DOI: 10.1002/ejoc.200600673

A Novel C_3-Symmetric Triol as Chiral Receptor for Ammonium Ions

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Keywords: Chirality / Host-guest systems / Enantioselective recognition / Cyclotrimerization / Tripodal ligand

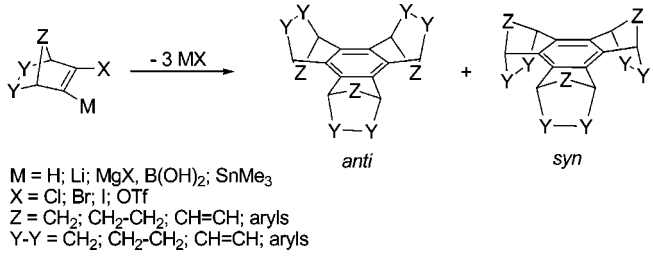
The enantiopure C_3-symmetric *syn*-benzotriborneol was efficiently obtained in an eight-step route. Of particular interest from a synthetic point of view are the potassium *tert*-butoxide promoted bromination of camphor hydrazone (**4**) and the observation that the protecting groups influence the *syn*/*anti* diasteroselectivity of the cyclotrimerization reaction of **12**–**14**. Complexation studies in deuteriochloroform revealed the capability of the cyclotrimer *syn*-**1** to act as host for ammonium ions, and in particular, the efficient chiral recognition of the two enantiomers of (1-phenylethyl)ammonium chloride.

Introduction

The interest during the last two decades of various research groups in the preparation of strained aromatic rings led to the synthesis of a large number of compounds arising from cyclotrimerization of three bicycloalkene units (Scheme 1).[1–5] These compounds were used as precursors of subunits of fullerene,[3j] as scaffolds for supramolecular chemistry,[3e] as starting material for the synthesis of trindane structures,[3m] and as basic structures for the study of Mills–Nixon effects or radical stabilization, which are features intrinsic to these molecules.[4c] The use of different reaction conditions and reagents largely improved the yields of the cyclotrimers and the *syn*/*anti* diastereoselectivity, key points for the development of supramolecular hosts. Indeed, *syn* cyclotrimers are valuable substrates because of the presence of two rigid bowl-shaped pockets, which could be properly functionalized in order to develop selective receptors. In particular, their deeper pocket conveys a peculiar cavity displaying particular electronic features useful for complexation.[3e]

Our contribution to this field was the development of an original reaction involving trimerization of vicinal bromotrimethylstannyl olefins with a copper promoter.[2h] This methodology led to the synthesis of a large variety of new compounds and to a deeper knowledge of the mechanism of cyclotrimerization reactions.

In a previous communication, the cyclotrimerization of suitably hindered enantiopure bicyclic vicinal bromotrimethylstannyl olefins bearing masked hydroxy groups was reported to give good yields and high diastereoselectivities in favor of the *syn* isomer.[2i]



Scheme 1. Synthesis of benzocyclotrimers using the cyclotrimerization reaction leads to formation of the *syn* and *anti* isomers. The most typical system involves the presence of a double bond with vicinal halogen and metal substituents.

The rigid C_3-symmetric structure of triol *syn*-**1** (Figure 1), bearing three hydroxy groups on the concave side of the molecule, prompted us to undertake a study of its complexation properties. The importance of C_3 symmetry in chiral recognition has been pointed out.[6] The highly chemo- and diastereoselective synthesis and the chiral recognition properties of this molecule are herein reported.

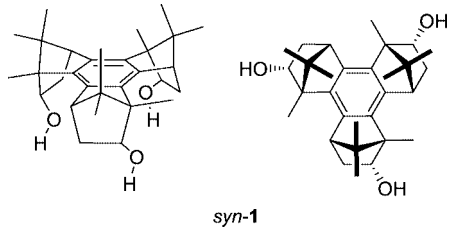


Figure 1. *syn*-Benzotriborneol *syn*-**1** presents three hydroxy groups in a rigid conformation describing a hydrophilic cavity.

Results and Discussion

Synthesis of Triols

The starting material for the preparation of the triol was the readily available (–)-bornyl acetate that was oxidized to

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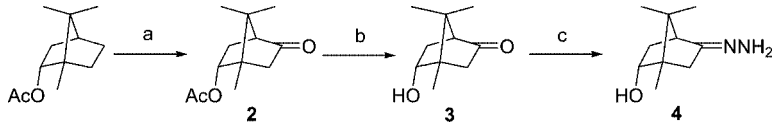


Scheme 2. Synthesis of the hydrazone precursor **4**. Reagents and conditions: a) CrO_3, AcOH, 140 °C (22%); b) KOH, EtOH, room temperature (95%); c) $H_2NNH_2{\cdot}H_2O$, H_2SO_4 (cat.), *n*BuOH, 110 °C (98%).

5-oxobornyl acetate (**2**) with chromium(VI) oxide in acetic acid with a constant 44% conversion and 50% yield based on consumed starting material (Scheme 2).[7] Many attempts were made in order to substitute chromium(VI) with less noxious reagents: the use of oxygen in the presence of hydroxyphthalimide with or without transition metals [$Co(acac)_3$] failed to produce a reasonable amount of the desired product.[8] The use of *tert*-butyl hydroperoxide in the presence of ruthenium(III) chloride afforded ketone **2** in reasonable amounts, but the purification was complicated by the presence of large amounts of byproducts.[9]

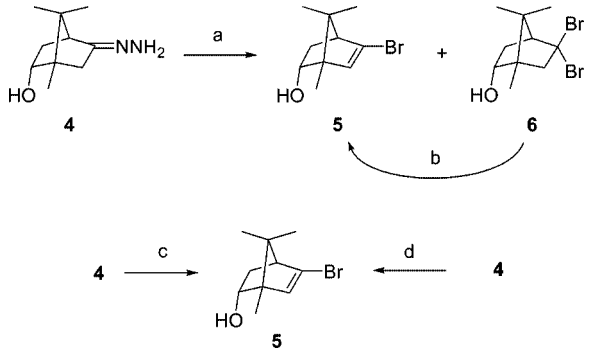
The subsequent saponification was achieved with potassium hydroxide in ethanol, affording **3** in nearly quantitative yield. The latter was converted into the hydrazone derivative **4** (95% yield) by heating to reflux with hydrazine hydrate in *n*-butanol using a Dean–Stark trap filled with molecular sieves (4 Å) (Scheme 2).[10]

The transformation of the hydrazone moiety into bromo olefin **5** was attempted in a first run with the use of pyridinium perbromate as the brominating reagent and pyridine as a proton scavenger, producing a mixture of products, identified by GC-MS and ^1H NMR as the desired olefin **5** and dibromide **6**, in a 2:1 ratio (Scheme 3).[2k] The mixture treated with potassium *tert*-butoxide in DMSO afforded pure **5** in 58% yield after flash chromatography (Scheme 3).[1b] In a second experiment, hydrazone **4** was treated with *N*-bromosuccinimide in pyridine, producing in a single step the olefin **5** free of dibromide **6** in 62% yield (FC).[11] A further improvement was achieved performing the reaction with bromine and potassium *tert*-butoxide in diethyl ether under sonication. Under these conditions the poor solubility of **4** and *tert*-butoxide in the solvent allowed the maintenance of the low concentrations required by the reaction. The use of potassium *tert*-butoxide as the base permitted the complete suppression of intermediate **6** and gave a clean reaction mixture that was conveniently purified by sublimation at reduced pressure, obtaining **5** in 74% yield (Scheme 3).

