A Novel Bornane Synthesis by an Old Idea

Baldur Föhlisch,* Derar Abu Bakr, and Peter Fischer

Institut für Organische Chemie der Universität Stuttgart, Pfaffenwaldring 55, D-70569 Stuttgart, Germany

baldur.foehlisch@po.uni-stuttgart.de

Received November 19, 2001

Aiming at a synthesis of spiro[2.4]hepta-4,6-dienes with a carbon substituent at C-4, we investigated solvolysis reactions of the thiatricycle **2**, obtained from spiro[2.4]hepta-4,6-diene (**1**) and thiophosgene by [4 + 2] cycloaddition. With methanol or ethanol a mixture of the esters **7** and **8** was formed. Desulfurization of the thionoesters **8** gave methyl and ethyl spiro[2.4]hepta-4,6-diene-4-carboxylate (**10a,b**). The corresponding alcohol (**11**) was prepared from **10b** by $LiAlH_4$ reduction. Ethene-tetracarbonitrile combined with the 4-substituted spiro[2.4]hepta-4,6-dienes to give the [4 + 2] cycloadducts **12a**−**c**. Diels−Alder reaction between **11** and 2-chloroacrylonitrile afforded the spiro-(bicyclo[2.2.1]hept-5-ene-7,1′-cyclopropane) derivative **14a** that was transformed in three steps to *rac*-10-hydroxycamphor (**17**). This synthesis of a bornane derivative opens opportunity for variations and thus may find further applications.

Introduction

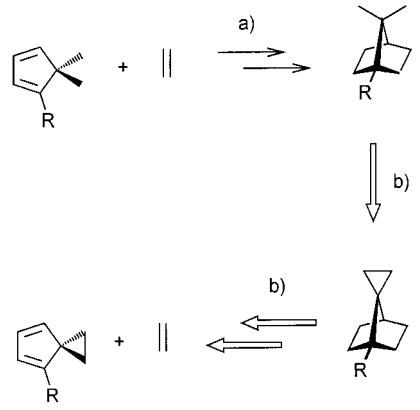
Having discovered the principle of the "diene synthesis" (later named Diels−Alder reaction, DAR), the efforts of the second pioneer were directed to the synthesis of terpenes with the bornane (camphane) skeleton.[1] These should be available by cycloaddition of 1,5,5-trimethylcyclopenta-1,3-diene with olefins, e.g., vinyl acetate. The idea has been realized by Alder and Windemuth, but 1,5,5-trimethylcyclopenta-1,3-diene had to be prepared in several steps from camphor.[2] To the best of our knowledge, however, a real (de novo) synthesis of appropriately substituted cyclopentadienes for the [4 + 2] cycloaddition has never been described.

To circumvent the difficulties with a synthesis of 1-substituted 5,5-dimethylcyclopentadienes, we aimed at a preparation of spiro[2.4]hepta-4,6-dienes bearing a carbon substituent at the 4-position (Scheme 1). Again, no viable route was found in the literature. Here we report a comparatively simple entry to spiro[2.4]hepta-4,6-diene-4-carboxylic acid esters and spiro[2.4]hepta-4,6-diene-4-methanol, using a *hetero*-DAR, and the utilization of these dienes for a synthesis of *rac*-10-hydroxycamphor by a *carbo*-DAR.

4-Substituted Spiro[2.4]hepta-4,6-dienes

As was found by Raasch,[3] spiro[2.4]hepta-4,6-diene (**1**), which is easily available from cyclopentadiene and 1,2-dihalogenoethanes in one step, combines with thiocarbonyl dichloride (thiophosgene) to form the [4 + 2] cycloadduct **2** (Scheme 2). We anticipated that this cyclic *gem*-dichlorothioether would undergo hydrolysis with formation of the corresponding thiolactone, in analogy to other cases.[4] Unfortunately, no defined product could be isolated from the dark hydrolysis mixture. Reaction of **2** with methanol or ethanol, however, gave a mixture of 7-mercaptospiro[2.4]hept-5-ene-4-carboxylic acid ester **7** and spiro[2.4]hept-5-ene-4-thiocarboxylic acid *O*-ester **8** (Scheme 2).

Scheme 1. [4 + 2] Cycloaddition Routes to the Bornane Skeleton[a]



[a] (A) Alder and Windemuth, for R = CH_3 (ref 2), (B) this work.

