methylenebicyclobutanecarbonitrile: 10 g (0.13 mol) of this compound was vigorously stirred with 30 g of HBr (47%) at room temperature for 24 h. The reaction mixture was treated with water and ether, and the ethereal phase was washed with a 10% $NaHCO_3$ solution, then with water, and finally with a saturated NaCl solution. After drying over $MgSO_4$ and evaporation, 18 g of a yellow liquid consisting mainly (95%) of the two isomers **4a** and **4s** was obtained. The isomers were purified by preparative gas chromatography. **4s**: ^{1}H NMR δ 1.95 (s, 3 H), 2.65-2.72, 2.92-3.0 (m, 4 H), 3.4-3.55 (m, 1 H); ^{13}C NMR δ 17.5 (CH_3), 33.8 (C-CN), 45.2 (CH_2), 58.4 (C-Br), 121.0 (CN); *m/e* (CI) 174-176, 127, 94. **4a**: ^{1}H NMR δ 1.90 (s, 3 H), 2.75-2.85, 2.95-3.2 (m, 5 H); ^{13}C NMR δ 17.5 (CH_3), 31.9 (C-CN), 45.1 (CH_2), 52.5 (C-Br), 120.5 (CN); *m/e* (CI) 176-174, 94, 72. Satisfactory C,H,N,Br analysis was obtained for the two isomers. The elimination product 3-methylbicyclobutanecarbonitrile is a known compound.[26] 3-Chlorocyclobutyl phenyl ketone (**5**) was prepared from the corresponding alcohol: 7 g (0.06 mol) of thionyl chloride was heated to 55 °C in a round-bottom flask equipped with reflux condenser and a separatory funnel. At this temperature 4.5 g (0.028 mol) of 3-hydroxycyclobutyl phenyl ketone[27] with 250 μL of DMF was added over 45 min through the separatory funnel. The reaction mixture was heated to 98 °C with mixing until HCl evolution ceased (2 h). It was then treated with water and $CHCl_3$, the chloroform layer was separated and washed with water and a 10% $NaHCO_3$ solution, and the mixture was dried and evaporated, yielding 6 g of red oil. Column chromatography (Kieselgel 60, hexane) of the oil gave (second fraction) 4.2 g (77% yield) of a mixture of the two isomers **5s** and **5a**. The isomers were separated and purified by preparative gas chromatography (0.5% Carbowax 20 M on Chromosorb P at 130 °C). **5s**: ^{1}H NMR δ 2.65, 2.95 (m, 4 H), 4.25 (p, 1 H), 4.5 (p, 1 H); ^{13}C NMR δ 51.0 (t, C-Cl), 36.6 (CH_2), 37.5 (C-CO), 199.6 (CO), 135.1, 128.3, 128.7 (C_6H_5); *m/e* (CI) 195-197, 159, 105, **5a**: ^{1}H NMR δ 2.65, 2.85 (m, 4 H), 3.8 (p, 1 H), 4.5 (p, 1 H); ^{13}C NMR δ 48.3, 37.5, 36.4, 198.1, 135.2, 128.3, 128.7, 135.2 (peak assignment as for **5a**); *m/e* (CI) 195-197, 159, 105. Satisfactory C,H analysis was obtained for the two isomers. 3-Chloro-1-deuteriocyclobutyl phenyl ketone was prepared by slow addition of 4 mL of trifluoroacetic anhydride to a cooled mixture of 4 mL of D_2O and 1.5 g (0.008 mol) of **5** (as an isomer mixture). The mixture was vigorously stirred for ca. 20 h at 60 °C under nitrogen, extracted with CH_2Cl_2, and washed with $NaHCO_3$ solution and water. Drying over $MgSO_4$ and evaporation of the ether gave 1.5 g of a mixture of the two isomers deuteriated α to the carbonyl group (90% by NMR) together with ca. 15% of an unidentified substance. 1-Bicyclobutyl phenyl ketone was obtained by dehydrochlorination of **5** according to the following procedure. To a 25-mL *t*-BuOH solution of 1 g of **5** (0.0052 mol) were added 5-mL portions of *t*-BuOK-*t*-BuOH solution (0.2 M) until GC analysis indicated that all the starting material had been consumed. At the end, 0.1 g of phenothiazine was added to the reaction mixture, which was then treated with water and ether. The ethereal layer was dried over $MgSO_4$ and most of the organic solvent was evaporated. The pure product was obtained by preparative gas chromatography (0.5% XE60 non-acid-washed on Chromosorb W, 95 °C). However, most of it decomposes on the column and separation yield is 5-10%: ^{1}H NMR δ 1.5 (d, 2 H), 2.6 (d, 2 H), 2.2 (m, 1 H), 7.1-8.1 (m, 5 H); *m/e* (EI) 157, 129, 115, 105, 77.

Kinetic Procedure. Stock solutions of the substrates containing biphenyl, naphthalene, or fluorene as internal standards in *t*-BuOH were prepared and mixed with the appropriate aliquots of *t*-BuOK-*t*-BuOH solutions. Crown ether when needed was added to the base stock solutions. Samples of 0.1 mL were periodically removed, quenched by 0.1 mL of water, and analyzed by gas chromatography.

Acknowledgment. Helpful discussions with Professors P. Ahlberg and D. J. McLennan are gratefully acknowledged.

Registry No. 2, 27744-70-3; **3s**, 110509-57-4; **3a**, 110509-58-5; **4s**, 110509-59-6; **4a**, 110509-60-9; **5s**, 110509-61-0; **5a**, 110509-62-1; 3-methylenecyclobutanecarbonitrile, 15760-35-7; 3-hydroxycyclobutyl phenyl ketone, 110509-63-2; *cis*-3-chloro-1-deuteriocyclobutyl phenyl ketone, 110509-64-3; *trans*-3-chloro-1-deuteriocyclobutyl phenyl ketone, 110509-65-4; 1-bicyclobutyl phenyl ketone, 24464-69-5.

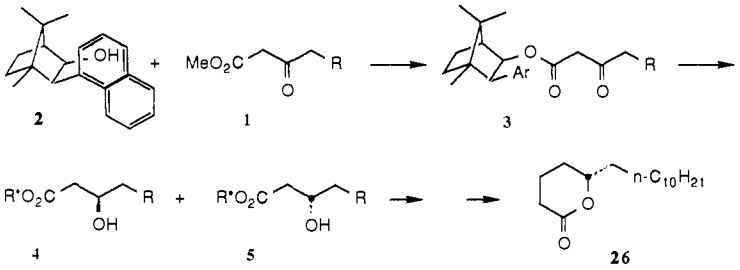
(26) Blanchard, E. P.; Cairncross, A. *J. Am. Chem. Soc.* **1966**, *88*, 487.
(27) Aurbach, D. Ph.D. Thesis, Bar-Ilan University, 1983.

Enantioselective Construction of Dialkylcarbinols: Synthesis of (-)-5-Hexadecanolide†

Douglass F. Taber,*[1] P. Bruce Deker, and Micheal D. Gaul[2]

Contribution from the Department of Chemistry, University of Delaware, Newark, Delaware 19716. *Received April 3, 1987*

Abstract: Alcohol **2** is designed to block one face of the carbonyls in the derived β-keto ester **3**. Hydride reduction can then



proceed either via the transition state in which the carbonyls are syn ($ZnCl_2$/$Zn(BH_4)_2$, **4:5** = 92:8) or via the alternative transition state in which the carbonyls are anti (Dibal·BHT, **4:5** = 4:96). Alkyl coupling of the primary tosylate of the 1,3-diol from $LiAlH_4$ reduction of **5** then opens a general enantioselective route to dialkylcarbinols.

With an increase in the complexity of the targets of natural product synthesis has come an increasing reliance on convergent synthetic design. A requisite for the desired convergence is the availability of synthetic intermediates of high optical purity. Current methods for enantioselective acyclic construction include direct incorporation of naturally derived starting materials,[3] enantioselective epoxidation of allylic alcohols,[4] hydride reduction of sterically biased ketones,[5] and addition of a carbon nucleophile

† Dedicated to Professor Gilbert Stork on the occasion of his 66th birthday.

(1) Fellow of the Alfred P. Sloan Foundation, 1983-1987.
(2) Undergraduate research participant, University of Delaware.
(3) Hannessian, S. *Total Synthesis of Natural Products: The "Chiron Approach"*; Pergamon: London, 1983.
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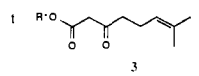
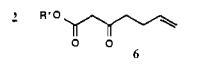
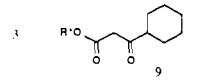
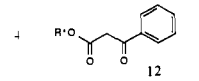
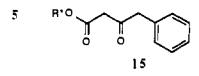
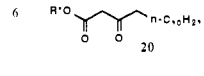
Table I. Stereoselective Reduction of β-Keto Esters

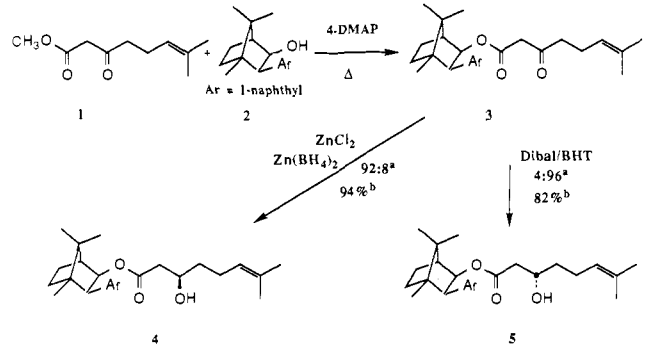
Entry	β-Ketoester	Method[a,b]	% Yield[c]	β-Hydroxyester Diastereomers ratio[d]
1	 3	A	94	92 : 8
		B	82	4 : 96
2	 6	A	92	92 : 8
		B	93	4 : 96
3	 9	A	96	90 : 10
		B	95	10 : 90
		B	--	4 : 96[e]
4	 12	A	93	93 : 7
		B	93	44 : 56
5	 15	A	96	90 : 10
		B	90	65 : 35
6	 20	A	94	94 : 6[f]
		B	98	1 : 99[f,g]

[a] General procedure: $Zn(BH_4)_2/ZnCl_2$—see Experimental Section. [b] General procedure: Dibal/BHT. [c] Yield is of product isolated by column chromatography and is based on consumed starting material. [d] Ratio by HPLC. [e] Recrystallization three times from 0.5 M hexane improved by the ratio to the extent indicated. [f] Ratio by ^1H NMR of alcohol methine multiplets; no separation was observed on HPLC. [g] The methine multiplet of the minor diastereomer was not detectable by ^1H NMR.