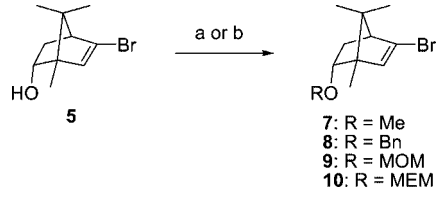
The protection of the hydroxy group with ethers (methyl or benzyl) and acetals [methoxymethyl (MOM) or 2-methoxyethoxymethyl (MEM)] was achieved with standard procedures, affording the expected products in good yields [80% (**7**), 74% (**8**), 95% (**9**), 92% (**10**)] (Scheme 4).[12–14]

It was observed that samples of **9** slowly decomposed to a compound less retained than **9** on silica gel. This side product was isolated and identified as the bis(acetal) **11**, which presumably arises from a transacetalization in the presence of traces of silica gel in the samples (Scheme 5).

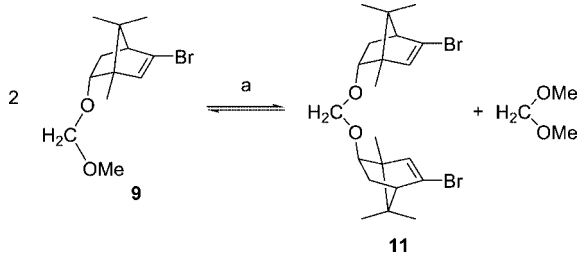
The protected bromobornenols **7**–**10** were treated with trimethyltin chloride in the presence of excess lithium diisopropylamide (Scheme 6) to afford, in most cases, good yields of stannyl derivatives [**12** (83%), **13** (86%), **14** (93%)].



Scheme 3. Synthesis of the bromobornenol **5**. Reagents and conditions: a) $PyHBr_3$, Py, Et_2O, room temperature, (2:1 ratio); b) *t*BuOK, DMSO, 0 °C (58%); c) NBS, Py, 0 °C (62%); d) Br_2, *t*BuOK, Et_2O, room temperature (74%).

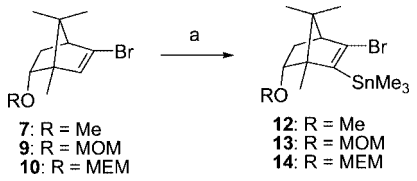


Scheme 4. Protection of the bromobornenol **5**. Reagents and conditions: a) i) NaH, Et_2O, 0 °C; ii) MeI or BnBr (80 or 74%); b) MOMCl or MEMCl, iPr_2NEt, CH_2Cl_2, room temperature (95 or 92%).



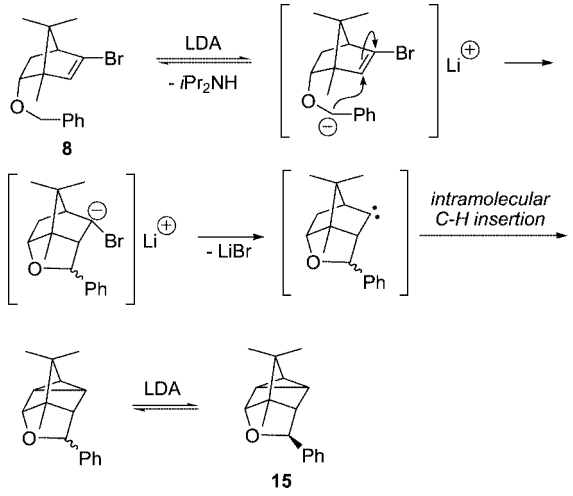
Scheme 5. Equilibrium between acetals **9** and **11**. Reagents and conditions: a) traces of silica gel, room temperature (variable amounts).

On the contrary, benzyl ether **8** afforded quantitatively a compound without the trimethylstannyl moiety and without the bromine atom. Complete characterisation, including homo- and heteronuclear two-dimensional NMR spectra, and comparison with related structures[15] allowed the determination of the final structure as **15**. This result was rationalized by assuming that lithium diisopropylamide abstracts a benzylic hydrogen atom and the resulting carban-



Scheme 6. Stannylation of protected bornenols **7**, **9**, **10**. Reagents and conditions: a) i) LDA, THF, room temperature; ii) Me_3SnCl (83, 86, 93%).

ion intramolecularly attacks the olefin in the closer position. The *gem*-bromo anion evolves to a carbene, which inserts at the methylene position (Scheme 7).[16] The high diastereoselectivity observed at the benzylic position is probably determined by the equilibrium promoted by the excess of lithium diisopropylamide.

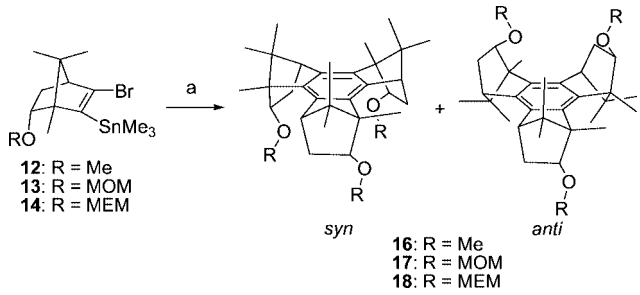


Scheme 7. Proposed mechanism of formation of **15**.

Trimerizations were performed using the well-established methodology based on the use of copper(I) 2-thiophenecarboxylate (CuTC).[2h–2k,3i–3l,5f] This reagent afforded good yields of trimers [**16** (82%), **17** (86%), **18** (93%)], with different *syn*/*anti* ratios, according to the protecting groups on the alcoholic moieties (Scheme 8). The highest stereoselectivity was obtained with methyl derivative **12**, which gave essentially pure *syn*-**16**, while MOM- and MEM-protected bornenols **13** and **14** afforded 85:15 and 83:17 *syn*/*anti* mixtures, respectively.[2k]

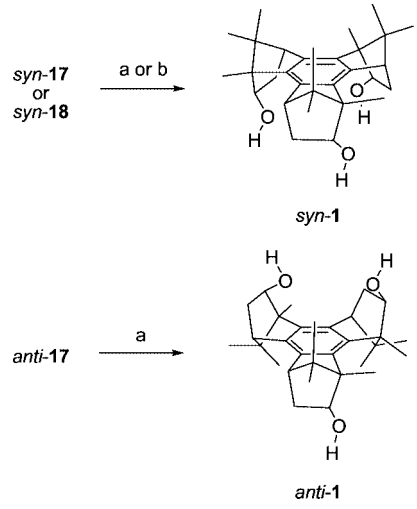
The variable amounts of isomers can be explained by the steric hindrance exerted by the protecting groups. Indeed, in the *anti* structures, only two substituents are forced to face each other, while in the *syn* isomers all the three ethers are close together in the concave portions of the molecules, and the energy gap increases with the bulkiness of the substituent. Nevertheless, a further interaction of ethers with copper can be taken into consideration to justify such high *syn* selectivity. In fact, the higher *syn*/*anti* ratios were obtained only with substrates containing heteroatoms.[3k,3l]

Despite the higher diastereomeric ratio obtained in the case of cyclotrimer **16**, the high stability of the methyl ether, which requires drastic cleavage conditions, makes this substrate unappealing for the preparation of triol *syn*-**1**.[17] The



Scheme 8. Synthesis of cyclotrimers **16**, **17**, **18**. Reagents and conditions: a) CuTC, NMP, 0 °C to room temperature [*syn*-**16** (78%), *syn*-**17** (72%), *syn*-**18** (77%)].

purification and separation of the isomers of **17** and **18** by flash chromatography was straightforward; *syn*- and *anti*-**1** were obtained in nearly quantitative yields by the cleavage of the acetals with hydrochloric acid in methanol at room temperature[18] or with a sulfonated polystyrene (Bayer K2613) in refluxing methanol. The latter methodology was preferred because of the lower amount of water contained in the resulting triols, as determined by ^1H NMR analysis (Scheme 9 and Table 1).



