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Studies on Rhodium-Catalyzed [5+2] Cocyclization Reactions

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to Juliane

Contents

Abbreviations

BCP	=	Bicyclopropylidene
DCE	=	1,2-Dichloroethane
DCM	=	Dichloromethane
DIBALH	=	Di-*iso*-butylaluminium hydride
DMAP	=	4-Dimethylaminopyridine
DME	=	1,2-Dimethoxyethane
DMF	=	*N,N*-Dimethylformamide
DMSO	=	Dimethyl sulfoxide
dppb	=	1,4-Bis(diphenylphosphino)butane
dppbe	=	1,2-Bis(diphenylphosphino)benzene
dppe	=	1,2-Bis(diphenylphosphino)ethane
LDA	=	Lithium di-*iso*-propylamine
TBDMS	=	*tert*-Butyl-dimethylsilyl
TCE	=	1,1,2,2-Tetrachloroethane
THF	=	Tetrahydrofuran
TFE	=	2,2,2-Trifluoroethanol
TMS	=	Trimethylsilyl
VCP	=	Vinylcyclopropane

A. Introduction and Background

The discovery and development of new chemical reactions is a major focus of research activities in organic chemistry. The chemical synthesis of molecules provided by Nature has traditionally been the arena in which the utility of new reactions is critically evaluated. A vast array of new methods and creative strategies has arisen from this activity.[1–6] The development of new strategies and reactions is also stimulated by efforts to rationally design syntheses of non-natural compounds with interesting molecular architectures. Concepts of bonding, binding, reactivity, as well as inter- and intramolecular interactions can then be examined. The reactions and classes of reactions which have found the broadest applicability in organic chemistry are those, that address the issues of stereo- and enantiocontrol and are compatible with a variety of functional groups. Reactions which form multiple bonds, rings, and/or stereocenters are particularly important tools for the efficient assembly of complex molecular structures.[7] Among those families of reactions discovered over the past 75 years, cycloaddition reactions hold a prominent place in the arsenal of synthetic methods currently available to organic chemists. Moreover, research activity in this field shows no signs of abatement.[8,9]

Cycloadditions have been promoted by heat, light, LEWIS acids, high pressure or sonication. Many of these reaction conditions require the presence of polarized functional groups in the substrate to facilitate transformation. In general, reactions of unactivated alkenes, dienes, allenes and acetylenes are notoriously poor and extreme conditions or special methods are necessary to achieve good yields of the cycloadducts. Particular difficulty is encountered in the cycloaddition of two unactivated species since homodimerization can be a competitive and dominant reaction pathway.

Metal catalysts provide new opportunities for highly selective cycloaddition reactions since complexation of the metal to an alkene, diene, or acetylene significantly modifies the reactivity of this moiety, opening the way for improved reactivity and novel chemistry.[10] One of the most important consequences of complexation is the temporary polarization and activation of otherwise unreactive species. In addition to

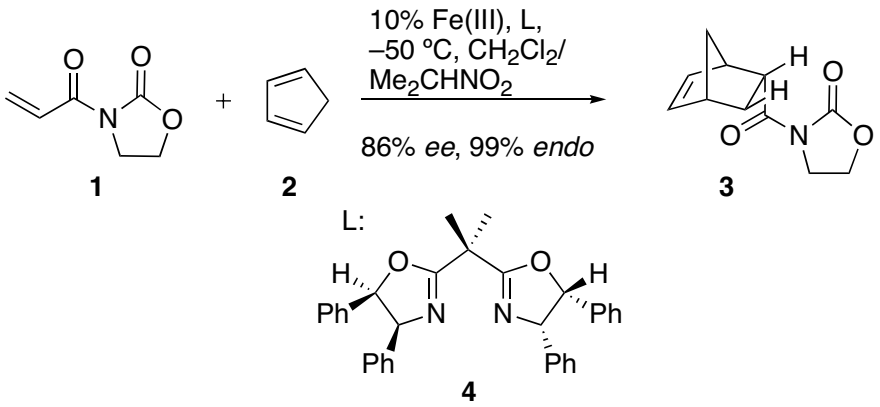
the rate enhancements observed in the presence of the metal catalyst, the opportunity to achieve enantioselective transformations by adding chiral ligands is one of the most attractive features of this strategy.

The remarkable versatility of the DIELS-ALDER reaction for the stereospecific construction of six-membered rings has made this reaction one of the most widely studied methods in organic chemistry.[11–15] The severity of the reaction conditions required for a purely thermal [4 + 2] cycloaddition depends on the substituents on the diene and on the dienophile. Various modifications have been developed to enhance the rate of the cycloaddition and to improve selectivities including the following: the use of high pressure,[16–19] ultrasound,[20–23] BROENSTED acids,[24–29] traditional LEWIS acids,[11–13, 30] special solvent effects,[31–36] molecular sieves,[37–40] adsorption on chromatography sorbents,[41–44] *in situ* radical cation formation,[45–47] and the use of transition metals.[48–50]

The past 15 years experienced a tremendous increase in the development of useful transition metal catalysts promoting cocyclization reactions. This interest stems from mild reaction conditions and the ability to modify the chemo- and regioselectivities as the metal and ligands are varied. Two main classes of metal-catalyzed DIELS-ALDER reactions can be identified. The metal either serves as a LEWIS acid and complexes to a carbonyl or other polarized group[48, 49] or the metal complexes to the π-bonds of the alkene or alkyne and the diene.[50–54]

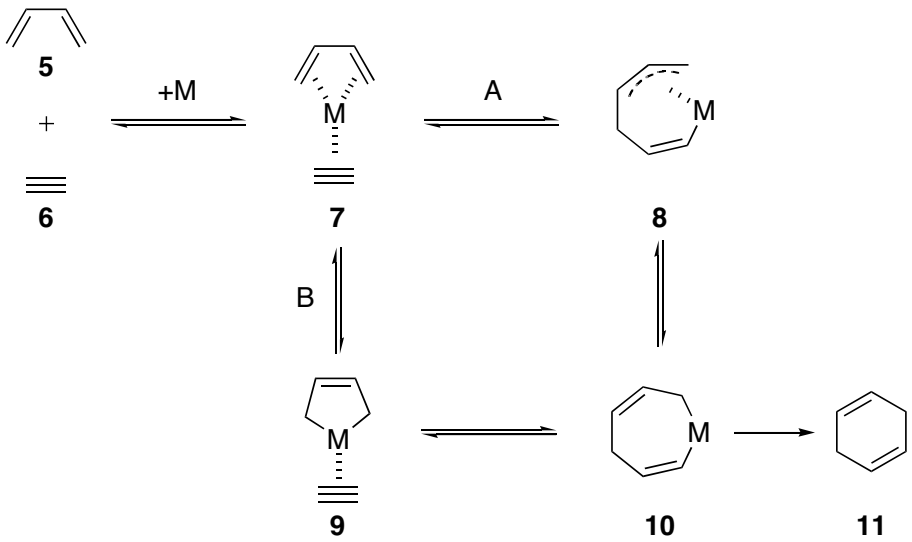
The vast majority of synthetically useful [4 + 2] cycloaddition reactions reported contain electronically dissimilar dienes and dienophiles. LEWIS acid catalysts were the first to be investigated and are now the most widely used ones. When the metal acts as a LEWIS acid, complexation with a functional group in the substrate generates a highly polarized η^1-complex. The enhancement in reactivity and regio- and stereoselectivity has been attributed to a change in the coefficients in the LUMO of the dienophile upon complexation.[11–13] Recently, impressive advancements in the development of new chiral ligands which induce high levels of enantioselectivity have been reported. Excellent enantionmeric exesses (*ee*'s) have been achieved although the range of dienes is still somewhat limited (Scheme 1).[11–13, 30, 48]

In contrast, dienes and dienophiles which are electronically similar undergo cycloadditions under more extreme reaction conditions which has severely limited their use in organic synthesis until the relatively recent discovery of metal catalysts which accelerate these reactions. Activation occurs by a combination of proximity- and



Scheme 1. LEWIS acid-catalyzed asymmetric DIELS-ALDER reactions.

complexation-induced polarization effects. Interaction of the π-bonds of the diene and the dienophile leads to the formation of the π-complex **7** (Scheme 2).

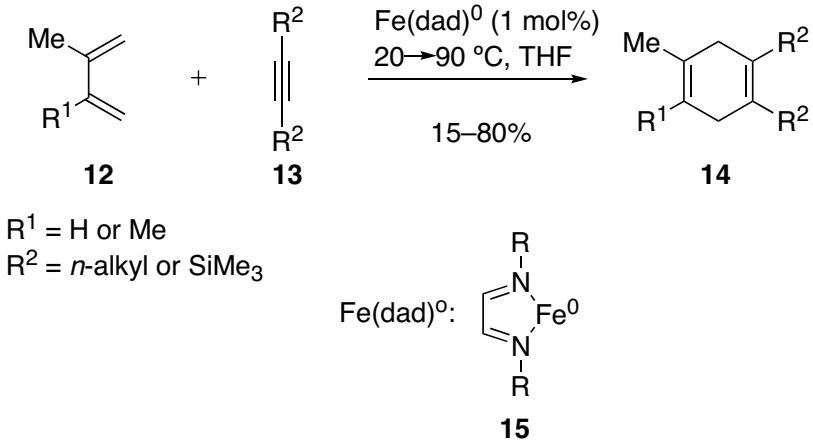


Scheme 2. Different pathways in the transition metal-catalyzed DIELS-ALDER reaction.

Oxidative coupling could occur via pathway A to generate an η^1,η^3-complex **8**.[51,52] A reasonable alternative would involve the formation of the metallacyclopentene **9** via pathway B. Both **8** and **9** could lead to the formation of the metallacycle **10** which could undergo reductive elimination of the metal to give the carbocycle and regenerate the active catalyst. To date, Rh, Ni, Ti, Fe and Pd have been reported to catalyze [4 + 2] cycloadditions.[50–54]

Early findings by FICINI et al.,[50] TOM DIECK et al.,[50] and MATSUDA et al.[51] on the use of low-valent iron and low-valent rhodium complexes to catalyze intermolecular [4 + 2] cycloadditions between 1,3-butadienes and unactivated alkynes were important breakthroughs in this area.

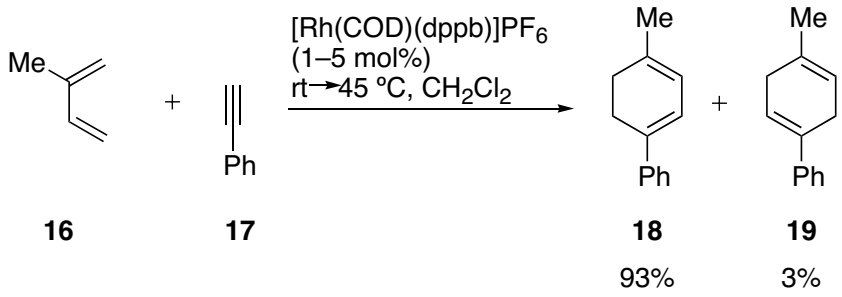
In the presence of "Fe(dad)^0" [generated *in situ* by reduction of Fe^{2+} or Fe^{3+} salts with Et_3Al or EtMgBr in the presence of diazadiene (dad)], internal alkynes react with 1,3-butadienes to afford [4 + 2] cycloadducts in moderate yields (Scheme 3).[50] Terminal alkynes do not undergo [4 + 2] cycloadditions under these conditions; trimerization of the alkyne was observed instead.



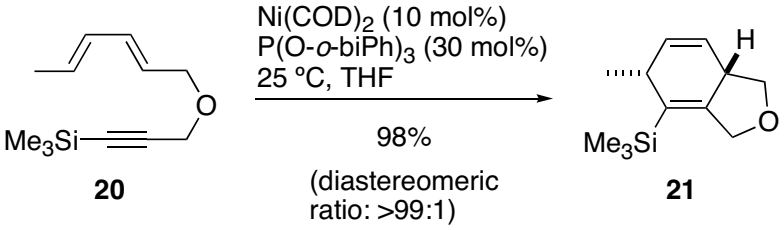
Scheme 3. Fe-catalyzed intermolecular [4 + 2] cycloadditions.

The cationic rhodium(I) complex, $[Rh(COD)(dppb)]^+$, in contrast to iron-based catalysts, catalyzed the [4 + 2] cycloadditions of terminal but not internal alkynes with dienes (Scheme 4).[52] Use of a rhodium catalyst with 2-substituted 1,3-butadienes and unactivated terminal acetylenes generated the *para* regioisomer. When R^1 = Me, conjugated 1,3-cyclohexadienes **18** were formed preferentially indicating that isomerization to the thermodynamically favored isomer occurred under these reaction conditions.

WENDER et al. studied the intramolecular variant of the dienyne DIELS-ALDER reaction and reported that nickel catalysts gave high yields of cycloadducts under mild conditions (Scheme 5). In contrast, thermal cycloadditions required prolonged heating at 80–200 °C. The diastereoselectivities reported range from modest to excellent (1.2:1 to >99:1).[51]

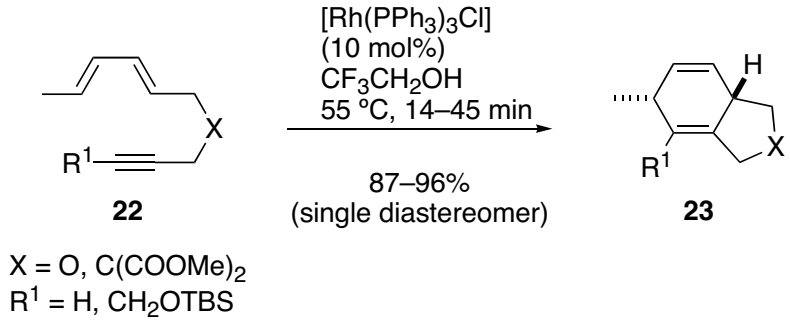


Scheme 4. A Rh-catalyzed intermolecular [4 + 2] cycloaddition.



Scheme 5. A Ni-catalyzed intramolecular [4 + 2] cycloaddition by WENDER et al.

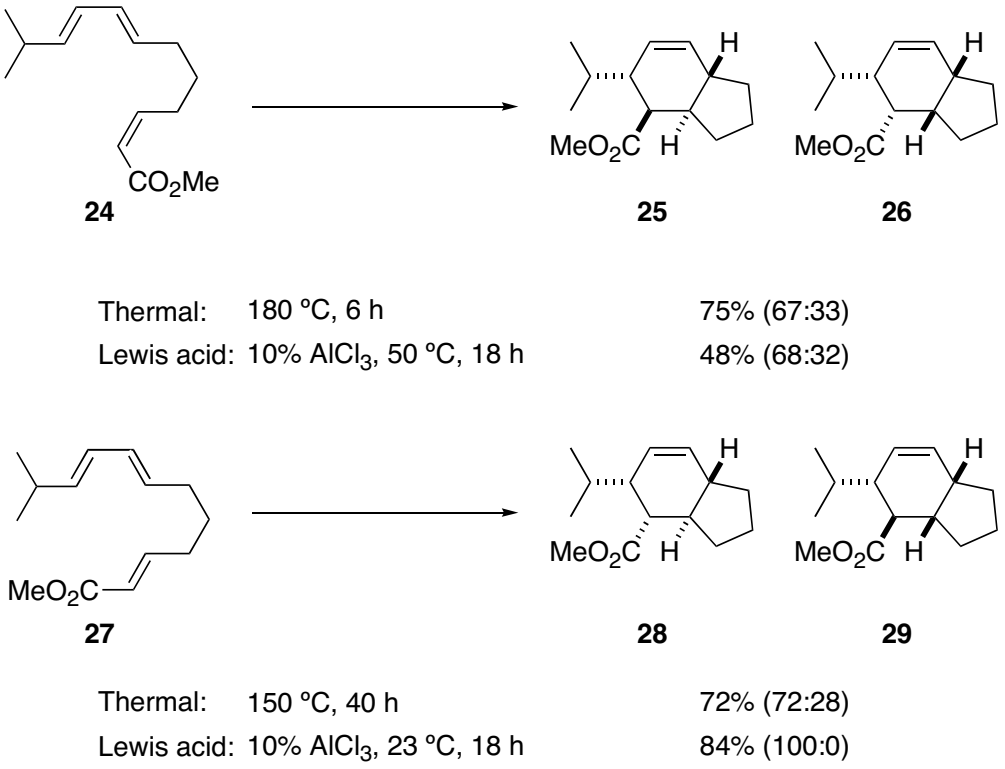
LIVINGHOUSE et al. recently observed the advantages of rhodium catalysts in intramolecular DIELS-ALDER reactions.[52] These cycloadditions are not confined to substrates bearing nonterminal alkynes as [4 + 2] addends. Terminal alkynes and, even more important, unactivated alkenes readily participate in the cycloadditions to provide the corresponding bicyclic products in good to excellent yields (Scheme 6).



