A One-Pot Sequence of Stille and Heck Couplings: Synthesis of Various 1,3,5-Hexatrienes and Their Subsequent 6π-Electrocyclizations

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Dedicated to Professor K. Barry Sharpless on the occasion of his 60th birthday

Abstract: Palladium-catalyzed cross-coupling reactions of 2-bromocyclohex-1-enyl triflates **7** and **11** with a variety of alkenylstannanes occurred chemoselectively at the site of the triflate leaving group to give bromobutadienes which readily underwent Heck reactions with acrylates and styrene. Both steps could be performed in the same flask to give differentially functionalized hexatrienes in up to 88% overall yield. With simple stannanes, the same catalyst precursor could be used for both coupling steps making it possible to perform the whole sequence with only one portion of catalyst. For some of the functionally substituted stannanes, specifically adjusted catalyst systems had to be used. The 1,3,5-hexatrienes obtained were further transformed, in particular the methoxy-substituted compounds **14a–c** were converted to bicyclo[4.4.0]decenones **30** (71–97%), bicyclo[4.3.0]nonenones **35** (74–93%), cyclodecynone **37a** (47%), and cyclononynone **39a** (15%). Thermal electrocyclizations of the other hexatrienes gave tetrahydronaphthalines **31** (60–61%), the tricyclic lactone **32** (72–75%) and decahydrophenanthrene **33** (75%) in good yields.

Keywords: bicyclic systems · chemoselectivity · cross-coupling · electrocyclic addition · palladium

Introduction

Six-membered carbocycles are quite abundant in organic compounds and accessible through a variety of methods. Among these the Diels–Alder reaction,[1] a [4+2] cycloaddition leading to cyclohexene derivatives, is by far the most versatile one. Others, for example the metal template-assisted {2+2+2} assembly of three alkynes or two alkynes and an alkene to give arenes and cyclohexadienes, respectively, are more or less restricted in their scope.[2] As we were in need for an alternative method for six-membered ring annelations onto cycloalkene skeletons,[3] we recently developed a new formal {2+2+2} assembly of cyclohexadiene moieties utilizing a twofold Heck coupling[4] of 1,2-dibromocyclohexene and -cyclopentene with acrylates and styrene to yield 1,6-disubstituted (*E*,*Z*,*E*)-1,3,5-hexatrienes (55–92% yield) with a central cycloalkene skeleton, and a subsequent thermal 6π-electrocyclization to afford 2,3-disubstituted 2,3,5,6,7,8-hexahydronaphthalene and 5,6-disubstituted 5,6-dihydroindane derivatives (50–95% yield).[5] In addition, the hexatrienes thus obtained can be utilized to prepare interesting bicyclic β-amino acids,[6a] strained 1,6-oxygen-bridged cyclodeca-1,5-dienes[6b] as well as highly functionalized cyclononenones and cyclodecenones.[6c] The scope of this method, however, is also somewhat limited, since the second Heck coupling in these sequences occurs always considerably faster than the first one, and thus it is impossible to prepare 1,3,5-hexatrienes with different substituents at the 1- and 6-position by consecutive couplings with two different alkenes.[5] Even when employing 2-halocyclohex-1-enyl perfluoroalkanesulfonates with their two distinctly different leaving groups except for the 2-chlorocyclohex-1-enyl nonafluorobutanesulfonate, no selective single coupling could be achieved, and the intermediate dienyl chloride was so unreactive that its replacement in a second Heck coupling occurred at best in 40% yield under a pressure of 10 kbar. While certain unsymmetrically 1,6-disubstituted 1,3,5-hexatrienes are accessible through 2-bromocyclohexene-1-carbaldehyde by Wittig–Horner–Emmons olefination and subsequent Heck coupling (51–86% overall yield),[5a] it is a more tedious route than a twofold coupling of a difunctional cyclohexene derivative with two different functionally substituted alkenes would be. Thus, it appeared attractive to try out such a differentiation of

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Supporting information for this article is available on the WWW under http://www.wiley-vch.de/home/chemistry/ or from the author. Experimental procedures and analytical data for compounds **14b**, **14c**, **20b**, **21b**, **21d**, **21e**, **24b**, **27b**, **27d**, **30b**, **30c**, **30f**, **31b**, **34b**, **34c**, **35b**, and **35c**.

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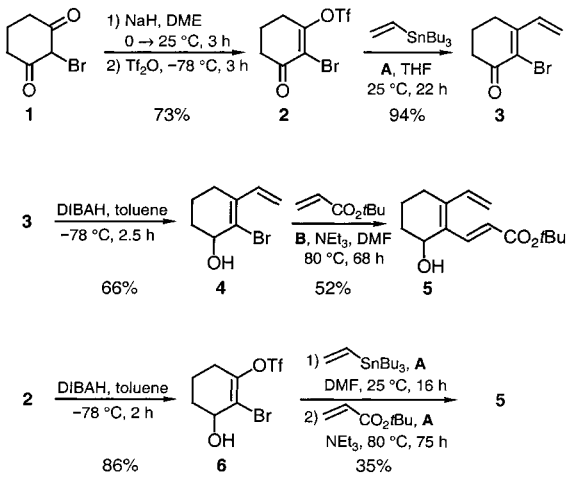
two different leaving groups on 1,2-disubstituted cycloalkenes in view of a report by Stille et al.[7, 8] on palladium-catalyzed cross-coupling reactions of alkenylstannanes with *p*-bromophenyl triflate which selectively occurred with either leaving group depending on the reaction conditions. Therefore a sequence of Stille and Heck cross-coupling reactions on 2-bromocyclohex-1-enyl triflates was developed.

Results and Discussion

As the first substrate for the intended Stille–Heck coupling sequence the bromoenol triflate **2** was prepared from bromocyclohexanedione **1** by deprotonation with sodium hydride and trapping of the enolate with trifluoromethanesulfonic acid anhydride (Tf_2O) (Scheme 1). The electron-withdrawing effect of the remaining carbonyl group in this compound was expected to facilitate the oxidative addition of the carbon–triflate bond to the palladium species and thus increase the reactivity difference of triflate versus bromide. Stille couplings of 3-oxocyclohex-1-enyl triflate without a bromide substituent with tributylethenylstannane have previously been reported.[9] The optimized conditions of Houpis[9b] [$Pd(OAc)_2$, PPh_3 in THF at 55 °C] were applied for the coupling of bromoenol triflate **2** with tributylethenylstannane. Complete conversion was achieved in 1 h to give the bromobutadiene **3** in 71 % isolated yield. The crude reaction mixture did neither reveal even traces of the twofold coupling product nor the butadienyl triflate. The yield of **3** could be increased to 94 % by performing the reaction at ambient temperature for 22 h, but unfortunately, an attempted subsequent Heck coupling of the bromobutadiene **3** with *tert*-butyl acrylate failed. Only decomposition of the starting material **3** occurred under various reaction conditions, and with different palladium precatalysts. This behavior was attributed to the carbonyl functionality in **3**, since 2-alkenyl-1-bromocyclohexenes generally undergo Heck reactions quite smoothly.[5a] Therefore, the bromocyclohexenone derivative **3** was reduced with diisobutylaluminum hydride (DIBAH) to give the allylic alcohol **4**, and indeed, this bromodienyl alcohol did undergo the Heck coupling with *tert*-butyl acrylate using [$Pd(PPh_3)_4$] as precatalyst to give the hexatriene **5** in 52 % yield (Scheme 1). This sequence of Stille coupling, reduction and Heck coupling gave the desired unsymmetrically substituted hexatriene **5** in 32 % overall yield from **2**.

According to the generally accepted mechanisms of the Stille[8] and Heck[4a] coupling, the catalytically active species is identical in both reactions: a 14-electron palladium(0) complex. Consequently, it should be possible to perform the sequence of Stille and Heck couplings on 2-bromocyclohex-1-enyl triflates as a one-pot procedure and eliminate one workup and purification step.[10] Therefore, the cyclohexenol **6**, prepared by DIBAH reduction of the cyclohexenone **2** (Scheme 1), was treated with tributylethenylstannane under the same conditions as applied for the bromoenol triflate **2**, but in DMF as solvent. After 16 h at room temperature complete conversion of the enol triflate functionality was detected, and the acrylate as well as triethylamine for the Heck reaction were added. A fresh portion of $Pd(OAc)_2$ and



Scheme 1. Development of the one-pot Stille–Heck sequence. **A**: $Pd(OAc)_2$, PPh_3. **B**: [$Pd(PPh_3)_4$]. Tf: SO_2CF_3.

PPh_3 was also necessary, as indicated by the formation of palladium black in the first step. The Heck reaction was terminated after 75 h at 80 °C, and the hexatriene **5** was isolated in 35 % yield.

These somewhat disappointing overall yields of unsymmetrically substituted 1,3,5-hexatrienes were attributed to the presence of the free hydroxyl functionality in **4** and **6**. Therefore, the bromoenol triflates **7** with a silyl-protected hydroxyl group and **11** without any additional substituent were tested (Scheme 2). 2-Bromocyclohex-1-enyl triflate (**11**) had previously been prepared from bromocyclohexanone **10** by deprotonation with lithium hexamethyldisilazide (LiHMDS) and trapping of the enolate with Tf_2O,[5a] but the isolated yield dropped considerably (from 39 to 23 %) when the reaction was performed on a 10 mmol instead of 1 mmol scale. Among different protocols for the synthesis of enol triflates,[11] the use of *N*-phenyltriflimide[11b] after deprotonation of **10** with LiHMDS consistently gave the best yields of **11** (62 %) even on a 30 mmol scale (Scheme 2). An exploratory test showed that **11** also underwent coupling with tributylethenylstannane chemoselectively to give the bromobutadiene **12** (71 % yield) as a single product (Scheme 2). The one-pot Stille–Heck protocol with tributylethenylstannane and *tert*-butyl acrylate on both **7** and **11** gave the unsymmetrical hexatrienes **8** and **13a** in 73 and 75 % yield, respectively (Table 1, entries 1, 2).

Again, all the catalyst had decomposed after the first coupling step, and a second portion of $Pd(OAc)_2$ had to be added for the Heck reaction to occur. Although additional lithium chloride prevented the precipitation of palladium black during the Stille coupling, it led to a significant prolongation of the reaction time, yet the hexatriene **13a** was isolated in 70 % yield after the subsequent Heck reaction with another portion of the catalyst being added (entry 3). These influences of chloride ions on Stille couplings of alkenyl triflates have previously been reported.[12] Thus, it is possible to add all of the $Pd(OAc)_2$ and PPh_3 at the beginning of the first step, and later just add the amine and acrylate to initiate the Heck reaction (entry 4). Although the yield of **13a** was slightly lower—most likely due to the Heck coupling being

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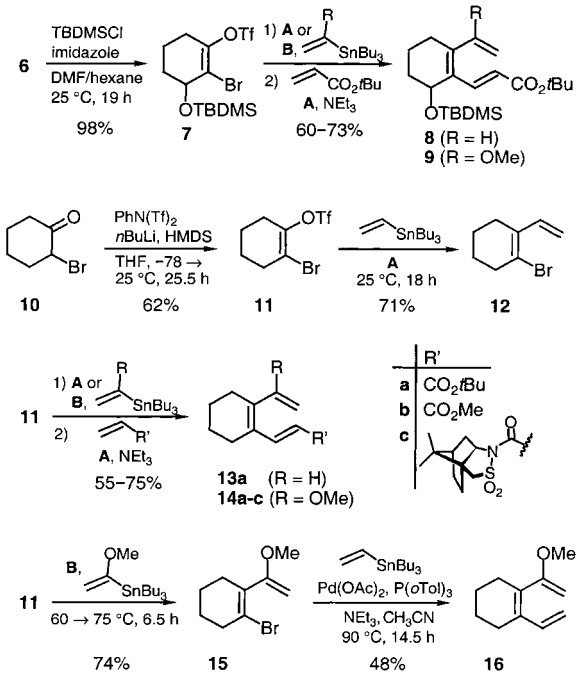
retarded by the additional lithium chloride—the result clearly showed that the same catalyst molecules remain available for the Heck catalytic cycle after having served in the Stille catalytic cycle.

In view of these positive results other stannanes were tested for their performance in the same sequence. Tributyl(1-methoxyethenyl)stannane did undergo clean and chemoselective couplings with the bromoenol triflates **7** and **11**, although elevated temperatures (60 – 70 °C) and the presence of LiCl were required. Although no decomposition of the catalyst was observed during the Stille reaction, a second portion of catalyst had to be added for the Heck coupling to occur, and the desired hexatrienes **9** and **14a** were isolated in 60 and 71 % yield, respectively (Scheme 2 and Table 1, entries 5, 6). With only 7 mol % of $Pd(OAc)_2$ added at the beginning for both steps, the Heck reaction of the intermediate bromobutadiene **15** proceeded less completely, probably due to catalyst decomposition, and 10 % of **15** were isolated



Scheme 2. Stille reactions with tributylethenyl- and tributyl(1-methoxyethenyl)stannane followed by Heck couplings. For details see Table 1.