Scheme 9. Deprotection of cyclotrimers **17** and **18**. Reagents and conditions: a) concd. HCl, MeOH, room temperature (quant.); b) acid resin, MeOH, 70 °C (quant.).

Table 1. Yields and ratios obtained for the different protections of hydroxy groups.

Protecting group	Protection (%)	Stannylation (%)	Cyclotrimerization (%)	*syn*/*anti* ratio	Deprotection (%)
Me	80	83	82	99:1	–
MOM	95	86	86	85:15	98
MEM	92	93	93	83:17	95

Complexation Experiments

It has been shown that enantiopure C_3-symmetric tripodal ligands exhibit interesting enantiodiscrimination properties toward chiral ammonium ions.[19] The complexation

properties of triol *syn*-**1** were studied by means of NMR complexation experiments. In order to test the complexation capabilities and the chiral recognition properties of *syn*-**1**, the chiral cation (1-phenylethyl)ammonium chloride (**19**) was chosen. Preliminary experiments showed that the addition of 1 equiv. of *rac*-(1-phenylethyl)ammonium chloride to a solution of the triol *syn*-**1** in deuteriochloroform leads to a splitting of the proton and carbon resonances of the ammonium ion due to formation of diasteromeric couples, and to a significant change in the chemical shifts of the proton resonances of *syn*-**1** caused by complexation.

In order to assess the chiral recognition capabilities of the triol, we started a deeper analysis of the system comparing the complexation capabilities of the triol *syn*-**1** with (1-phenylethyl)ammonium chlorides (+)-**19** and (–)-**19**. The complexes were characterized in deuteriochloroform by means of ^{1}H NMR Job plots to determine the stoichiometries (Figure 2) and ^{1}H NMR titrations to determine the association constants (Table 2, Figure 3) and complexation-induced changes in chemical shifts. The Job plots showed the clear formation of a 1:2 complex between the triol and the ammonium salt. This phenomenon had already been observed for systems possessing multiple binding sites.[20] In the case of multivalency of the system, the binding of the ammonium ion and its counterion is followed by the binding of a second ion pair. Ion pairs in fact tend to form aggregates or dimers in solution, especially when the cation has a small counteranion.[21]

The NMR titration experiments clearly showed that two different processes take place. The process that takes place at low concentrations is the complexation of the first ion pair, and the process at high concentrations is the binding of a second ion pair for the reformation of the dimer present in solution.[20] Binding association constants were deter-

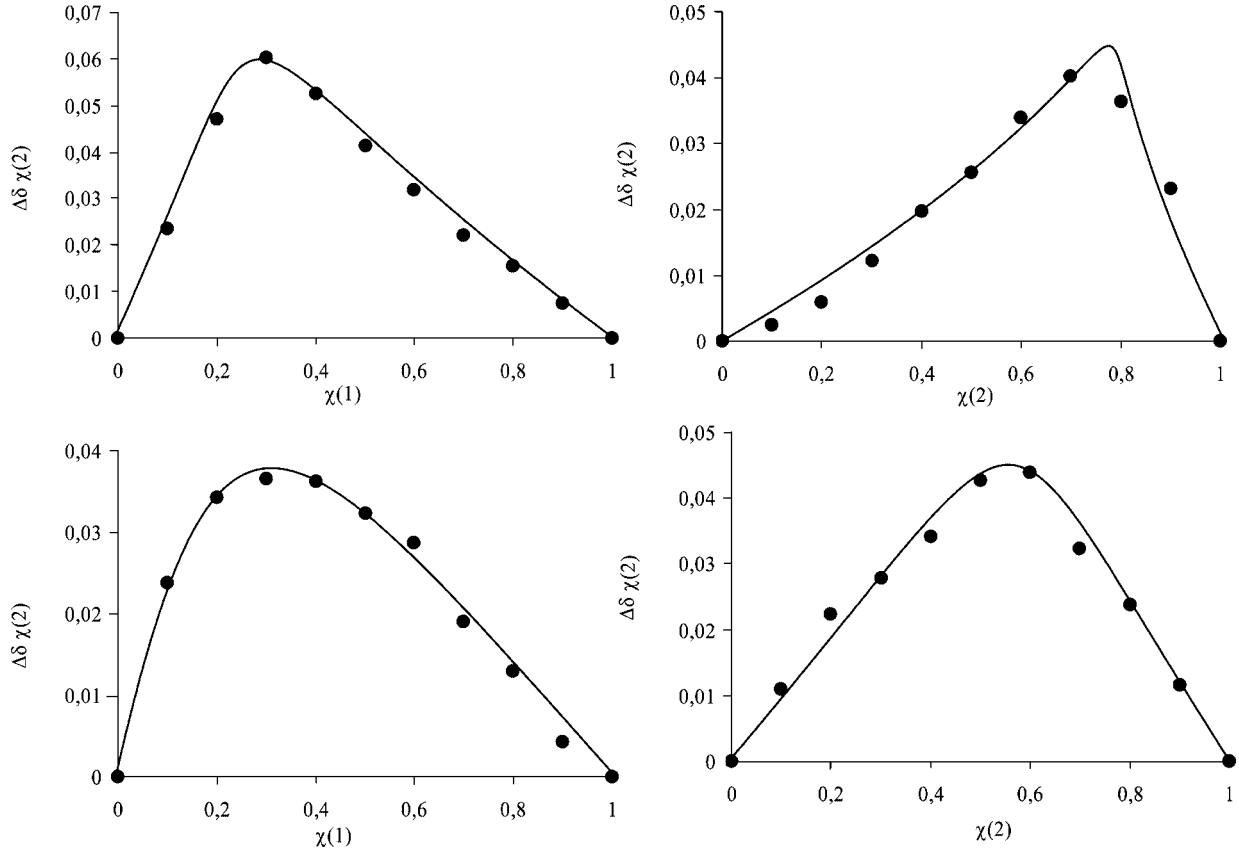


Figure 2. ^{1}H NMR Job plots for the binary mixtures *syn*-**1** and (+)-**19** and (–)-**19**.

Table 2. Association constants (K in M^{-1}) measured from ^{1}H NMR titrations in deuteriochloroform at 295 K and limiting complexation-induced changes in ^{1}H NMR chemical shifts ($\Delta\delta$ in ppm).

	K [M^{-1}][a]	a[b]	b	c	d	e	f	A	B	C	D
syn-**1** + (–)-**19** ⇔ *syn*-**1**·(–)-**19**	120 ± 15	0.0	0.0	–0.1	0.0	0.0	0.0	0.0	–0.2	–0.2	0.0
syn-**1**·(–)-**19** + (–)-**19** ⇔ *syn*-**1**·[(–)-**19**]$_2$	1220 ± 210	–0.4	–0.1	–0.3	–0.1	–0.1	0.0	0.0	–0.1	0.0	0.0
syn-**1** + (+)-**19** ⇔ *syn*-**1**·(+)-**19**	230 ± 18	–0.5	–0.1	–0.4	–0.1	–0.2	–0.1	0.0	–0.3	–0.5	0.0
syn-**1**·(+)-**19** + (+)-**19** ⇔ *syn*-**1**·[(+)-**19**]$_2$	2380 ± 180	–0.8	–0.2	–0.8	–0.2	–0.2	–0.1	0.0	0.1	–0.2	0.0

[a] Average values from at least two separate experiments. Titration data for 4 to 6 different signals were used to determine the association constant in each case. Errors are quoted as twice the standard error from the weighted mean (weighting based on the observed change in chemical shift). [b] See Figure 3 for the proton labelling.