Evidence for the alkoxycarbonyl group in **7a** is given by the IR (1740 cm^{-1}) and ^{13}C NMR (δ 173.7 ppm) spectra. The thiol group gives rise to a weak band at 2560 cm^{-1} (S−H stretching vibration). Apart from mechanistic considerations (vide infra), the *cis*-relationship of the substituents in **7** is indicated by the ^1H NMR spectrum, which shows a large constant for coupling between the SH and the vicinal CH protons ($^3J_{7H,SH}$ = 10.7 Hz), consistent with the conformation **7′,** in which these hydrogen atoms are held in an antiperiplanar position by the hydrogen bridge with an oxygen atom. Consequently, the substituents must be *cis*.

(1) For the history of the Diels Alder reaction see Alder's overview: Alder, K. Die Methode der Diensynthese. In *Neuere Methoden der präparativen Organischen Chemie*; Foerst, W., Ed.; Verlag Chemie: Berlin, 1943; Vol. 1, pp 251−358, especially p 308. Also see: Berson, J. A. *Tetrahedron* **1992**, *48*, 3−17.

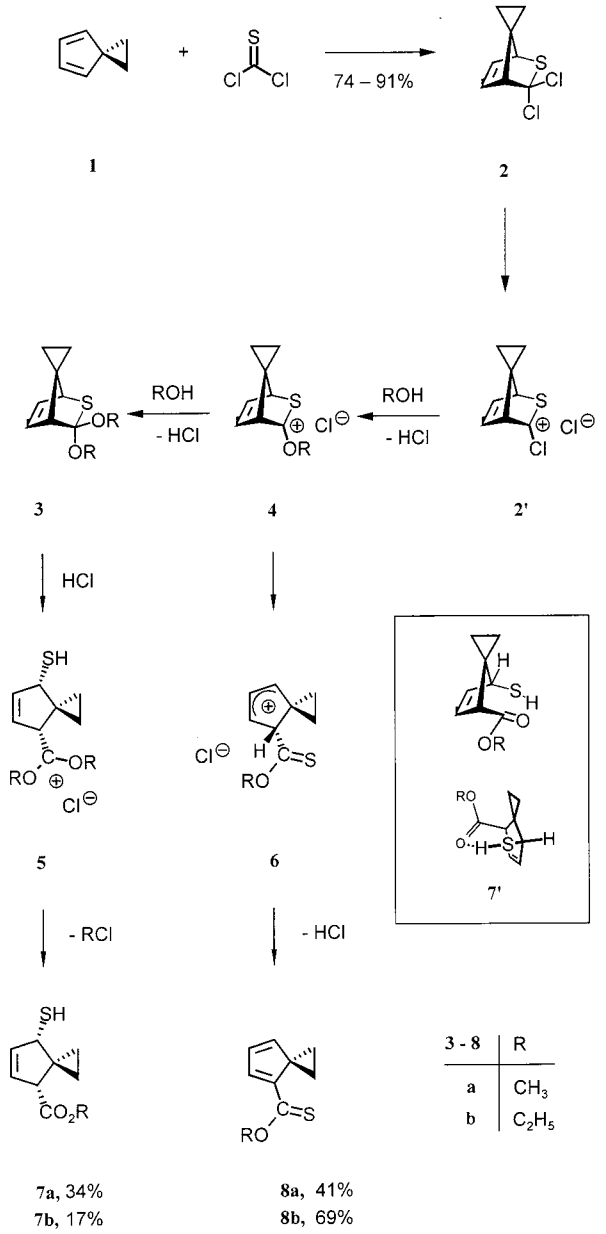
(2) (a) Alder, K.; Windemuth, E. *Liebigs Ann. Chem.* **1940**, *543*, 41−56. (b) Alder, K.; Windemuth, E. *Liebigs Ann. Chem.* **1940**, *543*, 28−40.

(3) Raasch, M. S. *J. Org. Chem.* **1975**, *40*, 161−171.

(4) (a) Reich, H. J.; Trend, J. E. *J. Org. Chem.* **1973**, *38*, 2637−2640. (b) Allgeier, H.; Winkler, T. *Tetrahedron Lett.* **1976**, *3*, 215−218.