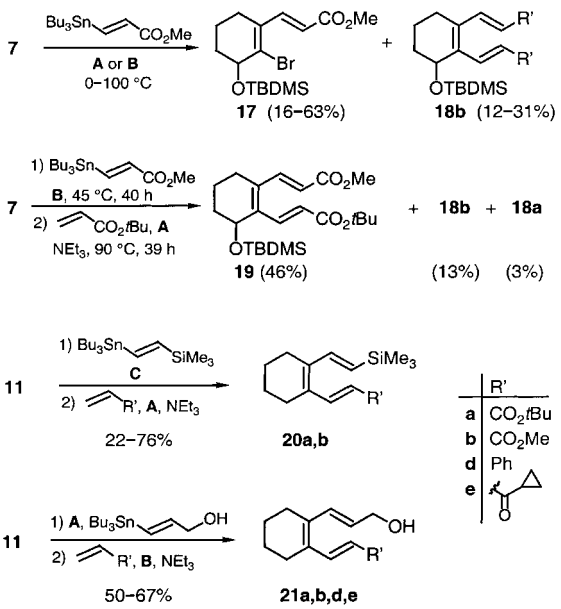
Table 1. Stille reactions with tributylethenyl- and tributyl(1-methoxyethenyl)stannane followed by Heck couplings with acrylates and acrylamides.

Entry	Starting material	Conditions[a] (mol % of $Pd(OAc)_2$) Stille	Heck	Product	T [°C] (t [h]) Stille	Heck	Yield[b] [%]
1	**7**	**A** (7)	**A** (7)	**8**	25 (21)	80 (22)	73
2	**11**	**A** (7)	**A** (7)	**13a**	25 (22)	90 (21)	75
3	**11**	**B** (7)	**A** (7)	**13a**	25 (73)	90 (18)	70
4	**11**	**B** (14)	–	**13a**	25 (51)	90 (40)	55[c]
5	**7**	**B** (7)	**A** (7)	**9**	60 (18)	90 (27)	60
6	**11**	**B** (7)	**A** (7)	**14a**	70 (20)	90 (42)	71
7	**11**	**B** (7)	–	**14a**	60 (34)	90 (40)	55[c]
8	**11**	**B** (7)	**A** (7)	**14b**	70 (40)	90 (63)	56
9	**11**	**B** (7)	**A** (7)	**14c**	70 (25)	90 (19)	62

[a] **A**: $Pd(OAc)_2$, PPh_3, DMF; **B**: as in **A**, plus 3 equiv LiCl. [b] Isolated yields. [c] Plus 10 % of **15**.

along with 55 % of **14a** (entry 7). Therefore the catalyst precursor was added in two portions in all subsequent experiments. For the Heck reaction with methyl acrylate and the *N*-acryloylcamphorsultame[13] the yields were slightly lower, but still reasonable (entries 8, 9). To achieve other combinations of functionalities in the 1,3,5-hexatrienes, the intermediate bromodienes **12** and **15** can also be coupled with a second alkenylstannane. This was demonstrated with **15** being coupled with tributylethenylstannane adopting a protocol of Quayle et al.[14] (Scheme 2) to give the 2-methoxy-1,3,5-hexatriene (**16**) in 48 % yield, but due to rapid decomposition of the catalyst, 21 mol % of $Pd(OAc)_2$ in three portions was necessary to achieve full conversion.

The Stille coupling of **7** with methyl (*E*)-3-(tributylstannyl)-acrylate also occurred with a certain degree of selectivity for the triflate leaving group, but apparently the electron-withdrawing methoxycarbonyl substituent in the bromodiene **17** formed first activates the carbon–bromide bond towards oxidative addition to such an extent that the formation of the biscoupling product **18b** could not be suppressed, and even with a 1.5-fold excess of the stannane, some of the starting material **7** was isolated as well (Scheme 3). By screening different conditions for the Stille coupling (DMF or CH_3CN as solvent, presence or absence of LiCl, reaction temperature 0 – 100 °C), the highest selectivity for the formation of **17** (63 % yield) was found upon running the reaction at 45 °C in DMF with LiCl present. Applying these optimized conditions for the first step, the one-pot Stille – Heck sequence with the bromoenol triflate **7** gave the product **19** in 46 % yield along with a small amount of **18b** (13 %) and traces of **18a** (3 %), the product of a twofold Heck coupling of **7** (Scheme 3).



Scheme 3. Stille reactions with various 2-substituted ethenylstannanes and subsequent Heck couplings. For details see Table 2.

For tributyl[(*E*)-2-trimethylsilylethenyl]stannane as a coupling partner, the usual catalytic system for the first step—$Pd(OAc)_2$ and PPh_3—turned out to be less suitable, as it led to partial desilylation of the product. However, with $[Pd(PPh_3)_4]$

which has previously been used to couple trimethyl(trimethylsilylethenyl)stannane with alkenyl triflates,[12c] the Stille reaction of **11** and the silylethenylstannane also occurred chemoselectively, and the subsequent Heck reaction with *tert*-butyl or methyl acrylate could be achieved upon addition of $Pd(OAc)_2$ and PPh_3 to afford the hexatrienes **20a** and **20b** in 76 and 22% yield, respectively (Scheme 3 and Table 2, entries 1, 2).

Table 2. Stille reactions with various 2-substituted ethenylstannanes and subsequent Heck couplings.

Entry	Starting material	Conditions[a] (mol% of Pd) Stille	Heck	Product	T [°C] (t [h]) Stille	Heck	Yield[b] [%]
1	**11**	**C** (5)	**A** (7)	**20a**	90 (20)	90 (24)	76
2	**11**	**C** (5)	**A** (7)	**20b**	90 (20)	90 (36)	22
3	**11**	**B** (7)	**A** (7)	**21a**	65 (50)	90 (24)	67
4	**11**	**A** (7)	**A** (7)	**21a**	65 (3)	90 (2)	15
5	**11**	**A** (7)	**B** (7)	**21a**	65 (3)	90 (38)	53
6	**11**	**A** (7)	**B** (7)	**21b**	65 (3)	90 (32)	56
7	**11**	**A** (7)	**B** (7)	**21d**	65 (3)	90 (53)	50
8	**11**	**A** (7)	**B** (7)	**21e**	65 (3)	95 (37)	65

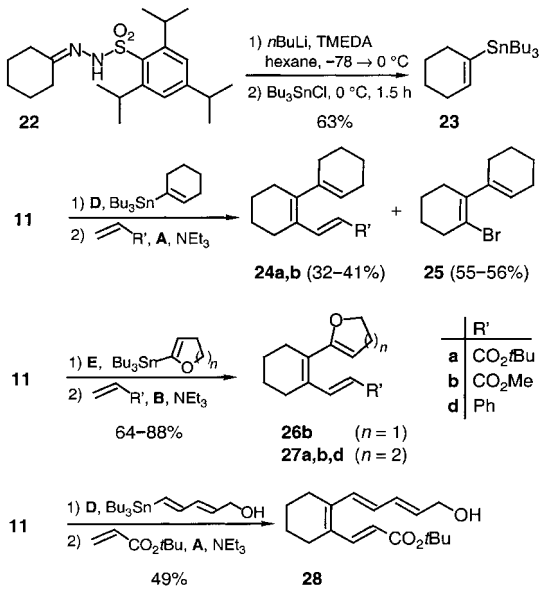
[a] **A**: $Pd(OAc)_2$, PPh_3, DMF; **B**: as in **A**, plus 3 equiv LiCl; **C**: $[Pd(PPh_3)_4]$, DMF, 3 equiv LiCl. [b] Isolated yields.

In contrast, $Pd(OAc)_2$ plus PPh_3 worked well for Stille couplings with tributyl(3-hydroxyprop-1-enyl)stannane (Scheme 3). In this case the addition of LiCl at the beginning significantly retarded the Stille coupling, yet the subsequent Heck reaction with another portion of catalyst gave the hexatriene **21a** in 67% yield (Table 2, entry 3). As previously observed, the Stille reaction proceeded much faster in the absence of LiCl, but side reactions in the Heck coupling led to a very low yield of **21a** (entry 4). When LiCl was added after completion of the Stille coupling, the final product **21a** was isolated in 53% yield (entry 5). These conditions were also suitable for Heck reactions with methyl acrylate (entry 6), styrene (entry 7), and cyclopropyl ethenyl ketone (entry 8).

In the attempted Stille couplings of tributyl(cyclohexenyl)-stannane (**23**),[15] obtained in 63% yield by treatment of cyclohexanone-2,4,6-triisopropylbenzenesulfonylhydrazone (**22**)[16] with *n*BuLi and then addition of tributyltin chloride (Scheme 4),[17] with the bromoenol triflate **11**, a selectivity issue occurred although again only the triflate acted as the leaving group. But with two different catalytic systems, $[Pd(PPh_3)_4]$ plus LiCl and $[Pd(PhCN)_2Cl_2]$ plus tri(2-furyl)-phosphine (TFP), the transfer of the cyclohexenyl group from **23** was accompanied by the transfer of a butyl group. This problem commonly appears in cross-coupling reactions of trialkyl(cyclohexenyl)stannanes, but has been overcome by Farina et al. employing a catalyst system consisting of $[Pd(PhCN)_2Cl_2]$, $AsPh_3$, and CuI.[18] In this system, the organic group most likely is not directly transferred from the stannane to the palladium species but via an organocopper intermediate which enhances the selectivity for the coupling of the alkenyl substituent. On the one hand these conditions also worked for the coupling of **23** with **11**, and the bromobutadiene **25** was formed as a single product (Scheme 4). On the other hand, one component of this catalytic system affected the outcome of the subsequent Heck reaction with additional $Pd(OAc)_2$ and PPh_3 as the catalyst precursor. After 2 h palladium black precipitated and even with a second portion of 7 mol% of $Pd(OAc)_2$ the conversion did not go to completion. Thus, only mixtures of the hexatrienes **24** and bromobutadiene **25** were isolated (Table 3, entries 1, 2).

In previously reported Stille couplings of cyclic stannylenol ethers a catalyst system consisting of $[Pd(dba)_2]$, TFP, and $ZnCl_2$ has proved to be advantageous.[19] Indeed, with only 2 mol% of $[Pd(dba)_2]$ the Stille coupling of **11** with stannylcycloalkenol ethers proceeded at ambient or slightly elevated temperature smoothly in 24 h and after subsequent Heck reaction with acrylates or styrene the hexatrienes **26** and **27** were obtained in up to 88% yield (Scheme 4 and Table 3, entries 3–6).

Finally, the conjugated tetraene **28** was prepared by a Stille–Heck coupling sequence with tributyl[(*E*,*E*)-5-hydroxypenta-1,3-dienyl]stannane[20] and *tert*-butyl acrylate (Scheme 4 and Table 3, entry 7). Although the same catalytic



Scheme 4. Stille reactions with cyclohexenyl-, oxacycloalkenyl- and dienyl-substituted stannanes followed by Heck couplings. For details see Table 3.

system was applied as in reactions with the cyclohexenylstannane **23**, the intermediate bromohexatriene was completely consumed under the Heck coupling conditions. Yet the overall yield was only 49%, and some side products were observed as well, indicating that some of the bromohexatriene was not converted to the desired product **28**.

As was previously demonstrated, hexatrienes such as **14**, **16** are perfectly set up for thermal 6π-electrocyclizations to produce oligofunctional ring-annelated cyclohexa-1,3-dienes.[5] The thermal transformation of a trimethylsilylenol ether corresponding to **16** has previously been reported by Scott et al. to produce the bicyclodecenone **30f** in only 34%

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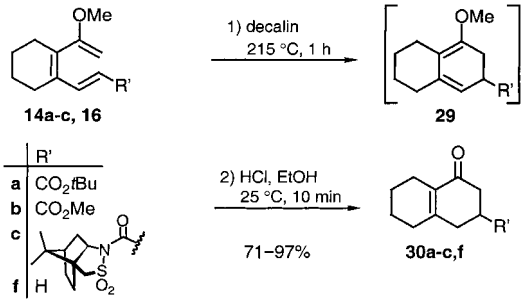
Table 3. Stille reactions with cyclohexenyl-, oxacycloalkenyl- and dienyl-substituted stannanes followed by Heck couplings.

Entry	Starting material	Conditions[a] (mol % of Pd) Stille	Heck	Product	T [°C] (t [h]) Stille	Heck	Yield[b] [%]
1	**11**	**D** (10)	**A** (14)	**24a**	65 (4)	95 (84)	41[c]
2	**11**	**D** (10)	**A** (14)	**24b**	65 (4)	95 (84)	32[d]
3	**11**	**E** (2)	**B** (7)	**26b**	40 (19)	95 (29)	64
4	**11**	**E** (2)	**B** (7)	**27a**	25 (26)	95 (35)	88
5	**11**	**E** (2)	**B** (7)	**27b**	40 (19)	95 (29)	64
6	**11**	**E** (2)	**B** (7)	**27d**	40 (19)	90 (44)	80
7	**11**	**D** (10)	**A** (7)	**28**	65 (5)	95 (39)	49

[a] **A**: $Pd(OAc)_2$, PPh_3, DMF; **B**: as in **A**, plus 3 equiv LiCl; **D**: $[Pd_2(dba)_3]\cdot CHCl_3$, $AsPh_3$, CuI, DMF, 3 equiv LiCl; **E**: $[Pd(dba)_2]$, TFP, $ZnCl_2$, DMF. [b] Isolated yields. [c] Plus 55% of **25**. [d] Plus 56% of **25**.

yield after 7 d in refluxing toluene, but the yield could be greatly increased to 84% applying a palladium-catalyzed transformation.[21] The poor yield in the thermal reaction was attributed to the high electron density caused by the presence of the silyloxy substituent in the starting material, therefore the hexatrienes **14** with their electron-withdrawing group were expected to cyclize more readily. However, heating compound **14a** at 145 °C in refluxing xylene, as had previously been found to be appropriate for the transformation of hexatrienes with electron-withdrawing substituents in both the 1- and the 6-position,[5a] proved to be unsuitable. Even after 39 h, the conversion of **14a** was incomplete, and a mixture of products was formed. But by heating compounds **14a**,**b** in decalin in a sealed thick-walled bottle at 215 °C, complete conversion was achieved within 80 min. Subsequent hydrolysis of the enol ether with 2 N HCl gave the bicyclodecenones **30a**,**b** in excellent yields (Scheme 5 and Table 4, entries 1, 2). Even the hexatriene **14c** with its chiral *N*-acryloylcamphorsultame moiety, gave the bicyclodecenone **30c** in quite good yield (entry 3), however, the stereochemical induction was poor with the two diastereomers being formed in a ratio of 59:41.