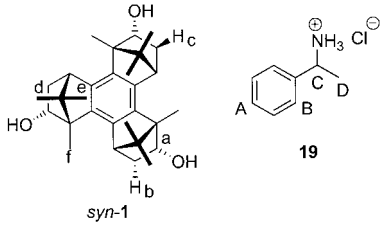


Figure 3. Proton labelling scheme for the titrations of Table 2.

mined using Hunter's NMRTit HGG program, and complexation was confirmed by NOESY experiments.[22] The binding constants and the complexation-induced changes in chemical shifts (CIS) are shown in Table 2. The titration experiments for both the enantiomers indicate a small first complexation constant followed by a larger second isotherm binding constant. CIS values are not easily interpretable due to the concurrent effects in the complexation coming from the ring current and the positive charge of the ammonium ion. The upfield chemical shifts for the proton close to the alcoholic position (a,b,c) and the low variation of the CIS for the methyl group at the top of the bridge (d,e), indicate the formation of an inclusion complex involving the cavity formed by the triols. This is also confirmed by the NOE observed between the methyne proton of the triol and the *o*-aryl and benzylic protons of the ammonium ion. The main difference between the two diastereoisomers is represented by the CIS values in the first binding constant. The largest upfield variation present for (+)-**19** could arise from a major level of interpenetration of the phenyl ring in the cavity.

The analysis of the binding constants of the two enantiomers makes evident the enantiodiscrimination of the triol. In each process, the affinity of the triol for (+)-**19** is double that of the other enantiomer, leading to the overall complexation constant being four times larger.

Conclusion

We described an effective procedure for the synthesis of an enantiopure C_3-symmetric functionalized cyclotrimer bearing three hydroxy groups in the lower rim. The introduction of functional groups in this rigid scaffold has been the prerequisite for the development of structures suitable for supramolecular chemistry investigations. In fact, the preliminary analysis of the complexation capabilities of this host revealed an interesting feature of the triol *syn*-**1**, that displayed good complexation and enantiodiscrimination capabilities with respect to the (1-phenylethyl)ammonium ion. The unique features of the three hydroxy groups of the triol and the possibility for further functionalization of the system open new interesting frontiers for future applications, which are presently under investigation.

Experimental Section

General: Reactions were carried out using standard techniques in flame-dried glassware cooled under argon. Commercial high purity reagents were employed without further purification. Dry THF and Et_2O were distilled prior to use from sodium/benzophenone. Dry diisopropylamine, DMSO and NMP were distilled prior to use from calcium hydride. Copper(I) 2-thiophenecarboxylate (CuTC) was obtained according to the procedure reported by Liebeskind.[23] The progress of the reactions was monitored by TLC, GC-MS or ^{1}H NMR spectroscopy. Gas-chromatographic analyses were performed with a 30 m, 0.25 mm i.d., Rtx-5MS capillary column (5:95 diphenyl/dimethylpolysiloxane). Flash-chromatographic purifications were performed with 230–400 mesh silica gel Merk 60. Melting points are uncorrected. Optical rotations were measured in a 10 cm cell.

(1*S*,2*R*,4*S*)-2-Hydroxy-1,7,7-trimethylbicyclo[2.2.1]heptan-5-one Hydrazone (4): A mixture of **3** (30 g, 178 mmol), hydrazine hydrate (70 mL, 1.4 mol) and concd. H_2SO_4 (1.0 mL) in *n*BuOH (150 mL) was refluxed in a Dean–Stark apparatus for 16 h, the trap being filled with molecular sieves (4 Å) (100 mL). The resulting solution was cooled, allowing the sulfate salts to settle on the bottom of the flask, the supernatant was filtered by suction, and the salts were washed with small amounts of Et_2O (3 × 10 mL). The filtrate was concentrated in vacuo and the resulting solid was triturated with *n*-hexane and filtered to afford a white powder (31.7 g, 98%). An analytical sample of **4** was prepared by recrystallization from CH_2Cl_2; m.p. 145–147 °C. $[\alpha]_D^{22}$ = +6.8 (*c* = 2.2, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.68 (br. s, 3 H), 4.15 (ddd, *J* = 9.8, 3.4, 1.6 Hz, 1 H), 2.52 (d, *J* = 17.0 Hz, 1 H), 2.46 (ddd, *J* = 13.6, 9.8, 4.6 Hz, 1 H), 2.26 (d, *J* = 4.6 Hz, 1 H), 1.84 (br. d, *J* = 17.0 Hz, 1 H), 1.25 (dd, *J* = 13.6, 3.4 Hz, 1 H), 0.99 (s, 3 H), 0.93 (s, 3 H), 0.84 (s, 3 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 162.4, 75.6, 53.5, 50.4, 48.3, 36.2, 29.8, 20.3, 17.8, 13.0 ppm. IR (KBr): $\tilde{\nu}$ = 3323, 3152, 2950, 1679, 1628, 1449, 1386, 1339, 1106, 1047, 981, 894, 855, 654 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 182 (17) [M$^+$], 164 (10), 149 (14), 123 (40), 79 (43), 55 (48), 41 (100). $C_{10}H_{18}N_2O$ (182.26): calcd. C 65.90, H 9.95; found C 65.88, H 9.94.

(1*S*,4*S*,6*R*)-3-Bromo-6-hydroxy-1,7,7-trimethylbicyclo[2.2.1]hept-2-ene (5). Method a: To a well-stirred slurry of pyridinium perbromate (7.7 g, 24.0 mmol) and pyridine (3.8 mL, 38.0 mmol) in Et_2O (100 mL) was added dropwise a solution of **4** (2.2 g, 12.0 mmol) in Et_2O (150 mL). Evolution of gas (N_2) was observed with a bubbler during the addition. After the addition was complete, the mixture was stirred for an additional 15 min, H_2O (100 mL) was added, and the layers were separated. The organic layer was washed with 2 M hydrochloric acid (3 × 50 mL), 3% $NaHCO_3$ (2 × 50 mL), and brine (50 mL), and then dried with $MgSO_4$. The resulting solution was concentrated at reduced pressure to afford a crude product containing a mixture of **5** and **6** in a 2:1 ratio. The mixture of **5** and **6** was diluted with dry DMSO (10 mL) and *t*BuOK (225 mg, 6.0 mmol) was added portionwise, at 0 °C under Ar. The resulting dark solution was stirred an additional 45 min, diluted with water (150 mL) and extracted with a 2:1 mixture of Et_2O/pentane (3 × 40 mL). The combined organic extracts were washed with water (3 × 10 mL), brine (20 mL), dried with $MgSO_4$ and concentrated. The residue was purified by flash chromatography (Et_2O/pentane, 3:7) to afford **6** (1.6 g, 58%) as a pale yellow solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ = 3.98 (br. d, *J* = 7.5 Hz, 1 H), 3.24 (d, *J* = 13.0 Hz, 1 H), 2.89 (d, *J* = 13.0 Hz, 1 H), 2.59 (d, *J* = 3.6 Hz, 1 H), 2.44 (m, 1 H), 2.21 (dd, *J* = 12.5, 2.5 Hz, 1 H), 1.33 (s, 3 H), 1.04 (s, 3 H), 0.88 (s, 3 H), (OH signal not observed) ppm. MS (EI, 70 eV): *m*/*z* (%) = 232–230 (18) [M$^+$ – HBr], 215–217 (17), 186–188 (16), 151 (67), 107 (100), 91 (91), 83 (91). **Method b:** To a solution of NBS (3.0 g, 17.0 mmol) in dry pyridine (20 mL) maintained at 0 °C under Ar, was added a solution of **4** (1.5 g, 8.2 mmol) in dry pyridine (10 mL). Evolution of gas (N_2) was observed with