10.1021/jo011087p CCC: $22.00
Published on Web 05/01/2002

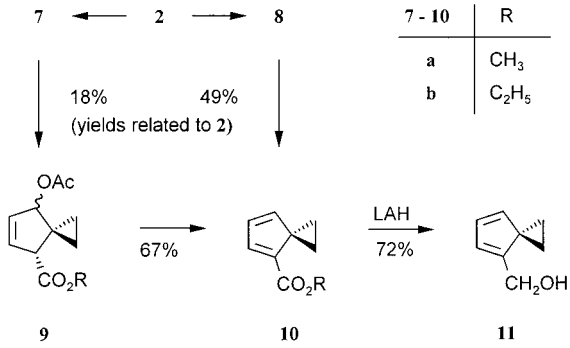
Scheme 2. Proposed Alcoholysis Mechanism with the Cycloadduct 2



Confirmation of the 1,3-diene structure of **8a** is supplied by three carbon resonances at δ 127.0, 139.7, and 151.6 ppm, each of the type CH, as indicated by means of the DEPT technique, and one resonance at δ 144.6 ppm lacking coupling with an attached proton. In the ^{1}H NMR of **8a** an ABX subspectrum is consistent with the three diene protons 7-H, 6-H, and 5-H. The alkoxythiocarbonyl group of **8** is discernible in the ^{13}C NMR spectrum by a signal at δ 203.95 ppm (for **8a)** and δ 203.6 ppm (for **8b)** and resonances at δ 56.9 (CH_3O) and δ 66.0 (CH_3CH_2O), respectively.[5] Moreover, the conjugated thiocarbonyl chromophore gives rise to an absorption band (presumably n $\rightarrow \pi^*$) in the UV/vis spectrum at λ_{max} 342 nm.

The mechanism shown in Scheme 2 may be deduced from these findings. Ionization of **2** in the polar protic solvent and solvolytic substitution of the covalently bound

Scheme 3. Synthesis of 11[a]



[a] The yields hold for R = C_2H_5

chloro substituent in the α-chlorothioether chloride ion pair **2′** gives the alkoxy-substituted ion pair **4.** Obviously **4** undergoes a second ionization with formation of the carbon−sulfur double bond, giving the cyclopentenylium cation **6**, which is further stabilized by the perpendicular spirocyclopropane ring in the bisected orientation. Deprotonation of the cation **6** yields the solvolysis product **8**.

Substitution of both chlorine atoms of **2** through the same intermediate **4** results in the tricyclic orthothioester **3**, which breaks down in the presence of the hydrochloric acid produced to give the dialkoxycarbenium ion pair **5**. A dealkylation, induced by nucleophilic attack of chloride ion, affords the ester **7**.

The alcoholysis products **7** and **8**, formed in 75−86% combined yield, could be separated by liquid chromatography on silica. Desulfurization of the thiocarboxylic acid esters gave the corresponding carboxylic acid esters. On treatment of **8a** with aqueous silver nitrate, the methyl ester **10a** was formed (Scheme 3), though in an unsatisfying 24% yield. To circumvent the chromatographic separation of the alcoholysis products **7** and **8**, the ethanolysis mixture of **2** was treated immediately with mercuric acetate.[6] Under these conditions **7b** was transformed to the acetoxy ester **9b**, a mixture of *cis*/*trans* diastereomers that could be partly separated by chromatography. We used the NMR spectra for a tentative configurational assignment (see the Supporting Information).

The acetoxy esters **9b** were removed from the diene ester **10b** by fractional distillation, affording the latter in 49% yield, related to **2**. Finally, the acetoxyester mixture could also be transformed to **10b** via a base-induced 1,4-elimination of acetic acid using LDA in THF. With $LiAlH_4$ in diethyl ether the ester **10b** was reduced to spiro[2.4]hepta-4,6-diene-4-methanol (**11**). As described for the thionoesters **8** (see the Supporting Information), the transformation products **10** and **11** also show the characteristic coupling constants for the "diene protons" 5-H, 6-H, and 7-H, consonant with those of the hydrocarbon **1**.[7]

Diels−Alder Reactions with Tetracyanoethylene

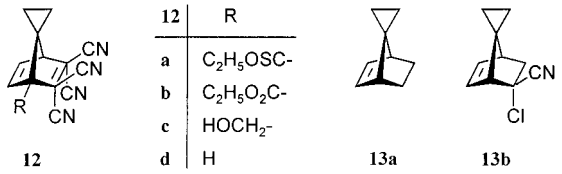
The spirodienes prepared as described were allowed to react with ethenetetracarbonitrile (TCNE) in acetonitrile. In analogy to the reaction of the parent hydro-

(5) (a) Meier, H.; Bühl, H. *J. Heterocycl. Chem.* **1975**, *12*, 605−606. (b) Bridges, A. J.; Whitham, G. H. *J. Chem. Soc., Perkin Trans. 1* **1975**, 1603−1606.