Scheme 6. Rh-catalyzed intramolecular [4 + 2] cycloadditions by LIVINGHOUSE et al.

In addition, Rh(I)-catalyzed cycloadditions are highly diastereoselective giving a

single cycloadduct in each case. By way of comparison, non-catalyzed intramolecular [4 + 2] cycloadditions of activated alkenes proceed at a much higher temperature to afford the cycloadducts in moderate yield with low selectivity (Scheme 7).[55] LEWIS acid-catalysts can only be used when an activating group is present in which case the yields and the selectivities are highly dependent on the geometry of the alkene.[55]

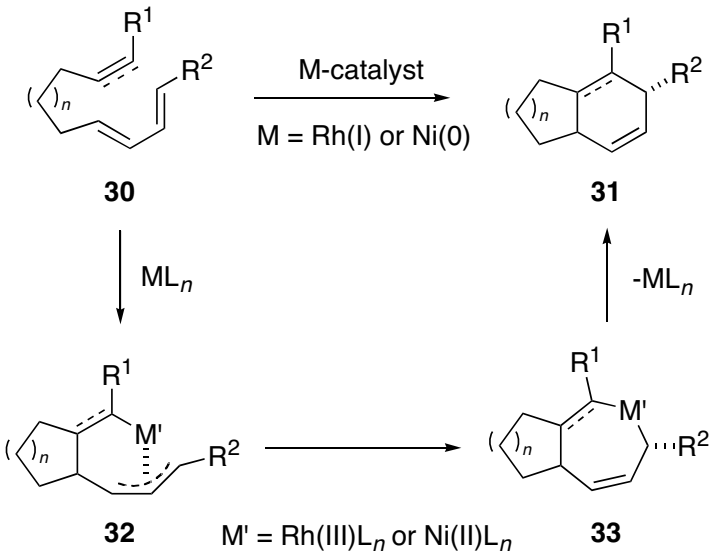


Scheme 7. Differences in the LEWIS acid-catalyzed and the thermal intramolecular [4 + 2] cycloaddition.

The mechanism of the intramolecular formal cycloadditions is presumed to follow a similar pathway for Rh(I)- and Ni(0)-catalysis (Scheme 8), which is related to the intermolecular process outlined in Scheme 2.[51,52]

Carbocyclization with concomitant oxidative addition would form an η^1,η^3-complex **32** [Rh(I) to Rh(III) and Ni(0) to Ni(II)], which would be followed by the formation of metallacycle **33**. Reductive elimination yields the corresponding cycloadduct **31** with regeneration of the active catalyst.

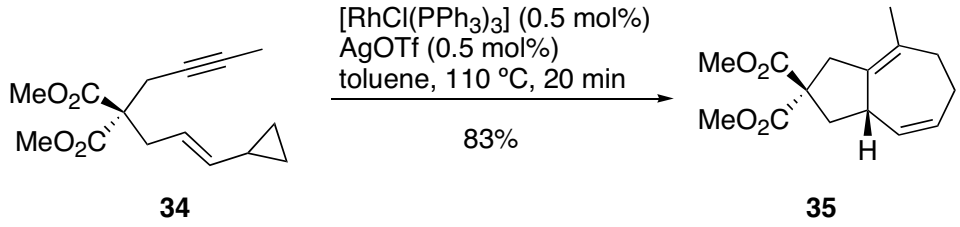
As outlined above, transition metal-catalyzed formal [4 + 2] cycloadditions are emerging as synthetically useful processes. For these obvious reasons, there has been no



Scheme 8. Mechanism for the Rh- or Ni-catalyzed formal intramolecular [4 + 2] cycloaddition.

shortage of attempts to develop homologous variants of this reaction and to extend the range of its application to the synthesis of seven-membered rings, a repeating feature in many important biologically active natural products.

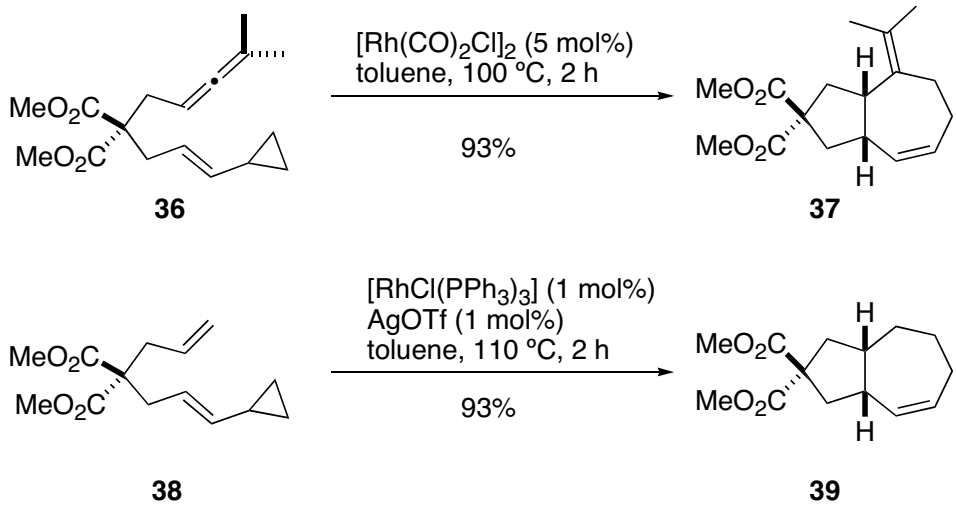
The first transition metal-catalyzed formal [5 + 2] cycloaddition reaction was published by WENDER et al.: A vinylcyclopropane reacts in analogy to a diene with an alkyne, tethered by a malonate or an ether.[56–58] The transformation is accomplished with WILKINSON's catalyst ([$Rh(PPh_3)_3Cl$]) and a silver salt (AgOTf) as additive (Scheme 9).



Scheme 9. An intramolecular formal [5 + 2] cycloaddition of a vinylcyclopropane to an alkyne.

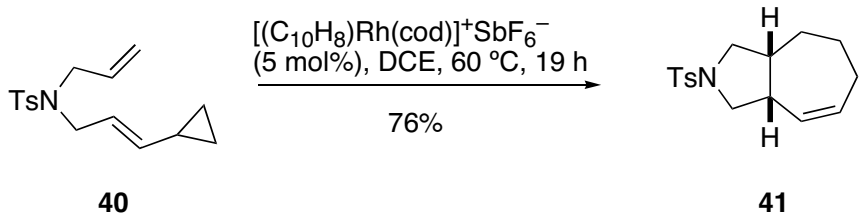
In the following years, WENDER et al. expanded the range of substrates adn found that besides alkynes, alkenes and allenes also react in excellent yields (Scheme 10). In

some cases it was necessary to modify the catalytic system. For specific precursors, $[Rh(CO)_2Cl]_2$ enhances the reactivity and catalyzes reactions which can't be done with WILKINSON's catalyst.[59–64]



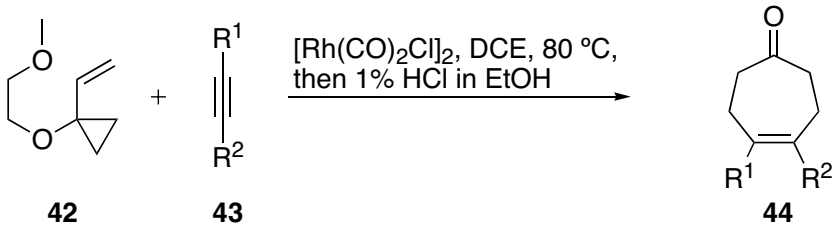
Scheme 10. Intramolecular formal $[5+2]$ cycloadditions of vinylcyclopropanes to alkenes and allenes.

Another enhancement in scope and yield was made by introducing a new catalyst, $[(C_{10}H_8)Rh(cod)]^+SbF_6^-$ (Scheme 11). Reaction times were greatly shortened, isomerization of the double bond was decreased and less side products were formed.[65]



Scheme 11. $[(C_{10}H_8)Rh(cod)]^+$ complexes as catalyst for the $[5+2]$ cocyclization reaction.

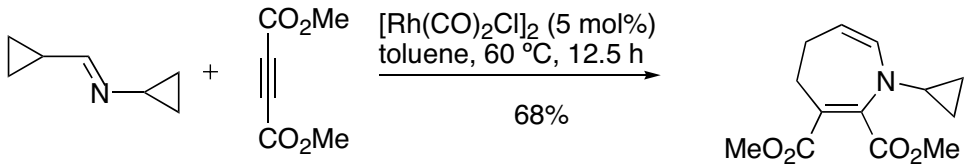
While the preassembly of the alkyne, alkene or allene moiety and the vinylcyclopropane within the intramolecular $[5+2]$ cocyclization reaction is advantageous, the syntheses of the precursors are sometimes complex and time consuming. Efforts were made to design an intermolecular version in which case vinylcyclopropanes were brought to reaction with a variety of alkynes. Crucial for good reactivity is a substituent in the 1-position at the vinylcyclopropane (Scheme 12).[66–68]



42 **43** **44**

Scheme 12. The intermolecular [5 + 2] cocyclization reaction.

Recently, a new heteroatom version of the intermolecular [5 + 2] cocyclization reaction was achieved. In addition of using cyclopropylaldimines directly, the imines can be prepared *in situ* from the corresponding aldehyde. The yields are good to excellent. Interestingly a cyclopropyl ring directly attached to the nitrogen remains untouched under the reaction conditions.(Scheme 13)[69]



45 **46** **47**

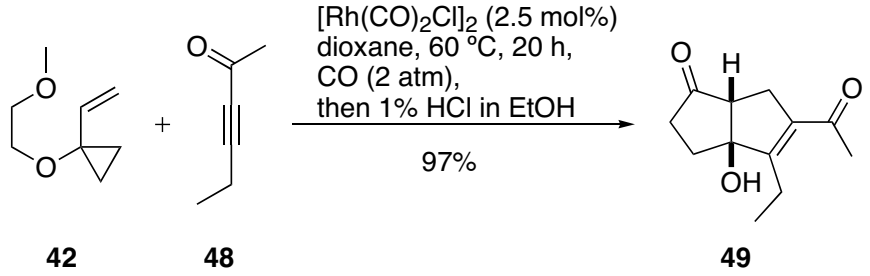
Scheme 13. [5 + 2] Cocyclization of a cyclopropylaldimine and alkyne **46**.

A further variation of the intermolecular [5 + 2] cocyclization reaction was achieved by the discovery that CO can be incorporated in the product by running the reaction under an atmosphere of CO. Starting from this result a [5 + 2 + 1] cocyclization reaction was designed in which a vinylcyclopropane reacts with an alkyne under a CO atmosphere (Scheme 14). The yields are generally very good, but carbonyl-substituted alkynes only are required for the reaction.[70]

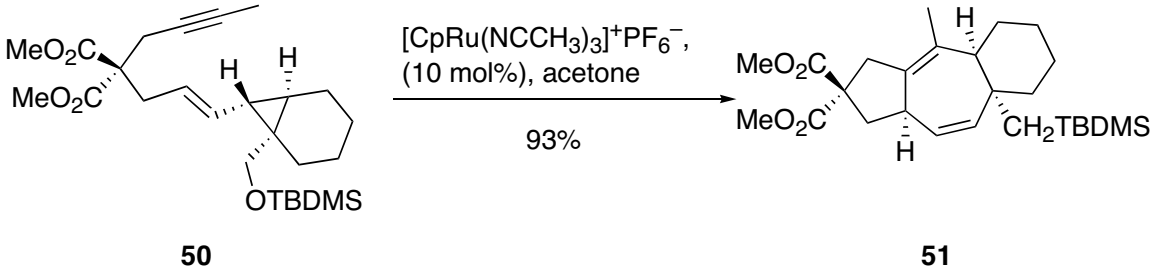
Trost et al. demonstrated that ruthenium is an active catalyst in the intramolecular formal [5 + 2] cycloaddition reactions. $[CpRh(MeCN)_3]^+PF_6^-$ catalyzes the reaction of a variety of vinylcyclopropanes with a tethered alkyne. The power of the reaction is impressively shown in the construction of tricyclic compounds (Scheme 15).[71–73]

The full range of [5 + 2] cocyclization reactionshas been extensively reviewed.[74, 75].

The transition metal-catalyzed formal [5 + 2] cycloaddition without doubt reveals



Scheme 14. A three-component $[5+2+1]$ cocyclization reaction.

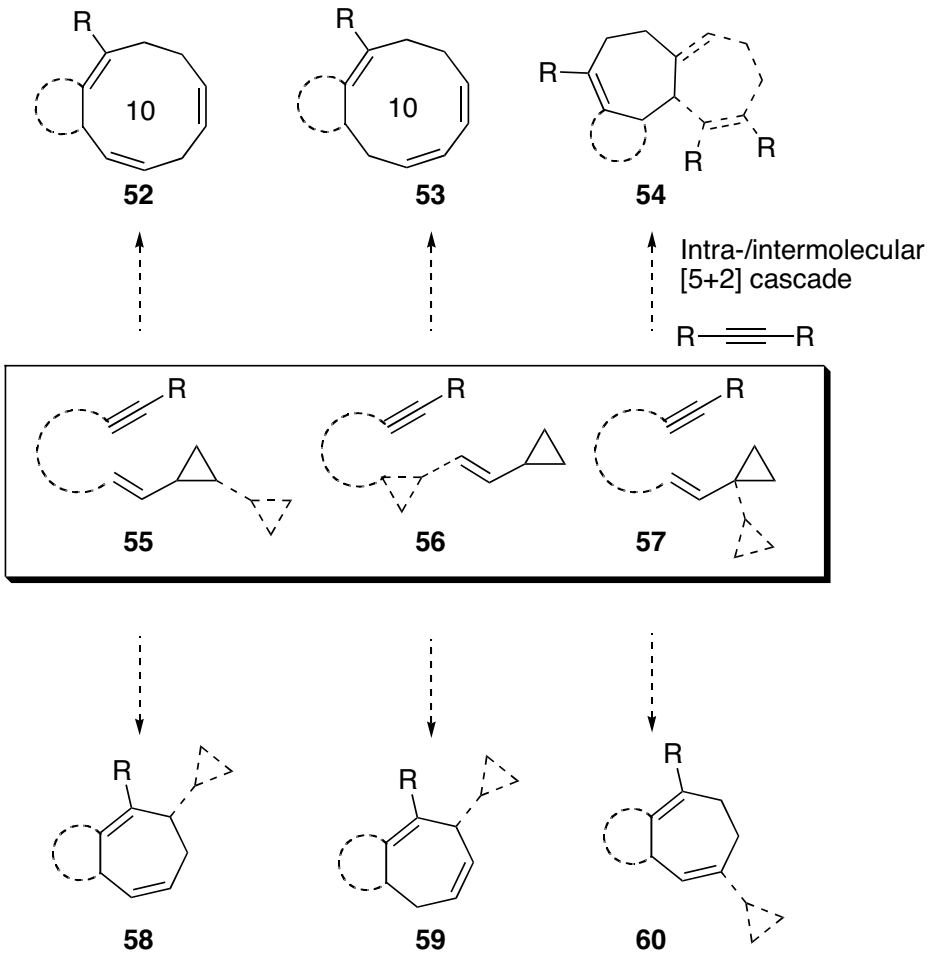


Scheme 15. Ru-catalyzed intramolecular cycloaddition of cyclopropylenyne.

a powerful method for the construction of seven-membered rings by connecting one two- and one five-carbon unit – the latter being a vinylcyclopropane moiety. An interesting modification would be the introduction of a second cyclopropyl group adjacent to the vinylcyclopropane unit. There is a variety of options to attach another cyclopropane moiety onto the vinylcyclopropane: At the 2- or 1-position (**55** or **57**) of the cyclopropyl group or at the vinyl portion of the vinylcyclopropane system **56**.