Scheme 5. Thermal 6π-electrocyclization of methoxy-substituted hexatrienes **14**, **16** and subsequent hydrolysis to yield bicyclo[4.4.0]decenones **30**. For details see Table 4.

Table 4. Thermal 6π-electrocyclizations of hexatrienes **14** and **16** with subsequent hydrolysis.

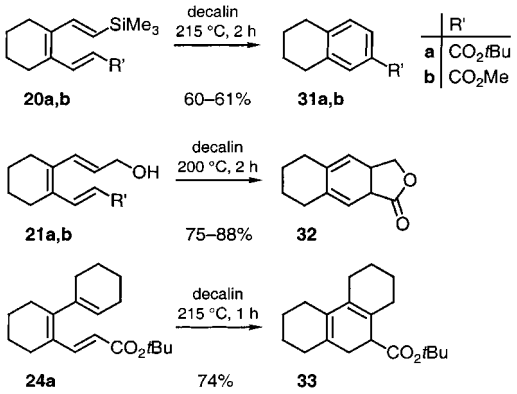
Entry	Starting material	Product	T [°C]	t [h]	Yield[a] [%]
1	**14a**	**30a**	215/1.3	93	
2	**14b**	**30b**	215	1	95
3	**14c**	**30c**	225	0.7	71[b]
4	**16**	**30f**	225	1.2	97

[a] Isolated yields. [b] Sum of 42% of diastereomer I and 29% of diastereomer II.

Under the same conditions, the hexatriene **16** without an electron-withdrawing group as present in compounds **14a**–**c** was converted to the bicyclodecenone **30f** in 97% yield (entry 4). Thus, the electron-withdrawing group cannot be a prerequisite for a low activation energy for a 6π-electrocyclization of a hexatriene, and the higher activation energies in the systems **14**, **16** must be due to the substituent in the 2-position which may disfavor the *sp*,*sp*-conformation that the system has to adopt towards the transition state of the cyclization.

The overall transformation of 2-bromocyclohexanone (**10**) via **11** and **14** or **16** corresponds to a cyclohexenone annelation, just like the well-known Robinson annelation. The new methodology may be regarded to complement the established sequence of Michael addition onto methyl ethenyl ketone with subsequent intramolecular aldol condensation, as it yields ring-annelated cyclohexenones with a different position of the carbonyl group and the α,β-unsaturation. While the core structure 4,4a,5,6,7,8-hexahydro-3*H*-naphthalen-2-one was obtained in 42% yield from cyclohexanone and methyl ethenyl ketone in the classical Robinson annelation,[22] the bicyclo[4.4.0]decenones **30** can be prepared in up to 41% yield starting from bromocyclohexanone **10**.

Under the conditions for the electrocyclization of compounds **14** and **16** some of the other unsymmetrically substituted hexatrienes were cyclized as well (Scheme 6).



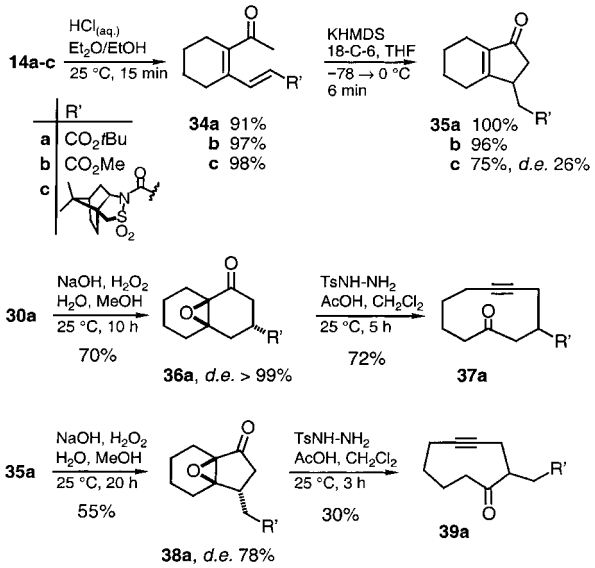
Scheme 6. Thermal transformations of hexatrienes **20**, **21**, and **24**.

Unfortunately, after 2 h at 215 °C the silyl-substituted derivatives **20a**,**b** did not give the desired cyclohexa-1,3-dienes with a versatile allylsilane moiety, but the tetrahydronaphthalenes **31a**,**b** (61 and 60% yield) resulting from formal dehydrodesilylation. Such processes have previously been observed to accompany electrocyclizations of 1,2-bis(2-trimethylsilylethenyl)cyclohexene at high temperatures.[23] In the thermal transformations of the alcohols **21a**,**b**, an intramolecular transesterification occurred after the electrocyclization, to afford the tricyclic lactone **32** in 75 and 88% yield, respectively. In contrast, the substrates **21d**,**e** ($R' = Ph$, cyclo-

propylcarbonyl), lacking the possibility of intramolecular lactonization, gave complex mixtures. Finally, the cyclohexenyl-containing hexatriene **24a** under the rather harsh conditions underwent cyclization with subsequent hydrogen migration to give the 1,2,3,4,5,6,7,8,9,10-decahydrophenanthrenecarboxylate **33** rather than the 1,2,3,4,5,6,7,8,8a,9-decahydrophenanthrene derivative.

In view of some of these secondary reactions of the readily formed cyclization products and the fact that attempted cyclizations of the oxacycloalkenyl-containing hexatrienes **26** and **27** failed, it would be desirable to explore alternative milder conditions, that is palladium-catalyzed cyclizations, for these transformations.

The 5-methoxy-substituted hexatrienes **14a–c** can also serve as starting materials for the preparation of bicyclo[4.3.0]nonenones **35**. Hydrolysis of **14a–c** by treatment with 2.0 N HCl gave the 3-(2-acetylcyclohex-1-enyl)acrylic acid derivatives **34a–c** in 91–98% yield. These, upon treatment with potassium hexamethyldisilazide (KHMDS) in the presence of 18[crown]-6 in THF afforded the bicyclo[4.3.0]-non-1(6)-en-7-one derivatives **35a–c** in good to excellent yields (Scheme 7). Since the α-C,H acidity of a ketone in



Scheme 7. Preparation of bicyclo[4.3.0]nonenones as well as cycloalkynones by Eschenmoser fragmentation of epoxybicyclo[4.*n*.0]alkenones.

general is higher than that of an ester, substoichiometric amounts of base (0.4 equiv) were sufficient to achieve total conversions. The stereoselectivity in this transformation of **34c** was disappointing, as the diastereomeric excess of the product **35c** did not exceed 26%.

The bicyclo[4.4.0]decenone **30a** and bicyclo[4.3.0]nonenone derivative **35a** thus accessible can serve as precursors to 10- and 9-membered ring compounds, since their enone moieties may be epoxidized and the resulting epoxyketones subjected to Eschenmoser fragmentations.[24] Upon treatment of **30a** and **35a** with alkaline hydrogen peroxide the epoxides **36a** and **38a** were obtained in good and moderate yield, respectively (Scheme 7). The subsequent treatment of **36a** with *p*-toluenesulfonylhydrazide (TsNH-NH_2) in acetic acid/methylene chloride gave the cyclodecynone **37a** in 72% yield. Under the same conditions the cyclononynone **39a** was obtained from **38a** in only 30% yield, and this yield could neither be improved under a variety of conditions nor could any other product such as the tosylhydrazone from **39a** be isolated.

Conclusion

The chemoselective one-pot sequence of Stille and Heck couplings on readily available bromoenol triflates offers a fast and flexible access to oligofunctional 1,3,5-hexatrienes. These compounds present themselves for thermal 6π-electrocyclizations and other further transformations to yield a variety of bicyclic and cyclic skeletons. While the previously reported[5] sequence of twofold Heck reaction on dibromocycloalkenes and subsequent electrocyclization was restricted to 1,3,5-hexatrienes with electron-withdrawing groups in the 1- and 6-position, this current approach exhibits fewer limitations in the substitution pattern and the types of substituents. It may therefore serve as a useful tool in organic synthesis, especially of terpenoid frameworks.[25]

Experimental Section

General: ^{1}H and ^{13}C NMR spectra: recorded in $CDCl_3$ solution at 250 MHz and 62.9 MHz, respectively. Chemical shifts are reported in δ, ppm relative to the residual $CHCl_3$ signal, recalculated relative to tetramethylsilane (TMS). The multiplicities of the ^{13}C signals were determined by the DEPT technique and are quoted as (+) for CH_3 and CH groups, (−) for CH_2 and (C_q) for quaternary carbons. MS: ionizing voltage of 70 eV. HRMS: preselected ion peak matching at $R \gg 10000$ to be within ± 2 ppm of the exact masses. Elemental analyses: Mikroanalytisches Labor der Universität Göttingen, Germany. Melting points are uncorrected. Solvents for extraction and chromatography were technical grade and distilled before use. Flash chromatography was performed using Merck Kieselgel 60 (200–400 mesh). Aluminum oxide (ICN Alumina N, Super I) was obtained from ICN Biomedicals. TLC analyses were performed using Macherey–Nagel precoated plates, 0.25 mm, Alugram Sil G/UV$_{254}$ (I) and Merck precoated silica gel 60 F_{254} aluminum sheets (II). All reactions were carried out under an atmosphere of dry nitrogen or argon in oven- and/or flame-dried glassware. Unless otherwise specified, solutions of NH_4Cl, NaCl, Na_2SO_3, and $NaHCO_3$ are saturated aqueous solutions. Tetrahydrofuran, decalin, 1,2-dimethoxyethane, toluene, hexane, and diethyl ether were distilled from potassium/benzophenone, tetramethylethylenediamine (TMEDA) was distilled from KOH, and CH_2Cl_2, NEt_3, acetonitrile, and DMF were distilled from CaH_2. 2-Bromocyclohexane-1,3-dione (**1**),[26] 2-bromocyclohexanone (**10**),[27] 1-[(1*S*)-10,10-dimethyl-3,3-dioxo-3λ^6-thia-4-azatricyclo-[5.2.1.0^{1,5}]dec-4-yl]propenone,[28] cyclopropyl ethenyl ketone,[29] tributyl(1-methoxyethenyl)stannane,[32] methyl (*E*)-3-(tributylstannyl)acrylate,[33] tributyl[(*E*)-2-trimethylsilylethenyl]stannane,[34] tributyl[(*E*)-3-hydroxyprop-1-enyl]stannane,[35] tributyl(4,5-dihydrofuran-2-yl)stannane,[32, 36] tributyl(5,6-dihydro-4*H*-pyran-2-yl)stannane,[37] tributyl[(*E*,*E*)-5-hydroxypenta-1,3-dienyl]stannane[20] and cyclohexanone-2,4,6-triisopropylbenzenesulfonylhydrazone (**22**)[16] were prepared as described in the literature.

2-Bromo-3-oxocyclohex-1-enyl triflate (2): 2-Bromocyclohexane-1,3-dione (**1**, 3.82 g, 20.0 mmol) was slowly added at 0°C to a suspension of sodium hydride (760 mg, 19 mmol, 60% in mineral oil) in 1,2-dimethoxyethane (80 mL). After 10 min the mixture was warmed to RT, stirred for 3 h, and then cooled to −78°C. Trifluoromethanesulfonic acid anhydride (5.20 g, 18.4 mmol) was added, and stirring was continued for 3 h at −78°C. The solvents were evaporated, the residue was dissolved in CH_2Cl_2 (150 mL), and the solution was washed with $NaHCO_3$ and H_2O (100 mL each). The aqueous layer was extracted with CH_2Cl_2 (100 mL), and the combined

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organic layers were dried over $MgSO_4$ and concentrated in vacuo. After column chromatography on silica gel (50 g, CH_2Cl_2), compound **2** (R_f = 0.67, $CHCl_3$) was obtained as a colorless oil (4.74 g, 73 %). IR (film): $\tilde{\nu}$ = 1703 cm^{-1} (C=O); ^1H NMR: δ = 2.11 (m, 2H), 2.60 (m, 2H), 2.79 (t, $^3J(H,H)$ = 6.1 Hz, 2H); ^{13}C NMR: δ = 20.2 (t, $^1J(C,H)$ = 132.5 Hz, –), 30.2 (t, $^1J(C,H)$ = 130.7 Hz, –), 36.5 (t, $^1J(C,H)$ = 130.8 Hz, –), 117.4 (C_q), 118.0 (q, $^1J(C,F)$ = 320.3 Hz, C_q), 163.7 (C_q), 190.1 (t, $^2J(C,H)$ = 6.8 Hz, C_q); MS (EI): *m*/*z* (%): 324/322 (79/79) $[M]^+$, 174/172 (11/11) $[M - CF_3SO_3H]^+$, 69 (100) $[CF_3]^+$; elemental analysis calcd (%) for $C_7H_6BrF_3O_4S$ (323.1): C 26.02, H 1.87; found: C 25.89, H 1.77.