(6) Ellis, J.; Frier, R. D.; Schibeci, R. A. *Aust. J. Chem.* **1971**, *24*, 1527−1529.

(7) Van de Ven, L. J. M.; De Haan, J. W. *J. Magn. Reson.* **1975**, *19*, 31−36.

carbon **1**, which gave **12d**,[8] the [4 + 2] cycloadducts **12a**−**c** were formed in 78−88% yield, at room temperature. This reaction may be considered as a classical proof for the constitution of the unexpected spirodienes **8** and their transformation products (**10**, **11**). Other cycloaddition modes with TCNE, such as [2 + 2], were ruled out by the NMR spectra, which are consistent with data for the spirotricycles **12d**, **13a**, and **13b** (see the Supporting



Information). Preservation of the C=S double bond with **8a** was indicated by UV/vis absorption at 343, 273, and 262 nm for **12a**, and two strong IR absorption bands at 1240 and 1265 cm^{-1}, occurring within the range anticipated for the C=S stretching vibration of *O*-alkyl thiocarboxylates.[9] Confirmation of the other functional groups came from the ^{13}C NMR and IR spectra (CN at 2220−2235 cm^{-1}, COOEt at 1725 cm^{-1}, CH_2OH at 3585 and 3505 cm^{-1}).

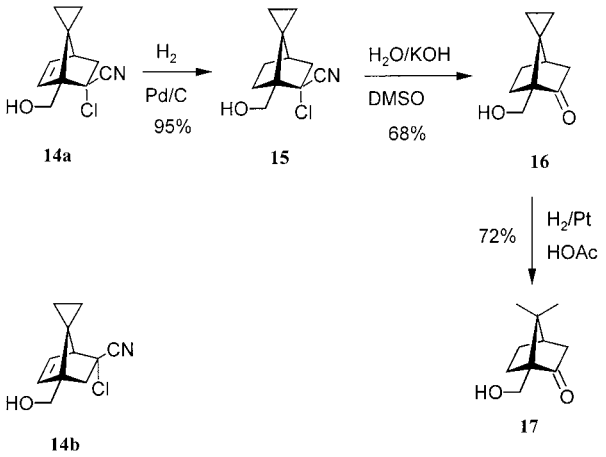
Synthesis of *rac*-10-Hydroxycamphor

To construct the bornane skeleton, 2-chloroacrylonitrile, a ketene equivalent, was made to react with the spiro alcohol **11**. In boiling benzene, the regioisomer bearing the functional groups vicinal to the hydroxymethyl substituent (**14a**) was formed preferentially (57−88% yield). The ^1H NMR spectrum showed signals of an ABX subsystem with coupling constant J_{AB} = 13.0 Hz, typical for geminal protons, i.e., a methylene group neighbored by and coupling with a bridgehead hydrogen (J_{AX} or J_{BX}), consequently 4-H.

A further isomer could be isolated by chromatography (ca. 2.5% yield), but in an impure state. A simple AB subsystem in the ^1H NMR spectrum, also with J_{gem} = 13.0 Hz, but showing no perturbation by coupling with a bridgehead proton (4-H) supplied confirmation of formula **14b**, the regioisomer (Scheme 4).

As for the geminal substituents in the case of **14a**, a fully ^1H,^{13}C-coupled NMR spectrum furnished proof of the *endo*-2-chloro-*exo*-2-cyano configuration. Namely, the cyano carbon resonance, at 110.0(0) ppm, is split into a doublet of doublets by vicinal coupling to 3-*exo*-H and 3-*endo*-H, respectively (^3J = 5.9 and 3.1 Hz). For a 2-*exo*-cyano group, the dihedral angle between the CN carbon and 3-*exo*-H is 0°, that between the CN carbon and 3-*endo*-H 120°. The Karplus relation in this case requires the larger vicinal coupling between the CN carbon and 3-*exo*-H. In fact, selective decoupling of the 3-*exo*-H resonance at 2.988 (i.e., 2.99) ppm removed the larger of

Scheme 4. Transformations with the Cycloadduct 14a



the ^3J couplings, that of the 3-*endo*-H resonance at 1.97(2) ppm the smaller one.