to an aldehyde, either using an enantiomerically pure nucleophile[6] or first dervatizing the aldehyde with an enantiomerically pure reagent.[7] We now report a complementary, highly flexible approach to such enantiomerically pure synthetic intermediates, based on the diastereoselective reduction of an enantiomerically pure β-keto ester.[8]

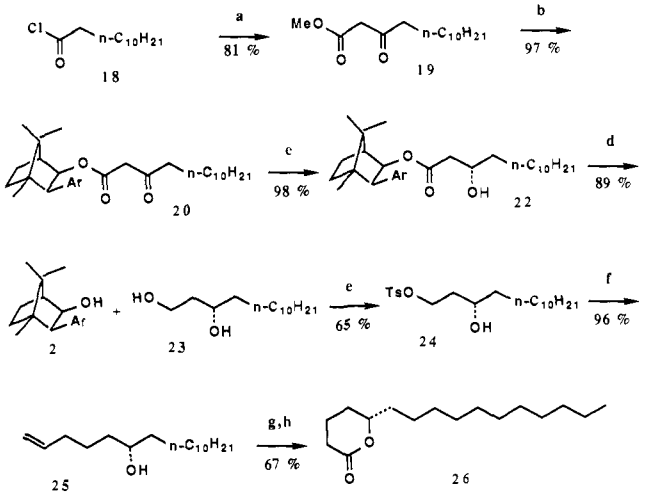
The key to this approach is the definition of the three-dimensional space surrounding the target ketone. The requisite enantiomerically pure β-keto ester **3** is available by 4-(dimethylamino)pyridine (4-DMAP) catalyzed exchange[9] of methyl ester

Scheme I



[a] Diastereomer ratio, by HPLC. [b] Chemical yield.

Scheme II[a]



[a] (a) LDA/methyl acetate, THF, -78 °C → room temperature (0.5 h). (b) **19** (3.0 equiv), **2** (1.0 equiv), 4-DMAP, toluene, reflux (40 h). (c) Dibal/BHT (0.66/1), toluene, -65 → -60 °C (1.5 h). (d) $LiAlH_4$ (3.0 equiv), THF, 0 °C. (e) TsCl (1.1 equiv), pyridine, -10 °C → room temperature. (f) Allylmagnesium chloride (5.0 equiv), THF, 0 °C (0.5 h), reflux (3 h). (g) O_3, MeOH, -78 → -60 °C (9 min); dimethyl sulfide (15 equiv), -60 °C → room temperature (12 h). (h) PCC (1.5 equiv), NaOAc/powdered 4A molecular sieves (5/1), CH_2Cl_2, room temperature.

1[10] with R*OH **2**[11] (Scheme I). We reasoned that in **3**, the expected extended conformation of the ester would define the position of the β-keto ester methylene with regard to the face-blocking arene. The ketone would, however, still be freely rotating. It was necessary to introduce an additional interaction to freeze out this rotation. This interaction could be either attractive or repulsive.

We reasoned that activation of the ketone by complexation with a bidentate metal ion should favor the syn conformation of the β-keto ester. In fact, exposure of β-keto ester **3** to anhydrous $ZnCl_2$ in toluene at room temperature, followed by cooling to -78 °C and addition of $Zn(BH_4)_2$,[12] leads to **4** and **5** in a ratio of 92:8. This ratio is significantly better than that usually observed from

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(6) Brown, H. C.; Jadhav, P. K. *J. Am. Chem. Soc.* **1983**, *105*, 2092.
(7) Johnson, W. S.; Lindell, S. D.; Elliott, J. D. *Tetrahedron Lett.* **1984**, *25*, 3947.
(8) (a) For the enantioselective reduction of β-keto esters derived from aryl ketones using chirally modified $LiBH_4$, see: Soai, K.; Yamanoi, T.; Hikima, H.; Oyamada, H. *J. Chem. Soc., Chem. Commun.* **1985**, 138. (b) For the enantioselective reduction of β-keto esters using high-pressure hydrogenation with chirally modified Raney nickel, see: Nakahata, M.; Imaida, M.; Ozaki, H.; Harada, T.; Tai, A. *Bull. Chem. Soc. Jpn.* **1982**, *55*, 2186. We thank a reviewer for bringing these references to our attention.
(9) Taber, D. F.; Amedio, J. C.; Patel, Y. K. *J. Org. Chem.* **1985**, *50*, 3618.
(10) LaLonde, R. T.; Muhammad, N.; Wong, C. F. *J. Org. Chem.* **1977**, *42*, 2113.
(11) (a) For the preparation of **1**, see: Taber, D. F.; Raman, K.; Gaul, M. D. *J. Org. Chem.* **1987**, *52*, 28. (b) Concurrently with our work, others have investigated chiral induction with modified bornyl esters. For leading references, see: Helmchen, G.; Schmierer, R. *Tetrahedron Lett.* **1983**, *24*, 1235. Oppolzer, W.; Chapuis, C. *Tetrahedron Lett.* **1983**, *24*, 4665. Somfai, P.; Tanner, D.; Olsson, T. *Tetrahedron* **1985**, *41*, 5973.
(12) For preparation of $Zn(BH_4)_2$, see: Grinsler, W. J.; Johnson, F. A.; Sloan, A. D. B. *J. Am. Chem. Soc.* **1960**, *82*, 6074. For stereoselective reductions using $Zn(BH_4)_2$, see: (a) Ito, Y.; Yamaguchi, M. *Tetrahedron Lett.* **1983**, *24*, 5385. (b) Nakata, J.; Oishi, T. *Tetrahedron Lett.* **1980**, *21*, 1641. (c) Corey, E. J.; Nicolaou, K. C.; Machida, Y.; Malmsten, C. L.; Samuelsson, E. *Proc. Natl. Acad. Sci. U.S.A.* **1975**, *72*, 3355.

the alternative yeast reduction of a long-chain β-keto ester.[13]

In a complementary fashion, activation of the ketone by complexation with a sterically demanding monodentate metal center should favor the anti conformation (in the transition state), leading to the diastereomeric product alcohol. In fact, reduction of **3** in toluene at −78 °C with the Dibal·BHT complex[14] yields **4** and **5** in a ratio of 4:96.[15]

We have carried out these reductions on a representative series of β-keto esters (Table I). In contrast to enzymatic reduction,[13] the product ratios do not deteriorate on increasing chain length. While the differentially shifted carbinol methines of **4** (^{1}H NMR: δ 3.00) and **5** (^{1}H NMR: δ 2.81) offered a convenient check of diastereoselectivity in the reduction, more precise product ratios were established by HPLC. The absolute stereochemistry of **5** was confirmed by reduction to the known[16] diol.

While aryl ketones are not handled efficiently (Table I, entries 4 and 5), alternative approaches already developed[8b] are particularly effective for such ketones. It should be noted that *sec*-alkylcarbinols such as those produced from this reduction are readily converted to trialkylated ternary centers[16] and amines,[17] and that β-hydroxy esters such as **5** can be α-alkylated with excellent diastereoselection.[18]

The ready availability of homologated dialkylcarbinols by this approach is illustrated by the synthesis (Scheme II) of (−)-5-hexadecanolide (**26**), a pheromone of the wasp *Vespa orientalis*.[19,20] Thus, $LiAlH_4$ reduction of **22** gives chiral diol **23**, $[\alpha]^{22}_D$ +3.50° (*c* 1.8, EtOH), along with the recovered chiral auxiliary **2** (94%). Treatment of **23** with *p*-toluenesulfonyl chloride selectively affords monotosylate **24**, which smoothly couples with allylmagnesium bromide, without copper catalysis,[21] to give **25**, $[\alpha]^{24}_D$ −2.33° (*c* 1.9, EtOH). Reductive ozonolysis, followed immediately by PCC oxidation,[20h] then gives the desired lactone **26**, $[\alpha]^{21}_D$ −37.1° (*c* 2.21, THF), mp 38.5–39.5 °C, in 37% overall yield from **22**. Comparison with literature specific rotation values for the enantiomer of **26** (literature values for the rotation of the "optically pure" enantiomer of **26** range from +36.5°[20f] to +40.2°[20j]) serves to confirm the stereochemistry of the initial reduction product **22**.

We have demonstrated in this work that by judicious design, it is possible to define the three-dimensional space around a chiral β-keto ester. In continuing work, we are exploring the diastereoselectivity of other transformations along the extended ester chain.

Experimental Section

General Methods. ^{1}H and ^{13}C NMR spectra were recorded on a Bruker AM-250 spectrometer as solutions in $CDCl_3$. ^{13}C multiplicities were determined with the aid of an INEPT[22] sequence, separating methyl and methine carbon (=up (u)) from methylene and quaternary carbon (=down (d)). Column chromatography was performed with TLC-mesh silica gel, following the procedure we have described.[23]

General Procedure for $Zn(BH_4)_2$ Stereoselective Reduction (Procedure A). $ZnCl_2$ (3 equiv), which had previously been dried in a vacuum oven at 75 °C for 24 h and stored in a desiccator, and β-keto ester (1 equiv) were suspended in toluene (0.02 M in β-keto ester) in a flame-dried, one-necked flask fitted with a septum, a magnetic stir bar, and an N_2 inlet. After 0.5 h of stirring at room temperture, the flask was cooled to −78 °C, and 0.03 M $Zn(BH_4)_2$ (3 mol equiv) as a slurry in toluene was added dropwise via syringe over 5 min.[12] Stirring was continued for 0.5–3.0 h at −78 °C. The reaction mixture was quenched with 3% aqueous H_3PO_4 (8 mol equiv) and extracted three times with EtOAc (0.01 M in β-keto ester).

General Procedure for Dibal·BHT Stereoselective Reduction (Procedure B). A solution of diisobutylaluminum 2,6-di-*tert*-butyl-4-methylphenoxide was prepared by analogy to the method of Yamamoto.[14] Thus, to vacuum oven dried (20 °C, 1 mmHg, 24 h) 2,6-di-*tert*-butyl-4-methylphenol (12 mol equiv) in toluene (0.1 M in β-keto ester) at 0 °C was added dropwise via syringe diisobutylaluminum hydride (1 M solution in toluene, 8 mol equiv). The solution was stirred at 0 °C for 1 h and then chilled to −78 °C. A solution of 0.1 M chiral β-keto ester (1 equiv) in toluene was added dropwise via syringe to the above reduction media and stirred at −78 °C for 0.5 h. The reaction was complete after warming to −65 to −60 °C for an additional 1.5 h. The reaction mixture was quenched with 10% aqueous HCl (6 mol equiv) and extracted three times with EtOAc (0.006 M in β-keto ester).

