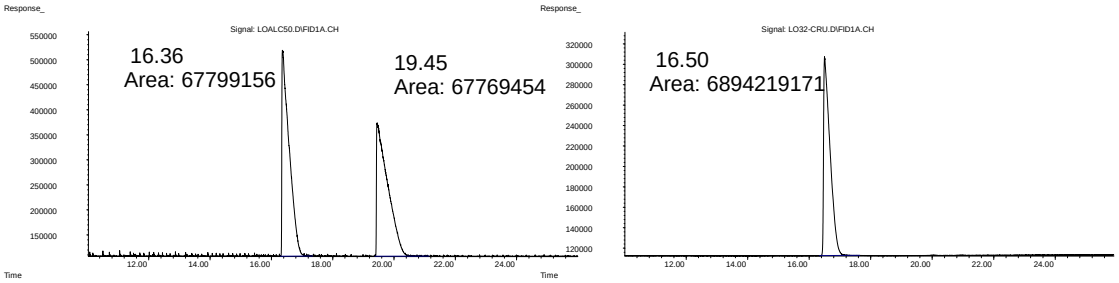
Following **GP5**, using (*S*)-1-(cyclohex-1-en-1-yl)ethanol (679 mg, 6.05 mmol) gave (*S*)-**1g** (966 mg, 64%) as a colourless oil. $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.40. δ_H (400 MHz, $CDCl_3$): 1.20 & 1.21 (12H, 2br. s, $CH(CH_3)_2$), 1.30 (3H, d, *J* 6.5, $CHCH_3$), 1.51-1.68 (4H, m, CH_2), 1.96-2.10 (4H, m, CH_2), 4.08 & 3.75 (2H, 2br. s, $CH(CH_3)_2$), 5.20 (1H, q, *J* 6.5, $CHCH_3$), 5.67-5.71 (1H, m, =CH). δ_C (100 MHz, $CDCl_3$): 19.3 (CH_3), 21.1 (br. s, CH), 22.4 (CH_2), 22.6 (CH_2), 24.4 (CH_2), 24.9 (CH_2), 45.6 (br. s, CH), 74.5 (CH), 122.9 (CH), 137.9 (4° C), 155.3 (4° C). ν_{max} (neat): 1050, 1285, 1439, 1662, 2929, 2965. **Elemental analysis**: calc. for $C_{15}H_{27}NO_2$: C, 71.10; H, 10.74; N, 5.53; Found: C, 71.56; H, 10.95; N, 5.63. **GCMS** (*M70*): T_R 7.34; MS calc. for $[C_{15}H_{27}NO_2]^{+\bullet}$ 253. Found: 253, 194, 146, 128, 109 (basepeak), 93, 86, 79, 67. $[\alpha]_D^{18}$ +1.6 (*c* 2.56, $CHCl_3$).

(*S*)-Pent-3-yn-2-yl diisopropylcarbamate

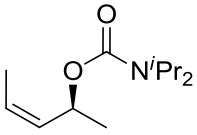


(*S*)-Pent-3-yn-2-yl diisopropylcarbamate was synthesised via two step procedure of enzymatic resolution followed by direct carbamoylation of the crude alcohol. To a stirred mixture of (*rac*)-pent-3-yn-2-ol (2.70 g, 32.1 mmol) and succinic anhydride (9.64 g, 96.3 mmol) in Et_2O (60 ml) at ambient temperature, PS-Amano lipase (1.28 g) was added. The reaction was monitored by chiral GC. After 6 h, >99:1 *er* was reached. The mixture was filtered through 5 cm of silica washed with Et_2O (50 ml). The filtrate was washed with sat. $NaHCO_3$ (4 × 100 ml) and the aqueous phases extracted with Et_2O (2 × 100 ml). The combined organic phases were washed with water (100 ml), brine, and dried over $MgSO_4$. The solvent was removed by slow distillation (atmospheric pressure, 40 °C) using a 15 cm Vigreux column. Once approximately 10 ml of solvent remained, the crude alcohol was carbamoylated following **GP5**, using NaH (60% dispersion in mineral oil, 712 mg, 17.8 mmol) in THF (36 ml), diisopropylcarbamoyl chloride (2.53 g, 15.4 mmol) and DMAP (70 mg), to give (*S*)-pent-3-yn-2-yl diisopropylcarbamate (2.11 g, 31%, 2 steps, >99:1 *er*).* $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.28. δ_H (400 MHz, $CDCl_3$): 1.21, 1.22 & 1.24 (12H, 3br. s, $CH(CH_3)_2$), 1.47 (3H, d, *J* 6.6,

CHC*H*$_3$), 1.84 (3H, d, *J* 2.2, CCH$_3$), 3.73 & 4.11 (2H, 2br. s, C*H*(CH$_3$)$_2$), 5.42 (1H, qq, *J* 6.6, 2.2, C*H*CH$_3$). δ_C (100 MHz, CDCl$_3$): 3.6 (CH$_3$), 21.1 (br. s, CH$_3$), 22.1 (CH$_3$), 45.8 (br. s, CH), 60.8 (CH), 78.7 (4° C), 80.1 (4° C), 154.8 (4° C). ν_{max} (neat): 1044, 1062, 1281, 1435, 1687, 2255, 2936, 2971. **Elemental analysis**: calc. for $C_{12}H_{21}NO_2$: C, 68.21; H, 10.02; N, 6.63; Found: C, 68.38; H, 9.73; N, 6.37. **GCMS** (*M70*): T_R 5.81; MS calc. for $[C_{12}H_{21}NO_2]^{+\bullet}$ 211. Found: 211, 196, 169, 152, 144, 130, 128, 86, 67 (basepeak). $[\alpha]_D^{17}$ −22.7 (*c* 2.56, CHCl$_3$). **er* was determined on the alcohol prior to carbamoylation using **Chiral GC**: (γ-CD, 50 °C, 1.3 ml/min, 15 psi) T_R 16.50 min. A note on stereochemistry: Two papers report different selectivity during the resolution of pent-3-yn-2-yl acetate with PS-Amano lipase.[22, 23] However, the optical rotation of (*S*,*Z*)-pent-3-en-2-yl diisopropylcarbamate **1g** was correlated with a reported optical rotation (see below), where **1g** was synthesised via another route



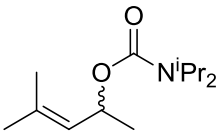
(*S*,*Z*)-Pent-3-en-2-yl diisopropylcarbamate 1g



To a stirred solution of (*S*)-pent-3-yn-2-yl diisopropylcarbamate (1.80 g, 8.54 mmol) and quinoline (0.52 ml, 1.28 mmol) in methanol (7 ml), Lindlar catalyst (90 mg, 0.43 mmol) was added. The flask was flushed with hydrogen and the mixture stirred for 4 days at ambient temperature. The mixture was filtered through Celite and the filter cake washed with Et$_2$O (20 ml). The solvent was removed *in vacuo* and the residue purified by flash column chromatography eluting 5% Et$_2$O/pentane to give (*S*,*Z*)-**1g** (1.44 g, 80%) as a colourless liquid. R_f (10% Et$_2$O/pentane) 0.38. δ_H (400 MHz, CDCl$_3$): 1.19 & 1.21 (12H, 2br.s, CH(C*H*$_3$)$_2$), 1.30 (3H, d, *J* 6.4, OCHC*H*$_3$), 1.72 (3H, dd, *J* 6.7, 1.7, C*H*$_3$CHCH), 3.69 & 4.13 (2H, 2br. s, C*H*(CH$_3$)$_2$), 5.44 (1H, ddq, *J* 10.8, 8.3, 1.7, OCHC*H*), 5.54 (1H, dqd, *J* 10.8, 6.7, 0.7, OCHCHC*H*), 5.62 (1H, dqd, *J* 8.3, 6.4, 0.7, OCH). δ_C (100 MHz, CDCl$_3$): 13.2 (CH$_3$), 21.0 (CH$_3$), 21.1 (br. s, CH$_3$), 45.5 (br. s, CH), 67.1 (CH), 126.0 (CH), 131.4 (CH), 155.4 (4° C). ν_{max} (neat): 1047, 1282, 1433, 1686, 2932, 2971. **Elemental analysis**: calc. for $C_{12}H_{23}NO_2$: C, 67.57; H, 10.87; N, 6.57; Found: C, 67.37; H, 10.72; N, 6.84. **GCMS** (*M70*): T_R 5.31; MS calc. for $[C_{12}H_{23}NO_2]^{+\bullet}$

213. Found: 213, 154, 146, 130, 86, 69 (basepeak). $[\alpha]_D^{25}$ +73.3 (*c* 1.5, CH_2Cl_2), Lit. −59.8 (*c* 1.1, CH_2Cl_2, for (*R*), >99:1 *er*).[21] Spectral data was in accordance with the literature.[21]

(*rac*)-4-Methylpent-3-en-2-yl diisopropylcarbamate 1h



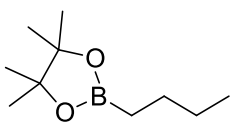
Following **GP5**, using (*rac*)-4-methylpent-3-en-2-ol (401 mg, 4.00 mmol) gave (*rac*)-carbamate **1h** (797 mg, 88%) as a colourless oil. $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.38. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.19 & 1.20 (12H, 2br. s, $CH(CH_3)_2$), 1.27 (3H, d, *J* 6.4, $CHCH_3$), 1.72 (6H, d, *J* 1.4, CCH_3), 3.76 & 4.06 (2H, 2br. s, $CHCH_3$), 5.19 (1H, dqq, *J* 8.7, 1.4, =CH), 5.53 (1H, dq, *J* 8.7, 6.4, $CHCH_3$). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 18.2 (CH_3), 21.1 (br.s, CH_3), 21.4 (CH_3), 25.8 (CH_3), 45.4 (br. s, CH), 68.4 (CH), 126.0 (CH), 134.6 (4° C), 155.5 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1039, 1282, 1686, 2875, 2932, 2970. **Elemental analysis**: calc. for $C_{23}H_{25}NO_2$: C, 68.89; H, 11.08; N, 6.16; Found: C, 68.24; H, 10.98; N, 6.54. **GCMS** (*M70*): T_R 5.73; MS calc. for $[C_{13}H_{25}NO_2]^{+\bullet}$ 227. Found: 227, 168, 146, 130, 101, 86, 83 (basepeak), 67, 55. Spectral data was in accordance with the literature.[21] NOTE: this carbamate was not cleanly deprotonated and so not used in lithiation/borylation (see **GP7**). For 5h at −78 °C, 32% D incorporation was obtained with unidentified side products dominating the crude reaction mixture.

Synthesis of reagent boronic esters from boronic acids

General procedure for esterification of boronic acids (GP5)

Boronic acid (1.0 mmol) and pinacol (1.0 mmol) were stirred in anhydrous Et_2O (1.0 ml) at ambient temperature under a nitrogen atmosphere for 15 h. Flame dried $MgSO_4$ (5 mmol) was added to the reaction mixture and stirring continued for 12 h. The reaction mixture was filtered and the solvent carefully removed *in vacuo*. The crude material was purified by distillation or flash column chromatography to yield pure boronic ester.

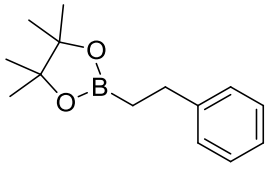
2-Butyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 1a



Following **GP6**, using *n*-butyl boronic acid (10.0 g, 98.1 mmol), purifying by flash column chromatography eluting 3% Et_2O/pentane gave boronic ester **2a** (18.2 g, 91%) as a colourless liquid. $\boldsymbol{R_f}$ (5% Et_2O/pentane) 0.66. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.77 (2H, t, *J* 7.6, BCH_2), 0.88 (3H, t, *J* 7.2, CH_3CH_2), 1.24 (12H, s, $C(CH_3)_2$), 1.28-1.43

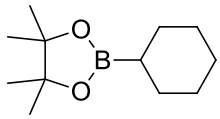
(4H, m, CH_2). δ_C (100 MHz, $CDCl_3$): 13.9 (CH_3), 24.8 (CH_3), 25.4 (CH_2), 26.2 (CH_2), 82.8 (4° C), *carbon attached to boron not observed*. ν_{max} (neat): 1145, 1317, 1370, 2861, 2929, 2979, 2958. **Elemental analysis**: calc. for $C_{10}H_{21}O_2B$: C, 65.25; H, 11.50; Found: C, 64.85 H, 12.03. **GCMS** (*M50*): T_R 7.03; MS calc. for $[C_{10}H_{21}BO_2]^{+\bullet}$ 184. Found: 184, 169, 129, 98, 85 (basepeak), 70, 59. Spectral data was in accordance with the literature.[24]

4,4,5,5-Tetramethyl-2-phenethyl-1,3,2-dioxaborolane 2b



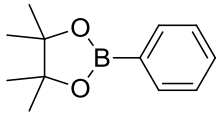
Following **GP6**, using phenylethyl boronic acid (6.0 g, 40 mmol), purifying by flash column chromatography eluting 2% Et_2O/pentane gave boronic ester **2b** (7.08 g, 76%) as a white solid. R_f (2% Et_2O/pentane) 0.43. δ_H (400 MHz, $CDCl_3$): 1.15 (2H, t, *J* 8.2, CH_2), 1.23 (12H, s, CH_3), 2.76 (2H, t, *J* 8.2, CH_2), 7.14-7.18 (1H, m, ArH), 7.21-7.29 (4H, m, ArH). δ_C (100 MHz, $CDCl_3$): 24.8 (CH_3), 29.9 (CH_2), 83.1 (4° C), 125.5 (CH), 128.0 (CH), 128.2 (CH), 144.4 (4° C), *carbon attached to boron not observed*. ν_{max} (neat): 703, 755, 848, 1139, 1318, 1372, 2979. **GCMS** (*M70*): T_R 6.92; MS calc. for $[C_{14}H_{21}BO_2]^{+\bullet}$ 232. Found: 232, 217, 175, 132, 105, 91, 84 (basepeak), 77. Spectral data was in accordance with the literature.[24]

2-Cyclohexyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 2c



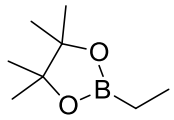
Following **GP6**, using cyclohexyl boronic acid (1.50 g, 11.7 mmol), purifying by flash column chromatography eluting 3% Et_2O/pentane gave boronic ester **2c** (2.21 g, 90%) as a colourless liquid. R_f (5% Et_2O/pentane) 0.66. δ_H (400 MHz, $CDCl_3$): 0.94-1.02 (1H, br. m, CHB), 1.24 (12H, s, $C(CH_3)_2$), 1.25-1.40 (5H, br. m, CH_2), 1.53-1.70 (5H, br. m, CH_2). δ_C (100 MHz, $CDCl_3$): 24.7 (CH_3), 26.7 (CH_2), 27.1 (CH_2), 27.9 (CH_2), 82.7 (4° C), *carbon attached to boron not observed*. δ_B (96 MHz, $CDCl_3$): 33.1. **LRMS** (CI) calc. for $[C_{12}H_{23}BO_2 + H]^+$ 211.2; found 211.2. ν_{max} (neat): 853, 1144, 1308, 1380, 2850, 2920, 2978. Spectral data was in accordance with the literature.[24]

4,4,5,5-Tetramethyl-2-phenyl-1,3,2-dioxaborolane 2e



Following **GP6**, using phenylboronic acid (1.23 g, 10 mmol) and Et_2O (6 mL), purifying by flash column chromatography eluting 3% Et_2O/pentane gave boronic ester **2e** (1.73 g, 85%) as a white solid. $\boldsymbol{R_f}$ (5% Et_2O/pentane) 0.57. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.37 (12H, s, $C(CH_3)_2$), 7.36-7.41 (2H, m, ArH), 7.45-7.50 (1H, m, ArH), 7.81-7.85 (2H, m, ArH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 24.9 (CH_3), 83.7 (4° C), 127.7 (ArCH), 131.2 (ArCH), 134.7 (ArCH), *carbon attached to boron not observed*. $\boldsymbol{\nu_{max}}$ (neat): 652, 1091, 1355, 1372, 1437, 1602, 2932, 2979. **Elemental analysis**: calc. for $C_{12}H_{17}O_2B$: C, 70.63; H, 8.40; Found: C, 70.60 H, 8.28. **GCMS** (*M70*): T_R 6.01; MS calc. for $[C_{12}H_{17}BO_2]^{+\bullet}$ 204. Found: 204, 189, 118, 105 (basepeak), 85, 77. Spectral data was in accordance with the literature.[25]

2-Ethyl-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 2g



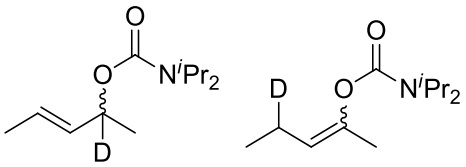
Following **GP6**, using ethyl boronic acid (12.0 g, 162 mmol), purifying the crude material by distillation (40-50 °C, ambient pressure) gave boronic ester **2g** (22.1 g, 87%) as a colourless liquid. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.74 (2H, q, *J* 7.8, CH_2), 0.94 (3H, t, *J* 7.8, CH_3), 1.23 (12H, s, CH_3). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 7.6 (CH_3), 24.7 (CH_3), 82.8 (4° C), *carbon attached to boron not observed*. $\boldsymbol{\delta_B}$ (96 MHz, $CDCl_3$): 33.4. **Elemental analysis**: calc. for $C_8H_{17}O_2B$: C, 61.58; H, 10.98; Found: C, 61.75; H, 10.72. **LRMS** (CI) calc. for $[C_8H_{17}BO_2]^+$ 156.1; found $[MH]^+$ 157.1. $\boldsymbol{\nu_{max}}$ (neat): 1150, 1216, 1316, 1367, 2678. Spectral data was in accordance with the literature.[26]

Lithiation-borylation of secondary allylic carbamates

General procedure for lithiation/deuteration of allylic carbamates (GP7)

To a vigorously stirred solution of carbamate (118 μmol) and TMEDA (19.5 μl, 130 μmol) in anhydrous Et_2O (1 ml) at −78 °C (acetone/$CO_{2(s)}$) under a nitrogen atmosphere, *s*-BuLi (1.3 M in hexane, 100 μl, 130 μmol) was added dropwise. The reaction mixture was stirred for *x* min before MeOD (0.1 ml) was added dropwise and the reaction allowed to reach ambient temperature over 30 min. The reaction mixture was diluted with Et_2O (1 ml) and passed through a silica pad in a Pasteur pipette, washed through with more Et_2O (15 ml) and the solvent removed *in vacuo*. The crude material was analysed by ^1H NMR to ascertain the amount of deuterium incorporation.