2-Bromo-3-hydroxycyclohex-1-enyl triflate (6): A solution of ketone **2** (3.741 g, 11.58 mmol) in toluene (64 mL) was treated with diisobutylaluminum hydride (12.7 mL, 13 mmol, 1.0 M in hexane) at – 78°C. The mixture was stirred for 2 h at – 78°C, quenched by addition of methanol (2 mL), diluted with Et_2O (100 mL) and washed with 2 N hydrochloric acid and H_2O (100 mL each). The aqueous layer was extracted with Et_2O (100 mL), and the combined organic layers were dried over Na_2SO_4 and concentrated in vacuo. Column chromatography on silica gel (70 g, CH_2Cl_2) yielded **6** (R_f = 0.37) as a colorless solid (3.22 g, 86 %). M.p. 34°C; ^1H NMR: δ = 1.73 – 2.04 (m, 4H), 2.43 (m, 2H), 2.68 (br s, 1H), 4.45 (m, 1H); ^{13}C NMR: δ = 18.1 (–), 29.5 (–), 30.8 (–), 70.4 (+), 118.2 (q, $^1J(C,F)$ = 320.3 Hz, C_q), 118.9 (C_q), 148.5 (C_q); MS (EI): *m*/*z* (%): 326/324 (16/16) $[M]^+$, 245 (100) $[M - Br]^+$, 69 (22) $[CF_3]^+$; elemental analysis calcd (%) for $C_7H_8BrF_3O_4S$ (325.1): C 25.86, H 2.48; found: C 25.82, H 2.38.

2-Bromo-3-(*tert*-butyldimethylsilyloxy)cyclohex-1-enyl triflate (7): A solution of the alcohol **6** (2.674 g, 8.225 mmol) in DMF (10 mL) was treated with imidazole (5.60 g, 82.3 mmol) and *tert*-butyldimethylsilyl chloride (16.5 mL, 50 % in hexane, d = 0.75 g mL^{-1}, 41.1 mmol) and stirred for 19 h at RT. The mixture was diluted with Et_2O (200 mL), washed with H_2O (2 × 100 mL), dried over Na_2SO_4, and concentrated in vacuo. Column chromatography on silica gel (130 g, CH_2Cl_2) yielded **7** [R_f = 0.30, petroleum ether (PE)] as a colorless solid (3.54 g, 98 %). M.p. 29°C; ^1H NMR: δ = 0.11 (s, 3H), 0.17 (s, 3H), 0.90 (s, 9H), 1.70 – 1.84 (m, 3H), 1.93 – 2.07 (m, 1H), 2.39 – 2.44 (m, 2H), 4.44 (m, 1H); ^{13}C NMR: δ = – 4.7 (+), – 4.6 (+), 17.6 (–), 18.0 (C_q), 25.7 (+), 29.5 (–), 32.4 (–), 71.2 (+), 118.2 (q, $^1J(C,F)$ = 320.3 Hz, C_q), 119.2 (C_q), 148.1 (C_q); MS (DCI, NH_3): *m*/*z* (%): 458/456 (100/97) $[M+NH_4]^+$; elemental analysis calcd (%) for $C_{13}H_{22}BrF_3O_4SSi$ (439.4): C 35.54, H 5.05; found: C 35.63, H 4.94.

2-Bromocyclohex-1-enyl triflate (11): *n*-Butyllithium (16.5 mL, 38.9 mmol, 2.36 M in hexane) was added to hexamethyldisilazane (HMDS) (6.54 g, 40.5 mmol) in THF (140 mL) at – 78°C. After 20 min, a solution of 2-bromocyclohexanone (**10**, 5.31 g, 30.0 mmol) in THF (30 mL) was added within 10 min. After additional 10 min, *N*-phenyltriflimide (11.25 g, 31.49 mmol) in THF (30 mL) was added within 8 min. The mixture was stirred for 30 min at – 78°C, for 8 h at 0°C and for 17 h at room temperature, concentrated in vacuo, and filtered through aluminum oxide (150 g, 5 % H_2O, PE/Et_2O 30:1). Column chromatography on silica gel (150 g, PE/Et_2O 30:1) yielded **11** (R_f = 0.52, PE/Et_2O 20:1) as a colorless oil (5.73 g, 62 %). For analytical data, see literature.[5a]

Tributyl(cyclohex-1-enyl)stannane (23): Hydrazone **22** (0.757 g, 2.00 mmol) was dissolved in a mixture of hexane and TMEDA (1:1, 20 mL) and cooled to – 78°C. *n*-Butyllithium (3.90 mL, 6.00 mmol, 1.54 M in hexane) was added within 8 min, and the deep red solution was stirred for 15 min at – 78°C and then slowly warmed to 0°C. When the evolution of nitrogen had ceased (10 min), tributyltin chloride (1.30 g, 4.00 mmol) was added within 10 min. After being stirred for 1.5 h at 0°C, the reaction mixture was poured into H_2O (30 mL), and the aqueous phase was extracted with Et_2O (30 mL). The combined organic layers were repeatedly washed with H_2O (30 mL), dried over $MgSO_4$, and concentrated in vacuo. After column chromatography on silica gel (40 g, hexane), **23** (R_f = 0.89) was obtained as colorless oil (0.465 g, 63 %). ^1H NMR: δ = 0.77 – 1.55 (m, 27H), 1.60 – 1.62 (m, 4H), 2.06 – 2.15 (m, 4H), 5.79 (m, 1H); ^{13}C NMR: δ = 8.8 (–), 12.7 (+), 22.7 (–), 23.7 (–), 27.4 (–), 27.5 (–), 29.2 (–), 31.9 (–), 137.2 (+), 140.5 (C_q); MS (EI): *m*/*z* (%): 371 (1) $[M]^+$, 311/312/313/314/315/316/317/318/319 (42/29/74/34/100/16/15/3/18) $[M - C_4H_{10}]^+$, 57 (16) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{18}H_{36}Sn$ (371.2): C 58.25, H 9.78; found: C 57.97, H 9.47.

General procedure for the one-pot sequence of Stille and Heck coupling of 2-bromocyclohex-1-enyl triflates (GP 1): In a Pyrex bottle containing a magnetic stirring bar, were placed $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (37 mg, 0.14 mmol), LiCl (127 mg, 3.00 mmol), and the bromoenol triflate (1.00 mmol). The bottle was sealed with a septum, evacuated, and purged with nitrogen. DMF (15 mL) was added, and the resulting suspension was purged with nitrogen in an ultrasonic bath for 10 min. After addition of the stannane (1.30 mmol), the septum was removed. The Pyrex bottle was sealed with a screw cap and heated under vigorous stirring for the stated time at the given temperature. When the reaction had ceased the reaction mixture was cooled down to RT and $Pd(OAc)_2$ (15 mg, 67 μmol), PPh_3 (37 mg, 0.14 mmol), NEt_3 (0.28 mL, 2.0 mmol), and the alkene (2.5 mmol) were added. The reaction mixture was stirred for the stated time at the given temperature. In case of acid-sensitive products (workup A) the reaction mixture was poured into Et_2O (70 mL) and NH_3 solution (5 %, 70 mL). The organic layer was washed with NH_3 solution (5 %, 40 mL), and the combined aqueous layers were extracted back once with Et_2O (80 mL). The combined organic layers were dried over K_2CO_3, concentrated in vacuo, and the residue was purified by column chromatography on aluminum oxide. Alternatively (workup B), the reaction mixture was poured into Et_2O and H_2O (70 mL each). The organic layer was washed twice with water (30 mL), and the combined aqueous layers were extracted back once with Et_2O (50 mL). The combined organic layers were dried over $MgSO_4$ and evaporated in vacuo, and the residue was purified by column chromatography on silica gel.

General procedure for the Heck coupling of bromobutadienes with alkenes (GP 2): In a Pyrex bottle containing a magnetic stirring bar, were placed $Pd(OAc)_2$ (9.0 mg, 40 μmol, 4 mol % per Br), PPh_3 (31 mg, 0.12 mmol) and the bromobutadiene (1.00 mmol). The bottle was sealed with a septum, evacuated, and refilled with nitrogen. DMF (15 mL) was added, and the resulting suspension was purged with nitrogen in an ultrasonic bath for 10 min. To the stirred solution were added NEt_3 (0.28 mL, 2.0 mmol) and the alkene (2.5 mmol). The septum was removed, and the Pyrex bottle was sealed with a screw cap and heated under vigorous stirring for the stated time at the given temperature. Then, the reaction mixture was cooled down to RT and worked up according to GP 1, workup B.

2-Bromo-3-ethenylcyclohex-2-enone (3): According to GP 1, (only Stille coupling, no LiCl added) the bromoenol triflate **2** (980 mg, 3.03 mmol) was treated with $Pd(OAc)_2$ (48 mg, 0.21 mmol), PPh_3 (111 mg, 0.423 mmol), and tributylethenylstannane (1.15 g, 3.63 mmol) in THF (50 mL) for 22 h at RT. The reaction mixture was concentrated in vacuo to yield after column chromatography on silica gel (120 g, PE/EtOAc 10:1) bromobutadiene **3** (R_f = 0.30) as a colorless oil (573 mg, 94 %). IR (film): $\tilde{\nu}$ = 1680 cm^{-1} (C=O); ^1H NMR: δ = 2.03 (m, 2H), 2.61 (m, 4H), 5.62 (d, $^3J(H,H)$ = 11.0 Hz, 1H), 5.80 (d, $^3J(H,H)$ = 17.4 Hz, 1H), 7.12 (dd, $^3J(H,H)$ = 11.0, $^3J(H,H)$ = 17.4 Hz, 1H); ^{13}C NMR: δ = 21.4 (–), 27.4 (–), 38.1 (–), 123.8 (–), 124.5 (C_q), 136.9 (+), 153.2 (C_q), 191.7 (C_q); MS (EI): *m*/*z* (%): 202/200 (96/98) $[M]^+$, 174/172 (60/62) $[M - C_2H_4]^+$, 121 (25) $[M - Br]^+$, 65 (100); elemental analysis calcd (%) for C_8H_9BrO (201.1): C 47.79, H 4.51; found: C 48.71, H 4.80.

2-Bromo-3-ethenylcyclohex-2-enol (4): A solution of the ketone **3** (86 mg, 0.43 mmol) in toluene (2.5 mL) was treated with diisobutylaluminum hydride (0.64 mL, 0.64 mmol, 1.0 M in hexane) at – 78°C. The mixture was stirred for 2.5 h at – 78°C, quenched by addition of methanol (0.5 mL), diluted with Et_2O (50 mL) and washed with 2 N hydrochloric acid and H_2O (30 mL each). The aqueous layer was extracted with Et_2O (30 mL), and the combined organic layers were dried over Na_2SO_4 and concentrated in vacuo. Column chromatography on silica gel (16 g, PE/EtOAc 10:1+5 % MeOH) afforded alcohol **4** (R_f = 0.35) as a colorless oil (57 mg, 66 %). ^1H NMR: δ = 1.64 – 1.73 (m, 1H), 1.75 – 1.97 (m, 3H), 2.14 – 2.26 (m, 1H), 2.31 – 2.42 (m, 1H), 2.82 (s, 1H), 4.35 (m, 1H), 5.27 (d, $^3J(H,H)$ = 11.0 Hz, 1H), 5.40 (d, $^3J(H,H)$ = 17.3 Hz, 1H), 6.85 (dd, $^3J(H,H)$ = 17.3, $^3J(H,H)$ = 11.0 Hz, 1H); ^{13}C NMR: δ = 17.7 (–), 27.2 (–), 31.9 (–), 71.5 (+), 117.4 (–), 127.5 (C_q), 135.4 (C_q), 136.6 (+); MS (EI): *m*/*z* (%): 204/202 (4/5) $[M]^+$, 123 (100) $[M - Br]^+$, 95 (13) $[M - Br - C_2H_4]^+$; $C_8H_{11}BrO$ (203.1).

***tert*-Butyl (*E*)-3-(2-ethenyl-6-hydroxycyclohex-1-enyl)acrylate (5), starting from 4**: According to GP 2, the bromobutadiene **4** (148 mg, 0.729 mmol) was treated with $[Pd(PPh_3)_4]$ (59 mg, 51 μmol), NEt_3 (0.20 mL, 1.4 mmol), and *tert*-butyl acrylate (233 mg, 1.82 mmol) in DMF (7 mL) for 68 h at 80°C. After column chromatography (30 g, PE/EtOAc 7:1), the hexatriene **5** (R_f = 0.24, PE/EtOAc 10:1) was obtained as a colorless oil (95 mg, 52 %). ^1H NMR: δ = 1.42 – 1.99 (m, 5H), 1.50 (s, 9H), 2.13 – 2.28 (m, 1H), 2.47 – 2.55 (m, 1H), 4.56 (m, 1H), 5.32 (d, $^3J(H,H)$ = 10.9 Hz, 1H), 5.46 (d, $^3J(H,H)$ = 17.2 Hz, 1H), 6.13 (d, $^3J(H,H)$ = 15.8 Hz, 1H), 7.06 (dd,

^3J(H,H) = 10.9, ^3J(H,H) = 17.2 Hz, 1H), 7.86 (d, ^3J(H,H) = 15.8 Hz, 1H); $C_{15}H_{22}O_3$ (250.4).

***tert*-Butyl (*E*)-3-(2-ethenyl-6-hydroxycyclohex-1-enyl)acrylate (5), starting from 6**: According to GP 1, the bromoenol triflate **6** (125 mg, 0.385 mmol) was treated with $Pd(OAc)_2$ (6.0 mg, 27 μmol), PPh_3 (14 mg, 53 μmol), and tributylethenylstannane (146 mg, 0.460 mmol) in DMF (7 mL) for 16 h at RT (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (6.0 mg, 27 μmol), PPh_3 (14 mg, 53 μmol), NEt_3 (0.21 mL, 1.5 mmol), and *tert*-butyl acrylate (246 mg, 1.92 mmol) were added, and the reaction mixture was stirred for 75 h at 80°C. After workup B and column chromatography on silica gel (15 g, PE/EtOAc 5:1), **5** was obtained as a colorless oil (34 mg, 35%).