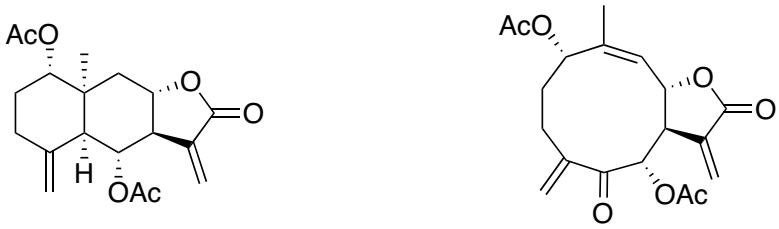
There are two possible outcomes for the reaction of these precursors: After insertion into the vinylcyclopropane a ring-enlargement to a ten-membered ring (**52** and **53**) could occur. This pathway is only possible for precursors like **55** and **56**, because the second cyclopropyl group in **57** is not in the position for an insertion of the carbon-metal bond. For this precursor the resulting cycloheptadiene **60** could react in a subsequent intermolecular $[5+2]$ cocyclization with another alkyne. The second possibility after insertion of the catalyst into the vinylcyclopropane is a reductive elimination, which would conserve the second cyclopropane ring (**58**, **59** and **60**).

The outcome of these experiments would give new insights into the mechanism of this type of cocyclization. Furthermore, both results would give a new elegant entry into structurally and pharmacologically interesting molecules. There are only few



Scheme 16. A new generation of precursors.

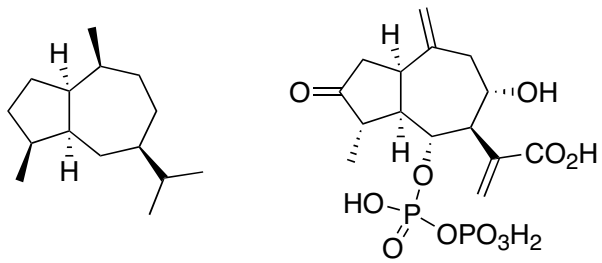
methods to build up ten-membered rings – metathesis[76] or palladium[77,78] catalyzed coupling reactions to name two of the most important. For example, elaganolactone A **61** and elaganolactone B **62** were recently isolated from the genus *Gonospermum elegans*, which is endemic to the Canary Islands. It was found that compounds **61** and **62** inhibited the growth of HL-60 promyelocytic leukemia cells in culture by apoptosis activation. Treatment of HL-60 cells with compounds **61** and **62** induced morphological changes and internucleosomal DNA fragmentation characteristic of apoptotic cell death. Interestingly, the ten-membered compound **62** is at least one order of magnitude more potent than **61**. This underlines the exceptional properties of this kind of macrocycles.[79]



61 **62**

Scheme 17. Elaganolactone A **61** and elaganolactone B **62** as examples for a biologically active compound containing a ten-membered ring.

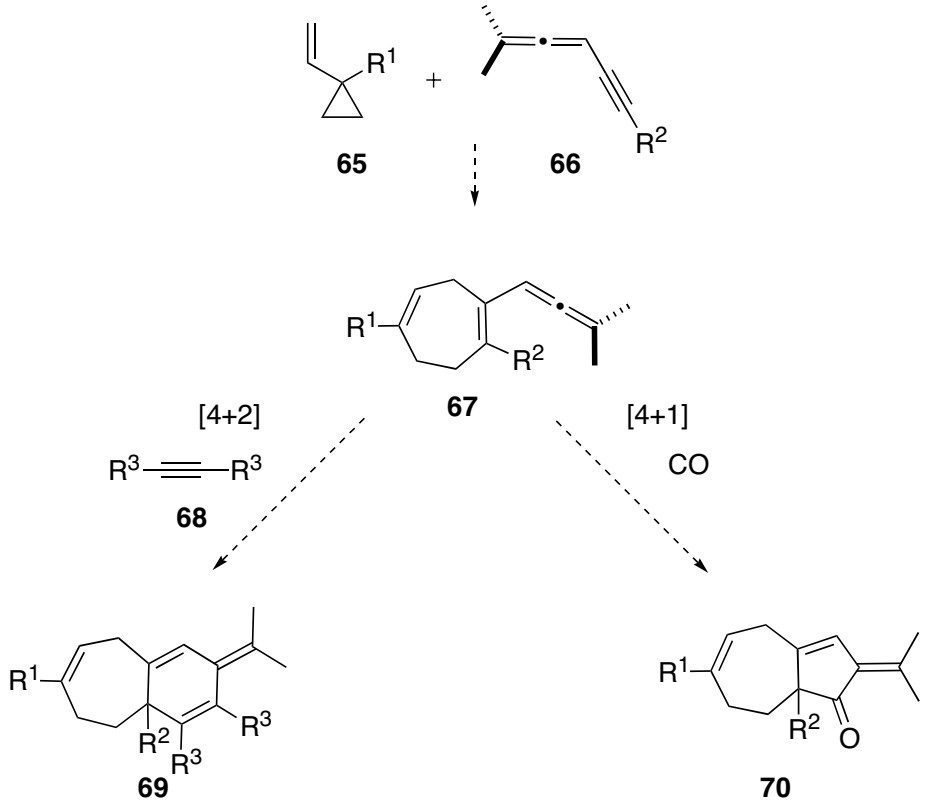
Bicyclic ring systems containing a seven-membered ring are also a structural feature in a variety of biologically active compounds. Compounds like **58**, **59** or **60** would be analogous to substances that are patented for life threatening diseases like AIDS (**63**)[80] or cancer (**64**).[81]



63 **64**

Scheme 18. Examples for pharmacologically active compounds with a bicyclo[5.3.0]decane skeleton.

In contrast to the vinylcyclopropane moiety, the 2-carbon component in the [5 + 2] cocyclization has been a subject of intensive research activities. As outlined previously apart from alkynes, allenes and alkenes can also be reacted, but only *intra*molecularly. Another focus of this thesis has been put in the variation of the 2-carbon building block. Employing alleneynes would open the opportunity to introduce a handle for further transformations. A [4 + 2] cycloaddition with another dienophile or a [4 + 1] cycloaddition reaction under an atmosphere of CO might succeed the first [5 + 2] cocyclization.



Scheme 19. A [5 + 2] cocyclization with alleneynes introducing a handle for further transformations.

The goals for this work can be summarized as follows:

- To develop of a synthesic access to a new generation of precursors for $[5+2]$ and $[5+2+3]$ cocyclizations, respectively.
- To testthe new generation of precursors under different cocyclization conditions (catalyst, solvent, temperature, additives).
- To apply of alleneynes in *inter*molecular $[5+2]$ cocyclizations.
- To explore further transformations of the potential products of the $[5+2]$ and $[5+2+1]$ cocyclizations.

B. Main Part

1. Exploration of the Rh-catalyzed intramolecular [5 + 2] Cocyclization of Vinylbicyclopropyls

In the introduction the formal [5 + 2] cycloaddition reaction was introduced as a very effective method for the construction of seven-membered rings. Alkynes, alkenes and allenes as well as heteroatoms are integrable in this powerful synthetic tool both, intramolecular and intermolecular.ed ring.

Starting from the mechanistic proposal by WENDER et al.[56] two mechanistic pathways are feasible:

A Firstly, formation of a metallacyclopentene; Insertion into the first cyclopropane ring, followed by the opening of the second cyclopropane ring.

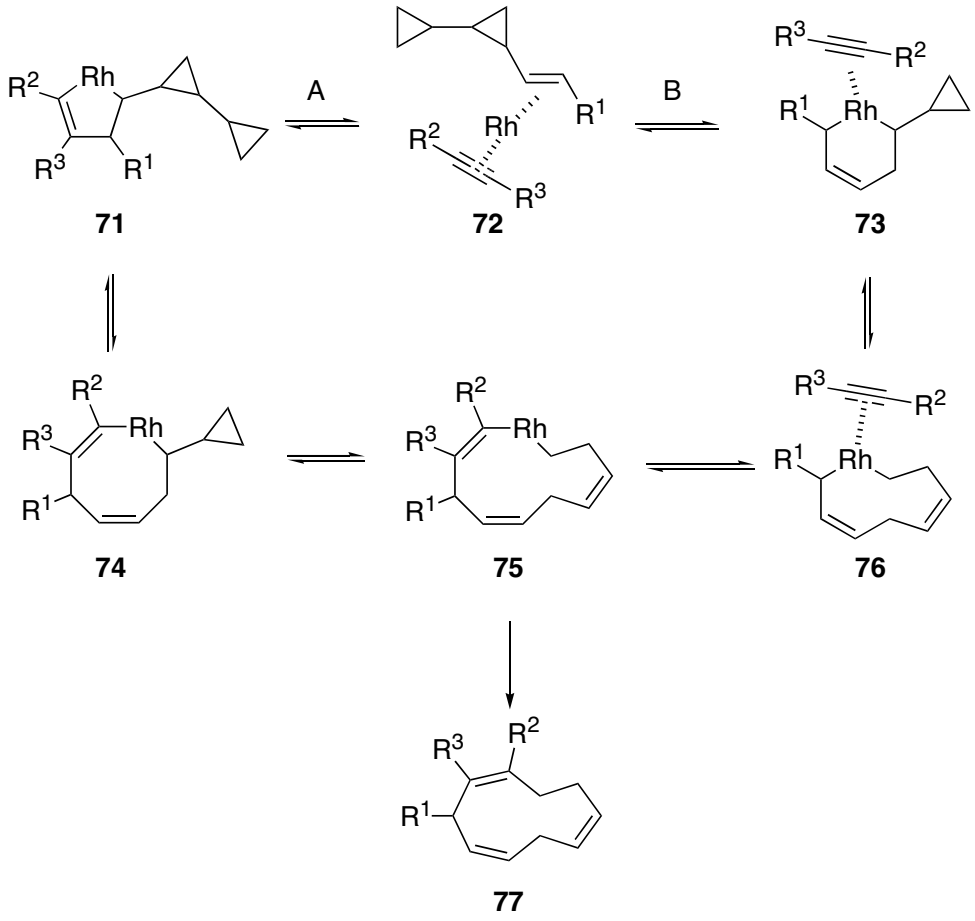
B Secondly, formation of a metallacyclohexene; Insertion into the second cyclopropane ring and insertion of the alkyne.

Finally, reductive elimination leads to the desired product.

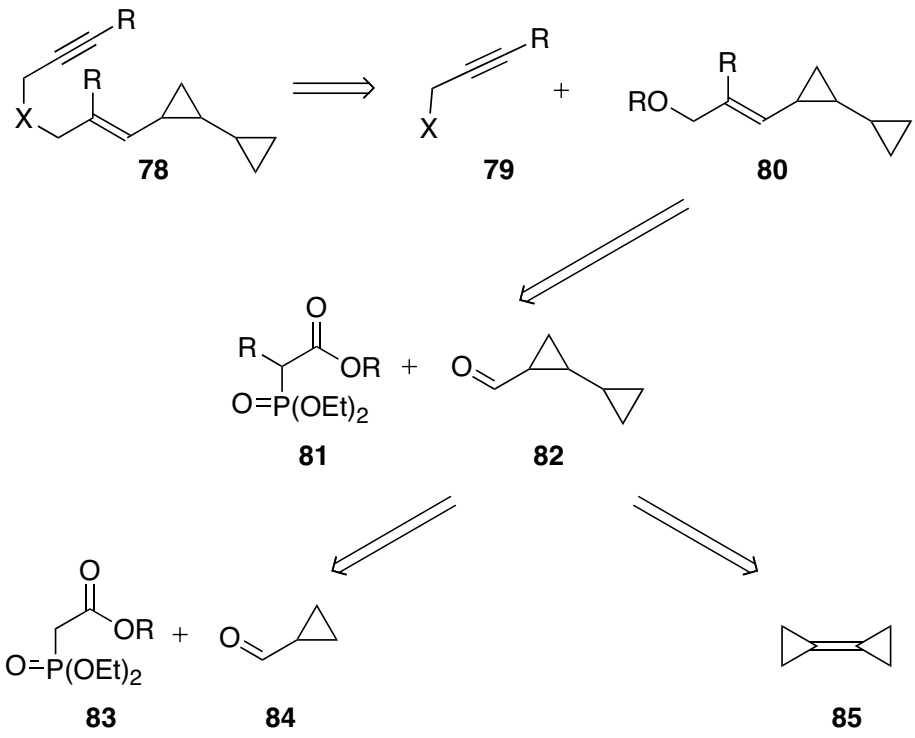
This hypothesis can be verified through the synthesis of a precursor and its cyclization. Apart from the development of a new method for the preparation of a ten-membered ring, this work will give new insights into the formal [5 + 2] cycloaddition reaction and answer open mechanistic questions.

1.1. The 1st-generation-precursor

The synthesis of the precursor can be devided into two parts, the build-up of the bicyclopropyl unit and the subsequent assembly of the whole precursor. Although, the bicyclopropyl moiety can be derived from bicyclopopylidene (BCP) (**85**) there are also other strategies, that construct the three membered rings one after the other.



Scheme 20. Extension of the [5 + 2] to a ([5 + 2]+3) cocyclization reaction.

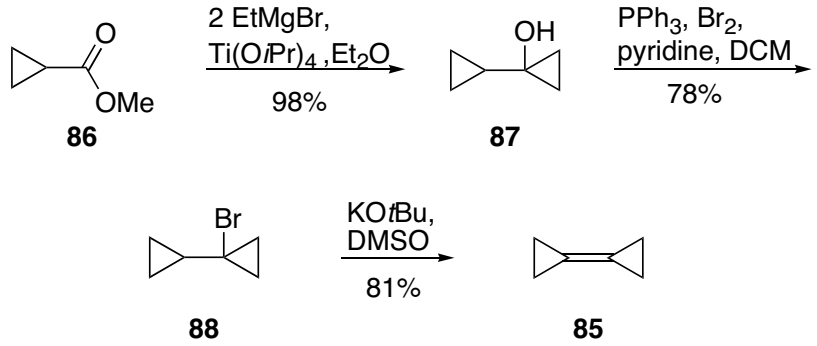


Scheme 21. Retro-synthetic analysis of the 1st-generation-precursor.

1.1.1. Synthesis of the bicyclopropylunit

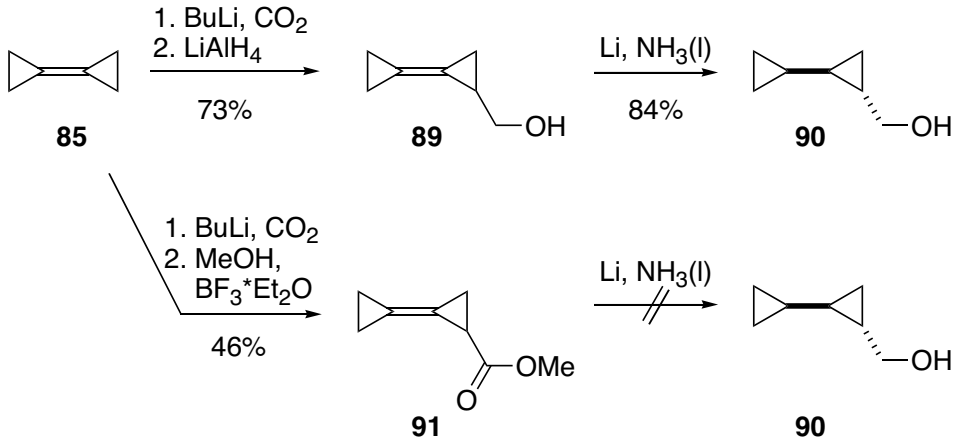
1.1.1.1. Bicyclopropylidene as starting material Functionalization of BCP is established in the group of DE MEIJERE in many different ways. Therefore, BCP seemed to be a good starting material to build up the bicyclopropyl unit.

BCP was made according to a protocol developed by DE MEIJERE et al.,[82] as outlined in Scheme 22.



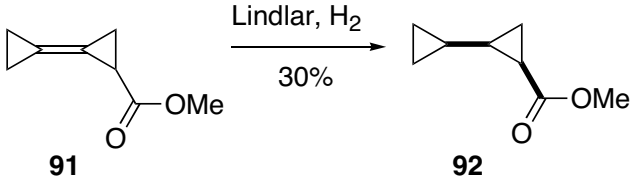
Scheme 22. Synthesis of BCP.