a bubbler during the addition. After the addition was complete, the mixture was stirred for an additional 45 min, H_2O (300 mL) was added and the mixture was extracted with a 2:1 mixture of Et_2O/pentane (3 × 50 mL). The combined organic layers were washed with 2 M hydrochloric acid (3 × 50 mL) and brine (50 mL), and were dried with $MgSO_4$. The resulting solution was distilled to remove volatile materials and the residue was purified by flash chromatography (eluent Et_2O/pentane, 3:7) to afford **5** (1.2 g, 62%) as a pale yellow solid. **Method c:** A flame-dried three-necked round-bottomed flask, equipped with a mechanical stirrer, an argon inlet with bubbler, and a dropping funnel, was placed in a sonication bath. Bromine (9.8 mL, 82.8 mmol) was added to a slurry of **4** (6.10 g, 33.5 mmol) and *t*BuOK (15.0 g, 134 mmol) in dry Et_2O (350 mL) under sonication and vigorous stirring conditions over 1 h. During the addition evolution of gas (N_2) was observed. Water (100 mL) was added to the resulting mixture, the layers were separated, and the lower layer was extracted with Et_2O (3 × 50 mL). The combined organic extracts were dried with $MgSO_4$, concentrated in vacuo, and the resulting red oil was purified by sublimation (110 °C at 7.5×10^{-2} Torr) to afford 5.7 g (74%) of **5** as colorless crystals; m.p. 66–69 °C. $[\alpha]_D^{22}$ = +72 (*c* = 2.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.78 (br. s, 1 H), 4.15 (dd, *J* = 7.5, 2.6 Hz, 1 H), 2.47 (ddd, *J* = 13.1, 7.5, 3.8 Hz, 1 H), 2.40 (dd, *J* = 3.8, 1.0 Hz, 1 H), 1.12 (s, 3 H), 1.06 (dd, *J* = 13.1, 2.6 Hz, 1 H), 0.94 (s, 3 H), 0.80 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 133.8, 128.5, 78.5, 60.34, 60.29, 59.3, 37.8, 20.1, 18.8, 10.5 ppm. IR (KBr): $\tilde{\nu}$ = 3353, 2956, 2869, 1584, 1449, 1382, 1288, 1060, 1053 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 186–188 (24) [$M^+ - C_2H_3OH$], 151 (10), 107 (99), 91 (100). $C_{10}H_{15}BrO$ (231.13): calcd. C 51.97, H 6.54; found C 51.79, H 6.51.

General Procedure for the Protection of Bromobornenol with Ethers: A 60% dispersion of NaH in mineral oil (160 mg, 6.9 mmol) was washed with pentane (3 × 5 mL) under argon. The resulting powder was suspended in dry Et_2O (10 mL), cooled in a ice bath, and **5** (1.06 g, 4.6 mmol) was added in one portion. The mixture was stirred for 15 min and BnBr or MeI (5.0 mmol) was added dropwise through a syringe. The mixture was allowed to warm to room temperature overnight, dry MeOH (0.2 mL) was added, and the mixture was stirred for an additional 30 min. Water (50 mL) was added, and the mixture was extracted with Et_2O (3 × 50 mL). The combined ethereal extracts were washed with H_2O (3 × 20 mL), dried with $MgSO_4$ and concentrated in vacuo. The residue was purified by flash chromatography (CH_2Cl_2/*n*-hexane, 1.5:8.5).

(1*S*,4*S*,6*R*)-3-Bromo-6-methoxy-1,7,7-trimethylbicyclo[2.2.1]hept-2-ene (7): Colorless oil (80%); b.p. 96–98 °C at 7.5×10^{-2} Torr. $[\alpha]_D^{22}$ = +54 (*c* = 1.4, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.75 (s, 1 H), 3.77 (dd, *J* = 7.0, 2.6 Hz, 1 H), 3.29 (s, 3 H), 2.41 (d, *J* = 4.0 Hz, 1 H), 2.26 (ddd, *J* = 12.5, 7.0, 4.0 Hz, 1 H), 1.20 (dd, *J* = 12.5, 2.6 Hz, 1 H), 1.13 (s, 3 H), 0.94 (s, 3 H), 0.82 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.12, 125.5, 88.0, 59.8, 59.4, 58.4, 57.5, 33.4, 19.7, 18.9, 11.1 ppm. IR (film): $\tilde{\nu}$ = 2959, 2873, 2820, 1587, 1451, 1389, 1363, 1277, 1229, 1098, 997, 917, 830, 729, 544 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 244–245 (2) [M^+], 186–187 (55), 107 (100), 91 (48). $C_{11}H_{17}BrO$ (245.16): calcd. C 53.89, H 6.99; found C 54.08, H 7.02.

(1*S*,4*S*,6*R*)-3-Bromo-6-benzyloxy-1,7,7-trimethylbicyclo[2.2.1]hept-2-ene (8): Colorless oil (74%). $[\alpha]_D^{22}$ = +36 (*c* = 5.0, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.40–7.25 (m, 5 H), 5.82 (br. s, 1 H), 4.57 (d, *J* = 12.4 Hz, 1 H), 4.41 (d, *J* = 12.4 Hz, 1 H), 3.97 (dd, *J* = 7.0, 2.6 Hz, 1 H), 2.42 (d, *J* = 3.7 Hz, 1 H), 2.24 (ddd, *J* = 12.5, 7.0, 3.7 Hz, 1 H), 1.28 (dd, *J* = 12.5, 2.6 Hz, 1 H), 1.13 (s, 3 H), 0.94 (s, 3 H), 0.78 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 139.4, 136.1, 128.7, 127.8, 127.7, 125.8, 86.0, 71.8, 60.5, 60.1, 58.8, 34.4, 20.2, 19.5, 11.6 ppm. IR (film): $\tilde{\nu}$ = 2960, 2863, 1586, 1455, 1096, 725, 683 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 320 (1) [M^+], 230 (65), 229 (59), 189 (40), 188 (56), 187 (46), 185 (72), 121 (72), 106 (100). $C_{17}H_{21}BrO$ (321.25): calcd. C 63.56, H 6.59; found C 63.81, H 6.62.

General Procedure for the Protection of Bromobornenol with Acetals: To a solution of **5** (2.3 g, 10.0 mmol) and *i*Pr_2NEt (3.5 mL, 30.0 mmol) in dry CH_2Cl_2 (15 mL), maintained at 0 °C under Ar, was added MOMCl or MEMCl (15.0 mmol) through a syringe. The mixture was allowed to warm to room temperature overnight. Dry MeOH (0.2 mL) was added, and the solution was stirred for an additional 30 min. Water (50 mL) was added, and the mixture was extracted with Et_2O (3 × 50 mL). The combined ethereal extracts were washed with H_2O (3 × 20 mL), dried with $MgSO_4$ and concentrated in vacuo. The residue was purified by flash chromatography.