General Procedure for Acid Chloride (Procedure C). A one-necked flask equipped with a septum, a magnetic stir bar, and an N_2 inlet needle was charged with carboxylic acid (1 equiv), DMF (3 drops), and CH_2Cl_2 (1 M). The flask was cooled to 0 °C and oxalyl chloride (1.5 equiv) was cautiously added via syringe. The flask was allowed to warm to room temperature over 1 h and then stirred at room temperature for 3 h. The material was concentrated by rotary evaporation, without further evacuation at the pump. The residual oil was used immediately without purification.

General Procedure for Acylation (Procedure D). Following the method of Rathke,[24] acylation was performed. Thus, diisopropylamine (3.1 equiv) was dissolved in THF (0.5 M in acid chloride) in a flame-dried, two-necked flask equipped with a septum, an N_2 inlet needle, a magnetic stir bar, and a low-temperature thermometer. The flask was cooled to −78 °C. *n*-BuLi (3.0 equiv) was added rapidly, but slowly enough that the internal temperature was ≤−40 °C. The temperature was brought to −10 °C by immersion in an ice/salt bath for 15 min and then the flask was recooled to −78 °C. Methyl acetate (3 equiv) was added at a rate that allowed the temperature to remain at or below −65 °C. This mixture was stirred at −78 °C for 5 min, and then acid chloride (1 equiv) was added all at once as a solution in THF. The −78 °C bath was removed immediately and the reaction was allowed to warm to room temperature. The mixture was diluted with 10% aqueous HCl and extracted with Et_2O (three times).

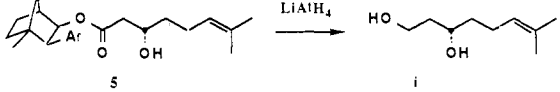
General Procedure for Ester Exchange (Procedure E). Ester exchange was accomplished by a method reported previously.[9] Thus methyl β-keto ester (3 equiv), 4,7,7-trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-ol (**2**)[11] (1 equiv), and 4-(dimethylamino)pyridine (0.5 equiv) were dissolved in toluene (1 M in β-keto ester) in a one-necked flask equipped with a reflux condenser, a septum, an N_2 inlet needle, and a magnetic stir bar. The mixture was stirred at reflux for 40 h, allowed to cool to room temperature, and quenched with aqueous NH_4Cl. The resulting solution was extracted with EtOAc and then bulb-to-bulb distilled (155 °C, 0.2 mmHg) to remove excess methyl β-keto ester. The residual oil was chromatographed.

Preparation of Methyl 7-Methyl-3-oxo-oct-6-enoate (1). β-Keto ester (32.83 mmol), prepared as by LaLonde,[10] was chromatographed on 100 g of silica gel, eluting with 15% EtOAc/petroleum ether (1100 mL). The first 500 mL was discarded. The next 500 mL was concentrated in vacuo to give **1** as a colorless oil: R_f (20% EtOAc/hexane) 0.47; ^{1}H NMR 1.61

(13) For leading references to the microbial reduction of β-keto esters, see: Sih, C. J.; Shieh, W. R.; Gopalan, A. S. *J. Am. Chem. Soc.* **1985**, *107*, 2993.

(14) For preparation, characterization, and use of diisobutylaluminum 2,6-di-*tert*-butyl-4-methylphenoxide in stereoselective reductions, see: Yamamoto, H.; Iguchi, S.; Nakai, H.; Hayashi, M. *J. Org. Chem.* **1979**, *44*, 1363 and references cited therein.

(15) The relative configuration of **5** was confirmed by reduction to diol i ($[\alpha]^{22}_D$ −5.45° (*c* 4.5, $CHCl_3$) (lit.[15] $[\alpha]^{18}_D$ +5.9° (*c* 2.0, $CHCl_3$)) for the enantiomer. It should be noted that the $[\alpha]_D$ reported for i is for material purified by silica chromatography. Distillation of i returned material having $[\alpha]^{22}_D$ −4.64° (*c* 1.5, $CHCl_3$).



5 i

(16) Hirama, M.; Noda, T.; Ito, S. *J. Org. Chem.* **1985**, *50*, 127.

(17) Mitsunobu, O. *Synthesis* **1981**, 1.

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Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 7-Methyl-3-oxo-6-octenoate (3). Following procedure E, **1** (2.616 g, 14.2 mmol) was transesterified with alcohol **2**. The residual oil (1.996 g) was chromatographed on 100 g of silica gel, eluting with 4.5% EtOAc/petroleum ether (1200 mL). The first 700 mL was discarded. The next 400 mL was concentrated in vacuo to give **3** as a colorless viscous oil: 1.887 g (92%); R_f 0.58; ^{1}H NMR 0.99 (s, 3 H), 1.23 (s, 3 H), 1.28 (s, 3 H), 1.51 (s, 3 H), 1.63 (s, 3 H), 1.15–2.05 (m, 9 H), 2.60 (s, 2 H), 4.06 (d, J = 8.8 Hz, 1 H), 4.77 (bt, J = 7.2 Hz, 1 H), 5.54 (d, J = 8.8 Hz, 1 H), 7.42 (m, 3 H), 7.62 (d, J = 7.7 Hz, 1 H), 7.68 (d, J = 7.7 Hz, 1 H), 7.80 (bd, J = 8.3 Hz, 1 H), 8.05 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.7 (u), 17.5 (u), 21.5 (u), 21.8 (d), 23.7 (u), 23.8 (d), 25.5 (u), 41.9 (d), 42.4 (d), 48.2 (d), 48.7 (d), 49.4 (d), 51.1 (u), 55.2 (u), 80.7 (u), 122.4 (u), 123.4 (u), 124.4 (u), 125.1 (u), 126.0 (u), 126.6 (u), 127.1 (u), 128.8 (u), 132.3 (d), 133.1 (d), 133.4 (d), 135.2 (d), 166.0 (d), 201.8 (d); IR 2972, 2962, 2957, 2934, 1744, 1722, 1256, 1242, 1236, 1229; MS 432 (M^+, 3), 263 (16), 262 (12), 247 (14), 179 (14), 171 (18), 170 (100), 169 (13), 165 (20), 153 (11); EI exact mass calcd for $C_{29}H_{36}O_3$: 432.266, obsd 432.266.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 7-Methyl-3(*R*)-hydroxy-6-octenoate (4). Following procedure A, **3** (0.020 g, 0.046 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (-78 °C, 1 h). The residual oil was chromatographed on 2 g of silica gel, eluting with 6% EtOAc/petroleum ether (65 mL). The first 15 mL was discarded. The next 5 mL was concentrated in vacuo to give recovered starting material **3** (0.003 g, 13%). The next 5 mL was discarded. The final 35 mL was concentrated in vacuo to give a mixture of **4** and **5** as a viscous oil: 0.016 g, 81% (94% based on consumed **3**); R_f 0.39. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.28 (s, 3 H), 1.34 (s, 3 H), 1.52 (s, 3 H), 1.63 (s, 3 H), 0.70–2.05 (m, 12 H), 3.00 (m, 1 H), 4.07 (d, J = 8.8 Hz, 1 H), 4.89 (bt, J = 7.2 Hz, 1 H), 5.57 (d, J = 8.8 Hz, 1 H), 7.35–7.54 (m, 3 H), 7.63 (d, J = 7.7 Hz, 1 H), 7.72 (d, J = 7.7 Hz, 1 H), 7.82 (bd, J = 8.3 Hz, 1 H), 8.02 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 17.6 (u), 21.6 (u), 23.8 (d), 24.0 (d), 25.6 (u), 35.8 (d), 41.4 (d), 42.4 (d), 48.3 (d), 49.4 (d), 51.2 (u), 55.4 (u), 67.0 (u), 80.1 (u), 123.5 (u), 123.7 (u), 124.5 (u), 125.2 (u), 126.1 (u), 126.9 (u), 127.1 (u), 128.9 (u), 131.8 (d), 133.1 (d), 133.5 (d), 135.4 (d), 171.6 (d); IR 3588, 3056, 2960, 2932, 2894, 2889, 1729, 1394, 1175, 1161; MS 306 (1), 281 (1), 263 (33), 262 (15), 179 (15), 178 (12), 171 (16), 170 (100), 169 (10), 165 (21), 155 (13), 153 (10), 152 (13), 141 (41), 137 (7). HPLC analysis at 277 nm showed two components, retention times = 110 and 118 min, in a ratio of 11.8:1. ^{1}H NMR of alcohol methine multiplets at 3.00 and 2.81 ppm gave an approximate ratio of 13:1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 7-Methyl-3(*S*)-hydroxy-6-octenoate (5). Following procedure B, **3** (0.599 g, 1.38 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed on 100 g of silica gel, eluting with 7% EtOAc/petroleum ether (1800 mL). The first 600 mL was discarded. The next 100 mL was concentrated in vacuo to give recovered starting material **3** (0.119 g, 20%). The next 400 mL was discarded. The final 600 mL was concentrated in vacuo to give a mixture of **4** and **5** as a viscous oil: 0.397 g, 66% (82% based on consumed **3**); R_f (20% EtOAc/hexane) 0.39. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.26 (s, 3 H), 1.35 (s, 3 H), 1.52 (s, 3 H), 1.66 (s, 3 H), 0.70–2.05 (m, 13 H), 2.81 (m, 1 H), 4.09 (d, J = 8.8 Hz, 1 H), 4.88 (bt, J = 7.2 Hz, 1 H), 5.53 (d, J = 8.8 Hz, 1 H), 7.35–7.57 (m, 3 H), 7.65 (d, J = 7.7, 1 H), 7.72 (d, J = 7.7, 1 H), 7.83 (d, J = 8.3, 1 H), 8.06 (d, J = 8.3, 1 H); ^{13}C NMR 14.5 (u), 17.4 (u), 21.3 (u), 23.6 (d), 23.6 (u), 25.4 (d), 35.6 (u), 41.8 (d), 42.2 (d), 48.0 (d), 49.1 (d), 50.9 (u), 55.0 (u), 66.8 (u), 79.6 (u), 123.3 (u), 123.5 (u), 124.3 (u), 125.1 (u), 125.9 (u), 126.5 (u), 126.9 (u), 128.7 (u), 131.2 (d), 132.8 (d), 133.2 (d), 170.7 (d). HPLC analysis at 277 nm showed two components, retention times = 110 and 118 min, in a ratio of 1:26.4. ^{1}H NMR of alcohol methine multiplets at 3.00 and 2.81 ppm gave an approximate ratio of 1:38.