Lithiation of BCP **85**, followed by quenching with CO_2 produced the carboxylic acid. It is known that reduction of the carboxylic acid under BIRCH conditions yields a mixture of diastereomers in a ratio of 3:1.[83] Thus, the carboxylic acid was immediatly reduced to the alcohol **89** with $LiAlH_4$.[125] BIRCH reduction then selectively resulted in *trans*-bicyclopropyl-2-yl-methanol (**90**) in 84% yield (Scheme 23). Attempts to reduce the bicyclopropylidene methyl ester (**91**) in the same way failed and lead to decomposition, probably caused by a mechanism similar to a BOUVEAULT-BLANC procedure (Na in EtOH), which was used for the reduction of esters before the discovery of $LiAlH_4$.[84]



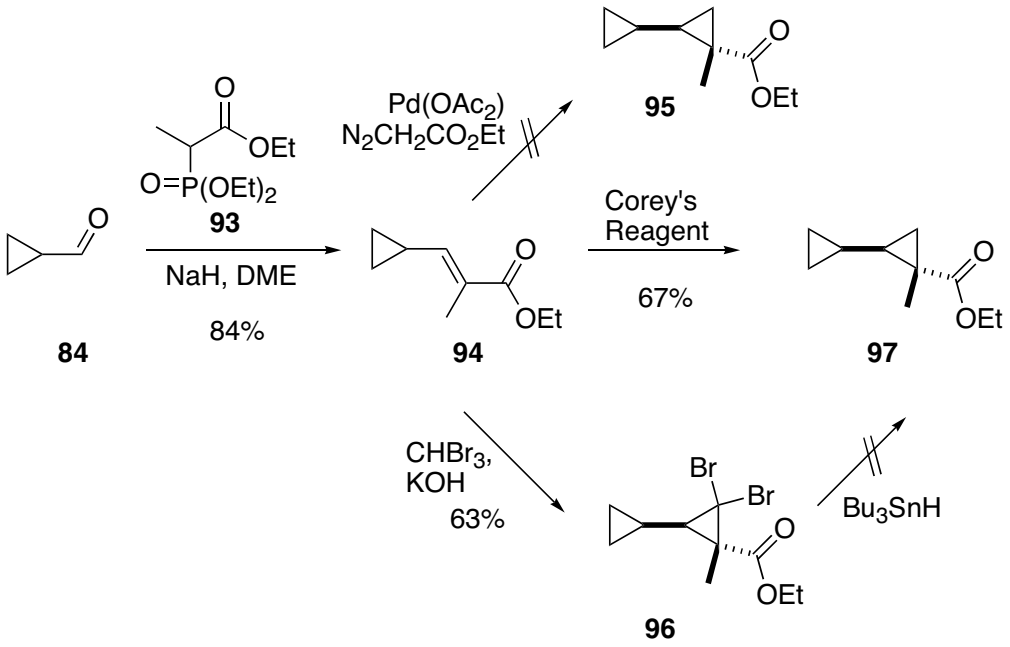
Scheme 23. Carbonylation and reduction of BCP under BIRCH conditions.

Reducing the substituted BCP under LINDLAR hydrogenation conditions should furnish the *cis*-isomer.[83] However, applying this protocol to bicyclopropyl-2-carboxylic acid methyl ester (**91**) showed only a very slow reaction. Even after three weeks only 30% of the material was converted to the desired product, which was not separable from the starting material by column chromatography. Also, the reaction was done on a mmol scale, which made this strategy very impractical.



Scheme 24. Reduction of substituted BCP **91** under LINDLAR conditions.

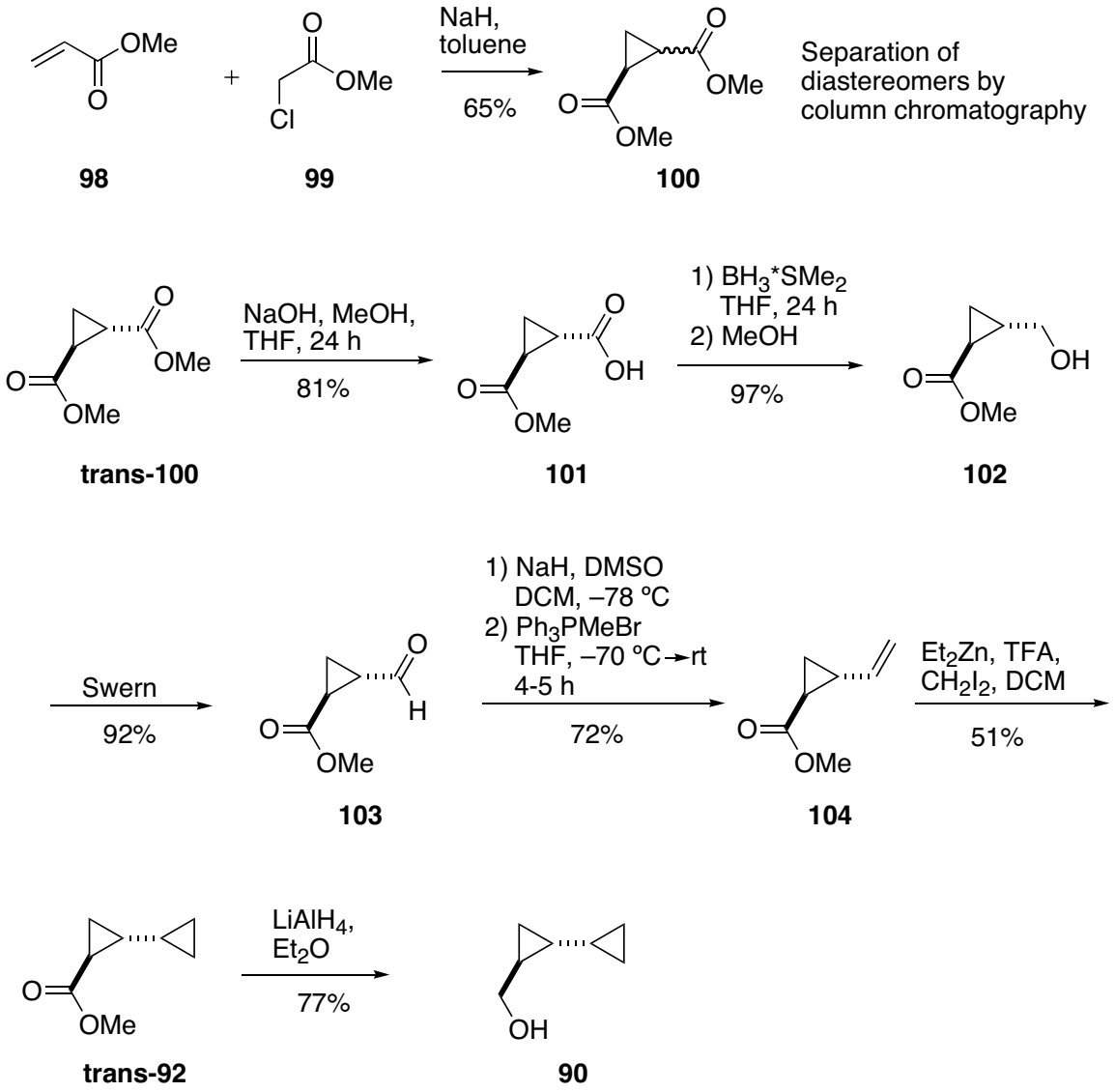
1.1.1.2. Preparation by Cyclopropanation of Vinylcyclopropanes Another approach started from vinylcyclopropanederivatives: The HORNER-WADSWORTH-EMMONS reaction of cyclopropyl carboxaldehyde (**84**) lead to the 3-cyclopropylacrylic acid methyl ester (**94**). COREY's reagent ($(CH_3)_3SO^+I^-$) turned out to be the method of choice for the cyclopropanation.[85] Palladium and diazomethane didn't react at all. Dibromomethane with KOH gave the desired dibromocyclopropane **96**, but replacing the bromine atoms didn't work in the desired fashion either.



Scheme 25. Synthesis starting from cyclopropylcarboxaldehyde (**84**).

Vinylcyclopropanes are also accessible starting from chloro-acetic acid methyl ester (**99**) with acrylic acid methyl ester (**98**). The *cis*- and *trans*-isomer of the resulting cyclopropane derivative **100** are separable by column chromatography and the diester **trans-100** can be selectively reduced at one esterfunctionality. Transformation of **102** by SWERN oxidation and WITTIG olefination, followed by cyclopropanation with diazomethane catalyzed by palladium gave the desired bicyclopropylester **trans-92**, which is readily reduced to the alcohol **90** with $LiAlH_4$.[127]

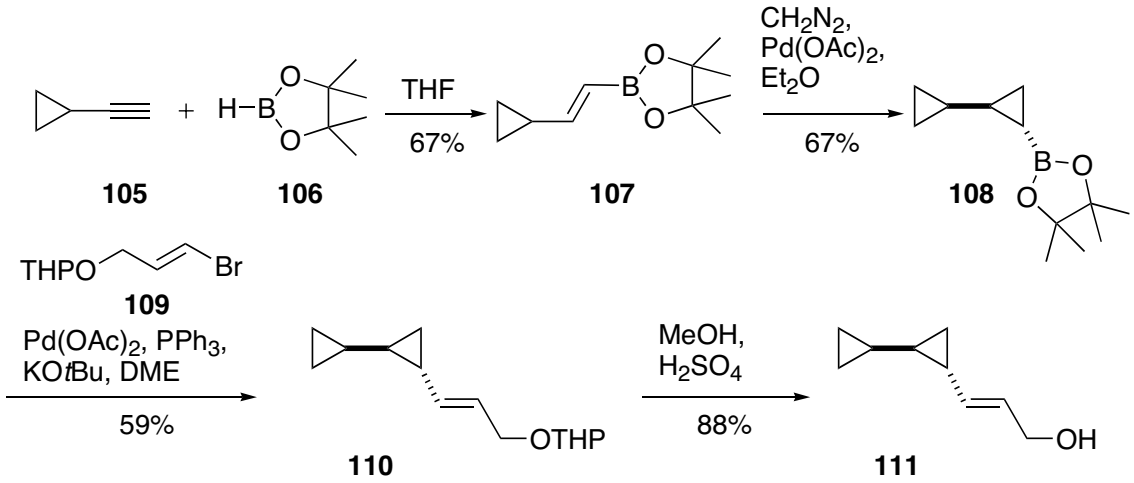
This route has the advantage that both isomers are easily available. Furthermore, the reactions can entirely be run on a big scale (mol) (Scheme 26).



Scheme 26. Synthesis starting from chloro-acetic acid methyl ester (**99**) and acrylic acid methyl ester (**98**).

1.1.1.3. Preparation by SUZUKI-coupling of bicyclopropylboronic acid A third strategy was established to build up the bicyclopropylunit. Cyclopropylacetylene (**105**), in large quantities available as a 50% solution in toluene, can be brought to reaction with pinacolborane (**106**) or catechol borane. The cyclopropylvinylboronic ester **107** can distereoselectively be cyclopropanated with diazomethane and $Pd(OAc)_2$.[86]

The vinylportion for the precursor can be attached to 2-(3-bromoallyloxy)tetrahydropyran (**109**) by SUZUKI-coupling.[127] Deprotection yielded the desired alcohol **111**, which can now be connected to a tether to complete the synthesis of the 1st-generation-precursor (Scheme 27).

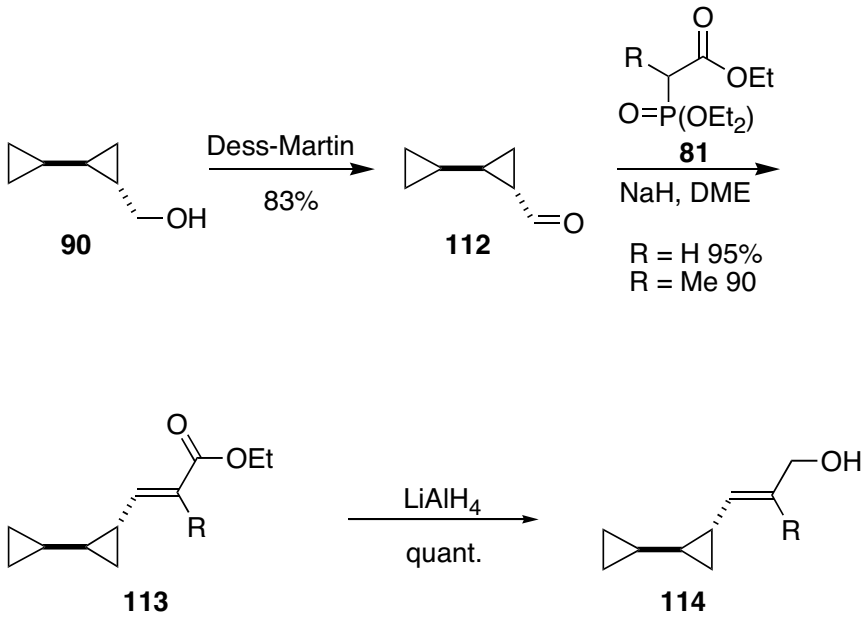


Scheme 27. Synthesis of the 1st-generation-precursor by SUZUKI-coupling.

This route using a SUZUKI-coupling exhibits the shortest way to prepare the alcohol **111** from commercial available starting materials. The desired molecule **111** is build up in only four linear steps.

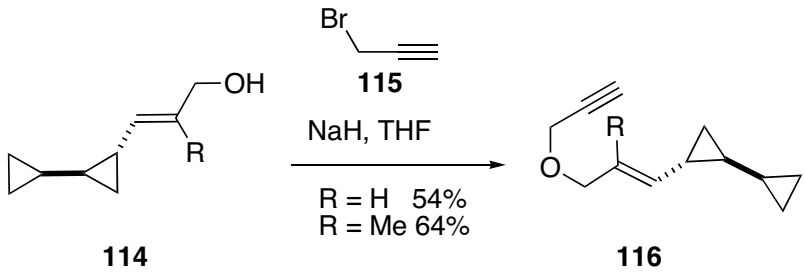
1.1.2. Assembly of the whole precursor

After setting up the bicyclopropyl unit it needs to be connected to the rest of a precursor for an intramolecular cocyclization. *trans*-Bicyclopropyl-2-yl-methanol (**90**) was oxidized by SWERN- or DESS-MARTIN oxidation to the aldehyde **112**, which was subsequently reacted by HORNER-WADSWORTH-EMMONS reaction to 3-bicyclopropyl-2-yl-acrylic acid ethyl ester (**113**). Reduction with $LiAlH_4$ or DiBAlH gave the desired alcohol **114**, which is now ready to be coupled to the desired precursor.



Scheme 28. Connection of the bicyclopropylunit to the vinylmoiety.

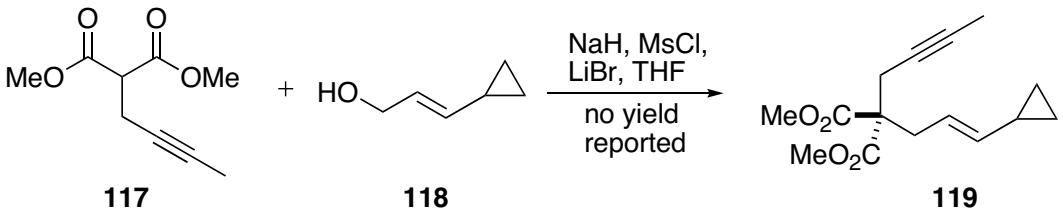
1.1.2.1. Etherbridged precursor Deprotonation of alcohol **114** with NaH followed by treatment with bromid **115** produced the etherbridged precursor (Scheme 29).



Scheme 29. Assembly of an etherbridged precursor.

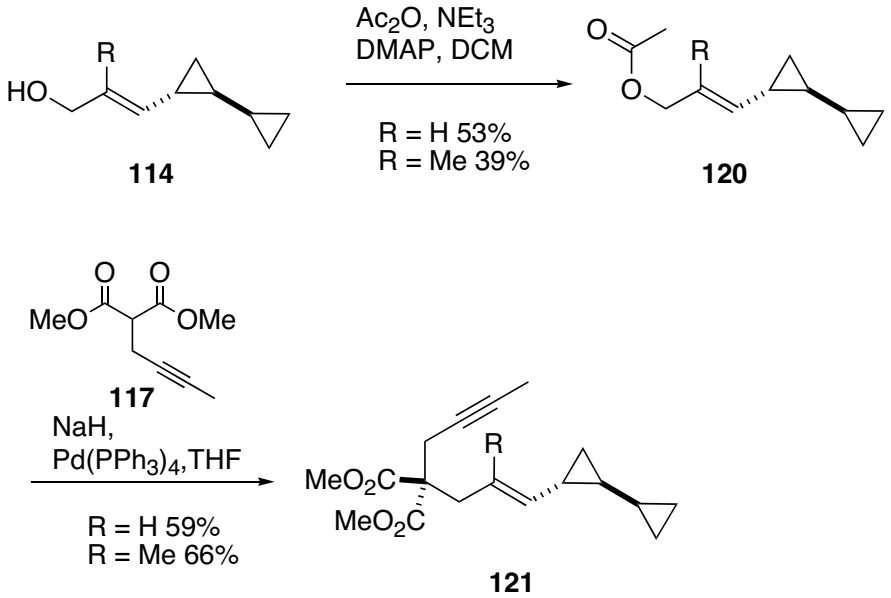
1.1.2.2. Malonate derived Precursor WENDER et al. prepared their precursors by converting the alcohol **118** to the corresponding mesylate, which was *in situ* transformed to a bromid and then coupled with the malonate **117** (Scheme 30).[56]

With the bicyclopropyl-2-yl-methanol (**114**) ring-opening probably occured under these conditions. Therefore, the coupling was undertaken relying on a procedure published by TROST et al.[88] Using this method precursors **121** were prepared in 26–31%



Scheme 30. Assembly of a malonate tethered precursor by WENDER et al.

yield from the allylic alcohol. Unfortunately, this strategy requires the preparation of the acetate, which adds an additional step.