(*rac*,*E*)-2-Deutropent-3-en-2-yl diisopropylcarbamate 1a-*d* and 4-deutropent-2-en-2-yl diisopropylcarbamate



Following **GP7** (*x* = 15 min) gave *deuterated carbamate* **1a-*d*** with 100% D incorporation and 3:1 α/γ selectivity. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.19 & 1.22 (12H, 2br. s, $CH(CH_3)_2$), 1.30 (3H, s, $CDCH_3$), 1.70 (3H, dd, *J* 6.4, 1.3, CH_3CHCH) 3.79 & 4.09 (2.3H, 2br. s, $CH(CH_3)_2$ & γ $CH(CH_3)_2$), 5.51 (1H, dq, *J* 15.4, 1.3, CH_3CHCH), 5.70 (1H, dq, *J* 15.4, 6.4, CH_3CH). *Extra peaks due to γ adduct (signals were spit slightly possibly due to E/Z isomers)*: 0.94 (0.9H, d, *J* 7.5, CH_3CHD), 1.24 & 1.26 (3.6H, 2br. s, $CH(CH_3)_2$), 1.89 (0.9H, d, *J* 1.1, $OCCH_3$), 1.96 (0.3H, qd, *J* 7.5, 7.2, CHD), 4.95 (0.3H, dq, *J* 7.2, 1.1, CH_3CHDCH). **HRMS** (CI) calc. for $[C_{12}H_{22}DNO_2 + H]^+$ 215.1870. Found 215.1873. **LRMS** (CI) calc. for $[C_{12}H_{22}DNO_2]$ 214.2. Found $[M + H]^+$ 215.2, $[HO(CO)N(^iPr)_2 + H]^+$ 146.1 (basepeak), $[M - O(CO)N(^iPr)_2]^+$ 69.1.

General procedure for lithiation/borylation of allylic carbamates (GP8)

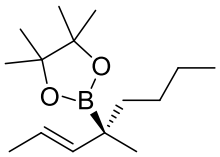
To a vigorously stirred solution of carbamate (1.00 mmol) and TMEDA (169 µl, 1.10 mmol) in anhydrous Et_2O (6 ml) at −78 °C (acetone/$CO_{2(s)}$) under a nitrogen atmosphere, *s*-BuLi (1.3 M in hexane, 0.85 ml, 1.10 mmol) was added dropwise over 5 min. The reaction mixture turned pale yellow. After *x* min (see each example), the borylating agent (1.30 mmol) was added dropwise over 5 min. Liquid boronic esters were added neat and solid boronic esters were added as a 2 M solution in anhydrous Et_2O. The reaction mixture was stirred at −78 °C for 30 min and then at ambient temperature for 6 h. Water (4 ml) was added and the phases separated. The aqueous phase was extracted with Et_2O (3 × 10 ml) and the combined organic phases were washed with brine and dried over $MgSO_4$. The solvent was removed *in vacuo* and the crude material purified by flash column chromatography eluting 2% Et_2O/pentane to yield pure tertiary boronic ester.

General procedure for small scale oxidation of tertiary boronic esters for determination of *er* (GP9)

To a stirred solution of boronic ester (~10 mg) in degassed THF (0.5 ml) containing BHT (~0.5 mg) at 0 °C (ice/water) under an atmosphere of nitrogen, an ice-cold degassed mixture of 3 M NaOH (0.45 ml) containing EDTA (1 g/l) and 30% aqueous H_2O_2 (0.25 ml) was added all at once. The reaction mixture was allowed to reach ambient temperature over night. After approximately 16 h, the reaction was diluted with water (1 ml) and extracted with Et_2O (4 × 1 ml). The combined

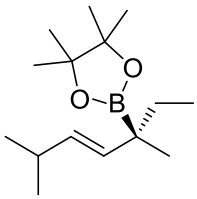
organic phases were concentrated *in vacuo* and redissolved in 20% Et_2O/pentane (1 ml) and passed through a Pasteur pipette containing approximately 2 cm of silica gel, washing through with 20% Et_2O/pentane (2 ml). The solution was directly analysed by chiral GC.

(*S*,*E*)-4,4,5,5-Tetramethyl-2-(4-methyloct-2-en-4-yl)-1,3,2-dioxaborolane 3aa



Following **GP8**, using *S*-**1a** (>99:1 *er*, 747 mg, 3.50 mmol, *x* = 15 min) and *n*-butyl pinacol boronic ester (0.96 ml, 4.55 mmol) gave *S-tertiary boronic ester* **3aa** (799 mg, 91%, 98:2 *er*)* as a colourless oil. $\boldsymbol{R_f}$ (2% Et_2O/pentane) 0.47. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.89 (3H, dd, *J* 7.0, 7.0, CH_2CH_3), 1.01 (3H, s, CCH_3), 1.15-1.33 (5H, m, CH_2), 1.22 & 1.23 (12H, 2s, $C(CH_3)_2$), 1.42-1.52 (1H, m, CH_2), 1.67 (1H, dd, *J* 6.2, 1.5, $CHCH_3$), 5.33 (1H, dq, *J* 15.6, 6.2, $CHCH_3$), 5.47 (1H, dq, *J* 15.6, 1.5, $CHCHCH_3$). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 14.1 (CH_3), 18.4 (CH_3), 20.6 (CH_3), 23.5 (CH_2), 24.6 (CH_3), 24.7 (CH_3), 28.0 (CH_2), 38.7 (CH_2), 83.0 (4 °C), 121.3 (CH), 138.4 (CH), *carbon attached to boron not observed*. $\boldsymbol{\nu_{max}}$ (neat): 1139, 1309, 1460, 2859, 2929, 2958, 2978. **Elemental analysis**: calc. for $C_{15}H_{29}O_2B$: C, 71.44; H, 11.59; Found: C, 70.97; H, 11.82. **GCMS** (*M70*): T_R 6.09; MS calc. for $[C_{15}H_{29}BO_2]^{+\bullet}$ 252. Found: 252, 237, 195, 139, 124, 101, 84 (basepeak), 69. **er* was determined by oxidation following **GP9** see below for traces and GC conditions.

(*S*,*E*)-2-(3,6-Dimethylhept-4-en-3-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 3bg



Following **GP8**, using *S*-**1b** (>99:1 *er*, 241 mg, 1.00 mmol, *x* = 15 min) and ethyl pinacol boronic ester (230 µl, 1.30 mmol) gave *tertiary boronic ester* **3bg** (215 mg, 85%, 98:2 *er*)* as a colourless oil. $\boldsymbol{R_f}$ (10% EtOAc/petrol) 0.77. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.84 (3H, dd, *J* 7.4, 7.4, CH_2CH_3), 0.96 (6H, d, *J* 6.8, $CH(CH_3)_2$), 1.00 (3H, s, CCH_3), 1.22 (12H, s, $C(CH_3)_2$), 1.31 (1H, dq, *J* 13.4, 7.4, $CHHCH_3$), 1.57 (1H, dq, *J* 13.4, 7.4, $CHHCH_3$), 2.25 (1H, sept.dd, *J* 6.8, 6.4, 0.7, $CH(CH_3)_2$), 5.29 (1H, dd, *J* 15.8, 6.4, $(CH_3)_2CHCH$), 5.38 (1H, dd, *J* 15.8, 0.7, $(CH_3)_2CHCHCH$). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 10.1 (CH_3), 19.8 (CH_3), 23.0 (CH_3), 24.5 (CH_3), 24.6 (CH_3), 31.3 (CH_2), 31.5 (CH), 82.9 (4° C), 134.0 (CH), 134.7 (CH). $\boldsymbol{\delta_B}$ (128 MHz, $CDCl_3$): 33.9. $\boldsymbol{\nu_{max}}$ (neat): 1140, 1307, 1459, 2870, 2960. **HRMS** (CI) calc. for $[C_{15}H_{29}BO_2 + H]^+$ 253.2339. Found 253.2342. **LRMS** (CI) calc. for $[C_{15}H_{29}BO_2 + H]^+$

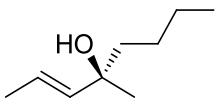
253.2. Found 253.2, 237.2, 223.2, 209.2, 125.1, 101.1 (basepeak), 83.1. $[\alpha]_D^{25}$ −2 (*c* 1, $CHCl_3$). **er* was determined by oxidation following **GP9** see below for traces and GC conditions.

General procedures for one pot lithiation/borylation/oxidation of allylic carbamates (GP10A & GP10B)

GP10A - To a vigorously stirred solution of carbamate (1.00 mmol) and TMEDA (169 µl, 1.10 mmol) in anhydrous Et_2O (6 ml) at −78 °C (acetone/$CO_{2(s)}$) under a nitrogen atmosphere, *s*-BuLi (1.3 M in hexane, 0.85 ml, 1.10 mmol) was added dropwise over 5 min. The reaction mixtures turned yellow. After *x* min (see each example), the borylating agent (1.30 mmol) was added dropwise over 5 min. Liquid boronic esters were added neat and solid boronic esters were added as a 2 M solution in anhydrous Et_2O. The reaction mixture was stirred at −78 °C for 30 min and then at ambient temperature for 6 h. Degassed THF (6 ml) containing BHT (~5 mg) was added and the reaction mixture stirred at 0 °C (water/ice bath). An ice-cold degassed mixture of 3 M NaOH (1.8 ml) containing EDTA (1 g/l) and 30% aqueous H_2O_2 (1.0 ml) was added all at once. The reaction mixture was allowed to reach ambient temperature over night. After approximately 16 h, the reaction was diluted with water (5 ml) and extracted with Et_2O (4 × 10 ml). The combined organic phases were washed with brine, dried over $MgSO_4$. The solvent was removed *in vacuo* and the crude material purified by flash chromatography eluting 30% Et_2O/pentane to yield pure tertiary alcohol.

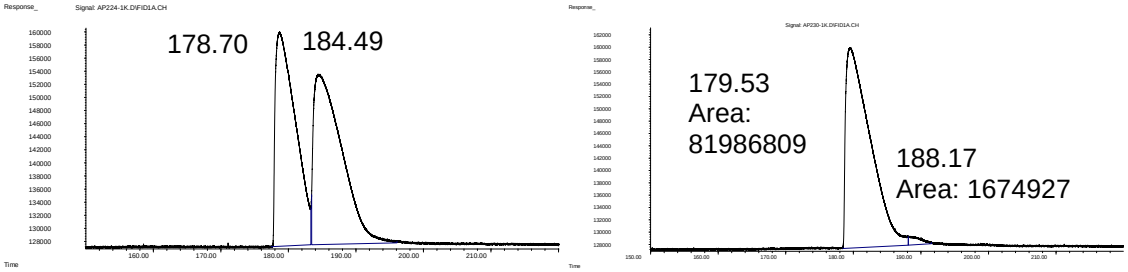
GP10B - As in **GP10A** except after the borylating agent was added and the reaction mixture stirred for 30 min, $MgBr_2$ (1 M in MeOH, 1.1 mmol) was added dropwise over 4 min and the reaction mixture stirred for 15 min before being allowed to reach ambient temperature.

(*R*,*E*)-4-Methyloct-2-en-4-ol 4aa

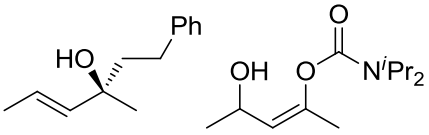


Following **GP10A** using *S*-**1a** (213 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and boronic ester (275 µl, 1.30 mmol), gave *R*-tertiary alcohol **4aa** (107 mg, 75%, 98:2 *er*) as a colourless liquid. $\boldsymbol{R_f}$ (20% Et_2O/pentane) 0.32. δ_H (400 MHz, $CDCl_3$): 0.91 (3H, dd, *J* 6.9, 6.9, CH_2CH_3), 1.26 (3H, s, CCH_3), 1.26-1.34 (4H, m, CH_2), 1.37 (1H, s, OH), 1.48-1.54 (2H, m, CH_2), 1.71 (3H, dd, *J* 6.1, 1.3, $CHCH_3$), 5.54 (1H, dq, *J* 15.6, 1.3, $CHCHCH_3$), 5.63 (1H, dq, *J* 15.6, 6.1, $CHCH_3$). δ_C (100 MHz, $CDCl_3$): 14.1 (CH_3), 17.7 (CH_3), 23.2 (CH_2), 26.3 (CH_2), 27.8 (CH_3), 42.6 (CH_2), 72.8 (4° C), 122.5 (CH), 138.2 (CH). ν_{max} (neat): 967, 1377, 1452, 2933, 2958,

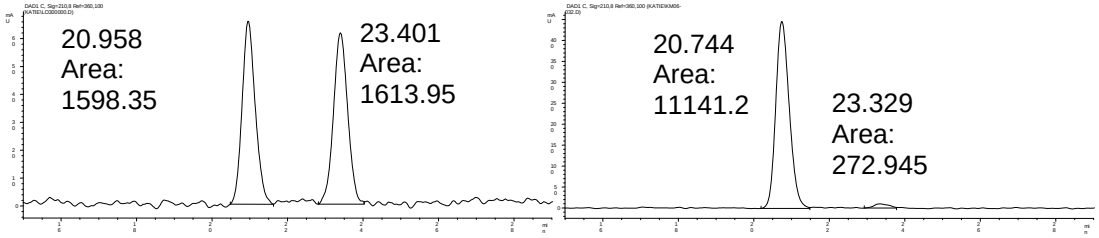
3369. **Elemental analysis**: calc. for $C_9H_{18}O_2$: C, 76.00; H, 12.76; Found: C, 75.53; H, 12.68. **GCMS** (*M30*): T_R 12.41; MS calc. for $[C_9H_{18}O]^{+\bullet}$ 142. Found: 142, 124, 109, 95, 85 (basepeak), 67. **Chiral GC** (*β*-CD, 40 °C for 3 min, ramp at 0.05 °C/min, 15.6 psi, 1.5 ml/min) T_R 179.53 min (major), 188.17 min (minor), Note: better separation was achieved upon reduction of the double bond, see below. Spectral data was in accordance with the literature.[27]



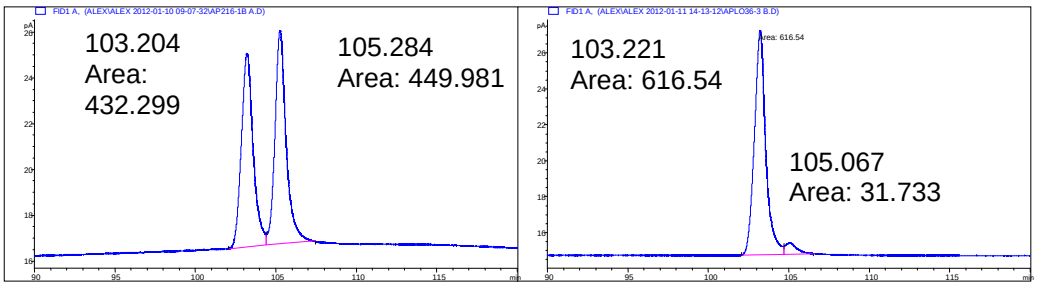
(*R*,*E*)-3-Methyl-1-phenylhex-4-en-3-ol 4ab and (*Z*)-4-hydroxypent-2-en-2-yl diisopropylcarbamate 6a



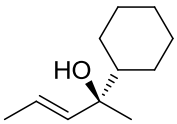
Following **GP10A** using (*S*,*E*)-**1a** (213 mg, 1.00 mmol, *x* = 15 min) and boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave (*R*,*E*)-*tertiary alcohol* **4ab** (175 mg, 92%, 98:2 *er*) as a colourless liquid. Following **GP10A** using (*S*,*Z*)-**1g** (213 mg, 1.00 mmol, *x* = 60 min) and boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave (*R*,***E***)-*tertiary alcohol* **4ab** (36 mg, 12%, 79:21 *er*) as a colourless liquid and *Z-secondary alcohol* **6a*** (124 mg, 54%, 95:5 *er*) as a colourless oil. Note the isomerisation of the double bond in the product tertiary alcohol **4ab** when (*S*,*Z*)-carbamate **1g** is used. ***Tertiary alcohol characterisation**: **R_f*** (20% Et_2O/pentane) 0.30. **δ_H** (400 MHz, $CDCl_3$): 1.34 (3H, s, CH_3), 1.42 (1H, s, OH), 1.74 (3H, dd, *J* 6.2, 1.3, CH_3), 1.77-1.92 (2H, m, $PhCH_2CH_2$), 2.60-2.72 (2H, m, $PhCH_2$), 5.60 (1H, dq, *J* 15.6, 1.3, CH_3CHCH), 5.70 (1H, dq, *J* 15.6, 6.2, CH_3CH), 7.16-7.22 (3H, m, ArH), 7.26-7.31 (2H, m, ArH). **δ_C** (100 MHz, $CDCl_3$): 17.7 (CH_3), 28.2 (CH_3), 30.5 (CH_2), 44.5 (CH_2), 72.7 (4° C), 123.0 (CH), 125.7 (CH), 128.3 (CH), 128.3 (CH), 137.8 (CH), 142.5 (4° C). **ν_{max}** (neat): 697, 968, 1453, 2934, 2967, 3383. **HRMS** (CI) calc. for $[C_{13}H_{18}O + Na]^+$ 213.1250. Found 213.1253. **LRMS** (CI) calc. for $[C_{13}H_{18}O]$ 190. Found 190, 85 (basepeak). HPLC: (IB, 1% ^{i}PrOH/hexane, 0.7 ml/min) T_R 20.74 min (major), 23.33 min (minor). $[\alpha]^{25}_D$ −110 (*c* 1, $CHCl_3$).