Preparation of (-)-(3*S*)-7-Methyl-6-octene-1,3-diol. To a stirred suspension of $LiAlH_4$ (0.104 g, 2.74 mmol) in dry THF (0.6 mL) was added dropwise a solution of **5** (0.396 g, 0.913 mmol) also in dry THF (1.2 mL) at 0 °C under N_2. The reaction mixture was allowed to come to room temperature over 1.5 h and then was quenched by sequential addition of H_2O (0.1 mL), 10% NaOH (0.1 mL), and additional H_2O (0.2 mL). The precipitated lithium salts were separated by filtration and washed with ethyl acetate (30 mL). The resulting filtrate was dried over Na_2SO_4 and concentrated in vacuo. The residual oily solid (0.405 g) was chromatographed on 10 g of silica gel, eluting with 15% EtOAc/petroleum ether (850 mL) and 30% EtOAc/petroleum ether (250 mL). The first 100 mL was discarded. The next 200 mL was concentrated in vacuo to give recovered chiral auxiliary **2** (0.233 g, 91%). The next 550 mL was discarded. The final 200 mL was concentrated in vacuo to give the desired diol as a colorless oil: 0.101 g (70%); R_f (60% EtOAc/hexane) 0.19; $[\alpha]^{22}_D$ -5.45° (c 4.5, $CHCl_3$).[14] Bulb-to-bulb distillation of chromatographed diol (~150 °C, 0.22 mmHg) gave 0.097 g (67% from **5**); $[\alpha]^{22}_D$ = -4.64° (c 1.5 $CHCl_3$); ^{1}H NMR 1.45–1.80 (m, 4 H), 1.63 (s, 3 H), 1.69 (s, 3 H), 2.09 (m, 2 H), 2.76 (bs, 1 H), 2.85 (bs, 1 H), 3.72–3.95 (m, 3 H), 5.14 (bt, J = 7.2 Hz, 1 H); ^{13}C NMR 17.6 (u), 24.2 (d), 25.7 (u), 37.6 (d), 38.3 (d), 61.7 (d), 72.0 (u), 123.9 (u), 132.2 (d); IR 3510, 3422, 3365, 3315, 3229, 2969, 2927, 2860, 1449, 1441, 1377, 1067.

Preparation of Methyl 3-Oxotetradecanoate (19). Following procedure D, lauroyl chloride (2.000 g, 9.14 mol) was acylated with methyl acetate. The crude product (2.623 g) was chromatographed on 75 g of silica gel with 6% EtOAc/petroleum ether (450 mL). The first 300 mL was discarded. The next 150 mL was concentrated in vacuo to give β-keto ester **19** as a colorless oil: 1.906 g (81%); R_f 0.60; ^{1}H NMR 0.88 (t, J = 6.4 Hz, 3 H), 1.27 (bs, 16 H), 1.59 (m, 2 H), 2.54 (t, J = 7.4 Hz, 2 H), 3.45 (s, 2 H), 3.73 (s, 3 H); ^{13}C NMR 13.9 (u), 23.3 (d), 28.8 (d), 29.2 (d), 29.3 (d), 29.5 (d), 31.8 (d), 42.9 (d), 48.8 (d), 52.1 (u), 167.5 (d), 202.6 (d); IR 2955, 2928, 2856, 1751, 1722, 1235, 1151; MS (CH_4 CI) 285 ($(M + C_2H_5)^+$, 16) 258 (23) 257 ($(M + H)^+$, 100), 256 (M^+, 6), 255 (20), 237 (12), 183 (39), 116 (8). Anal. Calcd for $C_{15}H_{28}O_3$: C, 70.27; H, 11.01. Found: C, 70.52; H, 11.08.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Oxotetradecanoate (20). Following procedure E, **19** (7.153 g, 27.90 mmol) was transesterified with **2**. The residual oil (4.795 g) was chromatographed on 100 g of silica gel, eluting with 4.5% EtOAc/petroleum ether (1200 mL). The first 500 mL was discarded. The next 700 mL was concentrated in vacuo to give **20** as a colorless viscous oil: 4.672 g (99%); R_f 0.62; ^{1}H NMR 0.88 (t, J = 6.4 Hz, 3 H), 0.99 (s, 3 H), 1.22 (s, 3 H), 1.27 (bs, 16 H), 1.28 (s, 3 H), 0.80–2.07 (m, 9 H), 2.61 (s, 2 H), 4.06 (d, J = 8.8 Hz, 1 H), 5.54 (d, J = 8.8 Hz, 1 H), 7.34–7.48 (m, 3 H), 7.61 (d, J = 7.4 Hz, 1 H), 7.67 (d, J = 8.1 Hz, 1 H), 7.79 (bd, J = 8.3 Hz, 1 H), 8.02 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.1 (u), 14.7 (u), 21.5 (u), 23.1 (d), 23.7 (u), 23.8 (d), 28.7 (d), 29.1 (d), 29.3 (d), 29.3 (d), 29.3 (d), 29.4 (d), 29.6 (d), 31.9 (d), 42.0 (d), 43.7 (d), 48.3 (d), 48.7 (d), 49.4 (d), 51.1 (u), 55.2 (u), 80.7 (u), 123.5 (u), 124.5 (u), 125.1 (u), 126.0 (u), 126.6 (u), 127.2 (u), 128.7 (u), 133.1 (d), 133.4 (d), 135.2 (d), 166.1 (d), 202.2 (d); IR 2985, 2939, 2921, 2858, 1755, 1752, 1747, 1730, 1718, 1712, 1232, 1087; MS 504 (M^+, 2), 280 (3), 262 (17), 247 (9), 225 (3), 171 (25), 170 (100), 169 (10), 165 (13), 142 (11), 141 (23), 121 (11); EI exact mass calcd for $C_{34}H_{48}O_3$: 504.3603, obsd 504.359.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*R*)-Hydroxytetradecanoate (21). Following procedure A, **20** (0.188 g, 0.373 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (-78 °C, 1 h). The residual oil was chromatographed on 20 g of silica gel with 6% EtOAc/petroleum ether (440 mL). The first 50 mL was discarded. The next 70 mL was concentrated in vacuo to give recovered starting material **20** (0.014 g, 7%). The next 110 mL was discarded. The final 210 mL was concentrated in vacuo to give a mixture of **21** and **22** as a viscous oil: 0.165 g, 87% (94% based on consumed **20**); R_f 0.48. For the major diastereomer: ^{1}H NMR 0.90 (t, J = 6.4 Hz, 3 H), 0.98 (s, 3 H), 1.23 (bs, 16 H), 1.31 (s, 3 H), 0.75–2.00 (m, 15 H), 2.96 (bs, 1 H), 4.05 (d, J = 8.8 Hz, 1 H), 5.56 (d, J = 8.8 Hz, 1 H), 7.32–7.49 (m, 3 H), 7.62 (d, J = 7.7 Hz, 1 H), 7.67 (d, J = 7.7 Hz, 1 H), 7.78 (bd, J = 8.3 Hz, 1 H), 8.01 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.0 (u), 14.7 (u), 22.6 (d), 23.8 (u), 23.9 (d), 25.1 (d), 29.2 (d), 29.3 (d), 29.4 (d), 29.5 (d), 29.6 (d), 31.8 (d), 35.8 (d), 41.4 (d), 48.2 (d), 49.3 (d), 51.1 (u), 55.5 (u), 67.3 (u), 80.0 (u), 123.5 (u), 124.4 (u), 125.1 (u), 126.0 (u), 127.3 (u), 128.1 (u), 129.2 (u), 133.0 (d), 133.4 (d), 135.4 (d), 171.5 (d); IR 3588, 3055, 2990, 2885, 2867, 2844, 2731, 1744, 1463, 1384, 1273, 1207, 1021; MS 506 (M^+, 4), 378 (2), 364 (3), 263 (16), 262 (29), 247 (8), 171 (13), 170 (100), 141 (10), 121 (8); EI exact mass calcd for $C_{34}H_{50}O_3$: 506.3759, obsd 506.375. ^{1}H NMR of alcohol methine multiplets at 2.96 and 2.74 ppm gave an approximate ratio 21:22 of 17:1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-yl 3(*S*)-Hydroxytetradecanoate (22). Following procedure B, **20** (1.190 g, 2.352 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed on 100 g of silica gel, eluting with 6% EtOAc/petroleum ether (1900 mL). The first 300 mL was discarded. The next 400 mL was concentrated in vacuo to give recovered starting material **20** (0.279 g, 23%). The next 300 mL was discarded. The final 900 mL was concentrated in vacuo to give only one diastereomer **22** (by

^1H and ^{13}C NMR) as a viscous oil: 0.900 g, 75% (98% based on consumed **20**); R_f 0.48; ^1H NMR 0.90 (t, J = 6.4 Hz, 3 H), 1.01 (s, 3 H), 1.25 (bs, 16 H), 1.34 (s, 3 H), 0.75–2.05 (m, 15 H), 2.74 (bs, 1 H), 4.08 (d, J = 8.8 Hz, 1 H), 5.52 (d, J = 8.8 Hz, 1 H), 7.38–7.52 (m, 3 H), 7.66 (d, J = 7.7 Hz, 1 H), 7.71 (d, J = 7.7 Hz, 1 H), 7.82 (d, J = 8.3 Hz, 1 H), 8.06 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.1 (u), 14.7 (u), 21.6 (u), 22.6 (d), 23.8 (d), 23.9 (u), 25.3 (d), 29.2 (d), 29.3 (d), 29.5 (d), 29.5 (d), 29.6 (d), 31.9 (d), 35.9 (d), 42.0 (d), 42.4 (d), 48.3 (d), 49.3 (d), 51.1 (u), 55.3 (u), 67.5 (u), 79.9 (u), 123.5 (u), 124.6 (u), 125.3 (u), 126.1 (u), 126.7 (u), 127.1 (u), 128.9 (u), 133.0 (d), 133.4 (d), 135.5 (d), 171.1 (d); IR 3588, 3056, 2990, 2885, 2867, 2844, 2731, 1744, 1463, 1384, 1273, 1207, 1021; MS 506 (M^+, 4), 378 (2), 364 (3), 263 (16), 262 (29), 247 (8), 171 (13), 170 (100), 141 (10), 121 (8); EI exact mass calcd for $C_{34}H_{50}O_3$: 506.3759, obsd 506.375.