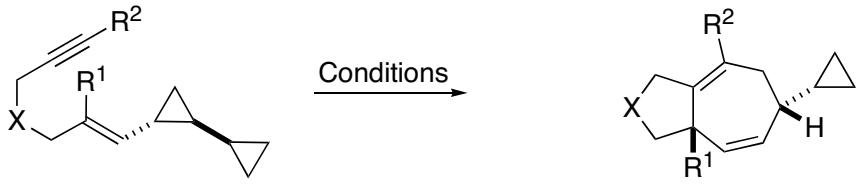
Scheme 31. Pd-catalysed assembly of a malonate tethered precursor.

1.1.3. Attempts of cyclization

After preparing the precursors first attempts of cyclization were undertaken under standard conditions .

1.1.3.1. Different Rh-catalysts and different solvents The first published intramolecular $[5+2]$ cyclizations were performed with WILKINSON's catalyst and silver triflate at 110 °C in toluene. Applying these conditions to the precursor **116-H** gave

Table 1. Overview of cyclization attempts I.

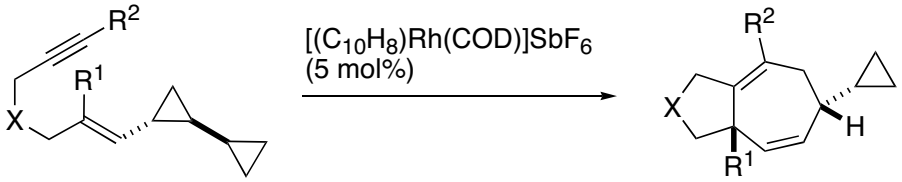


116-H/Me
121-H/Me

R^1 = H, R^2 = H, X = O **122**
R^1 = H, R^2 = Me, X = $C(CO_2Me)_2$ **123**

Entry	R^1	R^2	X	Catalyst	Solvent	Temp. (°C)	Time (h)	Result
1	H	H	O	$RhCl(PPh_3)_3$ (10 mol%), AgOTf (10 mol%)	Toluene	110	0.3	7%, Rest decomposition
2	Me	H	O	$RhCl(PPh_3)_3$ (1 mol%), AgOTf (1 mol%)	THF	60	18	Starting material + decomposition
3	Me	H	O	$RhCl(PPh_3)_3$ (10 mol%), AgOTf (10 mol%)	THF	60	18	Complex mixture, cyclopropaner-ing still there (NMR)
4	Me	H	O	$RhCl(PPh_3)_3$ (10 mol%), AgOTf (10 mol%)	Toluene	110	18	Complex mixture, cyclopropaner-ing still there (NMR)
5	Me	H	O	$[Rh(CO)_2Cl]_2$ (10 mol%)	DCE	80	3	Complex mixture, cyclopropaner-ing still there (NMR)
6	H	Me	$C(CO_2Me)_2$	$[Rh(CO)_2Cl]_2$ (5 mol%)	TFE-d_6	80	0.25	Quant. by NMR

Table 2. Overview of cyclization attempts II.



116-H/Me
121-H/Me

R^1 = H, R^2 = H, X = O **122**
R^1 = H, R^2 = Me, X = $C(CO_2Me)_2$ **123**

Entry	R^1	R^2	X	solvent	Temp. (°C)	Time (h)	Result
7	H	H	O	DCE	rt	24	90%
8	Me	H	O	DCE	rt	24	Different product 80%
9	H	Me	$C(CO_2Me)_2$	DCE	rt	1	67%
10	Me	Me	$C(CO_2Me)_2$	DCE	60	24	Starting material

the [5 + 2] adduct only. There was no insertion into the second cyclopropanering observed (entry 1, Table 2). In precursor **116-Me** a methyl substituent was introduced to rigidify the system. The analogous [5 + 2] precursor could be cyclized in excellent yield,[56] but applying the standard conditions (WILKINSON's catalyst/AgOTf) only resulted in a unseparable complex mixture, which showed the second cyclopropane ring still intact (NMR). Changing the solvent to THF, which is reported to work as good as toluene,[56] did not give the desired ten membered ring either (entry 2 and 3, Table 2). A second catalyst system as reported by WENDER et al.[59–64] – $[Rh(CO)_2Cl]_2$ in DCE – lead to the same outcome. They also reported that in some cases the Rh-dimer is not compatible to terminal alkynes, which was the case in both tested precursors.

The next step was to choose a malonate tether to ensure low volatility. Then, all substituents in the vinylcyclopropanepart were omitted and at last a methyl terminus was picked at the alkyne to avoid the problem described above. Applying the Rh-dimer in pure deuterated 2,2,2-trifluoroethanol (it behaves like a 5% TFA/DCE solvent mixture and the reaction could be followed by NMR) showed cleanly only the [5 + 2] adduct. This result could be verified by comparing the spectra with the analogous methyl substitued [5 + 2] precursor reported by WENDER et al.[58]

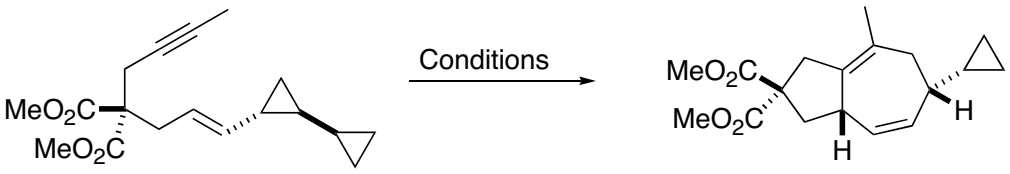
A similar result was observed using the $[(C_{10}H_8)Rh(COD)]SbF_6$ as catalyst.[65] Precursor **116-H** and **121-H** could cleanly be converted to the $[5+2]$ cycloadduct. In contrast **121-Me** showed no reaction, even at higher temperature. Precursor **116-Me** gave a product different from the expected $[5+2]$ cycloadduct.

1.1.3.2. Variation of the Metal of the catalyst $[5+2]$ cocyclizations are reported not only with rhodium as the catalytic active metal. TROST et al. published similar reactions with a ruthenium catalyst.[71–73]
Besides that, iridium[111,112] and palladium[89] are known to insert into cyclopropanes and to cyclize eneynes.[90]

Another transition metal which could be tested is nickel. It is successfully applied in cocyclizations, but is less common in opening cyclopropane rings.[91,92]

All results are summarized in Table 3. The same result as described for rhodium as catalyst was obtained with the conditions reported by TROST et al. for his $[5+2]$ reactions. Iridium and and palladium showed no reaction at all and only starting material was recovered.

Table 3. Overview of attempts of cyclizations with other metals.



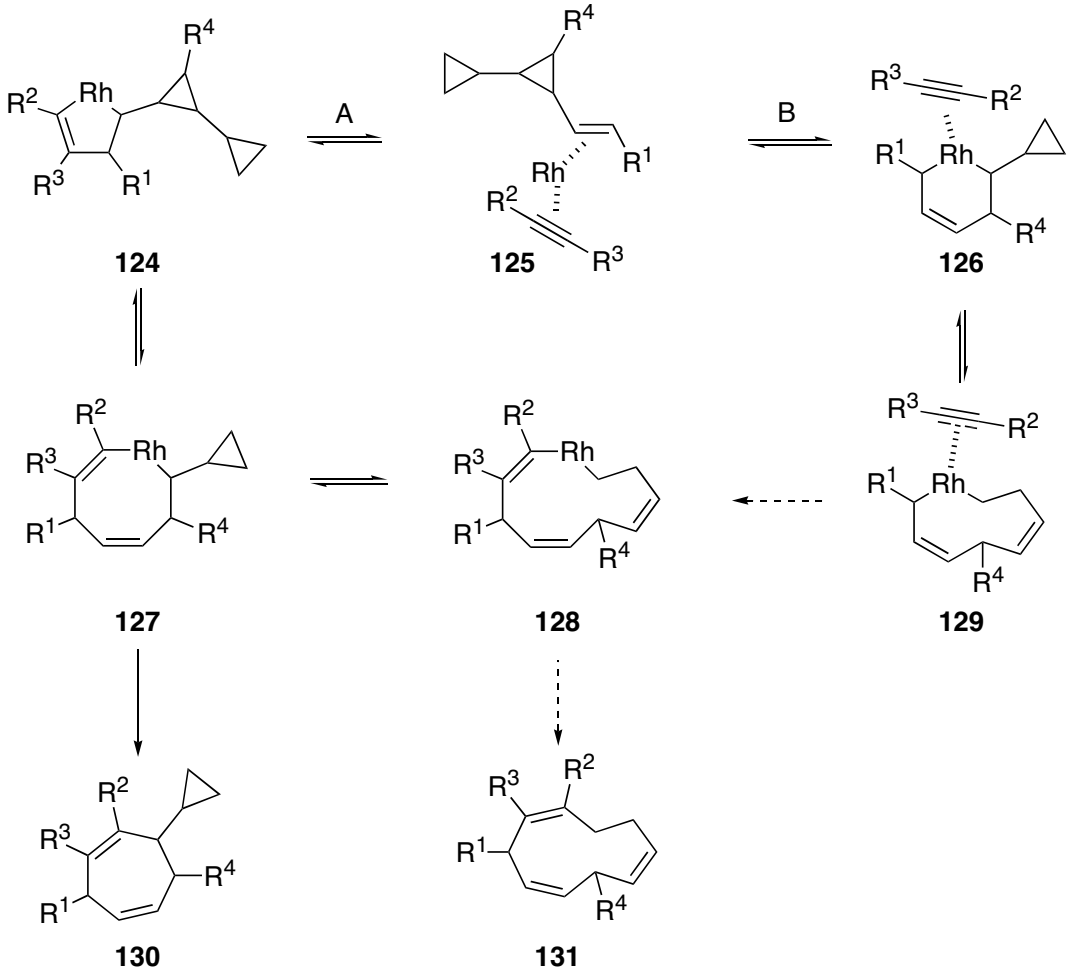
121-H **123**

Entry	Catalyst (5 mol%)	solvent	Temp. (°C)	Time (h)	Result
1	$[RuCp(CH_3CN)_3$	Acetone	rt	24	70% by GC/MS
2	$[Ir(CO)(PPh_3)_2]Cl$	Toluene	rt / 60	48	No reaction
3	$Pd(OAc)_2/PPh_3$	THF	rt / 60	48	No reaction

1.1.4. Rationalization of the results

As outlined in the introduction of this chapter, there are two mechanistic pathways which explain the formation of the $[5+2]$ cycloadduct. The first pathway which involves a metallacyclohexene and the second one incorporates the alkyne before the

opening of the cyclopropane by forming a metallacyclopentene. These two pathways can be transcribed to the proposed [5 + 2 + 3] cocyclization as outlined in Scheme 32. The critical step consists of the rearrangement of the cyclopropyl metallacyclooctadiene **127** to the metallacycloundecatriene **128** which then can undergo reductive elimination of the transition metal to the desired ten membered cycloadduct **131**. However, as only the formation of the seven membered ring **130** was observed it can therefore be concluded that the reductive elimination of the metallacyclooctadiene **127** is faster than the insertion into the second cyclopropanering.

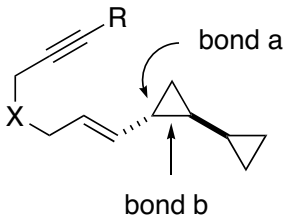


Scheme 32. Analysis along the catalytic cycle.

Another possibility to get a ringexpansion would be to modify the catalyst. Insertion into the cyclopropane ring should be easier for an electrondeficient metal, like $[Rh(CO)_2Cl]_2$ for example, which already is a rather electrondeficient rhodium

species. This could be another parameter to look further into.

However, this rationalization is only viable, if the 'right' bond – bond b – of the first cyclopropane ring is cleaved. If the metal inserts into bond a it is located in a 'homo-cyclopropylmethyl' position with respect to the second cyclopropane ring rendering a further insertion unfavorable.[94] By introducing a second cyclopropane ring, there are now two different cyclopropanebonds which might be cleaved. The design of a new precursor, a 2nd-generation-precursor, for a $[5+2+3]$ cocyclization should ensure the opening of the cyclopropyl bond which is adjacent to the second cyclopropyl ring (bond b).



Scheme 33. Desymmetration by introducing a second cyclopropane ring.

1.2. The 2nd-generation-precursor

1.2.1. Introduction

All arguments discussed above assumed that the higher substituted bond of the cyclopropanering was opened. WENDER et al. reported that in numerous cases in the formal [5 + 2] cycloaddition reaction of subsituted vinylcyclopropanes the less substituted bond is cleaved. However, in the case of an aldehyde, the major product results from cleaving the higher substituted bond.[57] This corresponds also to pyrolysis experiments and some other examples with substituted cyclopropanes, where always the higher substituted cyclopropyl bond is opened.[93]

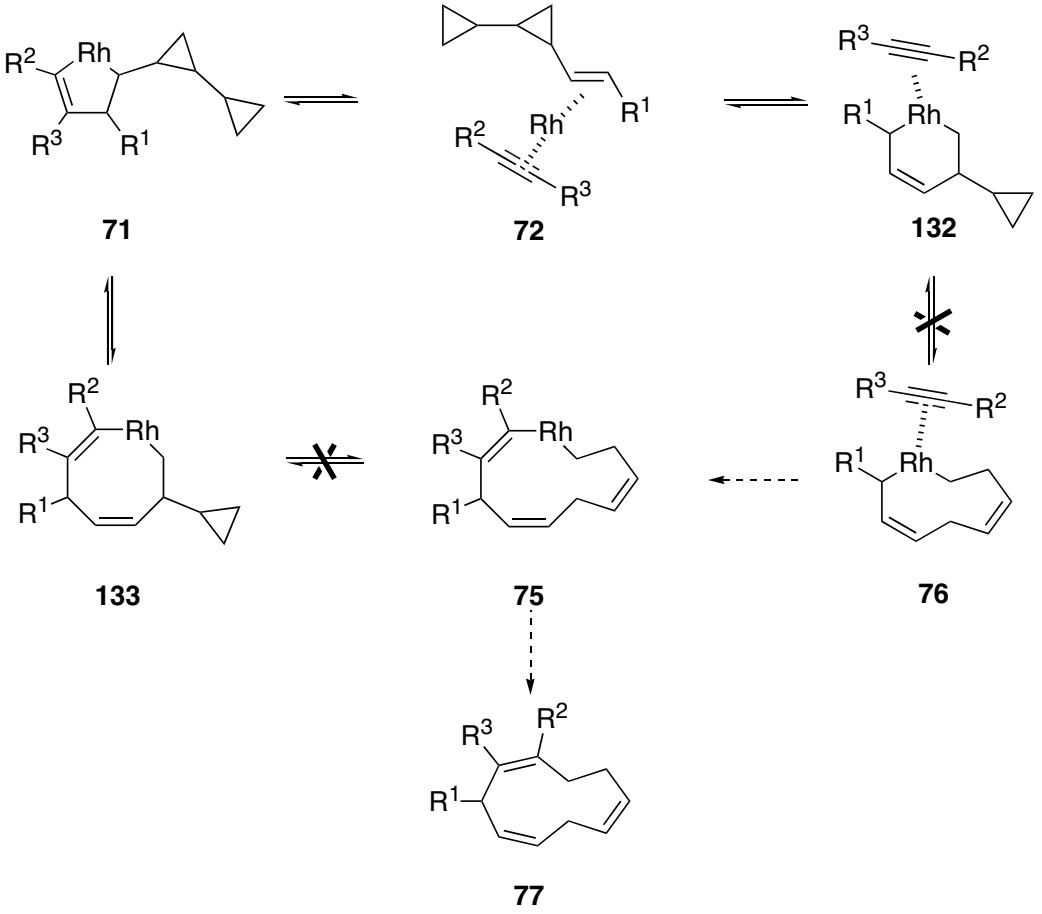
Redrawing the possible catalytic pathway under this assumption shows that a formation of a ten-membered cycle is very unlikely. In the metallacycloocadiene **133**, the metal is not in a cyclopropylmethyl position to the cyclopropane to ensure insertion. This would result in the [5 + 2] cycloadduct without the opening of the second cyclopropane ring and could also be validated by selectivity: Insertion into the less substituted cyclopropane bond should results in the regioisomer **133**, which corresponds to the regioisomer of the observed [5 + 2] cocyclization product.