Secondary alcohol characterisation*: R_f** (50% Et_2O/Pentane) 0.31. **δ_H** (400 MHz, $CDCl_3$): 1.23 (3H, d, *J* 6.4, OCHCH_3), 1.26 (12H, br. s, CH(CH_3)$_3$), 1.88 (3H, d, *J* 1.1, CCH_3), 2.73 (1H, s, OH), 3.84 & 4.08 (2H, 2br. s, C*H*(CH_3)$_3$), 4.42 (1H, dq, *J* 8.8, 6.4, OC*H*), 5.15 (1H, dq, *J* 8.8, 1.1, OCHC*H*). **δ_C** (100 MHz, $CDCl_3$): 20.1 (CH_3), 20.4 (br. s, CH_3), 21.4 (br. s, CH_3), 22.2 (CH_3), 45.9 (br. s, CH), 46.9 (br. s, CH), 62.1 (CH), 121.5 (CH), 145.9 (4° C), 153.6 (4° C). **ν_{max}** (neat): 1133, 1258, 1680, 2877, 2933, 2971, 3412. **HRMS** (CI) calc. for $[C_{12}H_{23}NO_3 + H - H_2O]^+$ 212.1651. Found 212.1640. **LRMS** (CI) calc. for $[C_{12}H_{23}NO_3]^+$ 229.2. Found 229.2, 212.2, 128.1 (basepeak). **Chiral GC** (*β*-CD, 80 °C, 3 min then ramp at 0.2 °C/min, 2 ml/min, 22.8 psi) T_R 103.2 min (major), 105.1 min (minor).Z* configuration was assigned on the basis of a strong NOE between C=CH (5.15 ppm) and CCH_3 (1.88 ppm).

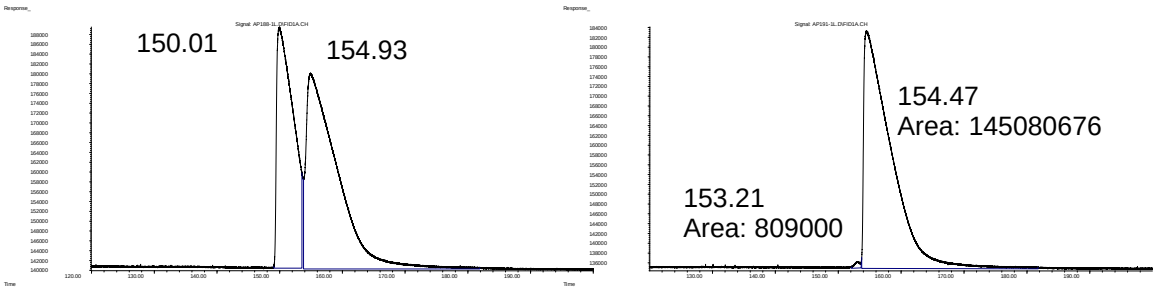


(*R*,*E*)-2-Cyclohexylpent-3-en-2-ol 4ac

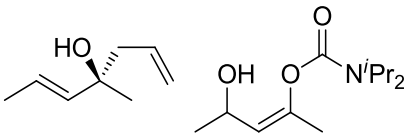


Following **GP10B** using *S*-**1a** (213 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and cyclohexyl pinacol boronic ester **2c** (294 µl, 1.30 mmol), gave *S-tertiary alcohol* **4ac** (127 mg, 76%, 99:1 *er*) as a colourless liquid. Following **GP10A**, using *S*-**1a** (213 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min), gave **4ac** (145 mg, 87%, 95:5 *er*) as a colourless liquid. **R_f** (15% Et_2O/pentane) 0.38. **δ_H** (400 MHz, $CDCl_3$): 0.90-1.33 (6H, m), 1.22 (3H, s, CCH_3), 1.85 (1H, s, OH), 1.71 (3H, dd, *J* 6.0, 1.2, CHCH_3), 1.63-1.69 (1H, br. m), 1.73 -1.83 (4H, br. m), 5.53 (1H, dq, *J* 15.6, 1.2, CH_3CHC*H*), 5.61 (1H, dq, *J* 15.6, 6.0, CH_3C*H*). **δ_C** (100 MHz, $CDCl_3$): 17.8 (CH_3), 25.2 (CH_3), 26.5 (CH_2), 26.6 (CH_2), 26.7 (CH_2), 27.2 (CH_2), 27.4 (CH_2), 48.5 (CH_3), 74.7 (4° C), 122.8 (CH), 137.3 (CH). **ν_{max}** (neat): 970, 1450, 2853, 2922, 3411. **HRMS** (CI) calc. for

$[C_{11}H_2O + H]^+$ 169.1592. Found 169.1588. **Chiral GC** (β-CD, 70 °C, 32 psi, 3.6 ml/min) T_R 154.47 min (major), 153.93 min (minor). $[\alpha]_D^{25}$ −2 (*c* 1.5, $CHCl_3$).

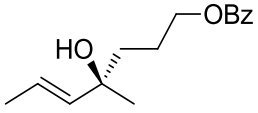


(*R*,*E*)-4-Methylhepta-1,5-dien-4-ol 4ad and (*Z*)-4-hydroxypent-2-en-2-yl diisopropylcarbamate 6a



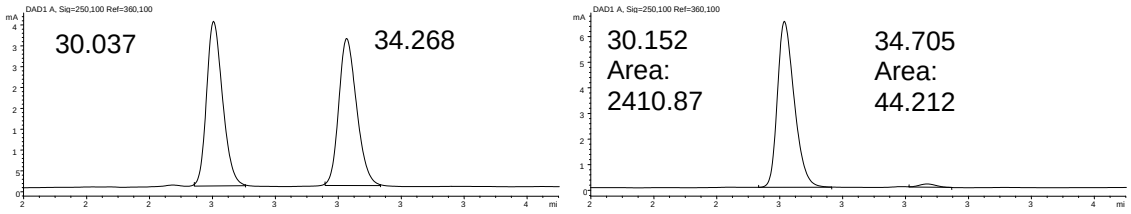
Following **GP10A** using *S*-**1a** (213 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and allyl pinacol boronic ester **2d** (244 µl, 1.30 mmol), gave *R*-tertiary alcohol **4ad** (96 mg, 77%, 98:2 *er*)* as a colourless liquid and *Z-secondary alcohol* **6a** (16 mg, 7%, 76:24 *er*)† as a colourless oil. ***Tertiary alcohol characterisation***: R_f (15% Et_2O/pentane) 0.38. δ_H (400 MHz, $CDCl_3$): 1.27 (3H, s, CCH_3), 1.62 (1H, s, OH), 1.71 (3H, dd, *J* 6.1, 1.3, $CHCH_3$), 2.25 (1H, dddd, *J* 13.6, 7.9, 1.1, 1.1, CC*H*H), 2.32 (1H, dddd, *J* 13.6, 7.0, 1.1, 1.1, CC*H*H), 5.12 (1H, dddd, *J* 16.9, 2.4, 1.1, 1.1, CH=CH*H*), 5.14 (1H, dddd, *J* 10.3, 2.4, 1.1, 1.1, CH=C*H*H), 5.56 (1H, dq, *J* 15.4, 1.3, CH_3CHCH), 5.65 (1H, dq, *J* 15.4, 1.3, CH_3CH), 5.80 (1H, dddd, *J* 16.9, 10.3, 7.9, 7.0, C*H*=CH_2). δ_C (100 MHz, $CDCl_3$): 17.6 (CH_3), 27.7 (CH_3), 42.7 (CH_2), 71.8 (4° C), 118.8 (CH_2), 123.0 (CH), 134.0 (CH), 137.6 (CH). ν_{max} (neat): 912, 968, 1375, 1438, 2920, 2975, 3385. **LRMS** (CI) calc. for $[C_9H_{18}O - H_2O]$ 109.1. Found 109.1. $[\alpha]_D^{25}$ +36 (*c* 1.5, $CHCl_3$). **er* was determined by hydroboration of the terminal olefin and oxidation followed by benzoylation of the primary alcohol, according to the procedure below. Spectral data was in accordance with the literature.[28] †Spectroscopic data, determination of *er* and major enantiomer was as in the reaction with *Z*-carbamate **1g**.

(*R*,*E*)-4-Hydroxy-4-methylhept-5-en-1-yl benzoate

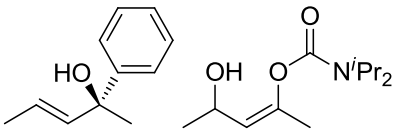


To a stirred solution of tertiary alcohol **4ad** (16 mg, 69 µmol) in THF (0.5 ml) under an atmosphere of nitrogen at ambient temperature, 9-

borabicyclo(3.3.1)nonane (0.5 M in THF, 0.5 ml, 0.1 mmol) was added. The reaction mixture was stirred for 2 h and then oxidized by the addition of a mixture of 3 M NaOH (0.45 ml) and 30% aqueous H_2O_2 (0.25 ml). The reaction was stirred overnight. After approximately 16 h, water (1 ml) and Et_2O (1 ml) was added. The phases were separated and the aqueous phase extracted with Et_2O (3 × 1 ml). The solvent was removed from the combined organic phases *in vacuo*, and the residue redissolved in 20% Et_2O/pentane (0.5 ml). The crude solution chromatographed through a Pasture pipette containing 4 cm of silica gel eluting 20% - 100% Et_2O/pentane. The polar spot ($\boldsymbol{R_f}$ (Et_2O) 0.26) was collected and the solvent removed *in vacuo*. The residue was directly benzoylated by the successive addition of CH_2Cl_2 (1 ml), triethylamine (19 µl, 138 µmmol), benzoyl chloride (8 µl, 138 µmmol) and DMAP (~1 mg). The reaction mixture was stirred at ambient temperature overnight. After approximately 16 h, water was added and the reaction stirred for 1 h. The phases were separated and the aqueous phase extracted with CH_2Cl_2 (3 × 1 ml). The solvent was removed from the combined organic phases and the residue redissolved in pentane (0.5 ml). The crude solution chromatographed through a Pasture pipette containing 4 cm of silica gel eluting 0% - 40% Et_2O/pentane to give the title *compound* (5 mg, 29% over 2 steps, 98:2 *er*). $\boldsymbol{R_f}$ (50% Et_2O/pentane) 0.50. δ_H (400 MHz, $CDCl_3$): 1.33 (3H, s, CCH_3), 1.46, (1H, s, OH), 1.65-1.71 (2H, m, CH_2), 1.73 (3H, dd, *J* 6.2, 1.5, C*H*$_3$CH), 1.80-1.88 (2H, m, CH_2), 4.35 (2H, t, *J* 6.6, OCH_2), 5.57 (1H, dq, *J* 15.6, 1.5, CH_3CHCH), 5.69 (1H, dq, *J* 15.6, 6.2, CH_3CH), 7.44-7.49 (2H, m, ArH), 7.56-7.61 (1H, m, ArH), 8.05-8.09 (2H, m, ArH). δ_C (100 MHz, $CDCl_3$): 17.7 (CH_3), 23.7 (CH_2), 28.1 (CH_3), 38.9 (CH_2), 65.3 (CH_2), 72.5 (4° C), 123.1 (CH), 128.3 (CH), 129.5 (CH), 132.8 (CH), 137.6 (CH), 166.6 (4° C) *Aryl 4° C not observed*. **GCMS** (*M70*): T_R 8.60; MS calc. for $[C_{15}H_{20}O_3]^{+\bullet}$ 248. Found: 248, 164, 147, 122, 108, 105, 93, 85, 77. **Chiral HPLC** (IB, 1% ^{i}PrOH/hexane, 0.7 ml/min) T_R 30.15 min (major), 34.71 min (minor).

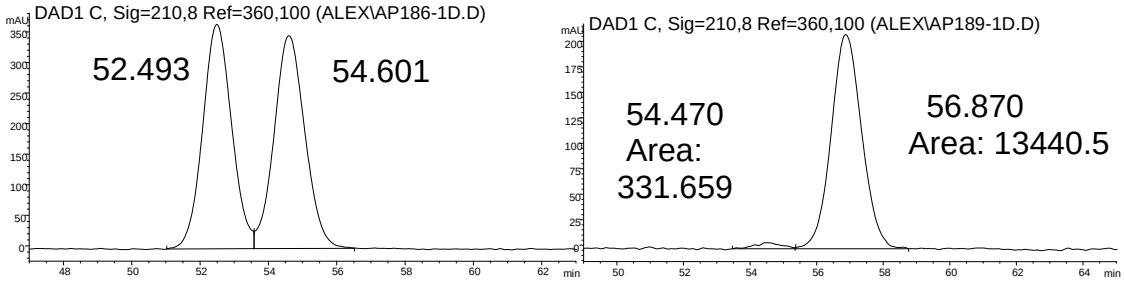


(*S*,*E*)-2-Phenylpent-3-en-2-ol 4ae and (*Z*)-4-hydroxypent-2-en-2-yl diisopropylcarbamate 6a

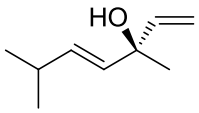


Following **GP10A** using *S*-**1a** (213 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and phenyl pinacol boronic ester **2e** (2 M in Et_2O, 0.65 ml,

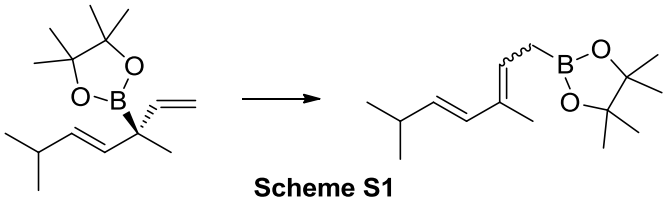
1.30 mmol), gave *S*-tertiary alcohol **4ae** (136 mg, 84%, 98:2 *er*) as a colourless liquid and *Z-secondary alcohol* **6a** (16 mg, 7%, ~50:50 *er*) † as a colourless oil. R_f (30% Et_2O/pentane) 0.54. δ_H (400 MHz, $CDCl_3$): 1.65 (3H, s, CCH_3), 1.74 (3H, dd, *J* 6.5, 1.5, $CHCH_3$), 1.87 (1H, s, OH), 5.69 (1H, dq, *J* 15.5, 6.2, $CHCH_3$), 5.82 (1H, dq, *J* 15.5, 1.5, $CHCHCH_3$), 7.23-7.28 (1H, m, ArH), 7.33-7.38 (2H, m, ArH), 7.46-7.49 (2H, m, ArH). δ_C (100 MHz, $CDCl_3$): 17.7 (CH_3), 29.8 (CH_3), 74.4 (4° C), 123.8 (CH), 125.2 (CH), 126.8 (CH), 128.1 (CH), 138.1 (CH), 147.2 (4° C). ν_{max} (neat): 697, 967, 1446, 2587, 2917, 2976, 3028, 3364. **LRMS** (CI) calc. for [$C_{11}H_{14}O$ + H] 163.1. Found 163.1, 145.1 (basepeak). **Chiral HPLC**: (IA, 0.4% ^{i}PrOH/hexane, 0.5 ml/min, 0 °C) T_R 56.87 min (major), 54.47 min (minor). $[\alpha]_D^{25}$ −2 (*c* 1.5, $CHCl_3$). Spectral data was in accordance with the literature.[29] †Spectroscopic data and determination of *er* was as in the reaction with *Z*-carbamate **1g**