Preparation of (+)-(3*S*)-Tetradecane-1,3-diol (23). To a stirred suspension of $LiAlH_4$ (0.202 g, 5.33 mmol) in dry THF (1.8 mL) was added dropwise a solution of **22** (0.900 g, 1.78 mmol) in dry THF (1.8 mL) at 0 °C under N_2. The reaction mixture was allowed to come to room temperature over 1.5 h and then was quenched by sequential addition of H_2O (0.20 mL), 10% NaOH (0.20 mL), and additional H_2O (0.40 mL). The precipitated lithium salts were separated by filtration and washed with ethyl acetate (95 mL). The resulting filtrate was dried over Na_2SO_4 and concentrated in vacuo. The residual oily solid (0.924 g) was chromatographed on 10 g of silica gel, eluting with 15% EtOAc/petroleum ether (525 mL), 30% EtOAc/petroleum ether (200 mL), and 40% EtOAc/petroleum ether (150 mL). The first 75 mL was concentrated in vacuo to give recovered chiral auxiliary **2** (0.419 g, 84%). The next 425 mL was discarded. The final 475 mL was concentrated in vacuo to give **23** as a yellow-white sticky solid: 0.366 g (89%); R_f (60% EtOAc/hexane) 0.24; $[A]^{22}$ = +3.30° (*c* 6.58 EtOH). Bulb-to-bulb distillation of chromatographed diol (~145 °C, 0.2 mmHg) gave a white waxlike solid: 0.351 g (86% from **22**); $[\alpha]^{22}_D$ +3.50° (*c* 1.8, EtOH); mp 56–56.5 °C (racemic); ^1H NMR 0.88 (t, J = 6.4 Hz, 3 H), 1.27 (bs, 18 H), 1.45 (m, 2 H), 1.68 (m, 2 H), 3.39 (bs, 2 H), 3.84 (m, 3 H); ^{13}C NMR 14.2 (u), 22.7 (d), 25.6 (d), 29.4 (d), 29.7 (d), 32.0 (d), 37.9 (d), 38.4 (d), 62.0 (d), 72.5 (u); IR 3639, 3539, 3379, 2956, 2924, 2873, 2856, 1550, 1467, 1254, 1218, 1070, 1008; MS (NH_3 CI): 248 (2), 230 (4), 214 (15), 213 (100), 195 (6), 125 (9), 111 (11), 109 (5). Anal. Calcd for $C_{14}H_{33}O_2$: C, 72.99; H, 13.12. Found: C, 73.26; H, 12.96.

Preparation of (+)-(3*S*)-1-(Tosyloxy)tetradecan-3-ol (24). A chilled solution of diol **23** (0.390 g, 1.70 mmol) in dry pyridine (1.5 mL) was added all at once via syringe to a −10 °C solution of tosyl chloride (0.355 g, 1.86 mmol) also in dry pyridine (1.5 mL). The reaction mixture was allowed to warm to room temperature while stirring was continued under an atmosphere of N_2. After being stirred at room temperature for 3 h, the reaction mixture was diluted with 50 mL of a chilled 75:25 mixture of Et_2O–$CuSO_4$(aq), washed with $CuSO_4$(aq) (3 × 10 mL) and brine (10 mL), dried over Na_2SO_4, and concentrated in vacuo. The residual crude material (0.632 g) was chromatographed on 10 g of silica gel with 15% EtOAc/petroleum ether (160 mL). The first 80 mL was discarded. The next 80 mL was concentrated in vacuo to give **24** as a white waxlike solid: 0.420 g (64%); R_f 0.22; $[\alpha]^{22}_D$ +10.42° (*c* 7.0, EtOH); ^1H NMR 0.88 (t, J = 6.4 Hz, 3 H), 1.25 (bs, 18 H), 1.37 (bs, 2 H), 1.64 (m, 1 H), 1.81 (m, 1 H), 2.23 (bs, 1 H, dilution dependent), 2.42 (s, 3 H), 3.68 (bs, 1 H), 4.18 (m, 2 H), 7.35 (d, J = 7.5 Hz, 2 H), 7.78 (d, J = 7.5 Hz, 2 H); ^{13}C NMR 13.9 (u), 21.4 (u), 22.5 (d), 25.3 (d), 29.2 (d), 29.4 (d), 31.7 (d), 36.0 (d), 37.3 (d), 67.5 (u), 67.9 (d), 127.7 (u), 129.7 (u), 132.8 (d), 144.6 (d); IR 3629, 3589, 3459, 2928, 2856, 1371, 1189, 1179, 1099, 970; MS (NH_3 CI) 402 ($M - NH_4^+$, 100), 384 (M^+, 17), 230 (25), 213 (45), 212 (21), 196 (13), 195 (88), 155 (6), 139 (67), 125 (59), 111 (85), 109 (15).

Preparation of (−)-(*S*)-Heptadec-1-en-6-ol (25). A 25-mL two-necked flask fitted with a reflux condenser, a magnetic stir bar, a septum, and an N_2 needle was charged with tosylate **24** (0.141 g, 0.36 mmol) dissolved in dry THF (3.65 mL) and chilled to 0 °C. A 2 M allylmagnesium chloride solution (0.913 mL (1.83 mmol) (Aldrich) was added dropwise via syringe over 10 min. Stirring was continued at 0 °C for an additional 20 min, at which time the cooling bath was removed and the mixture was refluxed for 3 h. The mixture was stirred at room temperature overnight and quenched by dilution with concentrated aqueous NH_4Cl (8.5 mL) and Et_2O (28 mL). Following separation of the organic and aqueous phases, the aqueous phase was again extracted with Et_2O (28 mL). The combined organic phases were washed with brine (2 × 10 mL), dried over Na_2SO_4, and concentrated in vacuo. The crude alcohol **25** (0.108 g) was chromatographed on 5 g of silica gel with 6% EtOAc/petroleum ether (80 mL). The first 20 mL was discarded. The next 60 mL was concentrated in vacuo to give alcohol **25** as a white oily solid: 0.090 g (96%); R_f 0.49; $[\alpha]^{24}_D$ −0.94° (*c* 4.5, EtOH). Bulb-to-bulb distillation of chromatographed **25** (135 °C, 0.2 mmHg) gave a waxlike white amorphous solid: 0.089 g (95% from **24**); $[\alpha]^{24}_D$ −2.33° (*c* 1.9, EtOH); ^1H NMR 0.87 (t, J = 6.4 Hz, 3 H), 1.27 (bs, 18 H), 1.43 (m, 7 H), 2.07 (m, 2 H), 3.60 (m, 1 H), 5.01 (m, 2 H), 5.82 (m, 1 H); ^{13}C NMR 14.0 (u), 22.6 (d), 24.9 (d), 25.6 (d), 29.3 (d), 29.6 (d), 29.7 (d), 31.8 (d), 33.7 (d), 36.8 (d), 37.4 (d), 71.6 (u), 114.1 (d), 138.6 (u), IR 3352, 2970, 2963, 2909, 2867, 2853, 2846, 1460, 915; MS (NH_3 CI) 272 (($M + NH_3$)$^+$, 43), 254 (M^+, 100), 237 (7), 235 (8), 167 (6), 139 (7), 125 (16), 123 (10), 111 (22), 109 (18). Anal. Calcd for $C_{17}H_{34}O$: C, 80.25; H, 13.12. Found: C, 80.42; H, 13.29.

Preparation of (−)-(*S*)-5-Hexadecanolide (26). Alcohol **25** (0.089 g, 0.35 mmol), pyridine (3 drops), and the indicator Sudan III (a few crystals) were dissolved in MeOH (3.51 mL) in a 10-mL reactivial fitted with a magnetic stir bar, a Teflon septum, a gas bubbler needle, and a gas outlet needle. The mixture was chilled to −78 °C, and O_3 was bubbled through the rapidly stirred mixture for 9 min (indicator color disappeared in 3 min). Excess ozone was purged from the chilled solution with O_2 (2 min) and N_2 (3 min). The reaction mixture, still at −78 °C, was charged with dimethyl sulfide (0.387 mL, 5.3 mmol) and allowed to warm to room temperature. After stirring overnight under an N_2 atmosphere, the reaction mixture was concentrated in vacuo. The crude lactol residue was oxidized without further purification. Thus a 25-mL one-necked flask fitted with a magnetic stir bar, a septum, and an N_2 needle was charged with PCC (0.114 g, 0.526 mmol), NaOAc (0.288 g, 3.51 mmol), powdered 4-Å molecular sieves (0.057 g), and CH_2Cl_2 (1.76 mL). A CH_2Cl_2 (1.76 mL) solution of crude lactol was introduced dropwise via syringe. The resulting brown mixture was stirred at room temperature for 24 h, diluted with EtOAc (20 mL), and filtered through a 2-g column of Florisil. The filtrate (23 mL) and washings (40 mL) were concentrated in vacuo and chromatographed on 5 g of silica gel with 10% EtOAc/petroleum ether. The first 42 mL was discarded. The next 56 mL was concentrated in vacuo to give lactone **26** as a yellow-white solid: 0.056 g (67%); R_f 0.28. Bulb-to-bulb distillation of chromatographed lactone (~165 °C, 0.2 mmHg) gave a white solid: 0.059 g (66% from **25**); mp 38.5–39.5 °C; $[\alpha]^{21}_D$ −37.13° (*c* 2.21, THF); ^1H NMR 0.88 (*t*, J = 6.4 Hz, 3 H), 1.27 (bs, 18 H), 1.42–1.78 (m, 4 H), 1.89 (m, 2 H), 2.53 (m, 2 H), 4.28 (m, 1 H); ^{13}C NMR 14.1 (u), 18.5 (d), 24.9 (d), 27.8 (d), 29.3 (d), 29.4 (d), 29.5 (d), 29.5 (d), 29.6 (d), 31.9 (d), 35.8 (d), 80.6 (u), 172.0 (d); IR 2956, 2950, 2925, 2856, 1742, 1238, 1050; MS (CH_4 CI) 295 (($M + C_3H_5$)$^+$, 5), 283 (($M + C_2H_5$)$^+$, 16), 256 (20), 255 (($M + H$)$^+$, 100), 254 (2), 237 (($M + H - H_2O$)$^+$, 44), 253 (13), 219 (10), 171 (7), 157 (6), 143 (6), 139 (6), 125 (6), 111 (6). Anal. Calcd for $C_{16}H_{30}O_2$: C, 75.54; H, 11.89. Found: C, 75.55; H, 11.72.