One explanation for the observed behavior could be based on steric hinderence: By introducing a second substituent which is bulkier than the cyclopropane, the insertion into the 'right' cyclopropane bond should be enforced. However, it would be best to add a third cyclopropane ring. In that case it does not matter which bond is cleaved – one cyclopropane ring would always end up in an methylcyclopropyl position to the metal. In doing so, there are four different diastereomers which can be considered. If the assumption of a steric argument is right the diastereomer, which goes through the least hindered transition state should react best. All four possibilities were analyzed and the *trans,trans,cis*-isomer **134** is likely to have the best properties.(Scheme 35)

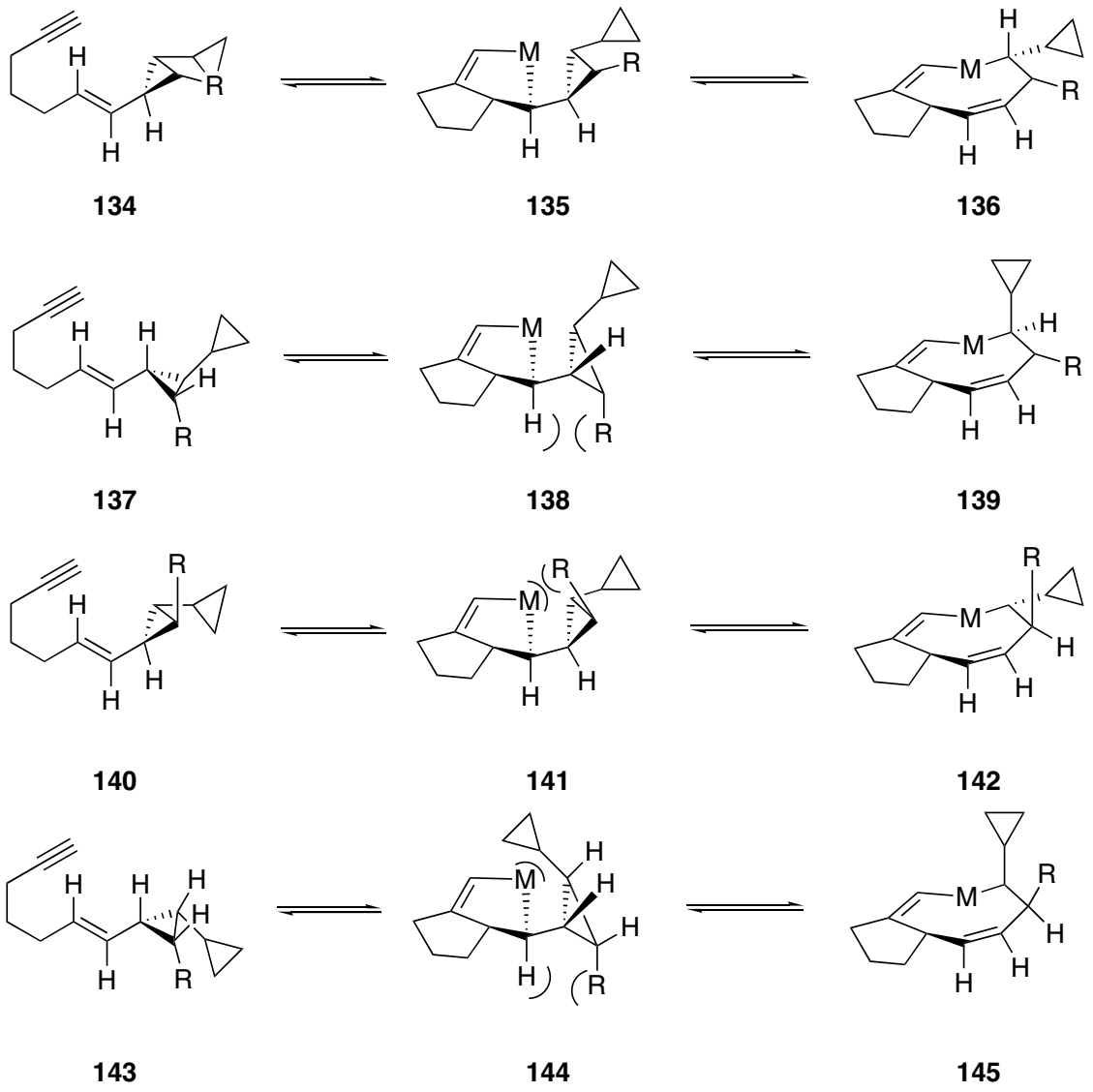
1.2.2. Preparation of the precursor

In order to verify the hypothesis formulated in the introduction the synthesis of three precursors was started: One had a third cylopropane ring, another had a *tert*-butyl substituent and the third came with a phenyl substituent. The synthesis of the two latter ones was abandoned after getting first results of the cyclopropyl precursor.

The preparation started from the terminal alkyne that the cyclopropane ring was attached to in two steps (Scheme 36). Reduction of the triple bond to the *cis*-



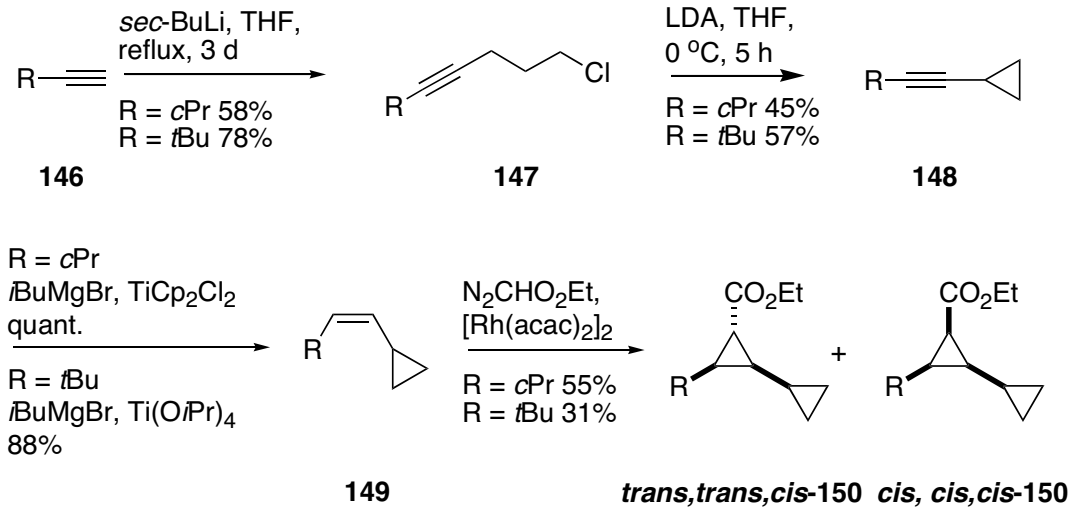
Scheme 34. Cleavage of the less substituted bond.



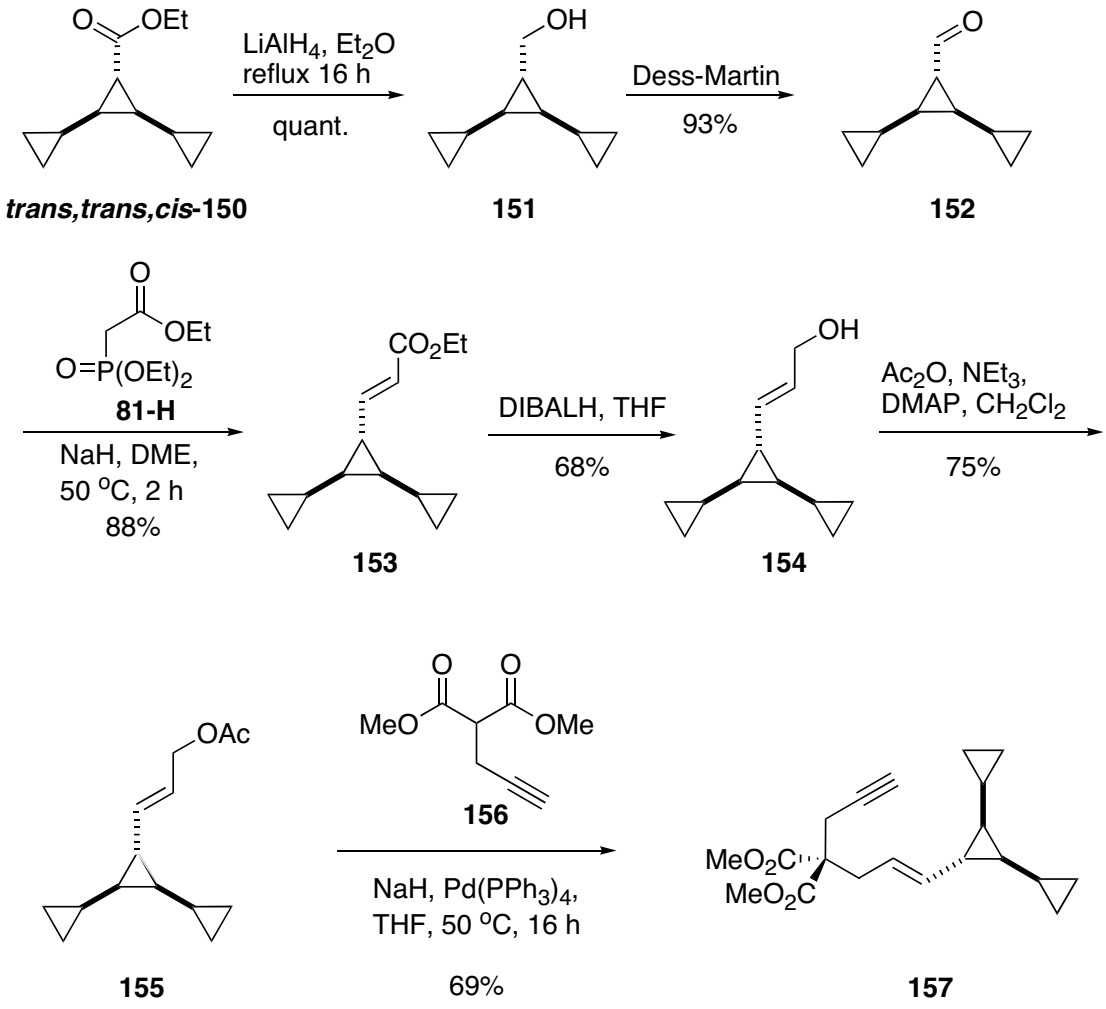
Scheme 35. Stereochemical analysis of the reaction pathway of a 2,3-disubstituted vinylcyclopropane.

alkene was achieved by a procedure with catalytic titanocene in the case of the bicyclopropylacetylene (**148-*c*Pr**), but didn't give any reaction with the cyclopropyl-*tert*-butylacetylene (**148-*t*Bu**). Fortunately the use of stoichometric amounts of $Ti(O\mathit{i}Pr)_4$ and ethyl-GRINGARD resulted in the desired product according to a modified procedure by SATO et al.[95] Cyclopropanation with diazoethylacetate and rhodiumacetate resulted in two diastereomers ***trans,trans,cis*-150** and ***cis,cis,cis*-150** which could be separated by column chromatography. For the next steps the desired isomer ***trans,trans,cis*-150** was used only. The sequence followed the one described above for the bicyclopropyl precursor (Scheme 37).

Reduction of the ester ***trans,trans,cis*-150** with $LiAlH_4$, followed by the DESS-MARTIN oxidation and the HORNER-WATSWORTH-EMMONS reaction gave the desired ester **153**. Attempts to reduce the α,β-unsaturated ester **153** with $LiAlH_4$ were unsuccessful, because reduction of the double bond occured was well. This is common for α,β-unsaturated esters,[87] but was surprising because the 3-bicyclopropyl-2-yl-acrylic acid ethyl ester (**113**) was converted without any problems (Scheme 28). The use of DIBALH though yielded the desired unsaturated alcohol **154**. Having achieved the alcohol **154** the synthesis of the desired precursor was accomplished according to the protocol of TROST et al.[88]



Scheme 36. Preparation of the precursor, Part I.

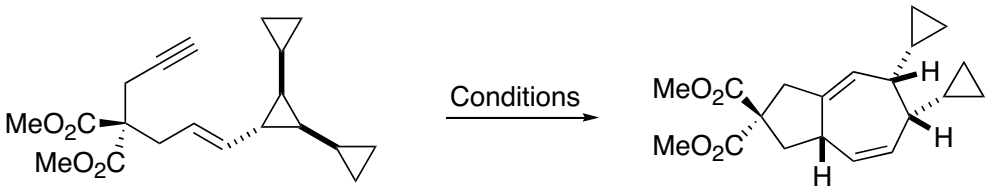


Scheme 37. Preparation of the precursor, Part II.

1.2.3. Attempts of cyclization

After the successful synthesis of a 2nd-generation-precursor first cocyclization experiments were carried out. Again, the catalysts used by WENDER et al. were used in combination with different solvents. Under conditions, using WILKINSON's catalyst or $[Rh(CO)_2Cl]_2$, the precursor decomposed and no product could be isolated (Table 4).

Table 4. Overview of attempts of cyclizations.



157 **158**

Entry	Catalyst	Solvent (Concentration)	Temp. (°C)	Time (h)	Result
1	$[Rh(CO)_2Cl]_2$ (10 mol%)	DCE (0.03 M)	80	15	Decomposition, polymerisation
2	$[Rh(CO)_2Cl]_2$ (5 mol%)	$CDCl_3$ (0.2 M)	40	48	Decomposition, polymerisation
3	$RhCl(PPh_3)_3$ (10 mol%), AgOTf (10 mol%)	Benzene-d_6 (0.1 M)	100	24	Decomposition, polymerisation
4	$[Rh(CO)_2Cl]_2$ (5 mol%)	TFE-d_3 (0.1 M)	80	0.25	Decomposition, polymerisation + at least 2 compounds
5	$[(C_{10}H_8)Rh(COD)]SbF_6$ (5 mol%)	DCE (0.1 M)	rt	24	67%
6	$[(C_{10}H_8)Rh(COD)]SbF_6$ (5 mol%)	DCE (0.1 M)	70	1	68%

The reaction was also followed by NMR. In contrast to the case of the 1st-generation-precursor the signals of **157** just vanished and only broad waves could be detected. Finally, the application of $[(C_{10}H_8)Rh(COD)]SbF_6$ yielded the $[5+2]$ cycloadduct **158** in nearly 70%. A higher reaction temperature only shortens the reaction time. As outlined in the introduction one of the two cyclopropane rings has to end up in a cyclopropylmethyl position of the rhodium during the catalytic process. The observation that no second insertion occures lead to the conclusion that the vinylcyclopropane has special properties as a whole unit which allow the insertion into the cyclopropane.

1.3. The 3rd-generation-precursor

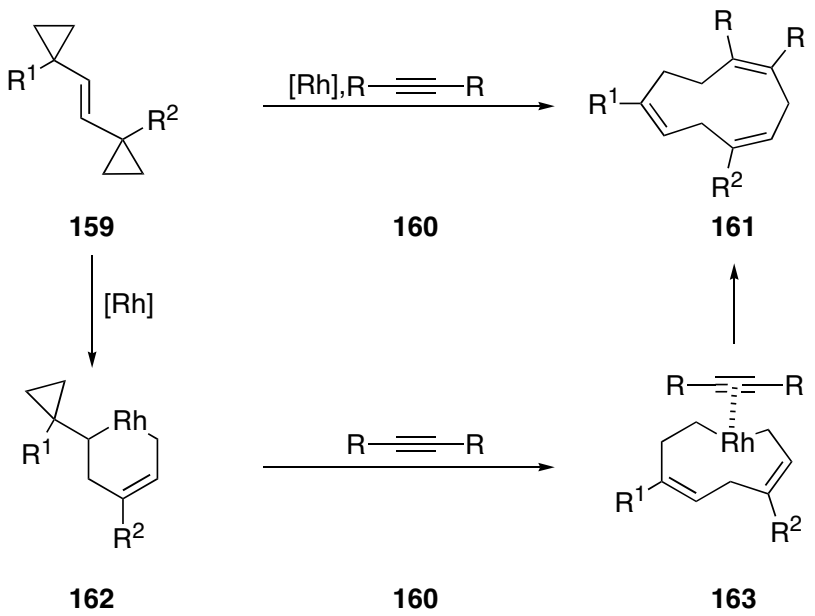
After this remarkable result a new precursor was designed. It needs to obey the following criteria:

- Both rings have to be adjacent to the double bond.
- The precursor has to be stable enough to survive the reaction.