An X-ray analysis of **14a** for structure determination was not possible since we did not succeed in growing appropriate crystals.

Having investigated the reaction of the parent spiro[2.4]hepta-4,6-diene (**1**) with 2-chloroacrylonitrile, Cantello et al. argued that repulsive interaction of the bulkier chloro substituent with the methylene groups of the spiro hydrocarbon in the Diels−Alder transition state would favor formation of the *exo*-nitrile **13b**.[10]

Hydrogenation of the chloronitrile **14a** over palladium on carbon catalyst gave the saturated tricycle **15**. Unmasking of the latent carbonyl group at C-2 was effected by the Paasivirta−Corey protocol, i.e., by treatment with aqueous potassium hydroxide;[11] dimethyl sulfoxide was used as the cosolvent.[12,13] The spiroketone **16** thus formed was treated in acetic acid with hydrogen gas over a platinum catalyst. The product showed two methyl signals in the NMR, thus indicating distal hydrogenolysis of the spirocyclopropane ring. The functional groups and the constitution of the product, i.e., *rac*-10-hydroxycamphor (**17**), were established by the IR (3450 (OH), 1735 (C=O) cm^{-1}) and NMR spectra.

Nonracemic 10-hydroxycamphor has been prepared from natural monoterpenes, namely, (+)-camphor[14−16] and β-pinene.[17]

Conclusions

This synthesis of bicycle **17** represents the first model for a neglected concept to construct molecules of the bornane class. Beyond the bornane field, the 4-substituted spiro[2.4]hepta-4,6-dienes **8**, **10**, and **11** and the corresponding carbaldehyde should find further applica-

(8) Murahashi, S.; Okumura, K.; Maeda, Y.; Sonoda, A.; Moritani, I. *Bull. Chem. Soc. Jpn.* **1974**, *47*, 2420−2425.

(9) Scheithauer, S.; Mayer, R. *Thio- and Dithiocarboxylic Acids and their Derivatives*; Senning, A., Ed.; Topics in Sulfur Chemistry Vol. 4; Georg Thieme Publishers: Stuttgart, Germany, 1979; pp 192 ff and 284. However, C=S stretching vibrations, appearing in the fingerprint region, are often coupled and hence are not good group vibrations: Molina, M. T.; Yanez, M.; Mo, O. The Thiocarbonyl group. In *The Chemistry of Double-bonded Functional Groups*; Patai, S., Rappoport, Z., Eds.; J. Wiley: Chichester, U.K., 1997; Suppl. A3, Chapter 23, pp 1355−1496.

(10) Cantello, B. C. C.; Mellor, J. M.; Webb, C. F. *J. Chem. Soc., Perkin Trans. 2* **1974,** 22−25.

(11) Paasivirta, J.; Krieger, H. *Suomen Kemistilehti* **1965**, *38B*, 182−183; *Chem. Abstr.* **1966**, *64*, 4965g.

(12) Corey, E. J.; Weinshenker, N. M.; Schaaf, T. K.; Huber, W. *J. Am. Chem. Soc.* **1969**, *91*, 5675−5677.

(13) Ipaktschi, J. *Chem. Ber.* **1972**, *105*, 1840−1853.

(14) Asahina, Y.; Ishidate, M. *Ber. Dtsch. Chem. Ges.* **1934**, *67*, 1202−1204.

(15) Dallacker, F.; Alroggen, I.; Krings, H.; Laurs, B.; Lipp, M. *Justus Liebigs Ann. Chem.* **1961**, *647*, 23−36.

(16) Martinez, A. G.; Vilar, E. T.; Fraile, A. G.; Cerero, S. de la Moya; Maroto, B. L. *Tetrahedron: Asymmetry* **2000**, *11*, 4437−4440.

(17) Villemin, D.; Hammadi, M. *Synth. Commun.* **1995**, *25*, 3141−3144.

tions in synthesis, e.g., both inter- and intramolecular C−C connections, especially cycloaddition reactions. Chiral spirodiene building blocks should be accessible. Reactions with transition-metal complexes, e.g., carbonyls, can easily be imagined. Emphasis should be laid on the utilization of the thionoester function in **8**, which, to the best of our knowledge, seems not have been investigated in the past. The first objective for further research, however, should be the elaboration of reaction conditions for a controlled, more selective solvolysis of Raasch's cycloadduct **2**, to form either **7** or **8** (Scheme 2). As yet, this is the weak point of our approach. Perhaps, cycloadducts of **1** with other thiocarbonic acid derivatives, i.e., thiophosgene equivalents, would be a better choice.