Preparation of Methyl 3-Oxo-6-heptenoate. β-Keto ester (2.719 mmol) prepared by the procedure of Weiler[25] was chromatographed on 100 g of silica gel, eluting with 7% EtOAc/petroleum ether (1100 mL). The first 500 mL was discarded. The next 500 mL was concentrated in vacuo to give β-keto ester as a colorless oil: R_f (20% EtOAc/hexane) 0.39; ^1H NMR 2.34 (m, 2 H), 2.66 (t, J = 8.1 Hz, 2 H), 3.47 (s, 2 H), 3.75 (s, 3 H), 5.03 (m, 2 H), 5.82 (m, 1 H); ^{13}C NMR 27.2 (d), 41.9 (d), 48.9 (d), 52.1 (u), 115.4 (d), 136.4 (u), 167.4 (d), 201.7 (d); IR 3081, 2956, 2850, 1751, 1723, 1658, 1630, 1449, 1437, 1236, 1150; MS 156 (M^+, 15), 138 (6), 128 (4), 125 (22), 124 (45), 123 (4), 111 (4), 102 (7), 101 (100); EI exact mass calcd for $C_8H_{12}O_3$: 156.0786, obsd 156.079.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Oxo-6-heptenoate (6). Following procedure E, methyl 3-oxo-6-heptenoate (0.129 g, 0.825 mmol) was transesterified with alcohol **2**. The residual oil (0.1102 g) was chromatographed on 5 g of silica gel, eluting with 4.5% EtOH/petroleum ether (60 mL). The first 25 mL was discarded. The next 35 mL was concentrated in vacuo to give chiral β-keto ester as a colorless viscous oil: 0.101 g (90%); R_f 0.57; ^1H NMR 0.97 (s, 3 H), 1.24 (s, 3 H), 1.29 (s, 3 H), 0.07–2.15 (m, 9 H), 2.60 (s, 2 H), 4.07 (d, J = 8.0 Hz, 1 H), 4.87 (m, 2 H), 5.55 (d, J = 8.0 Hz, 1 H), 5.55 (m, 1 H), 7.32–7.55 (m, 3 H), 7.62 (d, J = 7.7 Hz, 1 H), 7.68 (d, J = 7.7 Hz, 1 H), 7.79 (bd, J = 8.3 Hz, 1 H), 8.04 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.7 (u), 21.4 (u), 23.7 (u), 23.8 (d), 27.0 (d), 40.9 (d), 42.3 (d), 48.2 (d), 489.7 (d), 49.4 (d), 51.0 (u), 55.2 (u), 80.7 (u), 115.1 (d), 123.4 (u), 124.5 (u), 125.1 (u), 126.0 (u), 126.6 (u), 127.1 (u), 128.8 (u), 133.1 (d), 133.4 (d), 135.2 (d), 136.5 (u), 165.9 (d), 201.1 (d); IR 3081, 3056, 2956, 2889, 1744, 1736, 1717, 1395, 1252, 1232; MS 405 (17), 404 (M^+, 13), 265 (15), 264 (100), 263 (60), 262 (18), 179 (11), 171 (15), 170 (43), 165 (14), 141 (14), 121 (11), 109 (14); EI exact mass calcd $C_{27}H_{32}O_3$: 404.23513, obsd. 404.11398.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*R*)-Hydroxy-6-heptenoate (7). Following procedure A, **6** (0.025 g, 0.062 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (−78 °C, 2.5 h). The residual oil was chromatographed on 1 g of silica gel, eluting with 5% EtOAc/petroleum ether (60 mL). The first 16 mL was discarded. The next 4 mL was concentrated in vacuo to give recovered starting material **6** (0.003 g, 12%). The next 4 mL was dis-

(25) Weiler, L.; Huckin, S. N. *J. Am. Chem. Soc.* **1974**, *96*, 1082.

carded. The final 36 mL was concentrated in vacuo to give a mixture of **7** and **8** as a viscous oil: 0.020 g, 80% (92% based on consumed **6**); R_f 0.38. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.24 (s, 3 H), 1.32 (s, 3 H), 0.84–2.05 (m, 12 H), 3.02 (m, 1 H), 4.07 (d, J = 8.8 Hz, 1 H), 4.88 (m, 2 H), 5.56 (d, J = 8.8 Hz, 1 H), 5.60 (m, 1 H), 7.35–7.55 (m, 3 H), 7.64 (d, J = 7.7 Hz, 1 H), 7.72 (d, J = 7.7 Hz, 1 H), 7.82 (bd, J = 8.3 Hz, 1 H), 8.04 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.6 (u), 23.9 (u), 24.0 (d), 29.4 (d), 35.0 (d), 41.4 (d), 24.4 (d), 48.3 (d), 49.4 (d), 51.2 (u), 55.4 (u), 66.8 (u), 80.2 (u), 114.6 (d), 123.5 (u), 124.5 (u), 125.3 (u), 126.1 (u), 126.9 (u), 127.1 (u), 129.0 (u), 133.1 (d), 133.5 (d), 135.4 (d), 138.0 (u), 171.4 (d); IR 3584, 2960, 2942, 2890, 1724, 1394, 1196, 1173, 1021, 914; MS 406 (M^+, 2), 262 (13), 179 (12), 171 (13), 170 (100), 165 (15), 141 (18), 109 (12). HPLC analysis at 277 nm (flow rate = 0.30 mL/min) showed two components, retention times 78.4 and 84.6 min, in a ratio of 11:1. ^{1}H NMR of alcohol methine multiplets at 3.02 and 2.81 ppm gave an approximate ratio of 19:1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*S*)-Hydroxy-6-heptenoate (8). Following procedure B, **6** (0.025 g, 0.062 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed as for **7**, providing recovered starting material **6** (0.003 g, 10%) as well as a mixture of **7** and **8**: 0.021 g, 84% (93% based on consumed **6**); R_f 0.38. For the major diastereomer: ^{1}H NMR 1.01 (s, 3 H), 1.29 (s, 3 H), 1.35 (s, 3 H), 0.08–2.05 (m, 12 H), 2.81 (m, 1 H), 4.08 (d, J = 8.8 Hz, 1 H), 4.89 (m, 2 H), 5.53 (d, J = 8.8 Hz, 1 H), 5.60 (m, 1 H), 7.35–7.55 (m, 3 H), 7.66 (d, J = 7.7 Hz, 1 H), 7.72 (d, J = 7.7 Hz, 1 H), 7.85 (d, J = 8.3 Hz, 1 H), 8.07 (d, J = 7.7 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.6 (u), 23.9 (d), 24.0 (u), 29.6 (d), 35.0 (d), 42.0 (d), 42.5 (d), 43.8 (d), 49.4 (d), 51.2 (u), 55.3 (u), 67.0 (u), 80.0 (u), 114.6 (d), 123.5 (u), 124.6 (u), 125.4 (u), 126.2 (u), 126.8 (u), 127.2 (u), 129.0 (u), 133.0 (d), 133.4 (d), 135.5 (d), 138.0 (u), 171.0 (d); IR 3594, 2959, 2942, 2931, 1732, 1394, 1259, 1174, 1088, 1026; MS 406 (M^+, 3), 262 (12), 171 (19), 170 (100), 165 (13), 141 (22), 121 (70), 109 (11). HPLC analysis at 277 nm (flow rate = 0.30 mL/min) showed two components, retention times 96 and 104.2 min, in a ratio of 1:25. ^{1}H NMR of alcohol methine multiplets at 3.02 and 2.81 ppm gave an approximate ratio of 1:38.

Preparation of Methyl 3-Cyclohexyl-3-oxopropanoate. Following procedure C, cyclohexanecarboxylic acid (5.000 g, 39.0 mmol) was reacted with oxalyl chloride. The acid chloride so obtained was immediately acylated (general procedure D), providing 7.064 g of crude product. Column chromatography was performed on 100 g of silica gel, eluting with 8% EtOAc/petroleum ether (800 mL). The first 400 nmL was discarded. The next 400 mL was concentrated in vacuo to give β-keto ester as a yellow oil: 6.243 g (87%); R_f 0.48; ^{1}H NMR 1.05–1.50 (m, 5 H), 1.55–2.05 (m, 5 H), 2.48 (m, 1 H), 3.52 (s, 2 H), 3.69 (s, 3 H); ^{13}C NMR 25.1 (d), 25.4 (d), 27.8 (d), 46.6 (d), 50.4 (u), 51.7 (u), 167.5 (d), 205.3 (d); IR 2939, 2927, 2857, 1755, 1745, 1715, 1656, 1626, 1450, 1237; MS 187 (13), 186 (95), 185 (86), 184 (M^+, 20), 167 (13), 153 (12), 135 (15), 111 (100), 110 (28), 109 (15), 107 (12), 101 (18).