With these prerequisits a 3rd-generation-precursor was planned.

1.3.1. Theoretical analysis of the design of a cyclopropylvinylcyclopropyl precursor

To ensure that the second cyclopropane ring could also benefit from the effects of the conjugation with the double bond it would be best to detach the second ring from the first one. Emploing this strategy would eliminate the problem which bond of the first cyclopropane ring will be opened. This can be achieved if the second cyclopropanering is positioned at the other end of the vinyl portion (Scheme 38).

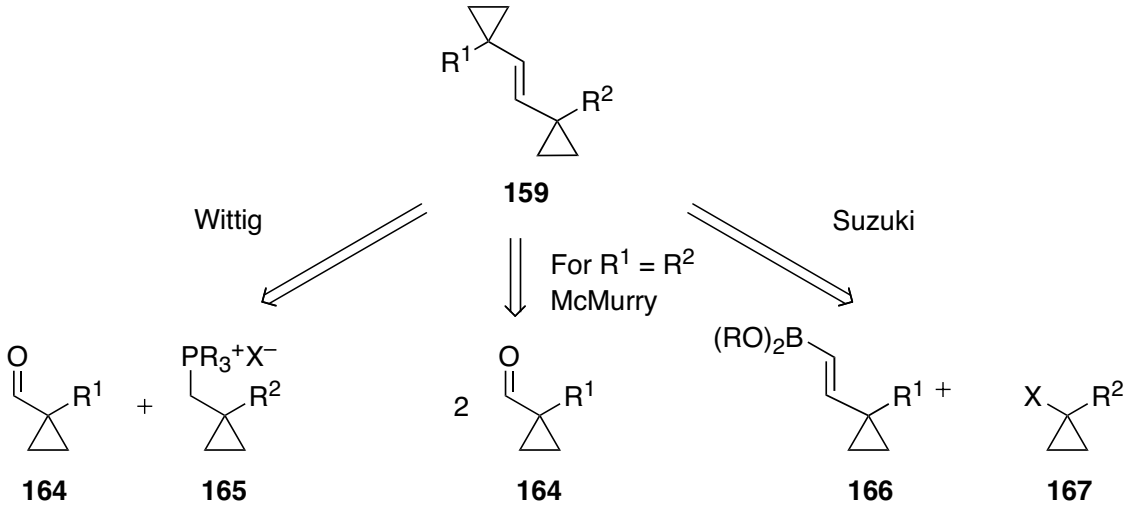


Scheme 38. Possible reaction pathway of a 3rd-generation-precursor.

In addition, a precursor for an intermolecular cocyclization reaction of this kind might be easily prepared by the McMurry coupling, Suzuki coupling or the Wittig reaction.

1.3.2. Preparation of the 3rd-generation-precursor

As suggested in the previous section, there are three possible ways of assembling the 3rd-generation-precursor. The strategies are summarized in Scheme 39.



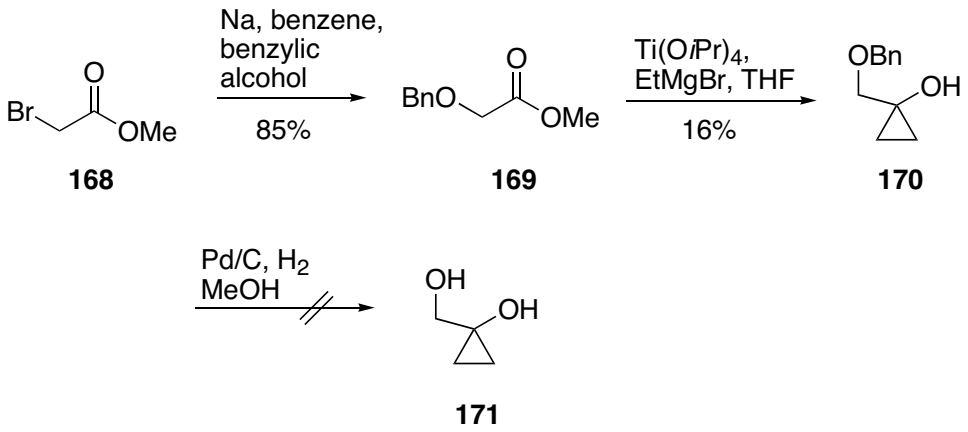
Scheme 39. Retrosynthtic analysis of for 3rd-generation-precursor (X = halogen).

1.3.2.1. Precursor for an intramolecular cyclization

Attempts for the preparation of 1-hydroxy-substituted cyclopropanes by the KULINKOVICH reaction 1-Hydroxy-substituted cyclopropanes are easily accessible by the KULINKOVICH reaction.[96] For the preparation of the 3rd-generation-precursor 1-hydroxymethylcyclopropanol (**171**) was needed. **171** would readily open the access to the 1-bromomethylcyclopropanol to synthesize the required WITTIG-salt **165**. Furthermore **171** could be used as starting material for the synthesis of the aldehyde **164**.

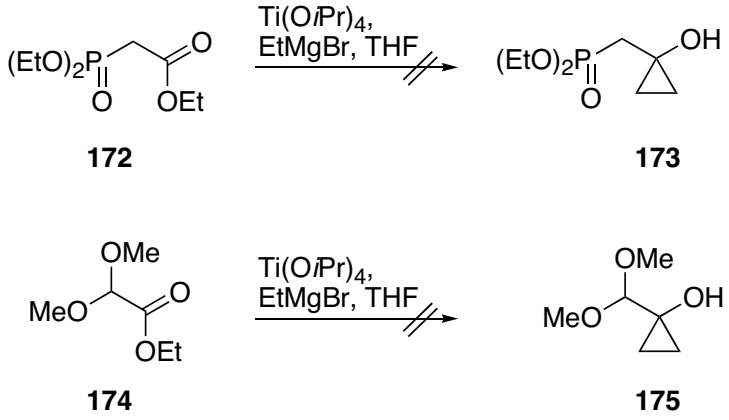
Therefore benzyloxy-acetic acid methyl ester (**169**) was prepared and subjected to the KULINKOVICH conditions. The desired cylopropanol **170** was obtained even though in low yield. The following deprotection by hydrogenation let to decomposition of the starting material (Scheme 40).

It is known that 3-(diethoxy-phosphoryl)-propionic acid methyl ester can be cyclopropanated under KULINKOVICH-conditions.[97] Also, 2-diphenylphosphanylmethyl-acetamide was reacted under similar conditions to obtain the desired cyclopropane,



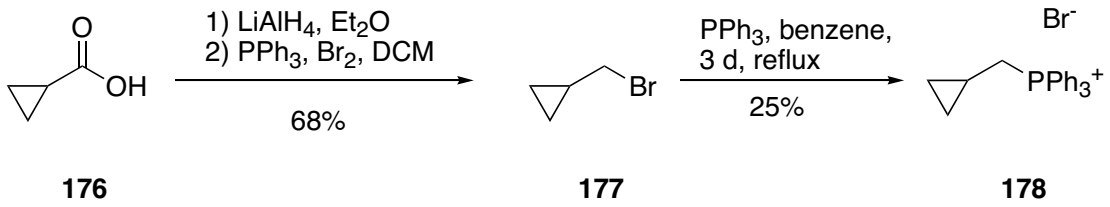
Scheme 40. Attempts to prepare 1-hydroxy-cyclopropanol (**171**) by the KULINKOVICH reaction.

while only in 21% yield. Nevertheless (diethoxy-phosphoryl)-acetic acid ethyl ester (**172**) was reacted under KULINKOVICH-conditions, but no cyclopropanated product could be isolated. In general, esters with substitution in α-position react poorly in KULINKOVICH-reactions. So, 3,3-dimethoxy-propionic acid ethyl ester can be converted smoothly to the 2,2-dimethoxyethyl-cyclopropanol.[98] Despite being only the one carbon smaller, the homologous dimethoxy-acetic acid ethyl ester **174** did not give the desired product under the same conditions (Scheme 41).



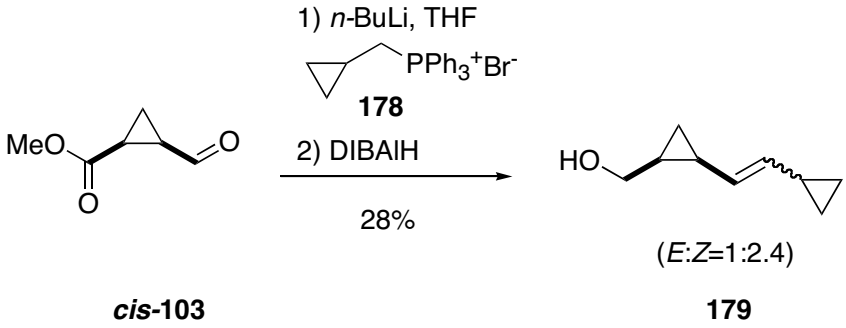
Scheme 41. Attempts to cyclopropanate (diethoxy-phosphoryl)-acetic acid ethyl ester (**172**) and dimethoxy-acetic acid ethyl ester (**174**) by the KULINKOVICH reaction.

Preparation by WITTIG-reaction The next strategy focused on the connection of the two cyclopropyl units by the WITTIG-reaction. *cis*-2-Formyl-cyclopropanecarboxylic acid methyl ester (***cis*-103**) was prepared as described previously. Following a literature procedure the WITTIG-salt **178** was made by refluxing the corresponding bromide **177** with triphenylphosphine in benzene for three days (25%).[99]



Scheme 42. Preparation of the WITTIG-salt **178**.

The WITTIG-reaction worked in moderate yield and produced a mixture of (*E*)- and (*Z*)-isomers (1:2.4) of the ester, which were not separable by column chromatography (Scheme 43).

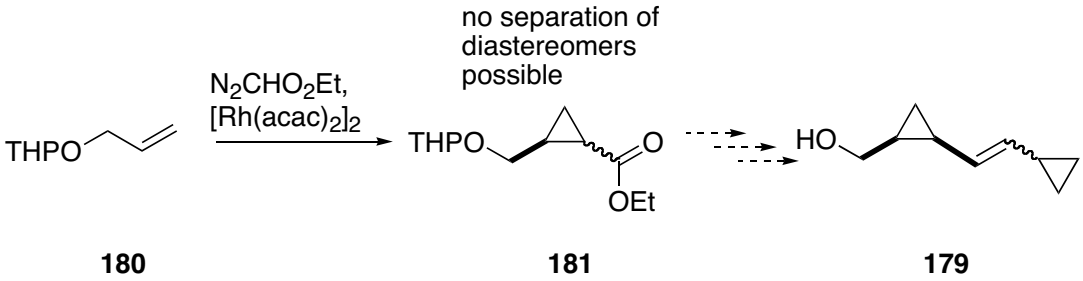


Scheme 43. Preparation of [2-(2-cyclopropyl-ethyl)-cyclopropyl]-methanol **(179**).

Both, the *cis*- and *trans*-isomer at the internal cyclopropane ring were prepared and reduction of the ester with DIBALH yielded the desired [2-(2-cyclopropyl-ethyl)-cyclopropyl]-methanol (**179**).

Starting from the protected allyl alcohol **180** promised to be a shorter way to make the alcohol **179** (Scheme 44). Unfortunately, it was not possible to separate the two isomers by column chromatography. Therefore this route was not pursued further.

Preparation by selective cyclopropanation of 2,4-dienols The following strategy emphasizes the selective formation of an (*E*)-double bond. CHARETTE et al.



180 **181** **179**

Scheme 44. Attempt for the preparation of [2-(2-cyclopropyl-ethyl)-cyclopropyl]-methanol (**179**) starting from allyl alcohol **180**.

developed a very elegant method to cyclopropanate 2,4-dienols with diethyl zink, diiodomethane and DME.[100] These three components form a complex which is a much milder reagent than the carbene prepared just from diethyl zink and dihalogenomethane.

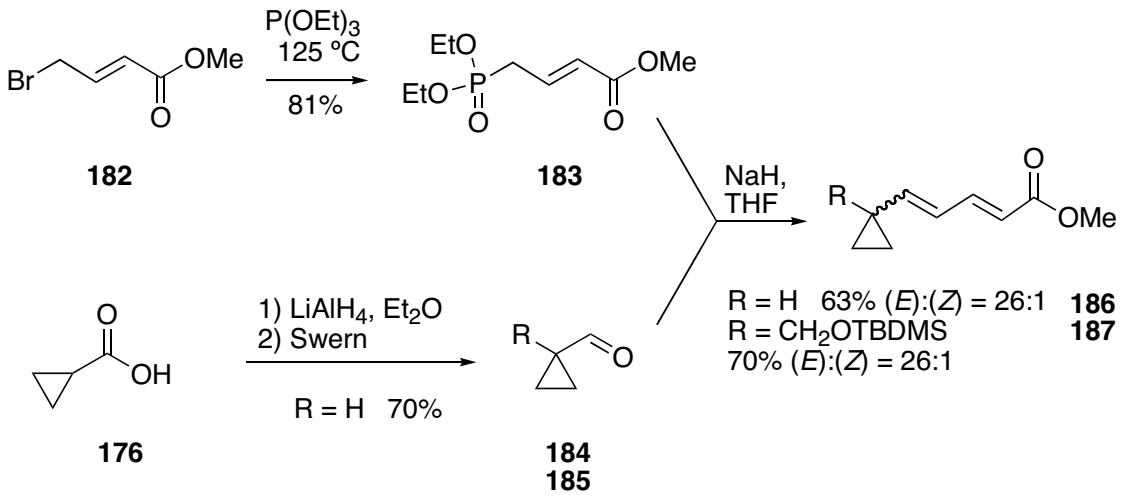
The 2,4-dienol was prepared by the HORNER-WADSWORTH-EMMONS-reaction from **183** and aldehyde **184**, followed by DIBALH reduction (Scheme 45).[101] The (*E*)- and the (*Z*)-isomer could be easily separated by column chromatography. The (*E*)-isomer only was used for the further synthesis. The cyclopropanation gave not only the desired mono-cyclopropanated product, but also the dicyclopropanated compound.

The same sequence was done starting from 1-(*tert*-butyl-dimethyl-silyloxymethyl)-cyclopropanecarbaldehyde (**185**) (The synthesis of **185** will be described in Scheme 50). In this case, the cyclopropanation yielded only the mono-cyclopropanated product. But 61% of the starting material were reisolated.

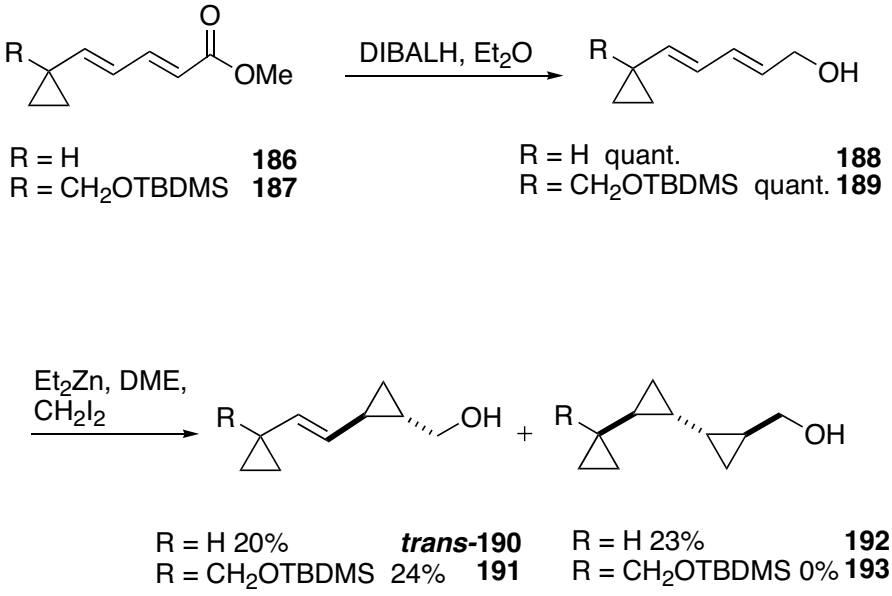
Unfortunately, only one isomer of 4-bromo-but-2-enoic acid methyl ester (**182**) is commercially available, hence another approach to access both isomers – *cis* and *trans* configured at the internal cyclopropane ring – was explored.