Experimental Section

General Procedures. Spiro[2.4]hepta-4,6-diene (**1**) was prepared according to a literature procedure.[18] Thiophosgene (>97%) and 2-chloroacrylonitrile (99%) were commercial products and used without further purification. Diethyl ether, benzene, and *n*-pentane were dried by refluxing over sodium and subsequent distillation. Ethanol was dried with sodium. For chromatographic separations, silica 60, 40−63 μm, was used. For elution, predried petroleum ether (PE) was distilled (bp 40−65 °C); ethyl acetate (EA) was dried over $CaCl_2$, distilled, and kept dry over 4 Å molecular sieves. Melting points were not corrected.

3′,3′-Dichlorospiro(cyclopropane-1,7′-[2]thiabicyclo-[2.2.1]hept[5]ene) (2). To a solution of thiophosgene (11.5 g, 0.10 mol) in dry *n*-pentane (40 mL), protected from atmospheric moisture and cooled in an ice bath was added dropwise with magnetic stirring **1** (13.0 g, 0.14 mol) in dry diethyl ether (20 mL). After 2 h the ice bath was removed, and the light red solution was cooled by means of a dry ice/acetone bath. A white solid precipitated which was filtered and washed with ice-cold *n*-pentane (20 mL), excluding moisture. The white solid was dried in vacuo with cooling in an ice bath [yield 18.87 g (91%), mp 64−65 °C (lit.[3] mp 61 °C, yield 74%)]. The substance decomposes on storing and should be used immediately. The ^{1}H NMR was in agreement with the data given in ref 3.

Ethanolysis of 2: Ethyl *cis*-7-Mercaptospiro[2.4]hept-5-ene-4-carboxylate (7b) and *O*-Ethyl Spiro[2.4]hepta-4,6-diene-4-thiocarboxylate (8b): Cycloadduct **2** (3.10 g, 15 mmol) was added portionwise and with magnetic stirring to dry ethanol (60 mL), chilled in an ice bath. The ice bath was removed, and stirring was continued for 1 h, whereupon the yellow solution became dark brown. The solvent was evaporated at reduced pressure at room temperature, finally using the vacuum of an oil pump. The remaining dark brown oil (2.74 g) was purified by chromatography. Separation of 2.60 g at silica (250 g) with PE/EA (30:1) gave a brown liquid (**8b**; 1.78 g, 69%); a second fraction was eluted with PE/EA (20:1), affording **7b** (465 mg, 17%) as a brown oil: IR (film) 3070, 2980, 2935, 2875 (CH), 2560 (SH), 1735 (C=O) cm^{-1}; MS (EI, 70 eV) *m*/*z* (rel intens) 198 (3) [M$^+$], 165 (44), 137 (4), 125 (23), 105 (4), 97.0 (10), 91 (100), 79 (24), 65 (18), 53 (4), 45 (7), 43 (10), 39 (14), 29 (79). Data for **8b**: IR (film) 3090, 2985, 2940, 2895, 2870 (CH), 1550 (C=C), 1460, 1440, 1395, 1370, 1285, 1260, 1215 cm^{-1}; UV/vis (ethanol) λ_{max} (log ϵ) 241 (3.86), 257 (shoulder, 3.72), 342 (4.10) nm. Anal. Calcd for $C_{10}H_{12}OS$ (180.3): C 66.63, H 6.71, S 17.78. Found: C 66.41, H 6.70, S 17.58.