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Cyclohexyl-3-oxopropanoate (9). Following procedure E, methyl 3-cyclohexyl-3-oxopropanoate (0.142 g, 0.769 mmol) was transesterified with chiral auxiliary **2**. The residual oil (0.114 g) was chromatographed on 5 g of silica gel, eluting with 2.25% EtOAc/petroleum ether (120 mL). The first 50 mL was discarded. The next 70 mL was concentrated in vacuo to give **9** as a yellow viscous oil: 0.110 g (99%); R_f 0.60; ^{1}H NMR 1.00 (s, 3 H), 1.25 (s, 3 H), 1.27 (s, 3 H), 0.70–2.08 (m, 16 H), 2.62 (s, 2 H), 4.05 (d, J = 8.8 Hz, 1 H), 5.51 (d, J = 8.8 Hz, 1 H), 7.32–7.52 (m, 3 H), 7.62 (d, J = 7.7 Hz, 1 H), 7.68 (d, J = 7.7 Hz, 1 H), 7.80 (bd, J = 8.3 Hz, 1 H), 8.00 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.7 (u), 23.8 (d), 25.1 (d), 25.1 (d), 25.5 (d), 27.4 (d), 27.5 (d), 29.6 (d), 46.2 (d), 48.2 (d), 49.3 (d), 50.0 (u), 50.9 (u), 55.1 (u), 80.6 (u), 123.4 (u), 24.3 (u), 125.0 (u), 125.9 (1), 126.5 (u), 127.1 (u), 128.7 (u), 133.1 (d), 133.3 (d), 135.3 (d), 166.3 (d), 204.8 (d); IR 2958, 2933, 2857, 1743, 1712, 1640, 1624, 1451, 1394, 1236; MS 432 (3), 322 (9), 262 (15), 247 (10), 171 (30), 170 (100), 169 (11), 165 (13), 142 (16), 141 (17), 121 (13), 111 (11); EI exact mass calcd for $C_{29}H_{36}O_3$: 432.2664, obsd 432.266.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Cyclohexyl-3(*S*)-hydroxypropanoate (10). Following procedure A, **9** (0.025 g, 0.058 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (−78 °C, 2.5 h). The residual oil was chromatographed on 1 g of silica gel, eluting with 4% EtOAc/petroleum ether (80 mL). The first 16 mL was discarded. The next 4 mL was concentrated in vacuo to give recovered starting material **9** (0.004 g, 15%). The next 4 mL was discarded. The final 52 mL was concentrated in vacuo to give a mixture of **10** and **11** as a viscous oily solid: 0.020 g, 81% (96% based on consumed **9**); R_f 0.49. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.25 (s, 3 H), 1.30 (s, 3 H), 0.55–2.04 (m, 19 H), 2.68 (m, 1 H), 4.07 (d, J = 8.9 Hz, 1 H), 5.54 (d, J = 8.9 Hz, 1 H), 7.38–7.52 (m, 3 H), 7.64 (d, J = 7.3 Hz, 1 H), 7.71 (d, J = 8.1 Hz, 1 H), 7.82 (db, J = 6.9 Hz, 1 H), 8.02 (bd, J = 8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.5 (u), 24.0 (?), 25.8 (d), 26.2 (d), 27.7 (d), 28.4 (d), 38.9 (d), 42.4 (u), 42.4 (d), 48.3 (d), 49.4 (d), 51.1 (u), 55.4 (u), 71.3 (u), 80.2 (u), 123.5 (u), 124.5 (u), 125.2 (u), 126.1 (u), 126.9 (u), 127.1 (u), 128.9 (u), 133.1 (d), 133.5 (d), 135.5 (d), 172.1 (d); IR 3594, 3056, 2944, 2925, 2918, 2855, 1727, 1450, 1394, 1259, 1178; MS 434 (M^+, 2), 262 (20), 179 (12), 171 (16), 170 (100), 165 (15), 141 (30), 137 (10), 121 (11). HPLC analysis at 277 nm showed two components, retention times 148 and 179 min, in a ratio of 9.2:1. ^{1}H NMR of alcohol methine multiplets at 2.68 and 2.32 ppm gave an approximation ratio of 8.9:1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Cyclohexyl-3(*R*)-hydroxypropanoate (11). Following procedure B, **9** (0.025 g, 0.058 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed on 2.5 g of silica gel, eluting with 6% EtOAc/petroleum ether (75 mL). The first 30 mL was discarded. The next 5 mL was concentrated in vacuo to give recovered starting material **9** (0.008 g, 33%). The next 15 mL was discarded. The final 25 mL was concentrated in vacuo to give a mixture of **10** and **11** as a viscous oily solid: 0.016 g, 62% (95% based on consumed **9**); R_f 0.49. For the major diastereomer: ^{1}H NMR 1.02 (s, 3 H), 1.28 (s, 3 H), 1.35 (s, 3 H), 0.50–2.05 (m, 19 H), 2.32 (m, 1 H), 4.08 (d, J = 8.8 Hz, 1 H), 5.50 (d, J = 8.8 Hz, 1 H), 7.37–7.57 (m, 3 H), 7.65 (d, J = 7.7 Hz, 1 H), 7.72 (d, J = 7.7 Hz, 1 H), 7.84 (bd, J = 8.3 Hz, 1 H), 8.08 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.6 (u), 23.8 (d), 23.9 (u), 25.8 (d), 25.9 (d), 27.9 (d), 28.5 (d), 39.4 (d), 42.5 (u), 48.3 (d), 49.3 (d), 51.1 (u), 55.4 (u), 71.9 (u), 79.9 (u), 123.6 (u), 124.6 (u), 125.4 (u), 125.9 (u), 126.7 (u), 127.2 (u), 129.0 (u), 133.1 (d), 133.4 (d), 135.6 (d), 171.7 (d); IR 3600, 3056, 2960, 2928, 2855, 1739, 1394, 1241, 1172, 1026; MS 434 (M^+, 2), 262 (17), 179 (14), 171 (17), 170 (100), 165 (22), 141 (27), 137 (14), 121 (11). HPLC analysis at 277 nm showed two components, retention times 148 and 179 min, in a ratio of 1:9.3. ^{1}H NMR of alcohol methine multiplets at 2.68 and 2.32 ppm gave a similar approximate ratio of 1:9. Recrystallization three times from 0.5 M hot hexane at room temperature improved the HPLC ratio to the extent of 1:26 for **10**:**11**.

Preparation of Methyl 3-Oxo-3-phenylpropanoate. Following procedure D, benzoyl chloride (4.13 mL, 35.6 mmol) was acylated. The residual crude β-keto ester (4.838 g) was chromatographed on 100 g of silica gel with 7% EtOAc/petroleum ether (1 L). The first 500 mL was discarded. The next 500 mL was concentrated in vacuo to give β-keto ester as a faintly yellow oil: 4.624 g (73%); R_f 0.37; ^{1}H NMR 3.72 (s, 3 H), 4.00 (s, 2 H), 7.46 (dd, J = 8.1, 8.8 Hz, 2 H), 7.57 (d, J = 8.1 Hz, 1 H), 7.92 (d, J = 8.8 Hz, 2 H); ^{13}C NMR 45.2 (d), 51.9 (u), 128.1 (u), 128.4 (u), 133.4 (u), 135.6 (d), 167.6 (d), 192.1 (d); IR 3069, 3031, 3000, 2954, 2850, 1747, 1692, 1654, 1627, 1269, 1261, 1204, 1185; MS 179 (46), 178 (M^+, 18), 106 (19), 105 (100).

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Oxo-3-phenylpropanoate (12). Following procedure E, methyl 3-oxo-3-phenylpropanoate (0.139 g, 0.782 mmol) was transesterified with chiral auxiliary **2**. The residual oil (0.111 g) was chromatographed on 5 g of silica gel, eluting with 4.5% EtOAc/petroleum ether (55 mL). The first 20 mL was discarded. The next 35 mL was concentrated in vacuo to give **12** as a yellow viscous oil: 0.100 g (90%); R_f 0.49; ^{1}H NMR 0.95 (s, 3 H), 1.17 (bs, 6 H), 0.85–2.10 (m, 5 H), 3.05 (d, J = 15.6 Hz, 1 H), 3.15 (d, J = 15.6 Hz, 1 H), 4.02 (d, J = 8.8 Hz, 1 H), 5.54 (d, J = 8.8 Hz, 1 H), 7.20–7.75 (m, 8 H), 7.55 (d, J = 7.7 Hz, 1 H), 7.62 (d, J = 7.7 Hz, 1 H), 7.77 (bd, J = 8.3 Hz, 1 H), 8.00 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.6 (u), 21.4 (u), 23.4 (u), 23.7 (d), 45.0 (d), 48.1 (d), 49.2 (d), 49.3 (d), 50.9 (u), 55.0 (u), 80.7 (u), 123.4 (u), 124.3 (u), 124.9 (u), 125.9 (u), 126.5 (u), 127.1 (u), 128.2 (u), 128.3 (u), 133.0 (u), 133.0 (d), 133.3 (d), 135.0 (d), 135.6 (d), 166.3 (d), 191.4 (d); IR 3056, 2959, 2888, 1741, 1693, 1637, 1601, 1451, 1411, 1262, 1185, 1021; MS 426 (M^+, 2), 180 (11), 179 (20), 178 (15), 172 (14), 171 (66), 170 (76), 169 (100), 168 (16), 167 (15), 166 (20), 165 (28), 164 (13), 153 (12), 152 (11), 142 (18), 141 (34), 121 (10), 105 (69).

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*S*)-Hydroxy-3-phenylpropanoate (13). Following procedure A, **12** (0.025 g, 0.059 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (−78 °C, 2.5 h). The residual oil was chromatographed on 1 g of silica gel, eluting with 4% EtOAc/petroleum ether (64 mL). The first 16 mL was discarded. The next 8 mL was concentrated in vacuo to give recovered starting material **12** (0.016 g, 63%). The next 4 mL was discarded. The final 36 mL was concentrated in vacuo to give a mixture of **13** and **14** as a viscous oil: 0.009 g, 35% (93% based on consumed **12**); R_f 0.40. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.27 (s, 3 H), 1.30 (s, 3 H), 0.85–2.18 (m, 8 H), 4.08 (d, J = 9.0 Hz, 1 H), 4.15 (bd, J = 8.8 Hz, 1 H), 5.57 (d, J = 8.8 Hz, 1 H), 6.94 (m, 2 H), 7.19 (7, 3 H), 7.45 (m, 3 H), 7.65 (d, J = 7.2 Hz, 1 H), 7.72