(*R*,*E*)-3,6-Dimethylhepta-1,4-dien-3-ol 4bf

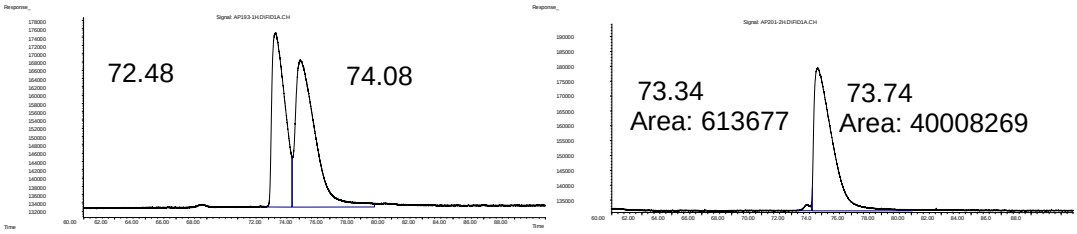


Following a slightly modified* procedure of **GP10B** using (*S*)-**1b** (241 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and vinyl pinacol boronic ester **2f** (222 µl, 1.30 mmol), gave *R-tertiary alcohol* **4bf** (111 mg, 79%, 98:2 *er*) as a colourless liquid. Following a slightly modified* procedure of **GP10A**, using *S*-**1b** (241 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min), gave **4bf** (113 mg, 81%, 90:10 *er*) as a colourless liquid. NOTE: This compound was found to be volatile and relatively unstable during flash column chromatography. Therefore care was taken during evaporation of solvents and flash column chromatography was run with a high flow rate (column contact time <5 min). *The time allowed for the migration was shortened to 1.5 h so as to avoid the side reaction of the 1,3-borotropic shift of the intermediate tertiary boronic ester (scheme S1).

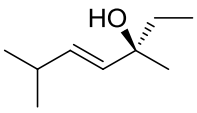


Scheme S1

$\boldsymbol{R_f}$ (20% Et_2O/pentane) 0.39. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.00 (6H, d, *J* 6.8, $CH(CH_3)_2$), 1.37, (3H, s, CCH_3), 1.57 (1H, s, OH), 2.30 (1H, sept.dd, *J* 6.8, 6.2, 1.1, $CH(CH_3)_2$), 5.06 (1H, dd, *J* 10.6, 1.2, CH=CHH), 5.24 (1H, dd, *J* 17.3, 1.2, CH=CHH), 5.52 (1H, dd, *J* 15.6, 1.1, ^{i}PrCHCH), 5.64 (1H, dd, *J* 15.6, 1.1, ^{i}PrCH), 5.97 (1H, dd, *J* 17.3, 10.6, CH=CHH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 22.4 (CH_3), 28.1 (CH_3), 30.7 (CH), 73.0 (4° C), 111.7 (CH_2), 132.6 (CH), 136.1 (CH), 144.4 (CH). $\boldsymbol{\nu_{max}}$ (neat): 917, 973, 1364, 1464, 2980, 2930, 3370. **HRMS** (CI) calc. for $[C_9H_{16}O + H - H_2O]^+$ 123.1174. Found 123.1170. **LRMS** (CI) calc. for $[C_9H_{16}O + H - H_2O]^+$ 123.1. Found 123.1, 109.1, 95.1, 85.0, 69.1, 59.1, 57.1 (basepeak). **Chiral GC**: (β-CD, 50 °C for 3 min, ramp at 0.1 °C/min, 14.2 psi, 1.2 ml/min) T_R 73.74 min (major), 73.34 min (minor). $[\alpha]_D^{18}$ +27.0 (*c* 2, $CHCl_3$).

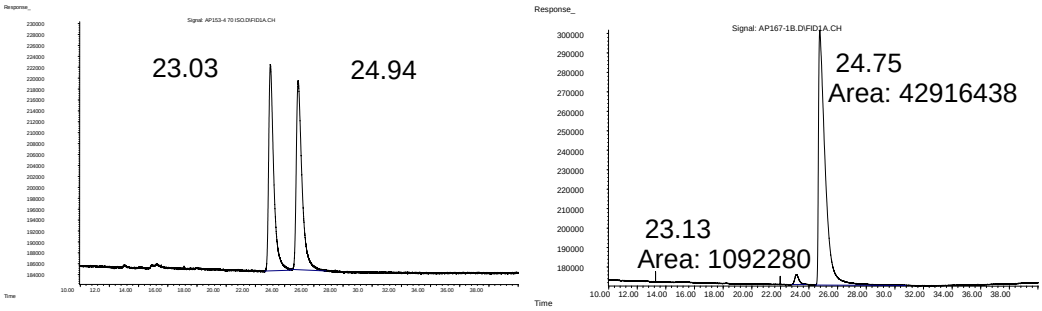


(*R*,*E*)-3,6-Dimethylhept-4-en-3-ol 4bg

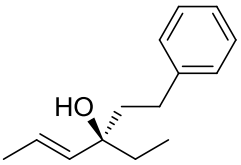


Following **GP10A** using *S*-**1b** (241 mg, 1.00 mmol, >99:1 *er*, *x* = 15 min) and ethyl pinacol boronic ester **2g** (231 µl, 1.30 mmol) gave *R-tertiary alcohol* **4bg** (102 mg, 72%, 98:2 *er*) as a colourless liquid. $\boldsymbol{R_f}$ (10% EtOAc/petrol) 0.28. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.87 (3H, dd, *J* 7.6, 7.6, CH_2CH_3), 1.00 (6H, d, *J* 6.9, $CH(CH_3)_2$), 1.26 (3H, s, CCH_3), 1.35 (1H, s, OH), 1.53 (1H, dq, *J* 13.4, 7.6, $CHHCH_3$), 1.56 (1H, dq, *J* 13.4, 7.6, $CHHCH_3$), 2.30 (1H, sept.dd, *J* 6.9, 6.6, 1.0, $CH(CH_3)_2$), 5.44 (1H, dd, *J* 15.7, 1.0, $(CH_3)_2CHCHCH$), 5.58 (1H, dd, *J* 15.7, 6.6, $(CH_3)_2CHCH$). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 8.3 (CH_3), 22.6 (CH_3), 27.5 (CH_3), 30.8 (CH_3), 35.3 (CH_2), 72.9 (4° C), 133.5 (CH), 135.2 (CH). $\boldsymbol{\nu_{max}}$ (neat): 973, 1112, 1375, 1462, 2870, 2962, 3381. **HRMS** (CI) calc. for $[C_9H_{18}O + H - H_2O]^+$ 125.1330. Found 125.1334. **Chiral GC**: (β-CD, 40 °C

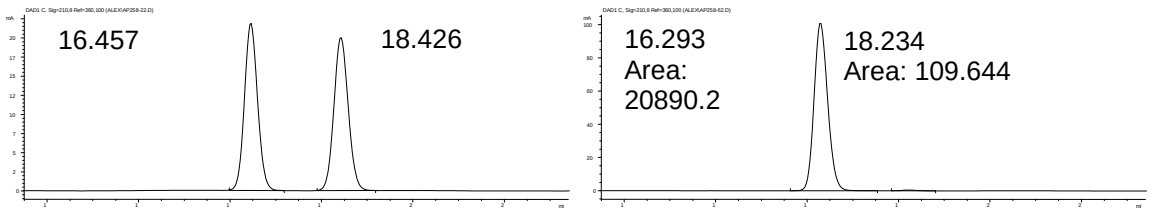
for 3 min, ramp at 2.5 °C/min, 16.1 psi, 1.5 ml/min) T_R 24.75 min (major), 23.13 min (minor). $[\alpha]_D^{25}$ +4 (*c* 1.46, $CHCl_3$).



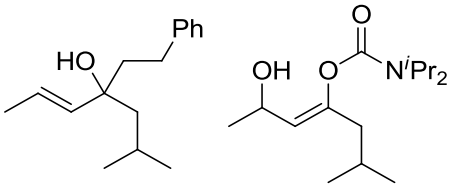
(*R*,*E*)-3-Ethyl-1-phenylhex-4-en-3-ol 4cb



Following **GP10B** using *S*-**1c** (227 mg, 1.00 mmol, >99:1 *er*, *x* = 30 min) and phenylethyl pinacol boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave *R-tertiary alcohol* **4cb** (169 mg, 83%, 99:1 *er*) as a colourless liquid. Following **GP10A**, using *S*-**1c** (227 mg, 1.00 mmol, >99:1 *er*, *x* = 30 min), gave **4cb** (177 mg, 87%, 96:4 *er*) as a colourless liquid. $\boldsymbol{R_f}$ (30% Et_2O/pentane) 0.46. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.89 (3H, t, *J* 7.5, CH_2CH_3), 1.38 (1H, s, OH), 1.57 (1H, dq, *J* 9.9, 7.5, $CHHCH_3$), 1.61 (1H, dq, *J* 9.9, 7.5, $CHHCH_3$), 1.76 (3H, dd, *J* 6.4, 1.5, CH_3CHCH), 1.82 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCH_2CHH$), 1.85 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCH_2CHH$), 2.62 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCHH$), 2.66 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCHH$), 5.50 (1H, dq, *J* 15.6, 1.5 CH_3CHCH), 5.68 (1H, dq, *J* 15.6, 6.4, CH_3CHCH), 7.16-7.22 (3H, m, ArH), 7.26-7.31 (2H, m, ArH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 7.8 (CH_3), 17.8 (CH_3), 30.1 (CH_2), 33.8 (CH_3), 42.4 (CH_2), 75.1 (4° C), 123.8 (CH), 125.7 (CH), 128.4 (CH), 136.3 (CH), 142.8 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 970, 1453, 1496, 1603, 1673, 2935, 2964, 3437. **HRMS** (CI) calc. for $[C_{14}H_{20}O + H - H_2O]^+$ 187.1487. Found 187.1483. **LRMS** (CI) calc. for $[C_{14}H_{20}O + H - H_2O]^+$ 187.2 .Found 187.2, 157.1, 145.1, 131.1, 117.1, 109.1, 105.1, 83.1 (basepeak). **Chiral HPLC**: (IB, 1% ^{i}PrOH/hexane, 0.7 ml/min) T_R 16.29 min (major), 18.23 min (minor). $[\alpha]_D^{18}$ −22.6 (*c* 3.4, $CHCl_3$).

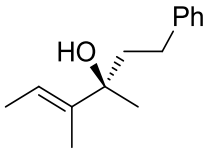


(*E*)-6-Methyl-4-phenethylhept-2-en-4-ol 4db and (*Z*)-2-hydroxy-6-methylhept-3-en-4-yl diisopropylcarbamate 6d

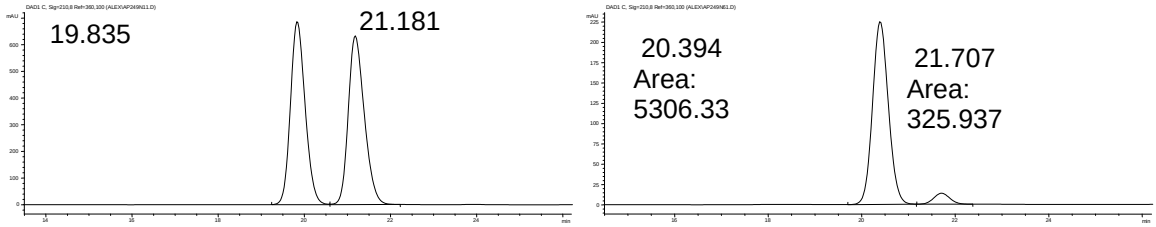


Following **GP10A** using *rac*-**1d** (255 mg, 1.00 mmol, *x* = 30 min) and phenylethyl pinacol boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave *rac*-tertiary alcohol **4db** (79 mg, 36%) as a colourless liquid and *Z-secondary alcohol* **6d*** (139 mg, 50%) as a colourless oil. ***Tertiary alcohol characterisation**: **R_f*** (10% Et_2O/pentane) 0.27. **δ_H** (400 MHz, $CDCl_3$): 0.94 (3H, d, *J* 6.8, $CH(CH_3CH_3)$), 0.96 (3H, d, *J* 6.6, $CH(CH_3CH_3)$), 1.38 (1H, s, OH), 1.44-1.54 (2H, m, CH_2^{i}Pr), 1.72-1.95 (3H, m, $PhCH_2CH_2$ & $CH(CH_3)_2$), 1.77 (3H, dd, *J* 6.4, 1.5, CH_3CHCH), 2.61 (1H, ddd, *J* 13.6, 10.6, 5.7, PhC*H*H), 2.66 (1H, ddd, *J* 13.6, 10.6, 5.7, PhCH*H*), 5.51 (1H, dq, *J* 15.6, 1.5 CH_3CHCH), 5.68 (1H, dq, *J* 15.6, 6.4, CH_3CHCH), 7.16-7.21 (3H, m, ArH), 7.26-7.31 (2H, m, ArH). **δ_C** (100 MHz, $CDCl_3$): 17.7 (CH_3), 24.0 (CH), 24.6 (CH_3), 24.7 (CH_3), 30.0 (CH_2), 43.9 (CH_2), 50.2 (CH_2), 75.5 (4° C), 123.0 (CH), 125.6 (CH), 128.3 (CH), 128.4 (CH), 137.0 (CH), 142.7 (4° C). **ν_{max}** (neat): 927, 1453, 1497, 1603, 2952, 3027, 3472. **HRMS** (CI) calc. for $[C_{16}H_{24}O + H - H_2O]^+$ 215.1800. Found 215.1809. **LRMS** (CI) calc. for $[C_{16}H_{24}O + H - H_2O]^+$ 215.2. Found 215.2, 159.1, 119.1, 105.1, 91.1 (basepeak). ***Secondary alcohol characterisation**: **R_f*** (30% EtOAc/pentane) 0.43. **δ_H** (400 MHz, $CDCl_3$): 0.92 (3H, d, *J* 6.6, $CH_2CH(CH_3CH_3)$), 0.95 (3H, d, *J* 6.6, $CH_2CH(CH_3CH_3)$), 1.23 (3H, d, *J* 6.4, CH_3CHCH), 1.24 & 1.26 (12H, 2br. s, $NCH(CH_3)_2$), 1.77 (1H, tsept., *J* 7.2, 6.6, CH_2CH), 2.02 (2H, app. d, *J* 7.2, CH_2), 3.04 (1H, s, OH), 3.81-3.93 (1H, br. m, NCH), 3.97-4.09 (1H, br. m, NCH), 4.37 (1H, dq, *J* 9.0, 6.2, OCH), 5.11 (1H, d, *J* 9.0, CH_3CHCH). **δ_C** (100 MHz, $CDCl_3$): 20.3 (br. s, CH_3), 20.4 (br. s, CH_3), 21.4 (br. s, CH_3), 21.4 (br. s, CH_3), 22.2 (CH_3), 22.4 (CH_3), 25.7 (CH), 43.7 (CH_2), 46.0 (br. s, CH), 46.8 (br. s, CH), 62.0 (CH), 121.9 (CH), 148.4 (4° C), 153.7 (4° C). **ν_{max}** (neat): 1130, 1267, 1432, 1695, 2932, 2966, 3426. **Elemental analysis**: calc. for $C_{15}H_{29}NO_3$: C, 66.38; H, 10.77; N, 5.16; Found: C, 66.03; H, 10.73; N, 5.24. **LRMS** (CI) calc. for $[C_{25}H_{29}NO_2 + H - H_2O]^+$ 254.2. Found 254.2, 174.2, 155.2, 12.1, 127.1 (basepeak), 86.1. **Z* configuration was assigned on the basis of a strong NOE between C=CH (5.11 ppm) and CH_2 (2.02 ppm).