(1*S*,4*S*,6*R*)-3-Bromo-6-(methoxymethoxy)-1,7,7-trimethylbicyclo-[2.2.1]hept-2-ene (9): Eluent AcOEt/*n*hexane (0.5:9.5). Colorless oil (95%). $[\alpha]_D^{22}$ = +33 (*c* = 2.2, $CHCl_3$). ^{1}H NMR (300 MHz, $CDC1_3$): δ = 5.76 (br. s, 1 H), 4.63 (d, *J* = 6.9 Hz, 1 H), 4.59 (d, *J* = 6.9 Hz, 1 H), 4.14 (dd, *J* = 7.2, 2.8 Hz, 1 H), 3.34 (s, 3 H), 2.39 (br. s, 1 H), 1.23 (dd, *J* = 9.7, 2.8 Hz, 2 H), 1.13 (s, 3 H), 0.94 (s, 3 H), 0.81 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.7, 126.2, 96.2, 83.9, 60.5, 59.9, 58.8, 55.6, 35.1, 20.2, 19.4, 11.4 ppm. IR (film): $\tilde{\nu}$ = 2957, 2887, 1755, 1586, 1452, 1390, 1365, 1277, 1225, 1151, 1102, 1047, 1000, 919, 831, 774, 732 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 229–231 (5) [$M^+ - C_2H_6O$], 186–188 (32), 119–121 (91), 105–107 (100), 91 (57). $C_{12}H_{19}BrO_2$ (275.18): calcd. C 52.38, H 6.96; found C 52.57, H 6.96. Samples of **9**, upon standing at room temperature, slowly decomposed to a colorless solid material that was collected by suction filtration. Recrystallization from hot MeOH afforded pure acetal **11**, in variable amounts; m.p. 122–125 °C. $[\alpha]_D^{22}$ = +40 (*c* = 1.0, $CHC1_3$). ^{1}H NMR (300 MHz, $CDC1_3$): δ = 5.76 (s, 2 H), 4.62 (s, 2 H), 4.24 (dd, *J* = 7.1, 2.6 Hz, 2 H), 2.40 (br. d, *J* = 3.5 Hz, 2 H), 2.32 (ddd, *J* = 12.6, 7.1, 3.5 Hz, 2 H), 1.21 (dd, *J* = 12.6, 2.6 Hz, 2 H), 1.13 (s, 6 H), 0.95 (s, 6 H), 0.83 (s, 6 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 135.2, 125.8, 92.5, 82.3, 60.0, 59.4, 58.5, 34.4, 19.8, 19.0, 11.3 ppm. IR (KBr): $\tilde{\nu}$ = 2964, 2886, 1585, 1390, 1168, 1097, 1044, 727 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 243–245 (3) [$M^+ - C_{10}H_{13}BrO$], 229–231 (60), 187–189 (59), 171 (31), 163 (34), 149 (26), 121 (100). $C_{21}H_{30}Br_2O_2$ (474.27): calcd. C 53.18, H 6.38; found C 53.40, H 6.39.

(1*S*,4*S*,6*R*)-3-Bromo-6-[(2-methoxyethoxy)methoxy)]-1,7,7-trimethylbicyclo[2.2.1]hept-2-ene (10): Eluent AcOEt/*n*hexane (1.5:8.5). Colorless oil (92%). $[\alpha]_D^{22}$ = +41 (*c* = 0.9, $CHC1_3$). ^{1}H NMR (200 MHz, $CDC1_3$): δ = 5.75 (br. s, 1 H), 4.70 (br. s, 2 H), 4.20 (dd, *J* = 7.1, 2.6 Hz, 1 H), 3.80–3.50 (series of m, 4 H), 3.40 (s, 3 H), 2.39 (br. s, 1 H), 2.40–2.27 (m, 2 H), 1.22 (dd, *J* = 12.3, 2.6 Hz, 1 H), 1.11 (s, 3 H), 0.94 (s, 3 H), 0.82 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 135.2, 125.4, 94.8, 83.6, 71.7, 66.7, 60.0, 59.4, 59.0, 58.4, 34.7, 19.8, 19.0, 11.0 ppm. IR (film): $\tilde{\nu}$ = 2956, 2872, 1586, 1452, 1389, 1364, 1277, 1199, 1171, 1134, 1108, 1049, 1000, 982, 916, 852, 775 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 243–245 (2) [$M^+ - C_3H_7O_2$], 239 (8), 229–231 (35), 221 (24), 186 (45), 163 (54), 121 (80), 107 (100), 89 (70). $C_{14}H_{23}BrO_3$ (319.23): calcd. C 52.67, H 7.26; found C 52.59, H 7.26.

General Procedure for the Stannylation of Protected Bromobornenols: To a solution of dry diisopropylamine (3.3 mL, 25.0 mmol) in dry THF (25 mL), maintained at 0 °C under Ar, was added dropwise *n*BuLi (10.0 mL, 2.5 M solution in hexanes, 25.0 mmol), and the mixture was maintained at 0 °C for 15 min.

The protected bromobornenol (**7**–**10**) (10.0 mmol) was added through a syringe, and the mixture was stirred for an additional 15 min. Trimethyltin chloride (2.0 g, 10.0 mmol) was added in one portion, and the mixture was allowed to warm to room temperature overnight. The resulting solution was poured into water (100 mL) and extracted with Et_2O (3 × 50 mL). The combined organic extracts were washed with H_2O (50 mL), saturated aqueous NaCl (50 mL), dried with $MgSO_4$, and concentrated in vacuo to afford an oil that was purified by flash chromatography.

(1*S*,4*S*,6*R*)-3-Bromo-6-methoxy-1,7,7-trimethyl-2-(trimethylstannyl)bicyclo[2.2.1]hept-2-ene (12): Eluent CH_2Cl_2/hexane (1:9). Colorless oil (83%). $[\alpha]_D^{22}$ = +36 (*c* = 1.4, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.71 (dd, *J* = 7.0, 2.6 Hz, 1 H), 3.22 (s, 3 H), 2.40 (d, *J* = 3.7 Hz, 1 H), 2.18 (ddd, *J* = 12.4, 7.0, 3.7 Hz, 1 H), 1.18 (dd, *J* = 12.4, 2.6 Hz, 1 H), 1.15 (s, 3 H), 0.92 (s, 3 H), 0.80 (s, 3 H), 0.22 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 148.6, 138.0, 88.0, 64.6, 62.1, 57.8, 57.2, 33.6, 20.0, 19.0, 13.2, –7.9 ppm. IR (film): $\tilde{\nu}$ = 2987, 2958, 2873, 2819, 1553, 1450, 1388, 1361, 1276, 1183, 1113, 1095, 1051, 1013, 990, 773, 529, 513 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 392 (36) [M^+ – CH_3], 334 (80), 255 (61), 228 (100). $C_{14}H_{25}BrOSn$ (407.96): calcd C 41.22, H 6.18; found C 41.39, H 6.16.

(1*S*,2*S*,3*R*,4*S*,6*R*,7*R*,9*S*)-9-Phenyl-5,5′,6-trimethyl-8-oxatetracyclo[4.3.0.0^{2,4}.0^{3,7}]nonane (15): Eluent CH_2Cl_2/hexanes (3:7). Colorless crystals (97%); m.p. 71–73 °C. $[\alpha]_D^{22}$ = +28 (*c* = 0.5, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.40 (d, *J* = 7.1 Hz, 2 H), 7.33 (d, *J* = 7.1 Hz, 2 H), 7.20 (d, *J* = 7.1 Hz, 1 H), 5.07 (s, 1 H), 4.17 (d, *J* = 2.0 Hz, 1 H), 2.49 (d, *J* = 2.0 Hz, 1 H), 1.54–1.44 (m, 2 H), 1.28 (t, *J* = 5.0 Hz, 1 H), 0.84 (s, 3 H), 0.85 (s, 3 H), 0.57 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 143.4, 127.9, 126.1, 125.0, 87.3, 80.1, 52.5, 51.2, 45.4, 27.5, 22.2, 22.1, 19.4, 18.0, 8.4 ppm. IR (KBr): $\tilde{\nu}$ = 3056, 2956, 2856, 1462, 1034, 991, 710 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 240.2 (11) [M^+], 165 (7), 143 (75), 120 (29), 119 (100), 105 (29), 91 (65). $C_{17}H_{20}O$ (240.44): calcd. C 84.96, H 8.39; found C 84.66, H 8.42.