(d, J = 8.2 Hz, 1 H), 7.83 (bd, J = 8.3 Hz, 1 H), 8.04 (d, J = 8.5 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.6 (u), 23.9 (u), 24.0 (d), 42.4 (d), 43.5 (d), 48.4 (d), 49.4 (d), 51.1 (u), 55.4 (u), 69.5 (u), 80.4 (u), 123.6 (u), 124.5 (u), 125.3 (u), 125.4 (u), 126.1 (u), 126.9 (u), 127.2 (u), 127.5 (u), 128.3 (u), 129.0 (u), 133.1 (d), 133.5 (d), 135.5 (d), 142.2 (d), 170.9 (d); IR 3581, 3059, 3034, 2959, 2889, 1727, 1721, 1601, 1511, 1482, 1394, 1176, 1018; MS 428 (M^+, 2), 262 (19), 179 (16), 171 (21), 170 (100), 165 (22), 141 (30), 131 (38), 108 (12), 107 (48). HPLC analysis at 277 nm showed two components, retention times 70.8 and 89.4 min, in a ratio of 14/1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*R*)-Hydroxy-3-phenylpropanoate (14). Following procedure B, **12** (0.025 g, 0.059 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed on 2.5 g of silica gel, eluting with 6% EtOAc/petroleum ether (80 mL). The first 30 mL was discarded. The next 10 mL was concentrated in vacuo to give recovered starting material **12** (0.006 g, 26%). The next 5 mL was discarded. The final 35 mL was concentrated in vacuo to give a mixture of **13** and **14** as a viscous oil: 0.017 g, 69% (93% based on consumed **12**); R_f 0.39; ^{1}H NMR 0.99 (s, 3 H), 1.25, 1.27 (s, s, 3 H), 1.29, 1.32 (s, s, 3 H), 0.85–2.18 (m, 8 H), 3.66 (bd, J = 10.5 Hz, 0.5 H), 4.10 (m, 1.5 H), 5.88 (d, J = 8.8 Hz, 1 H), 6.94 (m, 2 H), 7.17 (m, 3 H), 7.38–7.57 (m, 3 H), 7.65 (d, J = 6.9 Hz, 1 H), 7.71 (bd, J = 7.7 Hz, 1 H), 7.83 (bd, J = 8.3 Hz, 1 H), 8.05, 8.10 (d, d, J = 8.3, 8.3 Hz, 1 H); ^{13}C NMR 14.7 (u), 21.6 (u), 21.6 (u), 23.9 (d), 23.9 (u), 24.0 (d), 42.4 (d), 42.5 (d), 43.5 (d), 43.9 (d), 48.3 (d), 48.4 (d), 49.4 (d), 49.4 (d), 51.1 (u), 51.1 (u), 55.5 (u), 69.8 (u), 80.1 (u), 80.4 (u), 123.6 (u), 123.8 (u), 124.5 (u), 124.6 (u), 125.4 (u), 125.4 (u), 126.1 (u), 126.2 (u), 126.7 (u), 126.9 (u), 127.2 (u), 127.3 (u), 127.5 (u), 128.3 (u), 129.0 (u), 133.1 (d), 133.4 (d), 133.5 (d), 135.5 (d), 135.7 (d), 142.2 (d), 142.4 (d), 170.7 (d), 170.9 (d); IR: 3581, 3063, 3038, 2959, 2932, 2889, 1738, 1730, 1394, 1176, 1027; MS 428 (M^+, 2), 262 (19), 176 (16), 171 (21), 170 (100), 165 (22), 141 (30), 131 (38), 108 (12), 107 (48). HPLC analysis at 277 nm showed two components, retention times 70.8, and 89.4 min, in a ratio of 1:1.3.

Preparation of Methyl 3-Oxo-4-phenylbutanoate. Following procedure D, phenylacetyl chloride (4.70 mL, 35.6 mmol) was acylated. The residual crude β-keto ester (6.538 g) was chromatographed on 100 g of silica gel with 2% EtOAc/petroleum ether (4100 mL). The first 2 L was discarded. The remaining 2100 mL was concentrated in vacuo to give β-keto ester as a yellow oil: 5.440 g (79.6%), R_f 0.33; ^{1}H NMR 3.45 (s, 2 H), 3.69 (s, 3 H), 3.80 (s, 2 H), 7.18–7.37 (m, 5 H); ^{13}C NMR 47.6 (d), 49.4 (d), 51.7 (u), 126.9 (u), 128.4 (u), 129.2 (u), 133.1 (d), 167.1 (d), 199.8 (d); IR 1750, 1720, 1460, 1440, 1420, 1325, 1290, 1240, 1200, 1160, 1029, 700; MS 192 (81), 122 (60), 119 (26), 118 (88), 107 (17), 105 (97), 101 (100); EI exact mass calcd for $C_{11}H_{12}O_3$: 192.079, obsd 192.078.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3-Oxo-4-phenylbutanoate (15). Following procedure E, methyl 3-oxo-4-phenylbutanoate (0.146 g, 0.757 mmol) was transesterified with chiral auxiliary **2**. The residual oil (0.111 g) was chromatographed on 5 g of silica gel, eluting with 4.5% EtOAc/petroleum ether (60 mL). The first 30 mL was discarded. The next 40 mL was concentrated in vacuo to give **15** as an oil: 0.091 g (82%); R_f 0.39; ^{1}H NMR 0.99 (s, 3 H), 1.23 (s, 3 H), 1.28 (s, 3 H), 0.90–2.00 (m, 5 H), 2.68 (m, 4 H), 4.07 (d, J = 8.8 Hz, 1 H), 5.56 (d, J = 8.8 Hz, 1 H), 6.70 (m, 2 H), 7.15 (m, 3 H), 7.35–7.52 (m, 3 H), 7.64 (bt, 2 H), 7.78 (d, J = 8.3 Hz, 1 H), 8.06 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.7 (u), 21.4 (u), 23.7 (u), 23.8 (d), 42.3 (d), 47.4 (d), 48.2 (d), 48.8 (d), 49.4 (d), 51.1 (u), 55.2 (u), 80.9 (u), 123.4 (u), 124.5 (u), 125.2 (u), 126.1 (u), 126.7 (u), 126.9 (u), 127.2 (u), 128.4 (u), 128.9 (u), 129.2 (u), 133.0 (d), 133.1 (d), 133.5 (d), 135.2 (d), 165.9 (d), 199.5 (d); IR 3065, 3034, 2960, 2889, 1742, 1719, 1648, 1601, 1550, 1497, 1395, 1232, 1022; MS 440 (M^+, 26) 330 (48), 247 (15), 229 (17), 171 (34), 170 (100), 161 (22), 121 (15); EI exact mass calcd for $C_{30}H_{32}O_3$: 440.2351, obsd 440.234.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*R*)-Hydroxy-4-phenylbutanoate (16). Following procedure A, **15** (0.025 g, 0.057 mmol) was stereoselectively reduced with $Zn(BH_4)_2$ (−78 °C, 2.5 h). The residual oil was chromatographed on 1 g of silica gel, eluting with 5% EtOAc/petroleum ether (88 mL). The first 20 mL was discarded. The next 4 mL was concentrated in vacuo to give recovered starting material **15** (0.003 g, 11%). The next 4 mL was discarded. The final 56 mL was concentrated in vacuo to give a mixture of **16** and **17** as a viscous oil: 0.021 g, 85% (96% based on consumed **15**); R_f 0.38. For the major diastereomer: ^{1}H NMR 1.00 (s, 3 H), 1.25 (s, 3 H), 1.31 (s, 3 H), 0.87–2.00 (m, 8 H), 2.12 (dd, J = 13.7, 6.1 Hz, 1 H), 2.29 (dd, J = 13.7, 7.1 Hz, 1 H), 3.24 (m, 1 H), 4.07 (d, J = 8.8 Hz, 1 H), 5.57 (d, J = 8.8 Hz, 1 H), 6.86 (m, 2 H), 7.21 (m, 3 H), 7.34–7.51 (m, 3 H), 7.65 (bt, 2 H), 7.78 (bd, J = 8.3 Hz, 1 H), 8.04 (d, J =8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.5 (u), 23.9 (?), 40.5 (d), 42.1 (d), 42.4 (d), 48.3 (d), 49.4 (d), 51.1 (u), 55.4 (u), 68.2 (u), 80.2 (u), 123.5 (u), 124.4 (u), 125.2 (u), 126.0 (u), 126.2 (u), 126.9 (u), 127.1 (u), 128.2 (u), 125.0 (u), 129.2 (u), 133.0 (d), 133.4 (d), 135.4 (d), 137.6 (d), 171.2 (d); IR 3588, 3063, 3031, 2959, 2930, 2889, 1732, 1394, 1176, 1160, 1020; MS 442 (M^+, 4), 264 (10), 263 (21), 247 (9), 179 (14), 171 (21), 170 (100), 165 (20), 141 (27), 121 (35); EI exact mass calcd for $C_{30}H_{34}O_3$: 442.2507, obsd 442.2509. HPLC analysis at 277 nm (0.025-mg sample) showed two components, retention times 88 and 98.4 min, in a ratio of 9:1. ^{1}H NMR of alcohol methine multiplets at 3.24 and 2.92 ppm gave an approximate ratio of 8.3:1.

Preparation of 4,7,7-Trimethyl-3-*exo*-(1-naphthyl)bicyclo[2.2.1]heptan-2-*exo*-yl 3(*S*)-Hydroxy-4-phenylbutanoate (17). Following procedure B, **15** (0.025 g, 0.057 mmol) was stereoselectively reduced with Dibal·BHT. The residual oil was chromatographed on 2.5 g of silica gel, eluting with 8% EtOAc/petroleum ether (75 mL). The first 30 mL was discarded. The next 5 mL was concentrated in vacuo to give recovered starting material **15** (0.006 g, 25%). The final 40 mL was concentrated in vacuo to give a mixture of **16** and **17** as a viscous oil: 0.017 g, 67% (90% based on consumed **15**); R_f 0.36. For the major diastereomer, see **16**. For the minor diastereomer: ^{1}H NMR 1.01 (s, 3 H), 1.29 (s, 3 H), 1.24 (s, 3 H), 0.92–2.01 (m, 8 H), 2.09 (dd, J = 13.7, 6.1 Hz, 1 H), 2.26 (dd, J = 13.7, 7.1 Hz, 1 H), 2.92 (m, 1 H), 4.09 (d, J = 8.8 Hz, 1 H), 5.55 (d, J = 8.8 Hz, 1 H), 6.89 (m, 2 H), 7.25 (m, 3 H), 7.35–7.55 (m, 3 H), 7.68 (bt, 2 H), 7.79 (bd, J = 8.3 Hz, 1 H), 8.06 (d, J = 8.3 Hz, 1 H); ^{13}C NMR 14.8 (u), 21.4 (u), 24.0 (u), 40.6 (d), 41.3 (d), 42.2 (d), 42.5 (d), 48.4 (d), 49.5 (d), 51.2 (u), 55.4 (u), 68.7 (u), 80.0 (u), 123.6 (u), 124.5 (u), 125.3 (u), 126.1 (u), 126.3 (u), 126.9 (u), 127.2 (u), 128.3 (u), 128.8 (u), 129.0 (u), 129.3 (u), 133.2 (d), 133.5 (d), 135.6 (d), 137.8 (d), 170.8 (d); IR 3588, 3063, 3031, 2960, 2946, 2931, 1731, 1394, 1260, 1177, 1160; MS 264 (15), 262 (61), 247 (34), 206 (41), 191 (30), 179 (44), 170 (100), 165 (46), 141 (49), 121 (50). HPLC analysis at 277 nm showed two components, retention times 95.4 and 106.8 min, in a ratio of 1:0.54. ^{1}H NMR of alcohol methine multiplets at 3.24 and 2.92 ppm gave an approximate ratio of 1:0.53.

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