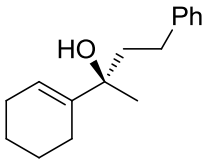
(*R*,*E*)-3,4-Dimethyl-1-phenylhex-4-en-3-ol 4eb



Following **GP10B** using *S*-**1e** (227 mg, 1.00 mmol, 98:2 *er*, *x* = 15 min) and phenylethyl pinacol boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave *R-tertiary alcohol* **4eb** (165 mg, 81%, 94:6 *er*, *x* = 15 min) as a colourless liquid. Following **GP10A**, using *S*-**1e** (227 mg, 1.00 mmol, >99:1 *er*), gave **4eb** (169 mg, 83%, 89:11 *er*) as a colourless liquid. $\boldsymbol{R_f}$ (30% Et_2O/pentane) 0.42. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.35 (3H, s, CH_3), 1.43 (1H, s, OH), 1.65-1.68 (6H, m, CH_3), 1.87 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCH_2CHH$), 1.90 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCH_2CHH$), 2.48 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCHH$), 2.58 (1H, ddd, *J* 13.8, 10.8, 6.6, $PhCHH$), 5.61-6.68 (1H, m, CH), 7.16-7.21 (3H, m, ArH), 7.26-7.31 (2H, m, ArH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 12.7 (CH_3), 13.3 (CH_3), 27.8 (CH_3), 30.5 (CH_3), 42.3 (CH_2), 75.7 (4° C), 117.5 (CH), 125.7 (CH), 128.3 (CH), 128.3 (CH), 140.1 (4° C), 142.6 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 702, 832, 1117, 1456, 1494, 1602, 1947, 2862, 2949, 2977, 3023, 3329. **Elemental analysis**: calc. for $C_{14}H_{20}O$: C, 82.30; H, 9.87; Found: C, 82.16; H, 9.82. **GCMS** (*M70*): T_R 7.28; MS calc. for $[C_{14}H_{20}O_2]^{+\bullet}$ 204. Found: 204, 186, 171, 157, 143, 129, 104, 99 (basepeak), 91, 77. **Chiral HPLC**: (IB, 1% ^{i}PrOH/hexane, 0.7 ml/min) T_R 20.39 min (major), 21.71 min (minor). $[\alpha]_D^{24}$ +26.0 (*c* 1, $CHCl_3$).

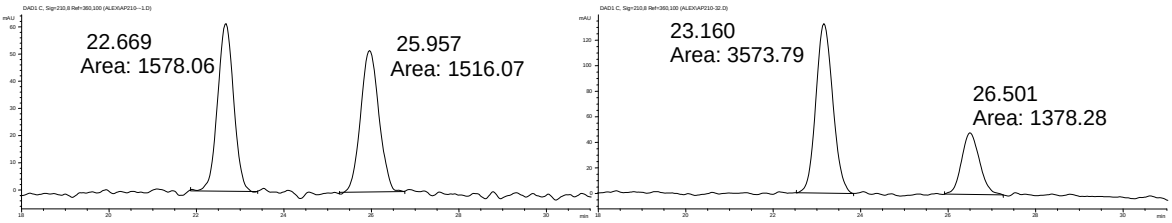


(*R*)-2-(Cyclohex-1-en-1-yl)-4-phenylbutan-2-ol 4fb



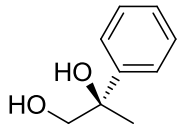
Following **GP10A** using *S*-**1f** (253 mg, 1.00 mmol, >99:1 *er*, *x* = 60 min) and phenylethyl pinacol boronic ester **2b** (2 M in Et_2O, 0.65 ml, 1.30 mmol), gave *R-tertiary alcohol* **4fb** (199 mg, 87%, 58:42 *er*) as a white amorphous solid. When *x* = 15 min, gave *R-tertiary alcohol* **4fb** (197 mg, 86%, 72:28 *er*). When *x* = 15 min and (*rac*/*trans*)-*N*,*N*,*N*',*N*'-tetramethylcyclohexane-1,2-diamine (TMCDA)[30] (1.1 eq) was used instead of TMEDA, gave (*R*)-*tertiary alcohol* **4fb** (167 mg, 73%, 59:41 *er*). $\boldsymbol{R_f}$ (25% Et_2O/pentane) 0.40. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.34 (3H, s, CH_3), 1.51 (1H, s, OH), 1.54-1.73 (4H, m, $CHCH_2CH_2CH_2$), 1.83-1.93 (2H, m, $OCCH_2$), 1.98-2.04 (2H, m, CH_2), 2.07-2.13 (2H, m, CH_2), 2.48-2.65 (2H, m, CH_2Ph), 5.78-5.82 (1H, m, C=CH), 1.15-7.21 (3H, m, ArH), 7.26-7.31 (2H, m, ArH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 22.3 (CH_2), 23.0 (CH_2), 24.8 (CH_2), 25.1 (CH_2), 27.7 (CH_3), 30.5 (CH_2), 42.2 (CH_2), 75.1 (4° C), 120.1

(CH), 125.6 (CH), 128.3 (CH), 128.3 (CH), 141.9 (4° C), 142.9 (4° C). ν_{max} (neat): 1101, 1377, 1453, 1493, 1602, 2856, 2927, 3266. **Elemental analysis**: calc. for $C_{16}H_{22}O$: C, 83.43; H, 9.63; Found: C, 83.75; H, 9.85. **GCMS** (*M70*): T_R 8.39; MS calc. for $[C_{16}H_{30}O]^{+\bullet}$ 230. Found: 230, 212, 197.183, 169, 155, 141, 129, 125 (basepeak), 121, 105, 91, 79, 77. HPLC: (IB, 1% ^{i}PrOH/hexane, 0.7 ml/min) T_R 23.16 min (major), 26.50 min (minor). $[\alpha]_D^{18}$ +7.1 (*c* 1.96, $CHCl_3$).



Determination of stereochemical outcome of the lithiation/borylation of secondary allylic carbamates

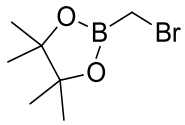
(*R*)-2-Phenylpropane-1,2-diol



The tertiary alcohol **4ae** (150 mg, 0.92 mmol) was dissolved in CH_2Cl_2/MeOH (1:1 v.v., 6 ml) was reacted with ozone at −78 °C for 5 min followed by reductive treatment with $NaBH_4$ (150 mg). The reaction mixture was then allowed to warm to ambient temperature and stirred for 1 h before the slow addition of sat. $NH_4Cl_{(aq)}$ (4 ml). Most of the organic solvent (~80%) was removed *in vacuo*. Water (1 ml) and EtOAc (4 ml) was added, the phases separated and the aqueous phase extracted with EtOAc (3 × 10 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 70% EtOAc/pentane to give the title compound (104 mg, 74%) as a colourless oil. R_f (70% EtOAc/pentane) 0.39. δ_H (400 MHz, $CDCl_3$): 1.55 (3H, s, CH_3), 1.88 (1H, br. s, OH), 2.63 (1H, br. s, OH), 3.64 (1H, d, *J* 11.0, C*H*H), 3.81 (1H, d, *J* 11.0, CH*H*), 7.27-7.31 (1H, m, ArH), 7.36-7.41 (2H, m, ArH), 7.45-7.49 (2H, m, ArH). δ_C (100 MHz, $CDCl_3$): 26.0 (CH_3), 71.1 (CH_2), 74.8 (4° C), 125.0 (CH), 127.2 (CH), 128.4 (CH), 144.9 (4° C). ν_{max} (neat): 1026, 1446, 1494, 2931, 2979, 3060, 3365. **GCMS** (*M70*): T_R 5.70; MS calc. for $[C_9H_{12}O]^{+\bullet}$ 152. Found: 152, 134, 121 (basepeak), 105, 91, 77. $[\alpha]_D^{24}$ −10.4 (*c* 1.83, $CHCl_3$), Lit. −10.6 (c 1.76, $CHCl_3$, 95% *e.e.*).[31] Spectral data was in accordance with the literature.[32]

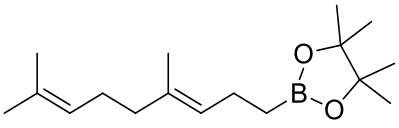
Synthesis of C30 Botryococcene

2-(Bromomethyl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane



Based on a procedure from Matteson and coworkers,[33, 34] to a solution of triisopropylborate (32.5 ml, 141 mmol) and dibromomethane (10.8 ml, 154 mmol) in anhydrous THF (200 ml) stirred at −78 °C (acetone/$CO_{2(s)}$) under an atmosphere of nitrogen, *n*-BuLi (1.6 M in hexane, 120 ml, 128 mmol) was added dropwise over 2 h via syringe pump at such a rate that the internal temperature did not rise above −75 °C. The resulting mixture was stirred for 1 h at −78 °C, and then the cooling bath was removed and stirred for 2 h at ambient temperature. The reaction mixture was cooled 0 °C (ice/water) and methanesulfonic acid (8.31 ml, 128 mmol) was added dropwise over 10 min. The reaction was allowed to reach ambient temperature and was stirred for 1 h. The reaction mixture was cooled 0 °C (ice/water) and pinacol (12.1 g, 128 mmol) was added in one portion. The reaction was stirred for 1 h at ambient temperature, after which, the volatiles were removed *in vacuo*. The solid residue was triturated with CH_2Cl_2 (50 ml). The suspension was filtered and the solid washed with CH_2Cl_2 (200 ml). The solvent was removed from the filtrate *in vacuo* and the residue distilled (42 – 44 °C at 3.5 – 5.1 mbar, Lit. b.p. 35 °C at 0.4 mbar or 72 – 75 °C at 6.0 – 6.7 mbar)[34] to give the bromomethyl B(pin) (23.3 g, 82%) as a colourless liquid that was stored in a freezer in the absence of light. δ_H (400 MHz, $CDCl_3$): 1.29 (12H, s, $C(CH_3)_2$), 2.59 (2H, s, CH_2). δ_C (100 MHz, $CDCl_3$): 24.6 (CH_3), 84.5 (4° C), *carbon attached to boron not observed*. ν_{max} (neat): 845, 1135, 1336, 2933, 2979. **Elemental analysis**: calc. for $C_7H_{14}BO_2Br$: C, 38.06; H, 6.39; Found: C, 38.78; H, 6.48. **GCMS** (*M50*): T_R 8.28; MS calc. for $[C_7H_{14}BO_2Br]^{+\bullet}$ 220/222. Found: 222, 220, 207, 205, 164, 162, 123, 121, 83 (basepeak), 59. Spectral data was in accordance with the literature.[34]

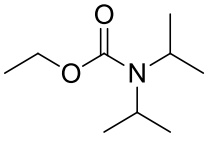
(*E*)-2-(4,8-dimethylnona-3,7-dien-1-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 8



Following a modified procedure from Yanagisawa *et al*,[35] Rieke magnesium[36] was prepared as follows: magnesium chloride (10.81 g, 113.6 mmol) was flamed dried in a Schlenk flask and was cooled under vacuum (~5 mbar). Once cooled, the flask was filled with argon and under a positive pressure of argon, napthalene (2.33 g, 18.2 mmol) was added. The flask was evacuated and filled with argon three times. To the solid magnesium chloride and napthalene, under a positive

pressure of argon, freshly cut lithium wire (~20 small shinny pieces, cut so as to produce a rough surface, 1.58 g, 227.1 mmol) was added followed by anhydrous THF (230 ml). The reaction mixture immediately turned dark grey upon the addition of THF. After stirring overnight (~14 h), the lithium had disappeared (it can be easily seen as it floats) and a shiny precipitate had formed (the solution remains dark grey). The reaction mixture was cooled to −98 °C (MeOH, $N_{2(l)}$) and geranyl chloride (prepared according to Clough and Pattenden,[37] and distilled, 7.50 ml, 40.4 mmol) in THF (20 ml) was added dropwise over 45 min via syringe pump at such a rate that the internal temperature did not rise above −95 °C. The reaction was stirred for 10 min and bromomethyl B(pin) (8.50 ml, 48.5 mmol) in THF (40 ml) was added over 1 h 15 min via a syringe pump at such a rate that the internal temperature did not rise above −95 °C. The reaction mixture was stirred for a further 2 h at <−95 °C. The cooling bath was removed and the reaction stirred for 4 h at ambient temperature before the reaction was cooled to 0 °C (ice/water) and saturated $NH_4Cl_{(aq)}$ (100 ml) was slowly added. Water (50 ml) and Et_2O (100 ml) was then added, the phases separated and the aqueous phase extracted with Et_2O (4 × 100 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 0 - 2% Et_2O/pentane to give *boronic ester* **8** (6.78 g, 60%, 98:2 *E*/*Z*)* as a colourless liquid. $\boldsymbol{R_f}$ (1% Et_2O/pentane) 0.21. δ_H (400 MHz, $CDCl_3$): 0.83 (2H, t, *J* 7.9, BCH_2), 1.25 (12H, s, $OC(CH_3)_2$), 1.60 (6H, s, CH_3), 1.68 (3H, s, CH_3), 1.93-1.99 (2H, m, CH_2), 2.02-2.14 (4H, m, CH_2), 5.07-5.17 (2H, m, CH). δ_C (100 MHz, $CDCl_3$): 16.0 (CH_3), 17.6 (CH_3), 22.3 (CH_2), 24.8 (CH_3), 25.7 (CH_3), 26.7 (CH_2), 39.7 (CH_2), 82.9 (4° C), 124.4 (CH), 126.5 (CH), 131.2 (4° C), 134.1 (4° C), *carbon attached to boron not observed*. δ_B (96 MHz, $CDCl_3$): 33.0 ν_{max} (neat): 1145, 1322, 1370, 1669, 2925, 2978. **Elemental analysis**: calc. for $C_{17}H_{31}BO_2$: C, 73.38; H, 11.23; Found: C, 73.51; H, 11.18. ***GCMS** (*M70*): T_R 7.80 (*E*) & 7.67 (*Z*); MS calc. for $[C_{17}H_{31}BO_2]^{+\bullet}$ 278. Found: 278, 263, 235, 151, 135, 101, 83, 69 (basepeak).

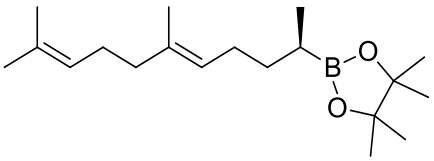
Ethyl diisopropylcarbamate



A solution of diisopropylcarbamoyl chloride (18.9 g, 115 mmol) and triethylamine (32.0 ml, 230 mmol) in ethanol (60 ml) was stirred under a nitrogen atmosphere at reflux for 16 h. The volatiles were removed *in vacuo* and the residue dissolved in Et_2O (40 ml) and water (40 ml). The phases were separated and the aqueous phase extracted with Et_2O (3 × 40 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column

chromatography eluting 10% Et_2O/pentane to give ethyl diisopropylcarbamate (17.4 g, 87%) as a colourless oil. $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.33. δ_H (400 MHz, $CDCl_3$): 1.19 & 1.29 (12H, 2s, $CH(CH_3)_2$), 1.26 (3H, t, *J* 7.1, CH_3CH_2), 3.90 (2H, br. s, $CH(CH_3)_2$), 4.13 (2H, q, *J* 7.1, CH_3CH_2). δ_C (100 MHz, $CDCl_3$): 14.6 (CH_3), 20.9 (br. s, CH_3), 45.8 (br. s, CH), 60.3 (CH_2), 155.8 (4° C). ν_{max} (neat): 1289, 1435, 1687, 2876, 2934, 2971. **GCMS** (*M70*): T_R 3.60; MS calc. for $[C_9H_{19}NO_2]^{+\bullet}$ 173. Found: 173, 158 (basepeak), 128, 116, 86, 72, 58. Spectral data was in accordance with the literature.[26]

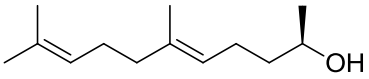
(*R*,*E*)-2-(6,10-Dimethylundeca-5,9-dien-2-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane 9