Desulfurization of 7b and 8b: Ethyl *cis*+*trans*-7-Acetoxyspiro[2.4]hept-5-ene-4-carboxylate (9b) and Ethyl Spiro[2.4]hepta-4,6-diene-4-carboxylate (10b). Dry ethanol (1 L) was chilled in an ice bath. With magnetic stirring, cycloadduct **2** (130.0 g, 0.628 mol) was added in portions, and the solution stirred for 15 h at 0 °C. The solvent was removed in a rotary evaporator, and the oily residue diluted with CH_2Cl_2 (500 mL). This solution was added dropwise to a suspension of $Hg(OAc)_2$ (318.7 g, 1.00 mol) in CH_2Cl_2 (1 L) at room temperature and stirred overnight. The solvent was removed in a rotary evaporator, and diethyl ether (1 L) was added to the remaining dark mixture of organic liquid and mercury salts. The mixture was filtrated, and the dark solid residue washed with diethyl ether (3 × 70 mL). The combined filtrates were concentrated in vacuo, and the remaining brown liquid distilled in a 15 cm Vigreux column at reduced pressure (water aspirator). After a forerun (30−35 °C (11 Torr), 25.01 g) with a mixture of acetic acid and acetic acid anhydride[6] (IR spectrum), the main fraction (58.56 g) was distilled at 92−96 °C/11 Torr, consisting mainly of the spirodiene **10b**, contaminated by minor amounts of acetic acid (anhydride). To remove these impurities, the distillate was diluted with diethyl ether (500 mL) and washed with saturated $NaHCO_3$ solution (2 × 100 mL) and then with water (2 × 100 mL). After being dried with $MgSO_4$, the ether solution was concentrated in a rotary evaporator, and the remaining liquid was distilled in vacuo (water aspirator) to yield 50.66 g (49%) of **10b** with bp 85−92 °C (11 Torr). Redistillation using a 20 cm Vigreux column gave bp 84−86 °C (11 Torr): IR (film) 1690 (C=O) cm^{-1}. Anal. Calcd for $C_{10}H_{12}O_2$ (164.2): C 73.15, H 7.37. Found: C 72.92, H 7.44. The liquid that remained after distillation of **10b** was distilled further, using an oil pump. The slightly yellow distillate (26.11 g) with bp 82−85 °C (0.01 Torr) proved to be a mixture of the *cis* and *trans* diastereoisomers of **9b** with a minor amount of **10b** (^{1}H NMR spectrum). A part of the mixture (2.7 g) was subjected to chromatography on silica (250 g, gravity column). Elution with PE/EA (15:1) gave 0.34 g of spirodiene **10b**. On further elution with PE/EA (4:1) the two diastereoisomers of **9b** were separated (0.86 and 0.74 g), in addition to a middle fraction consisting of a mixture of the two compounds (0.64 g). Data for the first eluted diastereomer *trans*-**9b**: IR (film) 1730 (C=O) cm^{-1}. Anal. Calcd for $C_{12}H_{16}O_4$ (224.3): C 64.27, H 7.19. Found: C 64.27, H 7.25. Data for the second eluted diastereomer *cis*-**9b**: IR (film) 1725 (C=O) cm^{-1}. Anal. Calcd for $C_{12}H_{16}O_4$ (224.3): C 64.27, H 7.19. Found C 63.93, H 7.21.

Spiro[2.4]hepta-4,6-diene-4-methanol (11). To a stirred slurry of $LiAlH_4$ (2.95 g, 77.7 mmol) in dry diethyl ether (50 mL), cooled in an ice bath, was added dropwise a solution of **10b** (8.21 g, 50.0 mmol) in dry diethyl ether (50 mL). The ice bath was removed, and stirring was continued at room temperature for 24 h. Then, water (5 mL) was added cautiously with cooling with an ice bath, followed by 15% aqueous sodium hydroxide solution (5 mL) and finally water (15 mL). The coarse solid formed was filtered off, washed with *tert*-butyl methyl ether (30 mL) and boiled with *tert*-butyl methyl ether (50 mL). The combined ether extracts were dried with $MgSO_4$, concentrated in vacuo, and distilled in a Kugelrohr apparatus at 70−75 °C (0.01 Torr), giving a colorless liquid (**11**; 4.40 g, 72% yield): IR (film) 3330 (br, OH) cm^{-1}. Anal. Calcd for $C_8H_{10}O$ (122.2): C 78.65, H 8.25. Found C 78.41, H 8.41.

2-Chloro-1-hydroxymethylspiro(bicyclo[2.2.1]hept-5-ene-7,1′-cyclopropane)-2-carbonitrile (14a). **11** (1.83 g, 15.0 mmol) and 2-chloroacrylonitrile (1.75 g, 20.0 mmol) were dissolved in dry benzene (10 mL) and heated to 80 °C with magnetic stirring for 22 h. The brown reaction mixture was filtrated over a short silica column and further eluted with PE/EA (3:2). After evaporation of the solvent under reduced pressure the residue was recrystallized from diethyl ether/pentane, giving 2.52 g (80%) of **14a** with mp 177−178 °C: IR (KBr) 3470 (br, OH), 2215 (CN) cm^{-1}. Anal. Calcd for $C_{11}H_{12}$-ClNO (209.7): C 63.01, H 5.77, N 6.68, Cl 16.91. Found C 63.16, H 5.84, Cl 16.98, N 6.66.