***tert*-Butyl (*E*)-3-[6-(*tert*-butyldimethylsilyloxy)-2-ethenylcyclohex-1-enyl]-acrylate (8)**: According to GP 1, the bromoenol triflate **7** (1.316 g, 2.995 mmol) was treated with $Pd(OAc)_2$ (47 mg, 0.21 mmol), PPh_3 (110 mg, 0.419 mmol) and tributylethenylstannane (1.14 g, 3.60 mmol) in DMF (30 mL) for 21 h at RT (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (47 mg, 0.21 mmol), PPh_3 (110 mg, 0.419 mmol), NEt_3 (0.83 mL, 6.0 mmol), and *tert*-butyl acrylate (960 mg, 7.49 mmol) were added, and the reaction mixture was stirred for 22 h at 80°C. After workup B and column chromatography (100 g, PE/EtOAc 25:1), the hexatriene **8** (R_f = 0.30, PE/EtOAc 60:1) was obtained as a colorless oil (795 mg, 73%), which could not be separated from traces of impurities. IR (film): $\tilde{\nu}$ = 1710 cm^{-1} (C=O); ^{1}H NMR: δ = 0.11 (s, 6H), 0.86 (s, 9H), 1.46–1.68 (m, 2H), 1.48 (s, 9H), 1.82–1.91 (m, 2H), 2.13–2.24 (m, 1H), 2.40–2.55 (m, 1H), 4.52 (m, 1H), 5.23 (d, ^3J(H,H) = 11.0 Hz, 1H), 5.39 (d, ^3J(H,H) = 17.3 Hz, 1H), 5.91 (d, ^3J(H,H) = 15.8 Hz, 1H), 7.00 (dd, ^3J(H,H) = 11.0, ^3J(H,H) = 17.3 Hz, 1H), 7.69 (d, ^3J(H,H) = 15.8 Hz, 1H); ^{13}C NMR: δ = −4.7 (+), −3.9 (+), 16.4 (−), 18.2 (C_q), 25.9 (+), 26.3 (−), 28.1 (+), 31.7 (−), 65.7 (+), 79.9 (C_q), 116.4 (−), 121.1 (+), 133.5 (C_q), 134.2 (+), 139.9 (+), 140.0 (C_q), 166.8 (C_q); MS (DCI, NH_3): *m*/*z* (%): 382 (100) $[M+NH_4]^+$, 250 (87) $[M+NH_4-HOSi(CH_3)_2C_4H_9]^+$; $C_{21}H_{36}O_3Si$ (364.6).

***tert*-Butyl (*E*)-3-[6-(*tert*-butyldimethylsilyloxy)-2-(1-methoxyethenyl)cyclohex-1-enyl]acrylate (9)**: According to GP 1, the bromoenol triflate **7** (879 mg, 2.00 mmol) was treated with $Pd(OAc)_2$ (31 mg, 0.14 mmol), PPh_3 (72 mg, 0.27 mmol), LiCl (254 mg, 5.99 mmol), and tributyl(1-methoxyethenyl)stannane (833 mg, 2.40 mmol) in DMF (40 mL) for 18 h at 60°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (32 mg, 0.14 mmol), PPh_3 (75 mg, 0.29 mmol), NEt_3 (0.56 mL, 4.0 mmol), and *tert*-butyl acrylate (641 mg, 5.00 mmol) was added, and the reaction mixture was stirred for 26.5 h at 90°C. Workup A and column chromatography on aluminum oxide (100 g, 2.5% H_2O, PE/Et_2O 50:1) afforded the hexatriene **9** (R_f = 0.20, PE/Et_2O 50:1, aluminum oxide) as a colorless solid (472 mg, 60%). M.p. 48°C; IR (KBr): $\tilde{\nu}$ = 1710 cm^{-1} (C=O); ^{1}H NMR: δ = 0.11 (s, 6H), 0.85 (s, 9H), 1.43–1.62 (m, 2H), 1.46 (s, 9H), 1.78–1.96 (m, 2H), 2.12–2.27 (m, 1H), 2.38–2.52 (m, 1H), 3.58 (s, 3H), 4.02 (d, ^2J(H,H) = 2.3 Hz, 1H), 4.27 (d, ^2J(H,H) = 2.3 Hz, 1H), 4.53 (m, 1H), 5.89 (d, ^3J(H,H) = 16.0 Hz, 1H), 7.61 (d, ^3J(H,H) = 16.0 Hz, 1H); ^{13}C NMR: δ = −4.7 (+), −3.8 (+), 16.3 (−), 18.1 (C_q), 25.9 (+), 28.2 (+), 29.9 (−), 31.5 (−), 55.0 (+), 64.4 (+), 79.7 (C_q), 86.6 (−), 119.1 (+), 133.3 (C_q), 141.9 (+), 143.6 (C_q), 160.8 (C_q), 167.1 (C_q); MS (DCI, NH_3): *m*/*z* (%): 414 (100) $[M+2H+NH_4]^+$, 412 (67) $[M+NH_4]^+$; elemental analysis calcd (%) for $C_{22}H_{38}O_4Si$ (394.6): C 66.96, H 9.71; found: C 66.97, H 9.64.

1-Bromo-2-ethenylcyclohex-1-ene (12): According to GP 1, (Stille coupling only, no LiCl added) the bromoenol triflate **11** (162 mg, 0.524 mmol) was treated with $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (19 mg, 72 μmol), and tributylethenylstannane (200 mg, 0.631 mmol) in DMF (10 mL) for 18 h at RT. The reaction mixture was worked up according to procedure B, and column chromatography on silica gel (30 g, pentane) afforded the bromobutadiene **12** (R_f = 0.42) as a colorless oil (70 mg, 71%). ^{1}H NMR: δ = 1.73 (m, 4H), 2.27 (m, 2H), 2.62 (m, 2H), 5.12 (d, ^3J(H,H) = 10.9 Hz, 1H), 5.26 (d, ^3J(H,H) = 17.2 Hz, 1H), 6.89 (dd, ^3J(H,H) = 10.9, ^3J(H,H) = 17.2 Hz, 1H); $C_8H_{11}Br$ (187.1).

***tert*-Butyl (*E*)-3-(2-ethenylcyclohex-1-enyl)acrylate (13a)**: According to GP 1, the bromoenol triflate **11** (155 mg, 0.501 mmol) was treated with $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (19 mg, 72 μmol), and tributylethenylstannane (239 mg, 0.754 mmol) in DMF (8 mL) for 22 h at RT (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (18 mg, 69 μmol), NEt_3 (0.14 mL, 1.0 mmol), and *tert*-butyl acrylate (161 mg, 1.26 mmol) were added, and the reaction mixture was stirred for 21 h at 90°C. After workup B and column chromatography on aluminum oxide (50 g, 2.5% H_2O, PE/Et_2O 50:1), the hexatriene **13a** (R_f = 0.30, PE/Et_2O 60:1) was obtained as a colorless oil (88 mg, 75%). IR (film): $\tilde{\nu}$ = 1706 cm^{-1} (C=O); ^{1}H NMR: δ = 1.49 (s, 9H), 1.65 (m, 4H), 2.25 (m, 2H), 2.32 (m, 2H), 5.18 (d, ^3J(H,H) = 11.0 Hz, 1H), 5.33 (d, ^3J(H,H) = 17.2 Hz, 1H), 5.80 (d, ^3J(H,H) = 15.6 Hz, 1H), 7.12 (dd, ^3J(H,H) = 11.0, ^3J(H,H) = 17.2 Hz, 1H), 7.96 (d, ^3J(H,H) = 15.6 Hz, 1H); ^{13}C NMR: δ = 22.0 (−), 22.1 (−), 26.1 (−), 26.2 (−), 28.2 (+), 80.0 (C_q), 114.9 (−), 118.2 (+), 131.2 (C_q), 133.4 (+), 140.1 (C_q), 140.2 (+), 167.1 (C_q); MS (DCI, NH_3), *m*/*z* (%): 252 (100) $[M+NH_4]^+$, 235 (24) $[M+H]^+$, 196 (45) $[M+NH_4-C_4H_8]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_2$ (234.3): C 76.88, H 9.46; found: C 76.96, H 9.63.

***tert*-Butyl (*E*)-3-[2-(1-methoxyethenyl)cyclohex-1-enyl]acrylate (14a)**: According to GP 1, the bromoenol triflate **11** (1.546 g, 5.002 mmol) was treated with $Pd(OAc)_2$ (79 mg, 0.35 mmol), PPh_3 (184 mg, 0.702 mmol), LiCl (636 mg, 15.0 mmol), and tributyl(1-methoxyethenyl)stannane (2.257 g, 6.502 mmol) in DMF (70 mL) for 20 h at 70°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (78 mg, 0.35 mmol), PPh_3 (183 mg, 0.698 mmol), NEt_3 (1.4 mL, 10 mmol), and *tert*-butyl acrylate (1.603 g, 12.51 mmol) were added, and the reaction mixture was stirred for 41.5 h at 90°C. Workup A and column chromatography on aluminum oxide (100 g, 5% H_2O, PE/Et_2O 50:1) afforded the hexatriene **14a** (R_f = 0.36, PE/Et_2O 20:1, aluminum oxide) as a colorless oil (942 mg, 71%). IR (film): $\tilde{\nu}$ = 1707 cm^{-1} (C=O); ^{1}H NMR: δ = 1.44 (s, 9H), 1.61 (m, 4H), 2.16 (m, 2H), 2.29 (m, 2H), 3.55 (s, 3H), 3.97 (d, ^2J(H,H) = 2.2 Hz, 1H), 4.22 (d, ^2J(H,H) = 2.2 Hz, 1H), 5.72 (d, ^3J(H,H) = 15.9 Hz, 1H), 7.75 (d, ^3J(H,H) = 15.9 Hz, 1H); ^{13}C NMR: δ = 21.9 (−), 22.0 (−), 25.0 (−), 28.0 (+), 29.7 (−), 54.8 (+), 79.7 (C_q), 86.0 (−), 117.6 (+), 131.1 (C_q), 142.4 (C_q), 143.3 (+), 160.9 (C_q), 167.0 (C_q); MS (EI): *m*/*z* (%): 264 (3) $[M]^+$, 208 (23) $[M-C_4H_8]^+$, 191 (11) $[M-OC_4H_9]^+$, 163 (100) $[M-CO_2C_4H_9]^+$, 57 (11) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{16}H_{24}O_3$ (264.4): C 72.69, H 9.15; found: C 72.84, H 9.09.

1-Bromo-2-(1-methoxyethenyl)cyclohex-1-ene (15): According to GP 1, the bromoenol triflate **11** (155 mg, 0.501 mmol) was treated with $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (18 mg, 69 μmol), LiCl (64 mg, 1.5 mmol), and tributyl(1-methoxyethenyl)stannane (260 mg, 0.749 mmol) in DMF (10 mL) for 3 h at 60°C and for 3.5 h at 75°C (only Stille coupling). Workup A and column chromatography on aluminum oxide (70 g, 5% H_2O, PE) yielded bromobutadiene **15** (R_f = 0.61) as a colorless oil (81 mg, 74%). ^{1}H NMR: δ = 1.68 (m, 4H), 2.25 (m, 2H), 2.53 (m, 2H), 3.57 (s, 3H), 4.09 (d, ^2J(H,H) = 2.5 Hz, 1H), 4.17 (d, ^2J(H,H) = 2.5 Hz, 1H); ^{13}C NMR: δ = 22.0 (−), 24.3 (−), 31.1 (−), 36.4 (−), 54.9 (+), 84.1 (−), 121.6 (C_q), 134.7 (C_q), 162.3 (C_q); MS (EI): *m*/*z* (%): 218/216 (43/40) $[M]^+$, 137 (65) $[M-Br]^+$, 79 (100) $[M-Br-C_3H_6O]^+$; $C_9H_{13}BrO$ (217.1).

2-Ethenyl-1-(1-methoxyethenyl)cyclohex-1-ene (16): According to GP 1, the bromobutadiene **15** (120 mg, 0.553 mmol) was treated with $Pd(OAc)_2$ (6.0 mg, 27 μmol), P(*o*Tol)$_3$ (17 mg, 56 μmol), NEt_3 (40 μL, 0.29 mmol), and tributylethenylstannane (210 mg, 0.662 mmol) in acetonitrile (5 mL) for 4 h at 90°C. After addition of $Pd(OAc)_2$ (6.0 mg, 27 μmol) and P(*o*Tol)$_3$ (17 mg, 56 μmol), stirring was continued for 6 h at 90°C. $Pd(OAc)_2$ (6.0 mg, 27 μmol), P(*o*Tol)$_3$ (17 mg, 56 μmol), and tributylethenylstannane (88 mg, 0.28 mmol) were added, and the reaction mixture was stirred for 4.5 h at 90°C. After workup A and column chromatography on aluminum oxide (40 g, 5% H_2O, pentane), hexatriene **16** (R_f = 0.55) was obtained as a colorless oil (44 mg, 48%). ^{1}H NMR: δ = 1.64 (m, 4H), 2.23 (m, 4H), 3.58 (s, 3H), 3.98 (d, ^2J(H,H) = 2.0 Hz, 1H), 4.19 (d, ^2J(H,H) = 2.0 Hz, 1H), 4.96 (d, ^3J(H,H) = 10.9 Hz, 1H), 5.16 (d, ^3J(H,H) = 17.6 Hz, 1H), 6.85 (dd, ^3J(H,H) = 10.9, ^3J(H,H) = 17.6 Hz, 1H); ^{13}C NMR: δ = 22.2 (−), 22.5 (−), 24.4 (−), 29.7 (−), 54.8 (+), 84.6 (−), 111.4 (−), 132.7 (C_q), 135.2 (C_q), 136.4 (+), 162.2 (C_q); $C_{11}H_{16}O$ (164.2).