(1*S*,4*S*,6*R*)-3-Bromo-6-(methoxymethoxy)-1,7,7-trimethyl-2-(trimethylstannyl)bicyclo[2.2.1]hept-2-ene (13): Eluent CH_2Cl_2/*n*-hexane (1:9). Colorless oil (86%). $[\alpha]_D^{22}$ = +38 (*c* = 1.0, $CHCl_3$). ^{1}H NMR (300 MHz, $CDC1_3$): δ = 4.59 (d, *J* = 6.8 Hz, 1 H), 4.53 (d, *J* = 6.8 Hz, 1 H), 4.10 (dd, *J* = 7.2, 2.7 Hz, 1 H), 3.34 (s, 3 H), 2.40 (d, *J* = 3.6 Hz, 1 H), 2.28 (ddd, *J* = 12.5, 7.2, 3.6 Hz, 1 H), 1.21 (dd, *J* = 12.5, 2.6 Hz, 1 H), 1.16 (s, 3 H), 0.93 (s, 3 H), 0.81 (s, 3 H), 0.23 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 147.0, 138.3, 95.6, 83.4, 64.4, 62.1, 57.7, 55.2, 34.8, 19.9, 19.0, 13.1, –7.9 ppm. IR (film): $\tilde{\nu}$ = 2955, 2882, 1552, 1449, 1388, 1363, 1275, 1186, 1151, 1102, 1046, 1013, 919, 773, 717, 529 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 423–425 (29) [M^+ – CH_3], 335–337 (72), 229–231 (44), 165 (49), 41 (100). $C_{15}H_{27}BrO_2Sn$ (437.99): calcd. C 41.13, H 6.21; found C 41.19, H 6.20.

(1*S*,4*S*,6*R*)-3-Bromo-6-[(2-methoxyethoxy)methoxy]-1,7,7-trimethyl-2-(trimethylstannyl)bicyclo[2.2.1]hept-2-ene (14): Eluent AcOEt/*n*-hexane (2:8). Colorless oil (93%). $[\alpha]_D^{22}$ = +37 (*c* = 1.2, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.69 (d, *J* = 7.0 Hz, 1 H), 4.64 (d, *J* = 7.0 Hz, 1 H), 4.11 (dd, *J* = 7.2, 2.7 Hz, 1 H), 3.78–3.52 (series of m, 4 H), 3.41 (s, 3 H), 2.37 (d, *J* = 3.7 Hz, 1 H), 2.72 (ddd, *J* = 12.3, 7.2, 3.7 Hz, 1 H), 1.18 (dd, *J* = 12.3, 2.7 Hz, 1 H), 1.16 (s, 3 H), 0.89 (s, 3 H), 0.79 (s, 3 H), 0.20 (s, 9 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 148.2, 138.4, 94.7, 83.6, 71.7, 66.7, 64.5, 62.1, 59.0, 57.7, 34.8, 19.9, 19.0, 13.1, –7.9 ppm. IR (film): $\tilde{\nu}$ = 2956, 2873, 1551, 1450, 1388, 1363, 1172, 1106, 1046, 1013, 773, 529, 512 cm^{-1}. $C_{17}H_{31}BrO_3Sn$ (482.04): calcd. C 42.36, H 6.48; found C 42.46, H 6.47.

General Procedure for the Cyclotrimerization of Protected Bromo(stannyl)bornenols: To a solution of the protected bromo(stannyl)bornenol (5.0 mmol) in dry NMP (15 mL), maintained at –20 °C under Ar, CuTC (1.43 g, 7.5 mmol) was added portionwise. The well-stirred mixture was allowed to warm to room temperature overnight. The resulting slurry was diluted with 20% aqueous NH_3 (50 mL) and extracted with AcOEt (3 × 50 mL). The combined organic extracts were washed with H_2O (50 mL) and saturated aqueous NaCl (50 mL), dried with $MgSO_4$ and concentrated in vacuo to afford an oil that was purified by flash chromatography.

***syn*-(1*R*,2*R*,4*S*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-3,4,7,8,11,12-Hexahydro-2,6,10-trimethoxy-1,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*syn*-16):** Eluent Et_2O/hexanes (1:9). Colorless crystals (78%) from hot MeOH; m.p. 139–140 °C. $[\alpha]_D^{22}$ = +84 (*c* = 1.0, $CHCl_3$). ^{1}H NMR (200 MHz, $CDCl_3$): δ = 3.82 (dd, *J* = 8.2, 3.0 Hz, 3 H), 3.08 (s, 9 H), 2.98 (d, *J* = 4.3 Hz, 3 H), 2.28 (ddd, *J* = 12.4, 8.2, 4.3 Hz, 3 H), 1.34 (s, 9 H), 1.25 (dd, *J* = 12.4, 3.0 Hz, 3 H), 0.94 (s, 9 H), 0.57 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.5, 134.0, 86.4, 57.1, 56.9, 56.4, 48.9, 33.3, 21.0, 19.3, 12.5 ppm. IR (KBr): $\tilde{\nu}$ = 3442, 2979, 2925, 2869, 2819, 1445, 1386, 1363, 1231, 1190, 1109, 1039, 1001, 647 cm^{-1}. MS (EI, 70 eV): *m*/*z* (%) = 492 (6) [M^+], 434 (39), 376 (54), 318 (100), 303 (31). $C_{33}H_{48}O_3$ (492.73): calcd. C 80.44, H 9.82; found C 80.62, H 9.83.

***anti*-(1*S*,3*R*,4*R*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-1,2,7,8,11,12-Hexahydro-3,6,10-tris(methoxymethoxy)-4,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*anti*-17):** Eluent Et_2O/hexanes (2:8). Colorless crystals (13%) from hot MeOH; m.p. 105–107 °C. $[\alpha]_D^{22}$ = +62 (*c* = 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.54–4.40 (series of m, 6 H), 4.17–4.09 (series of m, 6 H), 3.19 (s, 3 H), 3.18 (s, 3 H), 3.13 (s, 3 H), 2.98 (d, *J* = 4.1 Hz, 1 H), 2.72 (d, *J* = 4.0 Hz, 1 H), 2.67 (d, *J* = 4.0 Hz, 1 H), 2.51–2.29 (series of m, 3 H), 1.46 (s, 3 H), 1.45 (s, 3 H), 1.37 (s, 3 H), 1.25 (dd, *J* = 12.5, 3.2 Hz, 1 H), 1.07 (dd, *J* = 10.6, 3.2 Hz, 1 H), 1.03 (dd, *J* = 10.0, 2.7 Hz, 1 H), 0.97 (s, 3 H), 0.93 (s, 6 H), 0.59 (s, 3 H), 0.54 (s, 3 H), 0.47 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 141.8, 139.08, 139.07, 137.8, 136.0, 132.7, 96.0, 95.9, 95.7, 83.0, 82.5, 82.3, 58.5, 58.1, 57.5, 57.3, 57.0, 56.9, 54.95, 54.94, 54.8, 49.4, 49.2, 48.4, 36.2, 35.9, 34.8, 20.8, 20.72, 20.68, 19.9, 19.8, 19.3, 14.1, 14.0, 12.5 ppm. IR (KBr): $\tilde{\nu}$ = 2931, 1152, 1048, 917 cm^{-1}. $C_{36}H_{54}O_6$ (582.81): calcd. C 74.19, H 9.34; found C 74.46, H 9.31.

***syn*-(1*R*,2*R*,4*S*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-3,4,7,8,11,12-Hexahydro-2,6,10-tris(methoxymethoxy)-1,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*syn*-17):** Eluent Et_2O/hexanes (1:1). Colorless crystals (72%) from hot MeOH; m.p. 184–186 °C. $[\alpha]_D^{22}$ = +111 (*c* = 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.46 (d, *J* = 6.6 Hz, 3 H), 4.39 (d, *J* = 6.6 Hz, 3 H), 4.17 (dd, *J* = 8.0, 2.5 Hz, 3 H), 3.17 (s, 9 H), 3.00 (d, *J* = 3.9 Hz, 3 H), 2.38 (ddd, *J* = 12.4, 8.0, 3.9 Hz, 3 H), 1.35 (s, 9 H), 1.28 (dd, *J* = 12.4, 2.5 Hz, 3 H), 0.97 (s, 9 H), 0.63 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 140.7, 134.0, 95.5, 82.7, 57.0, 56.7, 54.8, 49.0, 34.8, 20.9, 19.2, 12.3 ppm. IR (KBr): $\tilde{\nu}$ = 2929, 2871, 1447, 1389, 1149, 1108, 1048, 922 cm^{-1}. $C_{36}H_{54}O_6$ (582.81): calcd. C 74.19, H 9.34; found C 73.99, H 9.33.