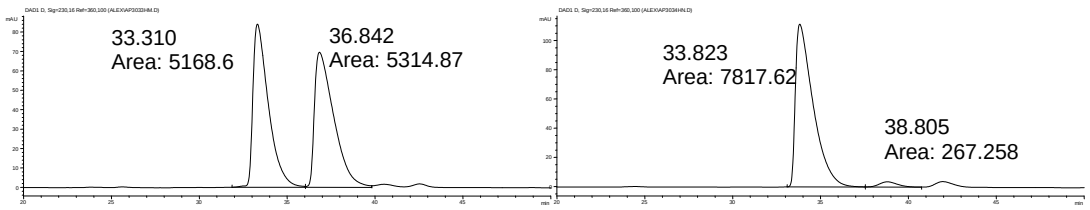
Following a procedure from Stymiest *et al*,[26] to a solution of ethyl diisopropylcarbamate (2.49 g, 14.4 mmol) and (−)-sparteine (3.14 ml, 13.7 mmol) in anhydrous Et_2O (48 ml) at −78 °C (acetone/$CO_{2(s)}$) under an atmosphere of nitrogen, *s*-BuLi (13.7 mmol, 10.5 ml) was added dropwise over 10 min. The reaction was stirred for 5 h at −78 °C, over which time the solution turned pale yellow. Boronic ester **8** (2.00 g, 7.19 mmol) in Et_2O (8 ml) was added dropwise over 10 min. The reaction mixture was stirred for 1 h at −78 °C and then the cooling bath removed. The reaction mixture was allowed to reach ambient temperature and then heated at reflux. After approximately 36 h the reaction was deemed complete as shown by the disappearance of the ate complex (~6 ppm) determined by ^{11}B NMR. The reaction mixture was allowed to reach ambient temperature and quenched with water (40 ml). The phases were separated and the aqueous phase extracted with Et_2O (3 × 50 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The residue was purified by flash column chromatography eluting 30 – 40% toluene/pentane to give *secondary boronic ester* **9** (1.97 g, 89%, >95:5 *er*)* as a colourless liquid. $\boldsymbol{R_f}$ (1% Et_2O/pentane) 0.28. δ_H (400 MHz, $CDCl_3$): 0.97 (3H, d, *J* 7.3, $CHCH_3$), 0.98-1.08 (1H, m, $CHCH_3$), 1.25 (12H, s, $OC(CH_3)_2$), 1.26-1.35 (1H, m, CH*H*), 1.44-1.54 (1H, m, C*H*H), 1.60 (6H, s, CCH_3), 1.68 (3H, s, CCH_3), 1.94-2.10 (6H, m, CH_2), 5.07-5.17 (2H, m, CCH). δ_C (100 MHz, $CDCl_3$): 15.4 (CH_3), 15.9 (CH_3), 17.7 (CH_3), 24.7 (CH_3), 24.8 (CH_3), 25.7 (CH_3), 26.7 (CH_2), 27.3 (CH_2), 33.3 (CH_2), 39.7 (CH_2), 82.8 (4° C) 124.4 (CH), 124.8 (CH), 131.2 (4° C), 134.7 (4° C), *carbon attached to boron not observed*. δ_B (96 MHz, Et_2O): 33.0. ν_{max} (neat): 1143, 1313, 1461, 1667, 2854, 2924, 2927. **Elemental analysis**: calc. for $C_{19}H_{35}BO_2$: C, 74.51; H, 11.52; Found: C, 75.41; H, 11.57. **GCMS** (*M70*): T_R 8.27; MS calc. for $[C_{19}H_{35}BO_2]^{+\bullet}$

306. Found: 306, 263, 163, 135, 123, 109 (basepeak), 101, 85, 69. $[\alpha]_D^{19}$ −8.40 (*c* 2.56, $CHCl_3$). **er* was determined by oxidation and converting a small sample of the alcohol (~10 mg) to the benzoate ester (**GP3**) and analysed by chiral HPLC (see below).

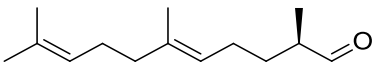
(*R*,*E*)-6,10-Dimethylundeca-5,9-dien-2-ol



To a stirred solution of boronic ester **9** (85 mg, 0.28 mmol) in degassed THF (3 ml) containing BHT (~2 mg) at 0 °C (ice/water) in an atmosphere of nitrogen, an ice-cold degassed mixture of 3 M NaOH (2 ml) containing EDTA (1 gl^{-1}) and 30% aqueous H_2O_2 (1 ml) was added all at once. The reaction mixture was allowed to reach ambient temperature over night. After approximately 16 h, the reaction was diluted with water (2 ml) and extracted with Et_2O (4 × 5 ml). The combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 30% Et_2O/pentane to give the title compound (50 mg, 92%, >95:5 *er*)* as a colourless oil. $\boldsymbol{R_f}$ (30% Et_2O/pentane) 0.38. δ_H (400 MHz, $CDCl_3$): 1.20 (3H, d, *J* 6.2, C*H*$_3$CH), 1.40-1.56 (3H, m, CH_2 & OH), 1.61 (3H, s, CH_3), 1.63 (3H, s, CH_3), 1.69 (3H, s, CH_3), 1.96-2.03 (2H, m, CH_2), 2.04-2.14 (4H, m, CH_2), 3.82 (1H, app. quint., *J* 6.2, CH_3C*H*), 5.09 (1H, br. t, *J* 6.7, CCH), 5.15 (1H, br. t, *J* 7.2, CCH). δ_C (100 MHz, $CDCl_3$): 16.0 (CH_3), 17.7 (CH_3), 23.5 (CH_3), 24.4 (CH_2), 25.7 (CH_3), 26.6 (CH_2), 39.2 (CH_2), 39.7 (CH_2), 68.0 (CH), 123.9 (CH), 124.2 (CH), 131.4 (4° C), 135.7 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 1127, 1375, 1448, 1669, 2856, 2966, 3337. **GCMS** (*M70*): T_R 6.42; MS calc. for $[C_{13}H_{24}O]^{+\bullet}$ 196. Found: 196, 153, 135, 123, 109 (basepeak), 95, 81, 69, 67. $[\alpha]_D^{25}$ −3.8 (*c* 2.4, $CHCl_3$), Lit. −3.6 (c 5, $CHCl_3$, >99:1 *er*).[38] **er* was determined by converting a small sample to the benzoate ester (**GP3**) and analysed by **Chiral HPLC**: (IC, 0.1% IPA/hexane, 0.7 ml/min) T_R 133.82 min (major) & 38.81 min (minor). Spectral data was in accordance with the literature.[38]

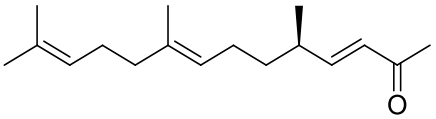


(*R*,*E*)-2,6,10-Trimethylundeca-5,9-dienal 10



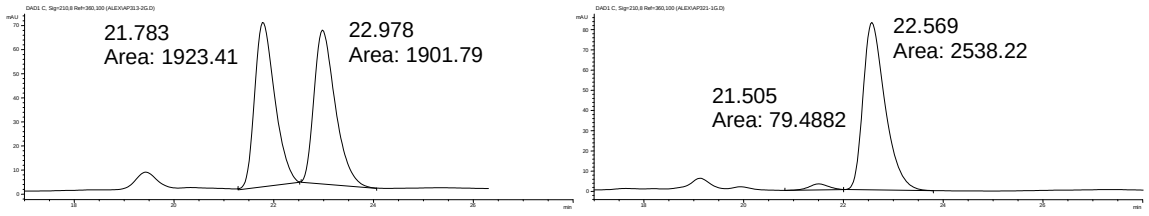
Following a procedure from Brown *et al*,[39] LDA was prepared as follows: To a stirred solution of diisopropyl amine (82 µl, 0.59 mmol) in THF (0.5 ml) under an atmosphere of nitrogen at 0 °C, *n*BuLi (1.6 M in hexane, 0.37 ml, 0.59 mmol) was added dropwise and the solution stirred for 1 h at 0 °C. To a stirred solution of boronic ester **9** (150 mg, 0.49 mmol) and CH_2Cl_2 (44 µl, 0.69 mmol) in THF (0.5 ml) under an atmosphere of nitrogen at −5 °C, LDA was added dropwise over 10 min. The mixture was stirred for 30 min at −5 °C, then heated to 60 °C and stirred for 1.5 h. The reaction was cooled to 0 °C and an ice-cold mixture of 3 M NaOH (2 ml) and 30% aqueous H_2O_2 (1 ml) was added all at once. The reaction was allowed to reach ambient temperature overnight (~16 h). Water (5 ml) and Et_2O (5 ml) was added and the phases separated. The aqueous phase was extracted with Et_2O (3 × 5 ml) and the combined organic phases were washed with brine, dried over $MgSO_4$ and the solvent removed *in vacuo*. The crude material was purified by flash column chromatography eluting 1.5-3% Et_2O/pentane to give aldehyde **10** (62 mg, 61%) as a pale yellow oil that was used immediately in the next step. $\boldsymbol{R_f}$ (3% Et_2O/pentane) 0.41. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.10 (3H, d, *J* 6.9, CHC*H*$_3$), 1.41 (1H, dddd, *J* 13.7, 8.1, 6.9, 6.9, CH*H*), 1.60 (3H, s, CH_3), 1.61 (3H, s, CH_3), 1.68 (3H, app. q, *J* 1.1, CH_3), 1.78 (1H, dddd, *J* 13.7, 8.4, 6.9, 6.9, C*H*H), 1.96-2.11 (6H, m, CH_2), 2.36 (1H, qddd, 6.9, 6.9, 6.9, 1.8, C*H*CH_3), 5.05-5.13 (2H, m, CCH), 9.63 (1H, d, *J* 1.8, CHO). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 13.3 (CH_3), 16.0 (CH_3), 17.7 (CH_3), 25.2 (CH_2), 25.7 (CH_3), 26.6 (CH_2), 30.6 (CH_2), 39.7 (CH_2), 45.8 (CH), 123.3 (CH), 124.2 (CH), 131.4 (4° C), 136.3 (4° C), 205.3 (CH). $\boldsymbol{\nu_{max}}$ (neat): 1452, 1668, 1726, 2705, 2855, 2918, 2967. **GCMS** (*M70*): T_R 6.85; MS calc. for $[C_{14}H_{24}O]^{+\bullet}$ 208. Found: 208, 165, 147, 135, 123, 107, 95, 81, 69 (basepeak), 55. $[\alpha]_D^{19}$ −23.5 (*c* 2.4, $CHCl_3$), Lit. +23.6 (c 1.37, $CHCl_3$, for *S*, unknown *er*).[40] Spectral data was in accordance with the literature.[41]

(*R*,3*E*,8*E*)-5,9,13-Trimethyltetradeca-3,8,12-trien-2-one 11

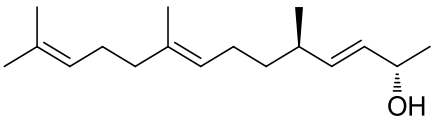


To a stirred suspension of lithium chloride (flame dried and cooled under vacuum, 116 mg, 2.73 mmol) in anhydrous acetonitrile (2 ml) under an atmosphere of nitrogen at ambient temperature, dimethyl(2-oxopropyl)phosphonate (377 µl, 2.73 mmol) and diisopropyl ethylamine (396 µl, 2.73 mmol) were added successively. The reaction mixture was stirred for 1 h and then aldehyde **10** (316 mg, 1.52 mmol) in anhydrous acetonitrile (5 ml) was added all at once. The reaction was stirred overnight at ambient temperature (~16 h) and then quenched with 0.1 M $HCl_{(aq)}$

(10 ml). The mixture was extracted with Et_2O (4 × 30 ml) and the combined organic phases were washed with sat. $NaHCO_{(aq)}$, brine and dried over $MgSO_4$. The solvent was removed *in vacuo* and the crude material purified by flash column chromatography eluting 6% Et_2O /pentane to give *enone* **11** (276 mg, 74%) as a colourless oil. $\boldsymbol{R_f}$ (6% Et_2O/pentane) 0.28. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 1.07 (3H, d, *J* 6.6, CHCH_3), 1.38-1.50 (2H, m, CHCH_2), 1.59 (3H, s, CH_3), 1.61 (3H, s, CH_3), 1.69 (3H, app. q, *J* 1.0, CH_3), 1.95-2.03 (4H, m, CH_2), 2.03-2.11 (2H, m, CH_2), 2.25 (3H, s, $COCH_3$), 2.34 (1H, app. spt., *J* 7.1, C*H*CH_3), 5.06-5.12 (2H, m, C=CH), 6.04 (1H, dd, *J* 15.9, 1.0, COCH), 6.70 (1H, dd, *J* 15.9, 7.8, COCHC*H*). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 16.0 (CH_3), 17.7 (CH_3), 19.4 (CH_3), 25.5 (CH_2), 25.7 (CH_3), 26.6 (CH_2), 26.9 (CH_3), 36.1 (CH_2), 36.2 (CH), 39.7 (CH_2), 123.7 (CH), 124.2 (CH), 129.6 (CH), 131.4 (4° C), 135.6 (4° C), 153.7 (CH), 198.9 (4° C). $\boldsymbol{\nu_{max}}$ (neat): 981, 1253, 1626, 1676, 1699, 2854, 2916, 2964. **Elemental analysis**: calc. for $C_{17}H_{28}O$: C, 82.20; H, 11.36; Found: C, 82.28; H, 11.41. **GCMS** (*M70*): T_R 8.18; MS calc. for $[C_{17}H_{28}O]^{+\bullet}$ 248. Found: 248,205,190, 179, 163, 147, 137, 121, 109, 98, 81, 69 (basepeak), 55. **Chiral HPLC** (IB, 0.1% ^{i}PrOH/hexane, 0.7 ml/min, 10 °C) T_R 22.57 min (major), 21.51 min. $[\alpha]_D^{20}$ –39.9 (*c* 2.04, Et_2O).



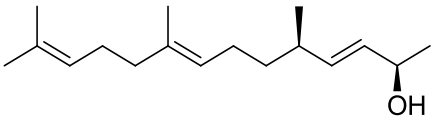
(2*S*,3*E*,5*R*,8*E*)-5,9,13-Trimethyltetradeca-3,8,12-trien-2-ol, 13



Following a procedure from Noyori *et al*,[42] enone **11** (169 mg, 0.680 mmol, 97:3 *er*) in anhydrous degassed isopropanol (7 ml) was placed into a vial containing K_2CO_3 (~1 mg) and $RuCl_2$[(*R*)-(DM-BINAP)][(*R*)-DAIPEN] (~1 mg, CAS:220114-32-9). The vial was placed into an autoclave and the vessel was filled with nitrogen by partial vacuum/backfill cycles (three times). Hydrogen was flushed through the vessel by pressurising with hydrogen (4 atm), and then allowing the pressure to drop slowly by opening the outlet tap. This was repeated three times. The vessel was pressurised to 8 atm and the reaction stirred for 24 h. The solvent was removed *in vacuo*, the crude material taken up in 20% Et_2O/pentane and filtered through a plug of silica gel, washing down with 20% Et_2O /pentane. The solvent was removed *in vacuo* to give *alcohol* **13** (165 mg, 97%, 96:4 *dr*)* as a colourless liquid. $\boldsymbol{R_f}$ (20% Et_2O/pentane) 0.30. $\boldsymbol{\delta_H}$ (500 MHz, $CDCl_3$): 0.98 & 0.99† (3H, 2d, *J*

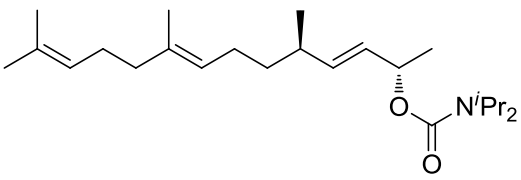
6.7, CH_2CHCH_3), 1.27 (3H, d, *J* 6.1, $HOCHCH_3$), 1.30-1.36 (2H, m, CH_2), 1.39 (1H, d, *J* 3.7, OH), 1.59 (3H, s, CH_3), 1.61 (3H, s, CH_3), 1.69 (3H, app. q, *J* 1.2, CH_3), 1.94-2.01 (4H, m, CH_2), 2.03-2.11 (2H, m, CH_2), 2.13 (1H, app. sept., *J* 6.7, CH_2CHCH_3), 4.24-4.31 (1H, m, HCO), 5.08-5.13 (2H, m, C=CH), 5.48 (1H, dd, AB, *J* 15.6, 5.5, C*H*=CH), 5.53 (1H, dd, AB, *J* 15.6, 6.7, CH=C*H*). δ_C (125 MHz, $CDCl_3$): 16.00 (CH_3), 17.68 (CH_3), 20.37 (CH_3), 20.45† (CH_3), 23.48 (CH_3), 23.58† (CH_3), 25.60 (CH_2), 25.68 (CH_3), 26.69 (CH_2), 35.69 (CH), 35.77† (CH), 36.88 (CH_2), 39.71 (CH_2), 68.96 (CH), 69.09† (CH), 124.35 (CH), 124.45 (CH), 131.27 (4° C), 132.53 (CH), 132.60† (CH), 134.94 (4° C), 136.66 (CH), 136.80† (CH). ν_{max} (neat): 970, 1060, 1375, 1451, 1668, 2853, 2853, 2914, 2966, 3334. **GCMS** (*M70*): T_R 7.98; MS calc. for $[C_{17}H_{30}O]^{+\bullet}$ 250. Found: 250, 232.217,189, 163, 147, 135, 121, 107, 95, 81, 69 (basepeak). $[\alpha]_D^{25}$ –29.5 (*c* 2.00, Et_2O). **dr* determined after carbamoylation.