Methyl (*E*)-3-[2-bromo-3-(*tert*-butyldimethylsilyloxy)cyclohex-1-enyl]-acrylate (17): According to GP 1, (only Stille coupling) the bromoenol triflate **7** (110 mg, 0.250 mmol) was treated with $Pd(OAc)_2$ (4.0 mg, 18 μmol), PPh_3 (9.0 mg, 34 μmol), LiCl (32 mg, 0.75 mmol), and methyl (*E*)-3-(tributylstannyl)acrylate (140 mg, 0.373 mmol) in DMF (5 mL) for 38.5 h at 45°C. Workup A and column chromatography on aluminum oxide (55 g, 3% H_2O, PE/Et_2O 10:1) yielded the starting material (14 mg, 13%) (R_f = 0.87) and bromobutadiene **17** (R_f = 0.49) as a colorless solid (59 mg, 63%). M.p. 42°C; IR (KBr): $\tilde{\nu}$ = 1726 cm^{-1} (C=O); ^{1}H NMR: δ = 0.12 (s, 3H), 0.18 (s, 3H), 0.91 (s, 9H), 1.65–1.93 (m, 4H), 2.10–2.20 (m, 1H), 2.28–2.37 (m, 1H), 3.77 (s, 3H), 4.36 (m, 1H), 5.99 (d, ^3J(H,H) = 16.0 Hz, 1H), 7.85 (d, ^3J(H,H) = 16.0 Hz, 1H); ^{13}C NMR: δ = −4.7 (+), −4.4 (+),

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17.2 (−), 18.1 (C_q), 25.8 (+), 27.6 (−), 33.4 (−), 51.7 (+), 72.3 (+), 120.4 (+), 133.3 (C_q), 134.9 (C_q), 144.7 (+), 167.2 (C_q); MS (EI): *m/z* (%): 361/359 (2/2) $[M-CH_3]^+$, 319/317 (100/98) $[M-C_4H_9]^+$; elemental analysis calcd (%) for $C_{16}H_{27}BrO_3Si$ (375.4): C 51.20, H 7.25; found: C 51.49, H 7.36.

Methyl (*E*)-3-{2-[(*E*)-2-*tert*-butoxycarbonylethenyl]-3-(*tert*-butyldimethylsilyloxy)cyclohex-1-enyl}acrylate (19): According to GP 1, the bromoenol triflate **7** (121 mg, 0.275 mmol) was treated with $Pd(OAc)_2$ (4.3 mg, 19 μmol), PPh_3 (10 mg, 38 μmol), LiCl (35 mg, 0.83 mmol), and methyl (*E*)-3-(tributylstannyl)acrylate (155 mg, 0.413 mmol) in DMF (10 mL) for 40 h at 45°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (4.3 mg, 19 μmol), PPh_3 (10 mg, 38 μmol), NEt_3 (77 μL, 0.55 mmol), and *tert*-butylacrylate (88 mg, 0.69 mmol) were added, and the reaction mixture was stirred for 39 h at 90°C. Workup A and column chromatography on aluminum oxide [80 g, 3% H_2O, PE/Et_2O 10:1 (440 mL), then PE/EtOAc 10:1] yielded the *tert*-butyl (*E*)-3-{2-[(*E*)-2-*tert*-butoxycarbonylethenyl]-3-(*tert*-butyldimethylsilyloxy)cyclohex-1-enyl}acrylate (**18a**) ($R_f = 0.31$, PE/Et_2O 10:1) as a colorless solid (4 mg, 3%), hexatriene **19** ($R_f = 0.19$, PE/Et_2O 10:1) as a colorless oil (54 mg, 46%) and methyl (*E*)-3-{2-[(*E*)-2-methoxycarbonylethenyl]-3-(*tert*-butyldimethylsilyloxy)cyclohex-1-enyl}-acrylate (**18b**) ($R_f = 0.10$, PE/Et_2O 10:1) as a colorless solid (14 mg, 13%).

Compound 19: IR (film): $\tilde{\nu} = 1721\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 0.11$ (s, 6H), 0.85 (s, 9H), 1.49 (s, 9H), 1.58 – 1.96 (m, 4H), 2.12 – 2.25 (m, 1H), 2.35 – 2.46 (m, 1H), 3.76 (s, 3H), 4.51 (m, 1H), 5.96 (d, $^3J(H,H) = 15.8$ Hz, 1H), 6.01 (d, $^3J(H,H) = 15.8$ Hz, 1H), 7.65 (d, $^3J(H,H) = 15.8$ Hz, 1H), 7.90 (d, $^3J(H,H) = 15.8$ Hz, 1H); ^{13}C NMR: $\delta = -4.8$ (+), −4.0 (+), 16.4 (−), 18.1 (C_q), 25.7 (+), 26.4 (−), 28.1 (+), 31.4 (−), 51.6 (+), 66.0 (+), 80.3 (C_q), 119.7 (+), 123.9 (+), 136.7 (C_q), 139.1 (+), 140.2 (C_q), 141.4 (+), 166.0 (C_q), 167.2 (C_q); MS (DCI, NH_3): *m/z* (%): 440 (100) $[M+NH_4]^+$, 291 (72) $[M-OSi(CH_3)_2C_4H_9]^+$; $C_{23}H_{38}O_5Si$ (422.6).

Compound 18b: M.p. 89°C; ^1H NMR: $\delta = 0.10$ (s, 3H), 0.11 (s, 3H), 0.84 (s, 9H), 1.56 – 1.72 (m, 2H), 1.82 – 1.94 (m, 2H), 2.13 – 2.27 (m, 1H), 2.37 – 2.50 (m, 1H), 3.76 (s, 3H), 3.77 (s, 3H), 4.53 (m, 1H), 6.04 (d, $^3J(H,H) = 15.7$ Hz, 2H), 7.78 (d, $^3J(H,H) = 15.8$ Hz, 1H), 7.91 (d, $^3J(H,H) = 15.7$ Hz, 1H); elemental analysis calcd (%) for $C_{20}H_{32}O_5Si$ (380.6): C 63.12, H 8.48; found: C 63.44, H 8.52.

Compound 18a: M.p. 54°C; ^1H NMR: $\delta = 0.08$ (s, 6H), 0.83 (s, 9H), 1.44 – 1.65 (m, 2H), 1.47 (s, 18H), 1.78 – 1.94 (m, 2H), 2.06 – 2.22 (m, 1H), 2.30 – 2.42 (m, 1H), 4.48 (m, 1H), 5.91 (d, $^3J(H,H) = 15.7$ Hz, 1H), 5.92 (d, $^3J(H,H) = 15.8$ Hz, 1H), 7.61 (d, $^3J(H,H) = 15.8$ Hz, 1H), 7.79 (d, $^3J(H,H) = 15.7$ Hz, 1H); elemental analysis calcd (%) for $C_{26}H_{44}O_5Si$ (464.7): C 67.20, H 9.54; found: C 67.48, H 9.55.

***tert*-Butyl (*E*)-3-{[(*E*)-2-trimethylsilylethenyl]cyclohex-1-enyl}acrylate (20a)**: According to GP 1, the bromoenol triflate **11** (309 mg, 1.00 mmol) was treated with $[Pd(PPh_3)_4]$ (58 mg, 50 μmol), LiCl (127 mg, 3.00 mmol), and tributyl[(*E*)-2-trimethylsilylethenyl]stannane (408 mg, 1.05 mmol) in DMF (16 mL) for 20 h at 90°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (55 mg, 0.21 mmol), NEt_3 (202 mg, 2.00 mmol), and *tert*-butyl acrylate (215 mg, 1.68 mmol) were added, and the reaction mixture was stirred for 24 h at 90°C. Workup A and column chromatography on silica gel (70 g, pentane/Et_2O 30:1) afforded the hexatriene **20a** ($R_f = 0.57$) as a colorless solid (234 mg, 76%). M.p. 74°C; IR (KBr): $\tilde{\nu} = 1706\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 0.11$ (s, 9H), 1.51 (s, 9H), 1.64 (m, 4H), 2.26 (m, 2H), 2.34 (m, 2H), 5.79 (d, $^3J(H,H) = 16$ Hz, 1H), 6.11 (d, $^3J(H,H) = 16$ Hz, 1H), 7.29 (d, $^3J(H,H) = 16$ Hz, 1H), 8.07 (d, $^3J(H,H) = 16$ Hz, 1H); ^{13}C NMR: $\delta = -1.2$ (+), 22.1 (−), 22.2 (−), 26.2 (−), 26.6 (−), 28.2 (+), 80.0 (C_q), 118.3 (+), 131.3 (+), 131.5 (C_q), 139.8 (+), 140.2 (+), 141.0 (C_q), 167.1 (C_q); MS (EI): *m/z* (%): 306 (9) $[M]^+$, 205 (21) $[M-CO_2C_4H_9]^+$, 73 (100) $[Si(CH_3)_3]^+$, 57 (20) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{18}H_{30}O_2Si$ (306.5): C 70.54, H 9.87; found: C 70.89, H 9.58.

***tert*-Butyl (*E*)-3-{2-[(*E*)-3-hydroxyprop-1-enyl]cyclohex-1-enyl}acrylate (21a)**: According to GP 1 the bromoenol triflate **11** (155 mg, 0.500 mmol) was treated with $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (27 mg, 0.10 mmol), LiCl (64 mg, 1.5 mmol), and tributyl[(*E*)-3-hydroxyprop-1-enyl]stannane (226 mg, 0.651 mmol) in DMF (8 mL) for 50 h at 65°C (Stille coupling). For the Heck coupling $Pd(OAc)_2$ (8.0 mg, 36 μmol), PPh_3 (27 mg, 0.10 mmol), NEt_3 (101 mg, 1.00 mmol), and *tert*-butyl acrylate (162 mg, 1.26 mmol) were added, and the reaction mixture was stirred for 24 h at 90°C. Workup A and column chromatography on silica gel (40 g, PE/Et_2O 1:1) yielded hexatriene **21a** ($R_f = 0.42$) as a yellow oil (89 mg, 67%). IR (film): $\tilde{\nu} = 3429\ cm^{-1}$ (OH), 1704 (C=O); ^1H NMR: $\delta = 1.50$ (s, 9H), 1.66 (m, 4H), 2.16 (br s, 1H), 2.26 (m, 2H), 2.34 (m, 2H), 4.27 (d, $^3J(H,H) = 6$ Hz, 2H), 5.81 (d, $^3J(H,H) = 16$ Hz, 1H), 5.97 (dt, $^3J(H,H) = 6$, $^3J(H,H) = 16$ Hz, 1H), 7.02 (d, $^3J(H,H) = 16$ Hz, 1H), 7.98 (d, $^3J(H,H) = 16$ Hz, 1H); ^{13}C NMR: $\delta = 22.1$ (−), 26.0 (−), 27.1 (−), 28.2 (+), 29.7 (−), 64.1 (−), 80.2 (C_q), 118.2 (+), 128.2 (+), 129.7 (+), 131.3 (C_q), 139.4 (C_q), 140.3 (+), 167.3 (C_q); MS (EI): *m/z* (%): 264 (3) $[M]^+$, 190 (52) $[M-C_4H_{10}O]^+$, 145 (98) $[M-CO_2C(CH_3)_3-H_2O]^+$, 57 (84) $[C(CH_3)_3]^+$; $C_{16}H_{24}O_3$ (264.4).

***tert*-Butyl (*E*)-3-(bicyclohexyl-1,1′-dien-2-yl)acrylate (24a)**: According to GP 1 the bromoenol triflate **11** (309 mg, 1.00 mmol) was treated with $[Pd_2(dba)_3]\cdot CHCl_3$ (104 mg, 0.100 mmol), $AsPh_3$ (25 mg, 82 μmol), LiCl (127 mg, 3.00 mmol), CuI (10 mg, 53 μmol), and tributyl(cyclohex-1-enyl)stannane (**23**, 390 mg, 1.05 mmol) in DMF (10 mL) for 4 h at 65°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (55 mg, 0.21 mmol), NEt_3 (202 mg, 2.00 mmol), and *tert*-butyl acrylate (320 mg, 2.50 mmol) were added, and the reaction mixture was stirred for 39 h at 95°C. Due to incomplete conversion and decomposition of the catalyst a second portion of $Pd(OAc)_2$ (16 mg, 71 μmol) and PPh_3 (55 mg, 0.21 mmol) was added, and the reaction mixture was stirred for 45 h at 95°C. Workup A and column chromatography on silica gel (60 g, pentane/Et_2O 30:1) afforded 2-bromobicyclohex-1-enyl (**25**, 133 mg, 55%) (R_f = 0.74, pentane) and hexatriene **24a** (117 mg, 41%) ($R_f = 0.46$) as colorless oils.

Compound 24a: IR (film): $\tilde{\nu} = 1704\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.41$ (s, 9H), 1.49 – 1.66 (m, 8H), 1.95 (m, 2H), 2.07 (m, 6H), 5.32 (m, 1H), 5.59 (d, $^3J(H,H) = 18$ Hz, 1H), 7.59 (d, $^3J(H,H) = 18$ Hz, 1H); ^{13}C NMR: $\delta = 22.1$ (−), 22.3 (−), 22.4 (−), 22.5 (−), 22.8 (−), 25.2 (−), 26.0 (−), 28.2 (+), 30.6 (−), 79.5 (C_q), 115.9 (+), 126.2 (+), 127.3 (C_q), 138.6 (C_q), 144.3 (+), 150.6 (C_q), 167.5 (C_q); MS (EI): *m/z* (%): 288 (2) $[M]^+$, 232 (73) $[M-C_4H_8]^+$, 187 (100) $[M-CO_2C(CH_3)_3]^+$, 145 (45) $[M-CO_2C(CH_3)_3-C_3H_6]^+$; elemental analysis calcd (%) for $C_{19}H_{28}O_2$ (288.4): C 79.12, H 9.78; found: C 78.98, H 9.79.