2-Chloro-1-hydroxymethylspiro(bicyclo[2.2.1]heptane-7,1′-cyclopropane)-2 -carbonitrile (15). A solution of cycloadduct **14a** (6.27 g, 29.9 mmol) in dry ethyl acetate (80 mL) was charged with palladium/carbon catalyst (300 mg) and shaken under hydrogen gas at atmospheric pressure. The catalyst was removed by filtration and the solvent evaporated under reduced pressure. The remaining white solid (6.05 g, 95%) with mp 180−182 °C dec was analytically pure: IR (KBr) 3490 (br, OH), 2215 (CN) cm^{-1}. Anal. Calcd for $C_{11}H_{14}ClNO$

(18) Kunitake, T.; Ochiai, T. *Macromol. Synth.* **1985**, *9*, 61−63.

(211.7): C 62.41, H 6.67, Cl 16.75, N 6.61. Found C 62.18, H 6.59, Cl 16.97, N 6.68.

1-Hydroxymethylspiro(bicyclo[2.2.1]heptane-7,1′-cyclopropane)-2-one (16). Potassium hydroxide (1.56 g, 27.8 mmol) was dissolved in DMSO (15 mL) and water (5 mL) with magnetic stirring at 50 °C and allowed to cool to room temperature. A solution of **15** (2.95 g, 13.9 mmol) in DMSO (15 mL) was added dropwise, with magnetic stirring. The mixture was heated to 70 °C for 24 h, poured into water (600 mL), and extracted with diethyl ether (3 × 200 mL). The combined ether extracts were dried with $MgSO_4$ and concentrated in vacuo. The remaining slightly yellow viscous oil was purified by chromatography on silica (250 g) with PE/EA (2:1, then 1:1), yielding 1.57 g of a white solid (**16**; 68%) with mp 152−154 °C: IR (KBr) 3415 (br, OH), 1730 (C=O) cm^{-1}. Anal. Calcd for $C_{10}H_{14}O_2$ (166.2): C 72.26, H: 8.49. Found C 72.04, H 8.44.

1-Hydroxymethyl-7,7-dimethylbicyclo[2.2.1]heptan-2-one (*rac*-10-Hydroxycamphor, 17). A solution of bicyclic ketone **16** (0.89 g, 5.35 mmol) in glacial acetic acid (60 mL) was charged with platinum(IV) oxide hydrate (120 mg) and shaken under hydrogen gas at atmospheric pressure. The catalyst was removed by filtration and the solvent evaporated under reduced pressure. The residue was taken up in CH_2Cl_2 (50 mL), washed with $NaHCO_3$ solution, and dried with $MgSO_4$. After evaporation of the solvent under reduced pressure, the remaining white solid (0.81 g) was recrystallized from petroleum ether (40−65 °C), yielding 650 mg (72%) of **17** with mp 200−202 °C (the mp of nonracemic 10-hydroxycamphor, prepared from (+)-camphor, was reported to be 220 °C,[14] 218 °C,[15] and 216−218 °C[16]): IR (KBr) 3450 (br, OH), 1735 (C=O) cm^{-1}. Anal. Calcd for $C_{10}H_{16}O_2$ (168.2): C 71.39, H 9.59. Found C 70.67, H 9.43.

Acknowledgment. We thank the analytical and spectroscopic service of the Institute of Organic Chemistry for gas chromatograms, spectra, and elemental analyses, especially Jochen Rebell (NMR) and Dr. Joachim Opitz (MS).

Supporting Information Available: Preparation of the methyl esters **7a**, **8a**, and **10a**, the transformation of **9b** to **10b**, preparation of the cycloadducts **12a**−**c** and **14b**, NMR peak assignments and the information from ^{13}C NMR/DEPT spectra, discussion of the EI-MS of **12a** and of the NMR spectra of the cycloadducts **12**−**14**, Copies of the ^1H NMR spectra of compounds **8a**, **8b**, **10a**, **10b**, **11**, **12a, 14a**, **14b**, **15**, **16**, and **17**, a ^{13}C NMR spectrum of the impure compound **14b**, and EI-mass spectra of the cycloadduct **12a** at 20 and 70 eV (Figures S1−S14). This material is available free of charge via the Internet at http://pubs.acs.org.

JO011087P