(2*R*,3*E*,5*R*,8*E*)-5,9,13-Trimethyltetradeca-3,8,12-trien-2-ol, 18



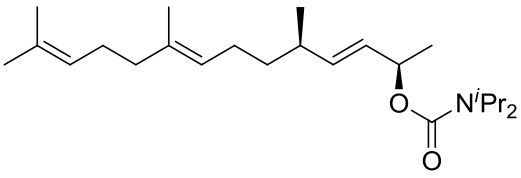
Following the above procedure, using enone **11** (221 mg, 0.89 mmol, 97:3 *er*) and $RuCl_2$[(*S*)-(DM-BINAP)][(*S*)-DAIPEN] (~1 mg, CAS: 220114-01-2), gave *alcohol* **18** (204 mg, 92%, 96:4 *dr*)* as a colourless liquid. δ_H (500 MHz, $CDCl_3$): 0.98† & 0.99 (3H, 2d, *J* 6.7, CH_2CHCH_3), 1.27 (3H, d, *J* 6.4, $HOCHCH_3$), 1.29-1.34 (2H, m, CH_2), 1.44 (1H, d, *J* 3.7, OH), 1.59 (3H, s, CH_3), 1.61 (3H, s, CH_3), 1.69 (3H, app. q, *J* 1.2, CH_3), 1.93-2.02 (4H, m, CH_2), 2.02-2.16 (2H, m, CH_2), 2.12 (1H, app. sept., *J* 6.7, CH_2CHCH_3), 4.24-4.30 (1H, m, CHO), 5.08-5.13 (2H, m, C=CH), 5.47 (1H, dd, AB, *J* 15.6, 6.1, C*H*=CH), 5.51 (1H, dd, AB, *J* 15.6, 6.7, CH=C*H*). δ_C (125 MHz, $CDCl_3$): 15.98 (CH_3), 17.67 (CH_3), 20.36† (CH_3), 20.45 (CH_3), 23.47† (CH_3), 23.56 (CH_3), 25.60 (CH_2), 25.68 (CH_3), 26.68 (CH_2), 35.69† (CH), 35.76 (CH), 36.89 (CH_2), 39.71 (CH_2), 68.96† (CH), 69.08 (CH), 124.35 (CH), 124.43 (CH), 131.26 (4° C), 132.52† (CH), 132.59 (CH), 134.92 (4° C), 136.64† (CH), 136.79 (CH). †*indicates minor diastereomer*. ν_{max} (neat): 970, 1060, 1375, 1451, 1668, 2853, 2853, 2915, 2966, 3328. $[\alpha]_D^{25}$ –19.5 (*c* 2.00, Et_2O). **dr* determined after carbamoylation. All other spectroscopic data matched **13**.

(2*S*,3*E*,5*R*,8*E*)-5,9,13-Trimethyltetradeca-3,8,12-trien-2-yl diisopropylcarbamate, 14



Following **GP5**, using alcohol **13** (155 mg, 0.619 mmol) gave *carbamate* **14** (223 mg, 95%, 96:4 *dr*)* as a colourless oil. $\boldsymbol{R_f}$ (10% Et_2O/pentane) 0.47. $\boldsymbol{\delta_H}$ (500 MHz, $CDCl_3$): 0.96 & 0.97† (3H, 2d, *J* 6.7, CH_2CHCH_3), 1.19 & 1.20 (12H, 2br. s, $CH(CH_3)_2$), 1.30 (2H, app. q, *J* 7.6, CH_2), 1.31 (3H, d, *J* 6.4, $OCHCH_3$), 1.57 (3H, s, CH_3), 1.60 (3H, s, CH_3), 1.67 (3H, app. q, *J* 1.2, CH_3), 1.88-2.00 (4H, m, CH_2), 2.00-2.15 (3H, m, CH_2 & OCHCH=CHC*H*), 3.78 & 4.03 (2H, 2br. s, NCH), 5.08 (2H, app. tquin., *J* 7.0, 1.2, C=CH), 5.27$^{¥}$ (1H, qd, *J* 6.4, 6.4, OCH), 5.44 (1H, ddd, *J* 15.6, 6.4, 0.9, OCHC*H*), 5.54 (1H, ddd, *J* 15.6, 6.7, 0.9, OCHCHC*H*). $\boldsymbol{\delta_C}$ (125 MHz, $CDCl_3$): 15.95 (CH_3), 17.63 (CH_3), 20.45 (CH_3), 20.85 (CH_3), 21.05 (br. s, CH_3), 25.53 (CH_2), 25.65 (CH_3), 26.66 (CH_2), 35.83† (CH), 35.87 (CH), 36.81† (CH_2), 36.86 (CH_2), 39.68 (CH_2), 45.65 (br. s, CH), 71.09† (CH), 71.16 (CH), 124.35† (CH), 124.36 (CH), 124.49† (CH), 124.51 (CH), 128.99 (CH), 131.15 (4° C), 131.17† (4° C), 134.77 (4° C), 134.80† (4° C), 137.73† (CH), 137.99 (CH), 155.19 (4° C). †*indicates minor diastereomer.* $^{¥}J^4$ *coupling not observed due to broadness of signal*. $\boldsymbol{\nu_{max}}$ (neat): 1043, 1282, 1435, 1689, 2871, 2927, 2967. **Elemental analysis**: calc. for $C_{24}H_{43}NO_2$: C, 76.34; H, 11.48; N, 3.71; Found: C, 76.68; H, 11.50; N, 3.95. **GCMS** (*M70*): T_R 9.55 (major) & 9.57 (minor); MS calc. for $[C_{24}H_{43}NO_2]^{+\bullet}$ 377. Found: 377, 308, 232, 217, 189, 163, 146, 135, 121, 107, 95, 81, 69 (basepeak), 55. $[\alpha]_D^{21}$ −16.0 (*c* 2.44, $CHCl_3$). *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 35.83 & 35.87, 36.81 & 36.86, 134.77 & 134.80, and 137.73 & 137.99. The spectrum was collected and analysed via the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2.

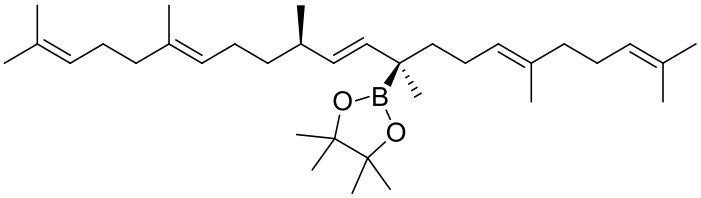
(2*R*,3*E*,5*R*,8*E*)-5,9,13-Trimethyltetradeca-3,8,12-trien-2-yl diisopropylcarbamate, 19



Following **GP5**, using alcohol **18** (185 mg, 0.739 mmol) gave *carbamate* **19** (262 mg, 94%, 96:4 *dr*)* as a colourless oil. $\boldsymbol{\delta_H}$ (500 MHz, $CDCl_3$): 0.97† & 0.98 (3H, 2d, *J* 6.7, CH_2CHCH_3), 1.20 & 1.21 (12H, 2br. s, $CH(CH_3)_2$), 1.31 (2H, app. q, *J* 7.3, CH_2), 1.32 (3H, d, *J* 6.4, $OCHCH_3$), 1.58 (3H, s, CH_3), 1.60 (3H, s, CH_3), 1.68 (3H, app. q, *J* 1.2, CH_3), 1.91-2.00 (4H, m, CH_2), 2.04-2.16 (3H, m, CH_2 & OCHCH=CHC*H*), 3.78 & 4.04 (2H, 2br. s, NCH), 5.09 (2H, app. tquin., *J* 7.0, 1.5, C=CH), 5.29$^{¥}$ (1H, qd, *J* 6.4, 6.4, OCH), 5.46 (1H, ddd, *J* 15.6, 6.4, 0.6, OCHC*H*), 5.55 (1H, ddd, *J* 15.6, 7.6, 0.6,

OCHCHC*H*). δ_C (125 MHz, $CDCl_3$): 15.95 (CH_3), 17.64 (CH_3), 20.45 (CH_3), 20.85 (CH_3), 21.05 (br. s, CH_3), 25.54 (CH_2), 25.66 (CH_3), 26.66 (CH_2), 35.84 (CH), 35.87† (CH), 36.82 (CH_2), 36.87† (CH_2), 39.69 (CH_2), 45.60 (br. s, CH), 71.10 (CH), 71.18† (CH), 124.36 (CH), 124.37† (CH), 124.50 (CH), 124.52† (CH), 128.98 (CH), 131.17† (4° C), 131.19 (4° C), 134.79† (4° C), 134.82 (4° C), 137.74 (CH), 138.00† (CH), 155.24 (4° C). †*indicates minor diastereomer.* ¥*J*^{4} *coupling not observed due to broadness of signal*. ν_{max} (neat): 1283, 1435, 1688, 2871, 2927, 2967. $[\alpha]_D^{19}$ −17.0 (*c* 2.44, $CHCl_3$). *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 35.84 & 35.87, 36.82 & 36.87, 71.10 & 71.18, and 137.74 & 138.00. The spectrum was collected and analysed via the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2. All other spectroscopic data matched **14**.

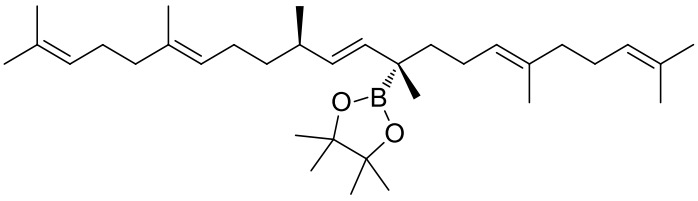
2-((6*E*,10*S*,11*E*,13*R*,16*E*)-2,6,10,13,17,21-Hexamethyldocosa-2,6,11,16,20-pentaen-10-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 15



Following **GP8** using carbamate **14** (163 mg, 0.432 mmol, 96:4 *dr*, *x* = 30 min) and boronic ester **8** (156 mg, 0.562 mmol) in Et_2O (0.5 ml), gave *tertiary boronic ester* **15** (202 mg, 91%, 94:6 *dr*)* as a colourless oil. R_f (1% Et_2O/pentane) 0.41. δ_H (400 MHz, $CDCl_3$): 0.96 (3H, d, *J* 6.7, CHC*H*$_3$), 1.06 (3H, s, CCH_3), 1.22 & 1.23 (12H, 2s, C(CH_3)$_2$), 1.23-1.37 (3H, m, CH*H* & C*HH*), 1.49-1.57 (1H, m, CH*H*), 1.59 (3H, s, CH_3), 1.60 (3H, s, CH_3), 1.61 (6H, s, CH_3), 1.69 (6H, s, CH_3), 1.85-2.02 (8H, m, CH_2), 2.02-2.14 (5H, m, CH_2 & C*H*CH_3), 5.08-5.18 (4H, m, C=CH), 5.17 (1H, dd, *J* 15.9, 7.9, CCHC*H*), 5.42 (1H, dd, *J* 15.6, 0.6, CC*H*CH). δ_C (125 MHz, $CDCl_3$): 15.84 (CH_3), 15.98 (CH_3), 17.66 (CH_3), 17.67 (CH_3), 20.29 (CH_3), 21.33 (CH_3), 24.28† (CH_2), 24.35 (CH_2), 24.55 (CH_3), 24.61† (CH_3), 24.62† (CH_3), 24.65 (CH_3), 25.67 (CH_3), 25.69 (CH_3), 25.78† (CH_2), 25.80 (CH_2), 26.73 (CH_2), 26.77 (CH_2), 36.86 (CH), 37.50 (CH_2), 37.53† (CH_2), 38.82† (CH_2), 38.86 (CH_2), 39.74 (CH_2), 82.93 (4° C), 124.44 (CH), 124.46 (CH), 124.86 (CH), 124.89† (CH), 125.12 (CH), 125.14† (CH), 131.16 (4° C), 131.18 (4° C), 133.24† (CH), 133.29 (CH), 134.39† (4° C), 134.40 (4 °C), 134.52† (4° C), 134.55 (4 °C), 135.45 (CH), 135.48† (CH), *carbon attached to boron not observed.* †*indicates minor diastereomer*. ν_{max} (neat): 1144, 1309, 1377, 1453, 1668, 2917, 2954, 2965. **Elemental analysis**: calc. for $C_{34}H_{59}BO_2$: C, 79.97; H, 11.65; Found: C, 79.99; H, 11.54. **GCMS** (*M70*): T_R 12.94; MS calc. for

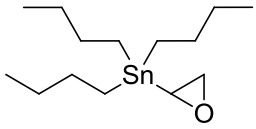
$[C_{34}H_{59}BO_2]^{+\bullet}$ 510. Found: 510, 441, 399, 360, 333, 317, 303, 289, 275, 249, 235, 221, 205, 191, 177, 163, 149, 136, 123, 109, 95, 82, 69 (basepeak). $[\alpha]_D^{20}$ −13.2 (*c* 2.28, $CHCl_3$). *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 24.34 & 24.28, 38.86 & 38.82, 133.29 & 133.24, and 134.55 & 134.52. The spectrum was collected and analysed using the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2.

2-((6*E*,10*R*,11*E*,13*R*,16*E*)-2,6,10,13,17,21-Hexamethyldocosa-2,6,11,16,20-pentaen-10-yl)-4,4,5,5-tetramethyl-1,3,2-dioxaborolane, 20



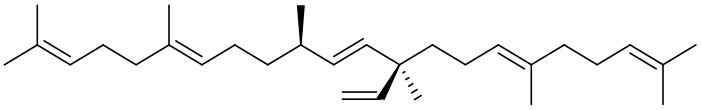
Following **GP8** using carbamate **19** (101 mg, 0.267 mmol, 96:4 *dr*, *x* = 30 min) and boronic ester **8** (97 mg, 0.347 mmol) in Et_2O (0.5 ml), gave *tertiary boronic ester* **20** (117 mg, 86%, 94:6 *dr*)* as a colourless oil. δ_H (400 MHz, $CDCl_3$): 0.96 (3H, d, *J* 6.8, CHC*H*$_3$), 1.05 (3H, s, CCH_3), 1.22 (12H, s, $C(CH_3)_2$), 1.23-1.38 (3H, m, CH*H* & C*HH*), 1.48-1.57 (1H, m, CH*H*), 1.58 (3H, s, CH_3), 1.60 (3H, s, CH_3), 1.61 (6H, s, CH_3), 1.69 (6H, s, CH_3), 1.84-2.01 (8H, m, CH_2), 2.01-2.14 (5H, m, CH_2 & C*H*CH_3), 5.07-5.19 (4H, m, C=CH), 5.17 (1H, dd, *J* 15.6, 7.9, CCHC*H*), 5.42 (1H, d, *J* 15.6, CC*H*CH). δ_C (125 MHz, $CDCl_3$): 15.84 (CH_3), 15.99 (CH_3), 17.66 (CH_3), 17.67 (CH_3), 20.27 (CH_3), 21.33 (CH_3), 24.28 (CH_2), 24.35† (CH_2), 24.55† (CH_3), 24.61 (CH_3), 24.62 (CH_3), 24.65† (CH_3), 25.68 (CH_3), 25.69 (CH_3), 25.78 (CH_2), 25.80† (CH_2), 26.73 (CH_2), 26.77 (CH_2), 36.86 (CH), 37.50† (CH_2), 37.53 (CH_2), 38.81 (CH_2), 38.85† (CH_2), 39.737 (CH_2), 39.743 (CH_2), 82.93 (4° C), 124.44 (CH), 124.46 (CH), 124.86† (CH), 124.89 (CH), 125.12† (CH), 125.13 (CH), 131.16 (4° C), 131.19 (4° C), 133.24 (CH), 133.29† (CH), 134.39 (4° C), 134.40† (4 °C), 134.52 (4° C), 134.55† (4 °C), 135.45 (CH), 135.48† (CH), *carbon attached to boron not observed.* †*indicates minor diastereomer*. ν_{max} (neat): 1144, 1309, 1377, 1453, 1670, 2917, 2954, 2965. $[\alpha]_D^{18}$ −19.9 (*c* 2.28, $CHCl_3$). *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 24.28 & 24.35, 133.24 & 133.29, and 134.55 & 134.52. The spectrum was collected and analysed using the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2. All other spectroscopic data matched **15**.