Compound 25: ^1H NMR: $\delta = 1.65$ (m, 8H), 2.17 (m, 4H), 2.19 (m, 2H), 2.51 (m, 2H), 5.42 (m, 1H); ^{13}C NMR: $\delta = 22.0$ (−), 22.6 (−), 22.8 (−), 24.7 (−), 25.0 (−), 26.6 (−), 31.9 (−), 36.3 (−), 117.6 (C_q), 124.1 (+), 140.0 (C_q), 140.2 (C_q); MS (EI): *m/z* (%): 242/240 (70/64) $[M]^+$, 161 (100) $[M-Br]^+$; analysis calcd for $C_{12}H_{17}Br$: 240.0513 (correct mass according to HRMS).

Methyl (*E*)-3-[2-(4,5-dihydrofuran-2-yl)cyclohex-1-enyl]acrylate (26b): According to GP 1 the bromoenol triflate **11** (309 mg, 1.00 mmol) was treated with $[Pd(dba)_2]$ (12 mg, 21 μmol), TFP (10 mg, 43 μmol), $ZnCl_2$ (300 mg, 2.20 mmol), and tributyl(4,5-dihydrofuran-2-yl)stannane (467 mg, 1.30 mmol) in DMF (16 mL) for 19 h at 40°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (55 mg, 0.21 mmol), LiCl (127 mg, 3.00 mmol), NEt_3 (202 mg, 2.00 mmol), and methyl acrylate (215 mg, 2.50 mmol) were added, and the reaction mixture was stirred for 29 h at 95°C. Workup A and column chromatography on aluminum oxide (100 g, 5% H_2O, pentane/Et_2O 10:1) afforded hexatriene **26b** ($R_f = 0.25$) as a colorless oil (150 mg, 64%). IR (film): $\tilde{\nu} = 1718\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.65$ (m, 4H), 2.27 (m, 4H), 2.72 (dt, $^3J(H,H) = 2$, $^3J(H,H) = 9$ Hz, 2H), 3.72 (s, 3H), 4.38 (t, $^3J(H,H) = 9$ Hz, 2H), 4.94 (t, $^3J(H,H) = 2$ Hz, 1H), 5.97 (d, $^3J(H,H) = 17$ Hz, 1H), 7.14 (d, $^3J(H,H) = 17$ Hz, 1H); ^{13}C NMR: $\delta = 22.0$ (−), 22.1 (−), 25.9 (−), 29.0 (−), 30.5 (−), 51.4 (+), 69.7 (−), 102.1 (+), 115.5 (+), 132.2 (C_q), 135.6 (C_q), 144.7 (+), 156.1 (C_q), 168.3 (C_q); MS (EI): *m/z* (%): 234 (30) $[M]^+$, 175 (100) $[M-CO_2CH_3]^+$, 133 (32) $[M-CO_2CH_3-C_3H_6]^+$; anal. calcd for $C_{14}H_{18}O_3$: 234.1255 (correct mass according to HRMS).

***tert*-Butyl (*E*)-3-{2-[5,6-dihydro-4*H*-pyran-2-yl]cyclohex-1-enyl}acrylate (27a)**: According to GP 1, the bromoenol triflate **11** (309 mg, 1.00 mmol) was treated with $[Pd(dba)_2]$ (12 mg, 21 μmol), TFP (10 mg, 43 μmol), $ZnCl_2$ (300 mg, 2.20 mmol), and tributyl(5,6-dihydro-4*H*-pyran-2-yl)stannane (485 mg, 1.30 mmol) in DMF (16 mL) for 26 h at 25°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (55 mg, 0.21 mmol), LiCl (127 mg, 3.00 mmol), NEt_3 (202 mg, 2.00 mmol), and *tert*-butyl acrylate (320 mg, 2.50 mmol) were added, and the reaction mixture was stirred for 35 h at 95°C. Workup A and column chromatography on aluminum oxide (100 g, 5% H_2O, pentane/Et_2O 15:1) yielded hexatriene **27a** ($R_f = 0.26$) as a colorless oil (256 mg, 88%). IR (film): $\tilde{\nu} = 1705\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.49$ (s, 9H), 1.64 (m, 4H), 1.85 (m, 2H), 2.09 – 2.22 (m, 4H), 2.30 (m, 2H), 4.03 (m, 2H), 4.66 (t, $^3J(H,H) = 4$ Hz, 1H), 5.71 (d, $^3J(H,H) = 15$ Hz, 1H), 7.85 (d, $^3J(H,H) = 15$ Hz, 1H); ^{13}C NMR: $\delta = 20.6$ (−), 22.1 (−), 22.2 (−), 22.3 (−), 25.3 (−), 28.2 (+),

29.5 (−), 66.3 (−), 79.7 (C_q), 102.2 (+), 117.2 (+), 131.0 (C_q), 142.3 (C_q), 143.8 (+), 152.1 (C_q), 167.3 (C_q); MS (EI): *m*/*z* (%): 290 (5) $[M]^+$, 234 (8) $[M-C_4H_8]^+$, 189 (100) $[M-CO_2C(CH_3)_3]^+$; anal. calcd for $C_{18}H_{26}O_3$: 290.1881 (correct mass according to HRMS).

***tert*-Butyl (*E*)-3-{2-[(*E*,*E*)-5-hydroxypenta-1,3-dienyl]cyclohex-1-enyl}-acrylate (28)**: According to GP 1 the bromoenol triflate **11** (309 mg, 1.00 mmol) was treated with $[Pd_2(dba)_3]\cdot CHCl_3$ (104 mg, 0.100 mmol), $AsPh_3$ (25 mg, 0.082 mmol), LiCl (127 mg, 3.00 mmol), CuI (10 mg, 0.053 mmol), and tributyl[(*E*,*E*)-5-hydroxypenta-1,3-dienyl]stannane (392 mg, 1.05 mmol) in DMF (10 mL) for 5 h at 65°C (Stille coupling). For the Heck coupling, $Pd(OAc)_2$ (16 mg, 71 μmol), PPh_3 (55 mg, 0.21 mmol), NEt_3 (202 mg, 2.00 mmol), and *tert*-butyl acrylate (320 mg, 2.50 mmol) were added, and the reaction mixture was stirred for 39 h at 95°C. Workup A and column chromatography on silica gel (65 g, pentane/Et_2O 1:1) afforded hexatriene **28** ($R_f = 0.32$) as a yellow oil (143 mg, 49%). IR (film): $\tilde{\nu} = 3426\ cm^{-1}$ (OH), 1704 (C=O); ^1H NMR: $\delta = 1.48$ (s, 9H), 1.64 (m, 4H), 2.25 (m, 2H), 2.34 (m, 2H), 3.64 (br s, 1H), 4.20 (d, $^3J(H,H) = 6$ Hz, 2H), 5.79 (d, $^3J(H,H) = 16$ Hz, 1H), 5.90 (dt, $^3J(H,H) = 6$, $^3J(H,H) = 15$ Hz, 1H), 6.36 (m, 2H), 6.99 (d, $^3J(H,H) = 15$ Hz, 1H), 7.96 (d, $^3J(H,H) = 16$ Hz, 1H); ^{13}C NMR: $\delta = 22.1$ (−), 22.2 (−), 26.3 (−), 26.8 (−), 28.2 (+), 63.4 (−), 80.2 (C_q), 118.0 (+), 129.2 (+), 129.7 (+), 131.7 (C_q), 132.2 (+), 133.2 (+), 138.6 (C_q), 140.1 (+), 167.3 (C_q); MS (EI): *m*/*z* (%): 290 (40) $[M]^+$, 171 (100) $[M-CO_2C(CH_3)_3-H_2O]^+$, 57 (92) $[C_4H_9]^+$; $C_{18}H_{26}O_3$ (290.4).

General procedure for the 6π-electrocyclization of the 2-methoxy-1,3,5-hexatrienes 14 and 16 (GP 3): In a Pyrex bottle containing a magnetic stirring bar, the hexatriene (0.20 mmol) and NEt_3 (0.1 mL, 0.7 mmol) were dissolved in decalin (10 mL), and the mixture was purged with nitrogen in an ultrasonic bath for 15 min. The bottle was sealed with a screw cap and the solution was stirred for a given time and temperature. The reaction mixture was hydrolyzed as described in the procedures and poured into a mixture of Et_2O and saturated $NaHCO_3$ solution (50 mL each). The aqueous phase was extracted with Et_2O (40 mL), and the combined organic layers were dried over $MgSO_4$. Et_2O was evaporated in vacuo and the resulting solution in decalin was separated by column chromatography on silica gel.

***tert*-Butyl 4-oxo-1,2,3,4,5,6,7,8-octahydronaphthalene-2-carboxylate (30a)**: According to GP 3, the hexatriene **14a** (600 mg, 2.27 mmol) was treated with NEt_3 (0.30 mL, 2.15 mmol) in decalin (30 mL) for 80 min at 215°C. The reaction mixture was cooled to RT and treated with a mixture of *t*BuOH (15 mL) and 2N HCl (3 mL) for 10 min. Column chromatography on silica gel [75 g, PE (200 mL), then PE/EtOAc 10:1] yielded compound **30a** ($R_f = 0.35$, PE/Et_2O 3:1) as a colorless solid (531 mg, 93%). M.p. 31°C; IR (KBr): $\tilde{\nu} = 1719\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.40$ (s, 9H), 1.52–1.70 (m, 4H), 2.16 (m, 4H), 2.41–2.65 (m, 4H), 2.81–2.93 (m, 1H); ^{13}C NMR: $\delta =$ 21.8 (−), 21.9 (−, 2C), 27.89 (+), 31.6 (−), 33.5 (−), 39.6 (−), 40.3 (+), 80.9 (C_q), 132.2 (C_q), 154.6 (C_q), 172.6 (C_q), 196.9 (C_q); MS (EI): *m*/*z* (%): 250 (<1) $[M]^+$, 194 (24) $[M-C_4H_8]^+$, 149 (100) $[M-CO_2C_4H_9]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_3$ (250.3): C 71.97, H 8.86; found: C 71.89, H 8.69.

General procedure for the 6π-electrocyclization of the 1,3,5-hexatrienes 20, 21, and 24 (GP 4): In a Pyrex bottle containing a magnetic stirring bar, the hexatriene was dissolved in decalin, and the mixture was purged with nitrogen in an ultrasonic bath for 15 min. The bottle was sealed with a screw cap, and the solution was stirred for a given time at 200–215°C. The reaction mixture was cooled down to RT, concentrated (40°C, 0.4 mbar) and purified by column chromatography on silica gel.

***tert*-Butyl 5,6,7,8-tetrahydronaphthalene-2-carboxylate (31a)**: According to GP 4, the hexatriene **20a** (24 mg, 78 μmol) was heated in decalin (10 mL) for 2 h at 210°C. Column chromatography on silica gel (5 g, pentane/Et_2O 30:1) afforded **31a** ($R_f = 0.39$) as a colorless oil (11 mg, 61%). IR (film): $\tilde{\nu} = 1714\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.58$ (s, 9H), 1.80 (m, 4H), 2.79 (m, 4H), 7.08 (d, $^3J(H,H) = 8$ Hz, 1H), 7.67 (m, 2H); ^{13}C NMR: $\delta = 22.9$ (−), 23.0 (−), 28.22 (+), 29.3 (−), 29.6 (−), 80.6 (C_q), 126.4 (+), 129.0 (+), 129.2 (C_q), 130.2 (+), 137.0 (C_q), 142.2 (C_q), 166.1 (C_q); MS (EI): *m*/*z* (%): 232 (26) $[M]^+$, 176 (100) $[M-C_4H_8]^+$, 131 (82) $[M-CO_2C(CH_3)_3]^+$; analysis calcd for $C_{15}H_{20}O_2$: 232.1463 (correct mass according to HRMS).

3a,5,6,7,8,9a-Hexahydro-3*H*-naphtho[2,3-c]furan-1-one (32): According to GP 4, the hexatriene **21a** (24 mg, 0.091 mmol) was heated in decalin (10 mL) for 2 h at 200°C. Column chromatography on silica gel (26 g, pentane/Et_2O 1:1) afforded hexatriene **21a** (6 mg, 25%) and **32** (13 mg, 75%) ($R_f = 0.47$) as colorless oils. IR (film): $\tilde{\nu} = 1759\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.59$ (m, 4H), 2.32 (m, 4H), 3.28 (m, 2H), 4.08 (m, 1H), 4.51 (m, 1H), 5.51 (m, 2H); ^{13}C NMR: $\delta = 23.6$ (−), 23.7 (−), 30.4 (−), 30.5 (−), 35.4 (+), 40.4 (+), 73.4 (−), 112.8 (+), 118.1 (+), 136.5 (C_q), 136.5 (C_q), 178.7 (C_q); MS (EI): *m*/*z* (%): 190 (56) $[M]^+$; analysis calcd for $C_{12}H_{14}O_2$: 190.0993 (correct mass according to HRMS).