***syn*-(1*R*,2*R*,4*S*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-3,4,7,8,11,12-Hexahydro-2,6,10-tris[(2-methoxyethoxy)methoxy]-1,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*syn*-18):** Eluent Et_2O/hexanes (7:3). Waxy solid (77%). $[\alpha]_D^{22}$ = +71 (*c* = 0.6, $CHCl_3$). ^{1}H NMR (200 MHz): δ = 4.51 (d, *J* = 6.9 Hz, 3 H), 4.46 (d, *J* = 6.9 Hz, 3 H), 4.19 (dd, *J* = 8.3, 2.8 Hz, 3 H), 3.59–3.37 (series of m, 12 H), 3.36 (s, 9 H), 2.96 (d, *J* = 4.1 Hz, 3 H), 2.37 (ddd, *J* = 12.5, 8.3, 4.1 Hz, 3 H), 1.31 (s, 9 H), 1.20 (dd, *J* = 12.5,

2.8 Hz, 3 H), 0.93 (s, 9 H), 0.58 (s, 9 H) ppm. ^{13}C NMR (50 MHz, $CDCl_3$): δ = 140.7, 133.8, 94.5, 82.4, 71.8, 66.3,65.9, 58.9, 57.0, 56.9, 34.9, 20.8, 19.2, 12.3 ppm. IR (KBr): $\tilde{\nu}$ = 2977, 2873, 1716, 1452, 1388, 1364, 1285, 1200, 1173, 1051, 932, 850 cm^{-1}. $C_{42}H_{66}O_9$ (714.97): calcd. C 70.56, H 9.30; found C 70.29, H 9.29.

***syn*-(1*R*,2*R*,4*S*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-3,4,7,8,11,12-Hexahydro-2,6,10-trihydroxy-1,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*syn*-1). Method a:** A solution of *syn*-**17** (100 mg, 0.17 mmol) in MeOH (10 mL) containing concd. HCl (3 drops) was stirred at room temperature for 24 h. The resulting mixture was concentrated in vacuo and the solid residue was washed with CH_2Cl_2 (3 × 2 mL) to afford an off-white powder; m.p. 250–252 °C. $[\alpha]_D^{22}$ = +105 (*c* = 0.8, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.11 (dd, *J* = 8.8, 2.7 Hz, 3 H), 3.00 (d, *J* = 4.0 Hz, 3 H), 2.57 (dd, *J* = 13.2, 8.8, 4.0 Hz, 3 H), 2.49 (br. s, 3 H), 1.31 (s, 9 H), 0.98 (dd, *J* = 13.2, 2.7 Hz, 3 H), 0.92 (s, 9 H), 0.55 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.1, 133.8, 77.6, 58.2, 57.9, 48.6, 38.6, 21.2, 19.1, 12.0 ppm. IR (KBr): $\tilde{\nu}$ = 3387, 2956, 1455, 1389, 1051 cm^{-1}. **Method b:** A solution of *syn*-**17** (1.41 g, 2.42 mmol) in MeOH (20 mL) containing acidic resin K2613 from Bayer (1.5 g) was refluxed for 24 h. The resulting mixture was filtered through a Celite pad, and the filter was washed with MeOH (3 × 10 mL). The filtrate was concentrated in vacuo and the residue was recrystallized from hot hexanes to afford 1.68 g (98%) of *syn*-**1**; m.p. 266–269 °C. $[\alpha]_D^{22}$ = +104 (*c* = 1.2, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.11 (dd, *J* = 8.9, 2.6 Hz, 3 H), 2.99 (d, *J* = 4.0 Hz, 3 H), 2.64–2.52 (m, 3 H), 2.49 (br. s, 3 H), 1.31 (s, 9 H), 0.97 (dd, *J* = 13.3, 2.8 Hz, 3 H), 0.93 (s, 9 H), 0.55 (s, 9 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 142.1, 133.8, 77.6, 58.2, 57.9, 48.6, 38.6, 21.2, 19.1, 12.0 ppm. IR (KBr): $\tilde{\nu}$ = 3348, 2960, 2367, 1663, 1571, 1459, 1058 cm^{-1}. $C_{30}H_{42}O_3$ (450.65): calcd. C 79.96, H 9.39; found C 80.17, H 9.38.

***anti*-(1*S*,3*R*,4*R*,5*R*,6*R*,8*S*,9*R*,10*R*,12*S*)-1,2,7,8,11,12-Hexahydro-3,6,10-trihydroxy-4,5,9,13,13′,14,14′,15,15′-nonamethyl-1,4:5,8:9,12-trimethanotriphenylene (*anti*-1):** Obtained by acid resin cleavage of *anti*-**17** in 96% yield; m.p. 132–135 °C. $[\alpha]_D^{22}$ = +64 (*c* = 0.7, $CHCl_3$). ^{1}H NMR (300 MHz, $CDCl_3$): δ = 4.22 (series of m, 3 H), 3.09 (d, *J* = 4.2 Hz, 1 H), 2.79 (d, *J* = 4.1 Hz, 1 H), 2.76 (d, *J* = 4.0 Hz, 1 H), 2.71–2.58 (series of m, 3 H), 1.51 (s, 3 H), 1.50 (s, 3 H), 1.40 (s, 3 H), 1.20 (br. s, 3 H), 0.99 (s, 3 H), 0.97 (s, 6 H), 0.94–0.83 (series of m, 3 H), 0.58 (s, 3 H), 0.57 (s, 3 H), 0.53 (s, 3 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 145.1, 140.1, 139.5, 138.7, 138.4, 133.4, 76.9, 76.7, 76.6, 60.8, 60.0, 59.5, 58.01, 57.98, 57.97, 49.4, 49.1, 48.2, 39.8, 39.4, 39.3, 21.4, 21.32, 21.28, 19.41, 19.40, 19.0, 14.1, 14.0, 11.9 ppm. IR (KBr): $\tilde{\nu}$ = 3380, 2953, 1472, 1400, 1051 cm^{-1}. $C_{30}H_{42}O_3$ (450.65): calcd. C 79.96, H 9.39; found C 80.00, H 9.36.

^{1}H NMR Titration Experiments: A 3.0 mL sample of host of known concentration (of the order of 1–10 mM) was prepared in $CDCl_3$. A portion (0.8 mL) of this solution was removed and a ^{1}H NMR spectrum was recorded. An accurately weighted sample of the guest was then dissolved in the remaining 2.2 mL of the host solution. This solution was almost saturated with guest to allow access to the top of the binding isotherm and contained host, so that the concentration of the host remained constant during the course of the titration. Aliquots of this solution were added successively to an NMR tube containing 0.5 mL of $CDCl_3$, the tube was shaken to mix the two solutions, and the ^{1}H NMR spectrum was recorded after each addition. The changes in chemical shift for each signal were recorded and analyzed with NMRTit HGG using an Apple Macintosh microcomputer. This program uses a Simplex procedure to fit the data to a binding isotherm that allows for dimerization of the host and guest and yields the association constant for formation of the 1:1 complex from the host and guest monomers and the limiting chemical shifts of the fully bound complex.

Acknowledgments

This work was co-funded by MIUR (Rome) within the PRIN national framework.

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Received: August 1, 2006
Published Online: November 9, 2006