Tributyl(oxiran-2-yl)stannane



Following a procedure from Chong *et al*,[43] to a stirred solution of tributyl(vinyl)stannane (4.00 g, 12.6 mmol) in $CHCl_3$ (25 ml) at ambient temperature, *m*-CPBA (75% wt, 3.92 g, 17.0 mmol) was added all at once. The mixture was stirred for 2 h and then filtered through cotton wool. The filter cake was washed with pentane (75 ml) and the filtrate concentrated *in vacuo*. The crude material was purified by flash column chromatography eluting 2% Et_2O/pentane to give the title compound (2.99 g, 71%) as a colourless liquid. $\boldsymbol{R_f}$ (2% Et_2O/pentane) 0.41. δ_H (500 MHz, $CDCl_3$): 0.91 (9H, t, *J* 7.3, CH_3), 0.94 (6H, dd, *J* 9.2, 7.3, CH_2), 1.32 (6H, app. sxt., *J* 7.6, CH_2), 1.43-1.62 (6H, m, CH_2), 2.61 (1H, app. t, *J* 4.9, CH), 2.66 (1H, app. t, *J* 4.9, CH), 2.99 (1H, app. t, *J* 5.8, CH). δ_C (125 MHz, $CDCl_3$): 8.6 (CH_2, *J* 339, 323), 13.7 (CH_3), 27.3 (CH_2, *J* 52), 29.0 (CH_2, *J* 21), 44.7 (CH_2, *J* 4), 45.1 (CH, *J* 385, 368). ν_{max} (neat): 867, 1464, 2852, 2872, 2924, 2956. **Elemental analysis**: calc. for $C_{14}H_{30}OSn$: C, 50.48; H, 9.08; Found: C, 50.65; H, 9.12. **GCMS** (*M70*): T_R 7.68; MS calc. for $[C_{14}H_{30}OSn]^{+\bullet}$ 334. Found: 291 (M – ), 277, 235, 179 (basepeak), 163, 121. Spectral data was in accordance with the literature.[43]

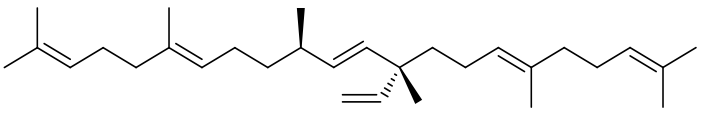
(6*E*,10*S*,11*E*,13*R*,16*E*)-2,6,10,13,17,21-Hexamethyl-10-vinyldocosa-2,6,11,16,20-pentaene, (10*R*,13*R*)-C30 botryococcene, 7



To a stirred solution of tributyl(oxiran-2-yl)stannane (196 mg, 0.588 mmol) in degassed THF (1 ml) at 0 °C under a nitrogen atmosphere, boronic ester **15** (75 mg, 0.147 mmol, 94:6 *dr*) in THF (5 ml) was added. The reaction flask was then cooled to −105 °C[¥] (MeOH/Et_2O/$N_{2(l)}$) and *n*BuLi (1.6M in hexane, 0.36 ml, 0.58 mmol) was then added via syringe pump over 20 min ensuring the bath temperature remained between −105 and −107 °C. After the addition was complete, the reaction mixture was stirred for 15 min at −105 to −107 °C. The cooling bath was not removed and the reaction was allowed to slowly approach ambient temperature. After 2 h the cooling bath was removed and the reaction mixture stirred for a further 2 h at ambient temperature. Ghosez reagent (95%, 123 µl, 0.882 mmol) was then added all at once and the reaction mixture heated at reflux for 24 h. The reaction was quenched with water (5 ml), Et_2O (10 ml) was added and the phases separated. The aqueous phase

was extracted with Et_2O (3 × 5 ml), then pentane (3 × 5 ml). The combined organic phases were washed with brine and dried over $MgSO_4$. The solvent was removed *in vacuo* and the residue purified by flash column chromatography eluting pentane to give C30 botryococcene **7** (29 mg, 48%, 94:6 *dr*)* as a colourless oil. $\boldsymbol{R_f}$ (pentane) 0.35. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.98 (3H, d, *J* 6.71, CHC*H*$_3$), 1.09 (3H, s, CH_3), 1.27-1.34 (2H, m, CH_2), 1.36-1.41 (2H, m, CH_2), 1.58 (3H, s, CH_3), 1.59 (3H, s, CH_3), 1.61 (6H, s, CH_3), 1.69 (6H, s, CH_3), 1.89-2.03 (8H, m, CH_2), 2.03-2.14 (5H, m, CH_2 & C*H*CH_3), 4.95 (1H, dd, *J* 17.4, 1.5, CH=CH*H*), 4.96 (1H, dd, *J*, 10.7, 1.5, CH=C*H*H), 5.11 (4H, app. qm, *J* 7.0, C=CH), 5.20 (1H, dd, *J* 15.7, 7.9, CHC*H*=CH), 5.36 (1H, dd, *J* 15.7, 0.9, CHCH=C*H*), 5.82 (1H, dd, *J*, 17.4, 10.7, C*H*=CHH). $\boldsymbol{\delta_C}$ (100 MHz, $CDCl_3$): 15.90 (CH_3), 15.97 (CH_3), 17.67 (CH_3), 17.68 (CH_3), 21.10† (CH_3), 21.14 (CH_3), 23.09† (CH_2), 23.11 (CH_2), 23.53† (CH_3), 23.56 (CH_3), 25.69 (CH_3), 25.70 (CH_3), 25.80† (CH_2), 25.81 (CH_2), 26.73 (CH_2), 26.75 (CH_2), 36.65† (CH), 36.68 (CH), 37.38 (CH_2), 39.72 (CH_2), 39.74 (CH_2), 41.30† (CH_2), 41.33 (CH_2), 42.02 (4° C), 111.10 (CH_2), 124.39 (CH), 124.42 (CH), 124.71 (CH), 124.83 (CH), 131.22 (4° C), 131.26 (4° C), 133.71† (CH), 133.74 (CH), 134.67 (4° C), 134.71 (4° C), 135.80† (CH), 135.82 (CH), 146.75 (CH), 146.77† (CH), †*indicates minor diastereomer*. $\boldsymbol{\nu_{max}}$ (neat): 911, 975, 1375, 1451, 1634, 1671, 2853, 2915, 2964. **GCMS** (*M70*): T_R 10.84; MS calc. for $[C_{30}H_{50}]^{+\bullet}$ 410. Found: 410,395, 367, 325, 299, 285, 271, 259, 257, 245, 231, 217, 203, 191, 189, 175, 161, 149, 135, 121, 109, 95, 81, 69 (basepeak), 55. $^{¥}$An internal temperature of less than −100 °C is required. *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 36.68 & 36.64, and 133.71 & 133.74. The spectrum was collected and analysed via the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2. Spectral data was in accordance with the literature[44, 45]

(6*E*,10*R*,11*E*,13*R*,16*E*)-2,6,10,13,17,21-Hexamethyl-10-vinyldocosa-2,6,11,16,20-pentaene, (10*R*,13*R*)-C30 botryococcene, 10-*epi*-7



Following the above procedure, using boronic ester **20** (62 mg, 0.121 mmol, 94:6 *dr*), gave 10-*epi*-**7** (25 mg, 50%, 94:6 *dr*)* as a colourless oil. $\boldsymbol{\delta_H}$ (400 MHz, $CDCl_3$): 0.98 (3H, d, *J* 6.71, CHC*H*$_3$), 1.09 (3H, s, CH_3), 1.27-1.34 (2H, m, CH_2), 1.36-1.41 (2H, m, CH_2), 1.58 (3H, s, CH_3), 1.59 (3H, s, CH_3), 1.61 (6H, s, CH_3), 1.69 (6H, s, CH_3), 1.89-2.03 (8H, m, CH_2), 2.03-2.14 (5H, m, CH_2 & C*H*CH_3), 4.95 (1H, dd, *J* 17.4, 1.5, CH=CH*H*), 4.96 (1H, dd, *J*, 11.0, 1.5, CH=C*H*H), 5.11 (4H, app. qm, *J* 7.0, C=CH), 5.21 (1H,

dd, *J* 15.9, 7.9, CHC*H*=CH), 5.36 (1H, dd, *J* 15.9, 0.9, CHCH=C*H*), 5.82 (1H, dd, *J*, 17.4, 11.0, C*H*=CHH). δ_C (100 MHz, $CDCl_3$): 15.90 (CH_3), 15.98 (CH_3), 17.67 (CH_3), 17.68 (CH_3), 21.09 (CH_3), 21.13† (CH_3), 23.09 (CH_2), 23.11† (CH_2), 23.53 (CH_3), 23.56† (CH_3), 25.69 (CH_3), 25.70 (CH_3), 25.79 (CH_2), 25.81† (CH_2), 26.73 (CH_2), 26.75 (CH_2), 36.64 (CH), 36.68† (CH), 37.37 (CH_2), 39.71 (CH_2), 39.74 (CH_2), 41.29 (CH_2), 41.33† (CH_2), 42.02 (4° C), 111.08 (CH_2), 124.39 (CH), 124.42 (CH), 124.71 (CH), 124.84 (CH), 131.23 (4° C), 131.26 (4° C), 133.71 (CH), 133.74† (CH), 134.67 (4° C), 134.73 (4° C), 135.79 (CH), 135.81† (CH), 146.76† (CH), 146.78 (CH), †*indicates minor diastereomer*. ν_{max} (neat): 911, 975, 1375, 1451, 1634, 1671, 2853, 2915, 2964. *Determined by average relative integrals of diastereomeric ^{13}C NMR signals at 36.65 & 36.68, 41.33 & 41.29, and 133.74 & 133.71. The spectrum was collected and analysed via the following parameters: 5 second relaxation delay, 2000 scans, 131072 original data points, and applying line broadening of 0.2. All other spectroscopic data matched **7**.

(10*S*,13*R*)-7	**(10*R*,13*R*)-7**	
Shift / ppm	Shift / ppm	multiplicity
15.90	15.90	CH_3
15.97	15.98	CH_3
17.67	17.67	CH_3
17.68	17.68	CH_3
21.14	21.09	CH_3
23.11	23.09	CH_2
23.56	23.53	CH_3
25.69	25.69	CH_3
25.70	25.70	CH_3
25.81	25.79	CH_2
26.73	26.73	CH_2
26.75	26.75	CH_2

36.68	36.64	CH
37.38	37.37	CH_2
39.72	39.71	CH_2
39.74	39.74	CH_2
41.33	41.29	CH_2
42.02	42.02	4° C
111.10	111.08	CH_2
124.39	124.39	CH
124.42	124.42	CH
124.71	124.71	CH
124.83	124.84	CH
131.22	131.23	4° C
131.26	131.26	4° C
133.74	133.71	CH
134.67	134.67	4° C
134.71	134.73	4° C
135.82	135.79	CH
146.75	146.78	CH

References

1. Armarego, W. L. F.; Perrin, D. D., *Purification of Laboratory Chemicals*, *Fourth Ed.*, The Bath Press, Bath, **1997**, p 192.

2. Nikolic, N. A.; Beak, P.; Reeder, M. R.; Boeckman Jr, R. K.; *Org. Synth., Coll. Vol.,* **1998**, *9*, 391.

3. Winkle, M. R.; Lansinger, J. M.; Ronald, R. C.; *J. Chem. Soc., Chem. Commun.,* **1980**, 87-88.

4. Still, W. S.; Kaha, M.; Mitra, A.; *J. Org. Chem.*, **1978**, *43*, 2923-2925.

5. Tanaka, K.; Kobayashi, T.; Mon, H.; Katsumura, S.; *J. Org. Chem.*, **2004**, *69*, 5606-5925.

6. Kocienski, P. J.; Christopher, J. A.; Bell, R.; Oho, B.; *Synthesis*, **2005**, *1*, 75-84.

7. Fleming, I.; Higgins, D.; Lawrence, N. J.; Thomas, A. P.; *J. Chem. Soc., Pekin Trans. 1*, **1992**, 3331-3349.

8. Stavinola, J. L.; Mariano, P. S.; Leone-Bay, A.; Swanson, R.; Bracken, C.; *J. Am. Chem. Soc.*, **1981**, *103*, 3148-3160.

9. Fleming, F. F.; Liu, W.; Ghosh, S.; Steward, O. W.; *J. Org. Chem.*, **2008**, *73*, 2803-2810.

10. Seebach, S.; Beck, A. K.; Schmidt, B.; Wang, Y. M.; *Tetrahedron*, **1994**, *50*, 4363-4384.

11. Gauthier, D.; Lindhardt, A. T.; Olsen, E. P. K.; Overgaard, J.; Skrydstrup, T.; *J. Am. Chem. Soc.*, **2010**, *132*, 7998-8009.

12. Jacquet, O.; Legros, J.-Y.; Coliboeuf, M.; Fiaud, J.-C.; *Tetrahedron*, **2008**, *64*, 6530-6536.

13. Hill, H. W. H.; Kenyon, J.; Phillips, H.; *J. Chem. Soc.*, **1936**, 576-583.

14. Goering, H. L.; Kimoto, W. I.; *J. Am. Chem. Soc.*, **1965**, *87*, 1748-1753.

15. Liang, J.; Hoard, D. W.; Khau, V. V.; Martinelli, M. J.; Moher, E. D.; Moore, R. E.; Titus, M. A.; *J. Org. Chem.*, **1999**, *64*, 1459-1463.

16. Lüssen, B. J.; Gais, H.-J.; *J. Org. Chem.*, **2004**, *69*, 4041-4052.

17. Herber, C.; Breit, B.; *Chem. Eur. J.*, **2006**, *12*, 6684-6691.

18. Hansson, S.; Heumann, A.; Rein, T.; Åkermark, B.; *J. Org. Chem.*, **1990**, *55*, 975-984.

19. Fleming, I.; Higgins, D.; Lawrence, M. J.; Thomas, A. P.; *J. Chem. Soc., Pekin Trans. 1*, **1992**, 3331-3349.

20. Krämer, T.; Hoppe, D.; *Tetrahedron Lett.*, **1987**, *28*, 5149-5152.

21. Schwark, J.-R.; Hoppe, D.; *Synthesis*, **1990**, *4*, 291-294.

22. Ogawa, J.; Xie, S. X.; Shimizu, S.; *Appl. Microbiol. Biotechnol.*, **1999**, *51*, 53-57.

23. Lowe, J. T.; Panek, J. S.; *Org. Lett.*, **2005**, *7*, 1529-1532.

24. Yamamoto, Y.; Fujikawa, R.; Umemoto, T.; Miyaura, N.; *Tetrahedron*, **2004**, *60*, 10695-10700.

25. Murata, M.; Oyama, T.; Watanabe, S.; Masuda, Y.; *J. Org. Chem.*, **2000**, *65*, 164-168.

26. Stymiest, J. L.; Dutheuil, G.; Mahmood, A.; Aggarwal, V. K.; *Angew. Chem. Int. Ed.*, **2007**, *46*, 7491-7494.

27. Shibuya, M.; Tomizawa, M.; Iwabuchi, Y.; *Org. Lett.*, **2008**, *10*, 4715-4718.

28. Kim, H. C.; Youn, J.-H.; Kang, S. H.; *Synlett*, **2008**, *16*, 2526-2528.

29. Uyanik, M.; Fukatsu, R.; Ishihara, K.; *Org. Lett.*, **2009**, *11*, 3470-3473.

30. Cole, A. P.; Mahadevan, V.; Mirica, L. M.; Ottenwaelder, X.; Stack, T. D. P.; *Inorganic Chemistry,* **2005**, *44*, 7345-7364.

31. Archelas, A.; Furstoss, R.; *J. Org. Chem.,* **1999**, *64*, 6112-6114.

32. Kiyotsuka, Y.; Katayama, Y.; Acharya, H. P.; Hyodo, T.; Kobayashi, Y.; *J. Org. Chem.,* **2009**, *74*, 1939-1951.

33. Michnick, T. J.; Matteson, D. S.; *Synlett,* **1991**, 631-632.

34. Matteson, D. S.; Soundararajan, R.; Ho, O. C.; Gatzweiler, W.; *Organometallics,* **1996**, *15*, 152-163.

35. Yanagisawa, A.; Habaue, S.; Yamamoto, H.; *J. Am. Chem. Soc.,* **1991**, *113*, 5893-5895.

36. Burns, T. P.; Rieke, R. D.; *J. Org. Chem.,* **1987**, *52*, 3674-3680.

37. Clough, J. M.; Pattenden, G.; *Tetrahedron,* **1981**, *37*, 3911-3920.

38. Vidal, D. M.; Fonseca, M. G.; Zarbin, P. H. G.; **2010**, *51*, 6704-6706.

39. Brown, H. C.; Singh, S. M.; Rangaishenvi, M. V.; *J. Org. Chem.,* **1986**, *51*, 3150-3155.

40. Yamazaki, N.; Suzuki, T.; Yuta, Y.; Kibayashi, C.; Aoyagi, S.; *Heterocycles,* **2008**, *75*, 285-290.

41. Marion, F.; Williams, D. E.; Patrick, B. O.; Hollander, I.; Mallon, R.; Kim, S. C.; Roll, D. M.; Feldberg, L.; Soest, R. V.; Anderson, R. J.; *Org. Lett.,* **2006**, *8*, 321-324.

42. Ohkuma, T.; Koizumi, M.; Doucet, H.; Pham, T.; Kozawa, M.; Murata, K.; Katayama, E.; Yokozawa, T.; Ikariya, T.; Noyori, R.; *J. Am. Chem. Soc.,* **1998**, *120*, 13529-13530.

43. Chong, J. M.; Mar, E. K.; *J. Org. Chem.,* **1992**, *57*, 46-49.

44. Metzger, P.; Casadevall, E.; Pouet, M. J.; Pouet, Y.; *Phytochemistry*, **1985**, *24*, 2995-3002.

45. Okada, S.; Murakami, M.; Yamaguchi, K.; *Phytochemical Analysis*, **1997**, *8*, 198-203.