***tert*-Butyl 1,2,3,4,5,6,7,8,9,10-decahydrophenanthrene-9-carboxylate (33)**: According to GP 4, the hexatriene **24a** (23 mg, 80 μmol) was heated in decalin (6 mL) for 1 h at 215°C. Column chromatography on silica gel (6 g, pentane/Et_2O, 100:1) afforded **33** ($R_f = 0.38$) as a colorless oil (17 mg, 74%). IR (film): $\tilde{\nu} = 1728\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.39$ (s, 9H), 1.49–2.63 (m, 18H), 2.71 (m, 1H); ^{13}C NMR: $\delta = 22.7$ (−), 22.8 (−), 23.1 (−), 23.2 (−), 24.7 (−), 25.2 (−), 28.0 (+), 29.3 (−), 30.5 (−), 31.8 (−), 45.7 (+), 79.9 (C_q), 125.4 (C_q), 127.1 (C_q), 128.1(C_q), 130.3 (C_q), 174.1 (C_q); MS (EI): *m*/*z* (%): 288 (19) $[M]^+$, 232 (61) $[M-C_4H_8]^+$, 187 (100) $[M-CO_2C(CH_3)_3]^+$; analysis calcd for $C_{19}H_{28}O_2$: 288.2089 (correct mass according to HRMS).

***tert*-Butyl (*E*)-3-(2-acetylcyclohex-1-enyl)acrylate (34a)**: A solution of the enol ether **14a** (49 mg, 0.19 mmol) in *t*BuOH (5 mL) and Et_2O (2 mL) was treated with 2.0N HCl (46 μL, 92 μmol) for 10 min at RT and then concentrated in vacuo. Column chromatography on silica gel (10 g, PE/EtOAc 15:1) yielded **34a** ($R_f = 0.19$, PE/EtOAc 20:1) as a colorless oil (42 mg, 91%). IR (film): $\tilde{\nu} = 1707\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.42$ (s, 9H), 1.63 (m, 4H), 2.20 (m, 2H), 2.26 (s, 3H), 2.31 (m, 2H), 5.82 (d, $^3J(H,H) =$ 15.7 Hz, 1H), 7.43 (d, $^3J(H,H) = 15.7$ Hz, 1H); ^{13}C NMR: $\delta = 21.5$ (−), 21.6 (−), 25.1 (−), 27.4 (−), 28.0 (+), 29.8 (+), 80.2 (C_q), 120.7 (+), 133.0 (C_q), 141.1 (+), 145.0 (C_q), 166.2 (C_q), 204.9 (C_q); MS (DCI, NH_3): *m*/*z* (%): 268 (100) $[M+NH_4]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_3$ (250.3): C 71.97, H 8.86; found: C 71.85, H 8.77.

General procedure for the intramolecular Michael addition of the 1-alkenyl-2-acetylcycloalkenes 34 (GP 5): A solution of the respective cycloalkene (0.30 mmol) and 18[crown]-6 (79 mg, 0.30 mmol) in THF (12 mL) was treated with potassium bis(trimethylsilyl)amide (KHMDS) (0.24 mL, 0.12 mmol, 0.5M in toluene) at −78°C and stirred for 2 min at −78°C and for 4 min at 0°C. MeOH (0.2 mL) and NH_4Cl solution (0.5 mL) was added, and the mixture was poured into NH_4Cl solution and Et_2O (40 mL each). The aqueous phase was extracted with Et_2O (30 mL), and the combined organic layers were dried over $MgSO_4$ and concentrated in vacuo.

***tert*-Butyl (3-oxo-2,3,4,5,6,7-hexahydro-1*H*-inden-1-yl)acetate (35a)**: According to GP 5, the cyclohexene **34a** (58 mg, 0.23 mmol) was treated with KHMDS (0.18 mL, 90 μmol, 0.5M in toluene) and 18[crown]-6 (61 mg, 0.23 mmol) to yield compound **35a** ($R_f = 0.31$, PE/EtOAc 5:1) as a colorless oil (58 mg, 100%). IR (film): $\tilde{\nu} = 1726$ (C=O), 1701 cm^{-1} (C=O); ^1H NMR: $\delta = 1.40$ (s, 9H), 1.52–1.76 (m, 4H), 2.10–2.22 (m, 5H), 2.31–2.43 (m, 1H), 2.54–2.66 (m, 2H), 3.04 (m, 1H); ^{13}C NMR: $\delta = 19.9$ (−), 21.4 (−), 22.0 (−), 26.1 (−), 28.0 (+), 38.4 (+), 38.8 (−), 41.1 (−), 81.0 (C_q), 139.3 (C_q), 171.0 (C_q), 174.1 (C_q), 207.4 (C_q); MS (EI): *m*/*z* (%): 250 (1) $[M]^+$, 194 (100) $[M-C_4H_8]^+$, 149 (70) $[M-CO_2C_4H_9]^+$, 57 (23) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_3$ (250.3): C 71.97, H 8.86; found: C 72.24, H 8.66.

***tert*-Butyl 5-oxo-11-oxatricyclo[4.4.1.0^{1,6}]undecane-3-carboxylate (36a)**: A solution of the bicyclo[4.4.0]decenone **30a** (255 mg, 1.02 mmol) in MeOH (3.5 mL) was treated with NaOH (0.10 mL, 6.0N, 0.60 mmol) at 15°C. Then, H_2O_2 (0.260 mL, 30%, 2.5 mmol) was added dropwise within 30 min, and the resulting mixture was stirred for 10 h at RT, diluted with Et_2O (80 mL) and washed with H_2O (3 × 40 mL). The aqueous layers were extracted with Et_2O (60 mL), and the combined organic layers were dried over Na_2SO_4 and concentrated in vacuo. Column chromatography on aluminum oxide (100 g, 5% H_2O, PE/Et_2O 3:1) yielded the diastereomeric pure epoxide **36a** ($R_f = 0.36$) as a colorless solid (191 mg, 70%). M.p. 34°C; IR (KBr): $\tilde{\nu} = 1726$ (C=O), 1701 cm^{-1} (C=O); ^1H NMR: $\delta = 1.15–1.54$ (m, 4H), 1.40 (s, 9H), 1.71–2.08 (m, 4H), 2.16–2.38 (m, 3H), 2.67 (ddd, $^3J(H,H) = 1.1$, $^3J(H,H) = 5.5$, $^2J(H,H) = 18.2$ Hz, 1H), 2.92 (m, 1H); ^{13}C NMR: $\delta = 19.6$ (−), 19.8 (−), 21.0 (−), 27.9 (+), 29.5 (−), 32.2 (−), 35.7 (+), 38.5 (−), 63.1 (C_q), 64.4 (C_q), 81.0 (C_q), 172.9 (C_q), 204.7 (C_q); MS (EI): *m*/*z* (%): 266 (<1) $[M]^+$, 210 (66) $[M-C_4H_8]^+$, 57 (100) $[C_4H_9]^+$;

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elemental analysis calcd (%) for $C_{15}H_{22}O_4$ (266.3): C 67.65, H 8.33; found: C 67.90, H 8.52.

***tert*-Butyl (9-oxocyclodec-3-yne)carboxylate (37a)**: A solution of the epoxide **36a** (72 mg, 0.27 mmol) in CH_2Cl_2 (3 mL) and AcOH (3 mL) was treated at 0°C with tosylhydrazide (58 mg, 0.31 mmol) and stirred for 40 min at 0°C and for 4.5 h at RT. The reaction mixture was poured into Et_2O and $NaHCO_3$ solution (50 mL each) and washed with $NaHCO_3$ solution (50 mL). The aqueous layer was extracted with Et_2O (80 mL), and the combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. Column chromatography on silica gel (12 g, PE/Et_2O 6:1) yielded alkyne **37a** ($R_f = 0.30$) as a colorless solid (49 mg, 72%). M.p. 44°C; IR (KBr): $\tilde{\nu} = 1720\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.42 - 1.77$ (m, 3H), 1.42 (s, 9H), 2.00 – 2.69 (m, 8H), 2.96 (ddd, $^3J(H,H) = 2.2$, $^3J(H,H) = 11.0$, $^2J(H,H) = 17.4$ Hz, 1H), 3.29 – 3.39 (m, 1H); ^{13}C NMR: $\delta = 18.1$ (–), 21.6 (–), 21.9 (–), 25.4 (–), 28.0 (+), 43.1 (–), 44.5 (+), 44.7 (–), 81.1 (C_q), 81.2 (C_q), 86.3 (C_q), 172.7 (C_q), 208.0 (C_q); MS (EI): *m*/*z* (%): 250 (<1) $[M]^+$, 194 (47) $[M - C_4H_8]^+$, 57 (100) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_3$ (250.3): C 71.97, H 8.86; found: C 72.22, H 8.81.

***tert*-Butyl (9-oxo-10-oxatricyclo[4.3.1.0^{1,6}]dec-7-yl)acetate (38a)**: A solution of the bicyclo[4.3.0]nonenone (**35a**, 348 mg, 1.39 mmol) in MeOH (5 mL) was treated with NaOH (0.14 mL, 6.0 N, 0.84 mmol) at 15°C. Then, H_2O_2 (0.35 mL, 30%, 3.4 mmol) was added within 30 min, and the resulting mixture was stirred for 4.5 h at RT. A second portion of H_2O_2 (0.21 mL, 30%, 2.1 mmol) was added dropwise at 15°C, and stirring was continued for 6 h at RT. A third portion of H_2O_2 (0.35 mL, 30%, 3.4 mmol) was then added as above, and stirring was continued for 9.5 h at RT. The reaction mixture was poured into Na_2SO_3 solution and Et_2O (40 mL each), and the organic layer was washed with NH_4Cl solution (30 mL), dried over Na_2SO_4 and concentrated in vacuo. Column chromatography on aluminum oxide [110 g, 5% H_2O, PE/EtOAc 9:1 (400 mL), then 5:1] yielded epoxide **38a** ($R_f = 0.31$, PE/EtOAc 12:1) as a colorless solid (203 mg, 55%) in a diastereomeric ratio of 89:11. M.p. 35°C; IR (KBr): $\tilde{\nu} = 1744$ (C=O), 1725 cm^{-1} (C=O); ^1H NMR, signals of the minor diastereomer are marked with "#": $\delta = 1.03 - 1.21$ (m, 2H), 1.27 – 1.52 (m, 2H), 1.35/1.38# (s, 9H), 1.60 – 2.62 (m, 8H), 2.73 (m, 1H); ^{13}C NMR, signals of the minor diastereomer are marked with "#": $\delta = 18.3$ (–), 19.1 (–), 19.2 (–)#, 19.4 (–)#, 19.5 (–), 23.6 (–), 25.3 (–)#, 27.8 (+), 34.3 (+), 35.8 (+)#, 35.8 (–)#, 37.0 (–), 38.2 (–)#, 38.5 (–), 64.5 (C_q), 64.9 (C_q)#, 69.2 (C_q)#, 69.9 (C_q), 80.7 (C_q)#, 81.1 (C_q), 170.4 (C_q), 171.1 (C_q)#, 210.0 (C_q); MS (EI): *m*/*z* (%): 266 (<1) $[M]^+$, 193 (67) $[M - OC_4H_9]^+$, 182 (100), 151 (71) $[M - CH_2CO_2C_4H_9]^+$, 57 (96) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_4$ (266.3): C 67.65, H 8.33; found: C 67.84, H 8.56.

***tert*-Butyl (9-oxocyclonon-3-ynyl)acetate (39a)**: A solution of the epoxide **38a** (39 mg, 0.15 mmol) in CH_2Cl_2 (2 mL) and AcOH (2 mL) was treated at 0°C with tosylhydrazide (25 mg, 0.13 mmol), stirred for 30 min at 0°C and for 135 min for RT, poured into Et_2O and $NaHCO_3$ solution (40 mL each) and washed with $NaHCO_3$ solution (30 mL). The aqueous phase was extracted with Et_2O (50 mL), and the combined organic layers were dried over $MgSO_4$ and concentrated in vacuo. Column chromatography on silica gel (18 g, PE/EtOAc 14:1) afforded alkyne **39a** ($R_f = 0.40$, PE/EtOAc 12:1) as a colorless solid (11 mg, 30%) and starting material (9 mg, 23%) ($R_f =$ 0.31, PE/EtOAc 12:1). M.p. 72°C; IR (KBr): $\tilde{\nu} = 1717\ cm^{-1}$ (C=O); ^1H NMR: $\delta = 1.40$ (s, 9H), 1.56 – 1.69 (m, 1H), 1.78 – 2.31 (m, 8H), 2.59 (ddd, $^3J(H,H) = 3.0$, $^3J(H,H) = 8.6$, $^2J(H,H) = 16.7$ Hz, 1H), 2.79 (dd, $^3J(H,H) = 10.4$, $^2J(H,H) = 17.0$ Hz, 1H), 3.02 (ddd, $^3J(H,H) = 2.1$, $^3J(H,H) = 8.9$, $^2J(H,H) = 16.7$ Hz, 1H), 3.24 – 3.37 (m, 1H); ^{13}C NMR: $\delta = 18.7$ (–), 21.3 (–), 22.9 (–), 28.0 (+), 28.7 (–), 37.2 (–), 45.5 (+), 45.7 (–), 80.9 (C_q), 82.0 (C_q), 89.8 (C_q), 171.2 (C_q), 209.5 (C_q); MS (EI): *m*/*z* (%): 250 (<1) $[M]^+$, 194 (61) $[M - C_4H_8]^+$, 149 (100) $[M - CO_2C_4H_9]^+$, 135 (36) $[M - CH_2CO_2C_4H_9]^+$, 57 (96) $[C_4H_9]^+$; elemental analysis calcd (%) for $C_{15}H_{22}O_3$ (250.3): C 71.97, H 8.86; found: C 71.67, H 8.58.

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