Preparation by SUZUKI coupling CHARETTE et al. published a convenient way to build up vinylcyclopropanes by SUZUKI coupling.[102] The necessary iodocyclopropanes were prepared by cyclopropanation of vinyliodides. In utilizing this procedure, both isomers of the desired iodocyclopropane were accessible to prepare the corresponding 3rd-generation-precursors (Scheme 47).

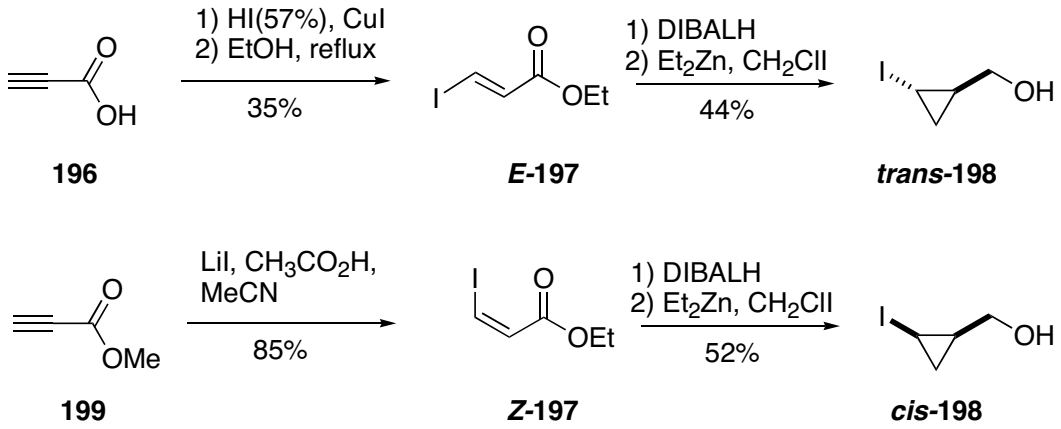
(2-Iodo-cyclopropyl)-methanol **198** was then reacted with 2-(2-cyclopropyl-vinyl)-



Scheme 45. Preparation of 5-cyclopropyl-penta-2,4-dienoic acid methyl ester (**186**) and **187**.

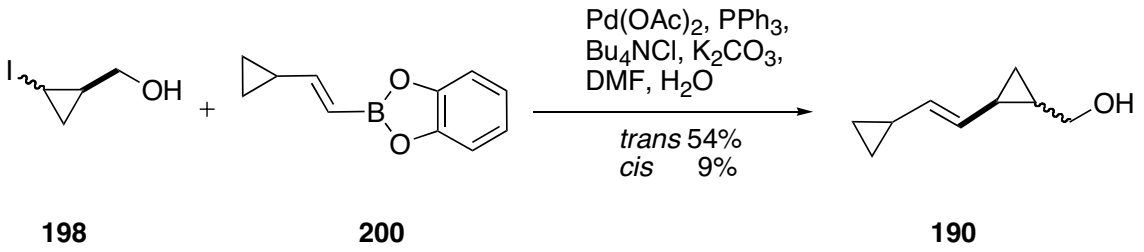


Scheme 46. Cyclopropanation of 5-cyclopropyl-penta-2,4-dienol (**188**) and **189**.



Scheme 47. Preparation of *cis*- and *trans*-(2-iodo-cyclopropyl)-methanol (**198**).[103–106]

benzo[1,3,2]dioxaborole (**200**), prepared *in situ* from cyclopropylacetylene and catecholborane, to provide the desired *trans*-[2-(2-cyclopropyl-vinyl)-cyclopropyl]-methanol (**190**) in moderate yield (Scheme 48).

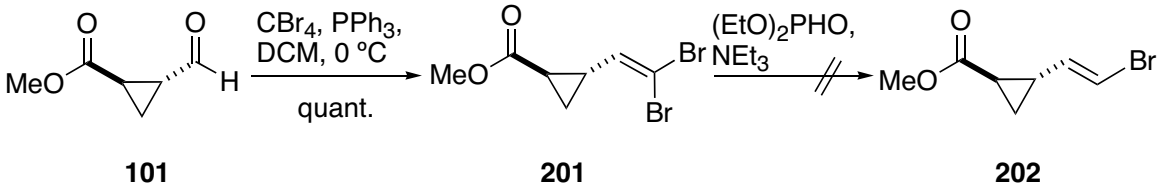


Scheme 48. SUZUKI coupling of *cis*- and *trans*-(2-iodo-cyclopropyl)-methanol (**198**) with 2-(2-cyclopropyl-vinyl)-benzo[1,3,2]dioxaborole (**200**).

Interestingly, the *cis*-[2-(2-cyclopropyl-vinyl)-cyclopropyl]-methanol (***cis*-190**) could only be obtained in 9%.

The other possible strategy via SUZUKI coupling starts from the vinyl bromid. The dibromid **201** was prepared in quantitative yield by the COREY-FUCHS reaction. However, the following selective *cis*-debromination didn't work at all.

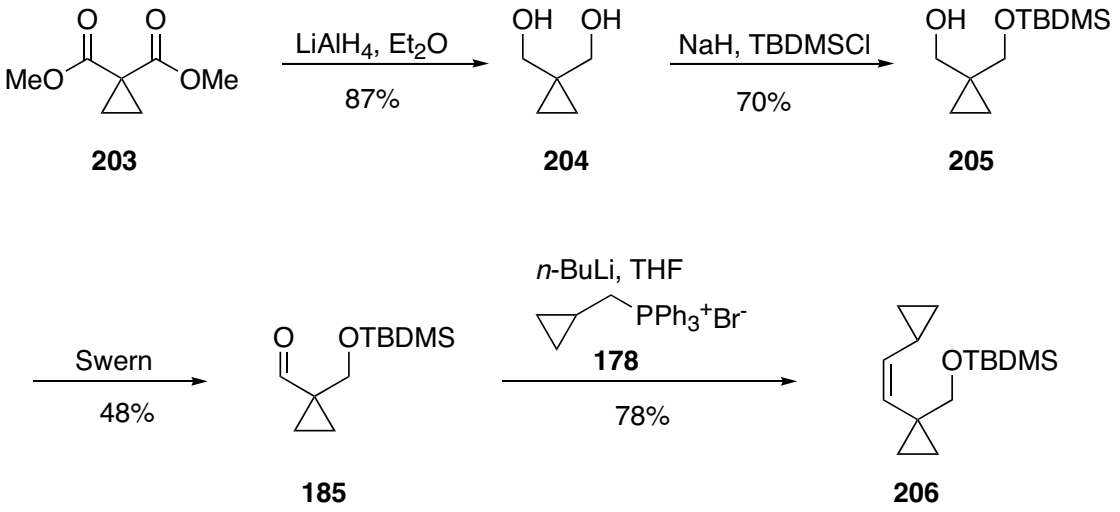
The final assembly was done in analogy to the 1st-generation precursor by an ether coupling with 1-bromo-2-butyne.



Scheme 49. Attempt to prepare the vinylbromid **202**.

1.3.2.2. Precursor for an intermolecular cyclization

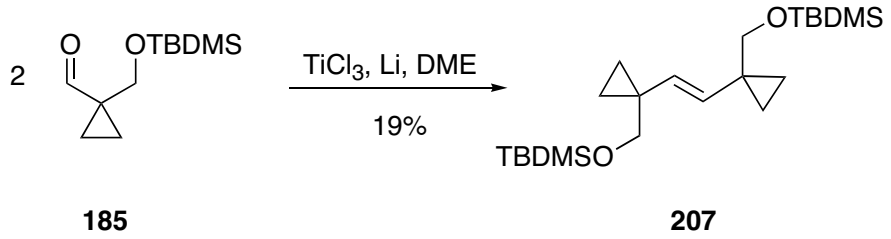
Synthesis of a 3rd-generation-precursor with 1-substitution at one cyclopropane ring WENDER et al. showed that substitution in the 1-position for a successful intermolecular [5 + 2] reaction is mandatory.[68] Therefore 1-(*tert*-butyl-dimethyl-silyloxymethyl)-cyclopropanecarbaldehyde (**185**) was prepared by reduction of cyclopropane-1,1-dicarboxylic acid dimethyl ester (**203**), selective monoprotection with TBDMSCl followed by SWERN oxidation. The aldehyde **185** was then coupled by the WITTIG reaction with **178** to yield *tert*-butyl-[1-(2-cyclopropyl-(*Z*)-vinyl)-cyclopropylmethoxy]-dimethylsilane (**206**) as one stereoisomer (Scheme 50).



Scheme 50. Preparation of *tert*-butyl-[1-(2-cyclopropyl-(*Z*)-vinyl)-cyclopropylmethoxy]-dimethyl-silane (**206**).

Synthesis of a 3rd-generation-precursor with 1-substitution at both cyclopropane rings In the case, that the (*Z*)-configuration might inhibit the reaction,

1-(*tert*-butyl-dimethyl-silyloxymethyl)-cyclopropanecarbaldehyde (**185**) was reacted in a McMurry reaction.[107] This precursor also contains 1-substitution at both cyclopropyl rings, which might facilitate the ring opening of the second cyclopropyl ring.



185 **207**

Scheme 51. Preparation of **207** by McMurry reaction.

1.3.3. Attempts of cyclization

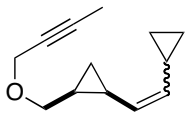
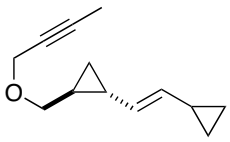
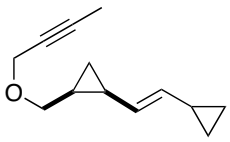
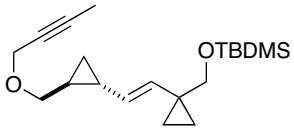
After successfully preparing the precursors they were subjected to the established cyclization conditions. In most cases, $[Rh(CO)_2Cl]_2$ (5 mol%) in DCE at 75–80 °C was applied, the best conditions reported by Wender et al. $[(C_{10}H_8)Rh(COD)]SbF_6$ was also employed.

1.3.3.1. Intramolecular cyclization

Preliminary considerations In case of the intramolecular cyclization there are four possible isomeric precursors, which were all prepared as mentioned above. In comparison with the precursors used by Wender et al. the 3rd-generation-precursors are much more rigidified by the introduction of the second cyclopropyl ring. Therefore, there should be a noticeable difference in reactivity.

Results The results are summarized in Table 5. Those precursors with no substitution in 1-position showed only sluggish reactivity. In all cases mostly starting material was re-isolated (Table 5, entry 1–4). In entry 1 and 2 a mixture of the (*E*)- and the (*Z*)-isomer was used for the reaction, while only the (*E*)-isomer was partially consumed. This led to the conclusion that the (*E*)-isomer might be more reactive. As shown in entry 3 and 4 even in the case of (*E*) configuration only 30% of the

Table 5. Overview of intramolecular cyclizations attempts using 3rd-generation-precursors.

Entry	Precursor	Conditions	Result
1	 *E*:*Z*, 1:2.4 **208**	$[Rh(CO)_2Cl]_2$ (5 mol%), DCE, 75 °C, 24 h	Re-isolation of starting material (20%), reduction of triple bond to double bond (30%), rest decomposition, no (*E*) was re-isolated
2	 *E*:*Z*, 1:2.4 **209**	$[Rh(CO)_2Cl]_2$ (5 mol%), DCE, 75 °C, 12 h	Re-isolation of starting material (55%), rest decomposition, no (*E*) was re-isolated
3		$[(C_{10}H_8)Rh(COD)]SbF_6$ (5 mol%), DCE, 75 °C, 24 h	No reaction
4	 ***E*-209**	$[Rh(CO)_2Cl]_2$ (5 mol%), DCE, 75 °C, 12 h	Re-isolation of starting material (70%), rest decomposition
5		$[Rh(PPh_3)_3Cl]_2$ (10 mol%), AgOTf (10 mol%), toluene, 100 °C, 24 h	Decomposition
6	 ***E*-208**	$[Rh(CO)_2Cl]_2$ (5 mol%), DCE, 75 °C, 12 h	Decomposition
7	 **210**	5 $[Rh(CO)_2Cl]_2$ (mol%), DCE, 75 °C, 12 h	Decomposition

material was transformed to a variety of products to which a specific structure could not be assigned to or lead to decomposition. In the case with a substituent in the 1-position (Table 5, entry 5) the starting material just decomposed over time. Hence, no product could be isolated and assigned.

1.3.3.2. Intermolecular cyclization

Preliminary considerations For the intermolecular cocyclization an alkyne addition partner had to be selected. In both cases, the two-component $[5+2]$ and the three-component $[5+2+1]$ cocyclization reaction, propynoic acid methyl ester (**199**) showed excellent results.[67,70] Another promising candidate was propargyl methyl ether (**211**). It was used by WENDER et al. for the optimization of the intermolecular formal $[5+2]$ cycloaddition with vinylcyclopropane **42**. As in the case of the intramolecular cocyclization there might be a difference in reactivity between (*E*)- and (*Z*)-isomer. The (*Z*)-isomer may be sterically more congested and not suitable for a coordination of rhodium with C=C and the following insertion into the cyclopropane ring.

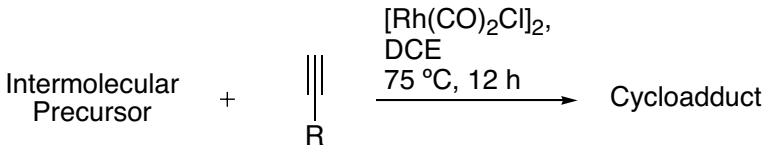
Results All prepared precursors were tested under standard conditions. The results are summarized in Table 6.

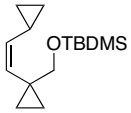
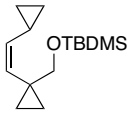
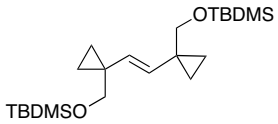
Similar to the intramolecular cases, only starting material was isolated. Both alkyne partners, electron rich and poor, gave similar results: Nearly no reaction. Even the (*E*)-isomer with 1-substitution on both cyclopropane rings showed almost no reaction (Table 6, entry 3).

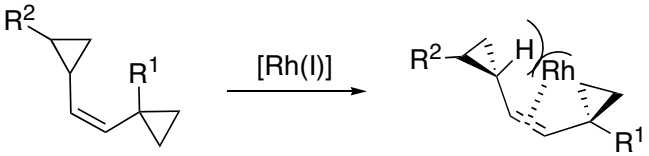
1.3.4. Rationalization of the results of the 3rd-generation-precursor

In both reactions, the intramolecular and the intermolecular cocyclization, mostly starting material was isolated. WENDER et al. mentioned the necessity of a *s-cis* conformation for the insertion of rhodium into the cyclopropane ring.[68] If a precursor shows (*Z*)-conformation an insertion might be sterically very hindered. The coordination with the double bond and the orientation of the cyclopropanering in such a way that an insertion is possible, was apparently blocked by the second cyclopropanering. This would explain the results for the (*Z*)-isomers and the observation, that the (*E*)-precursors decompose faster than the (*Z*)-configured analogoes.

Table 6. Overview of attempts of the intramolecular cyclizations of the 3rd-generation-precursor.



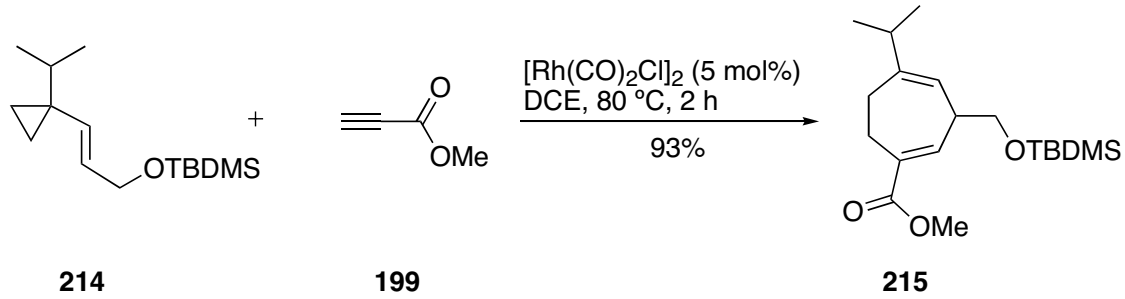
Entry	Precursor	R	Result
1	 **206**	CO_2Me	Re-isolation of starting material (61%), rest decomposition
2	 **206**	CH_2OMe	No reaction
3	 **207**	CO_2Me	Re-isolation of starting material (70%), rest decomposition



212 **213**

Scheme 52. Steric interactions in the coordination of Rh with a (*Z*)-precursor.

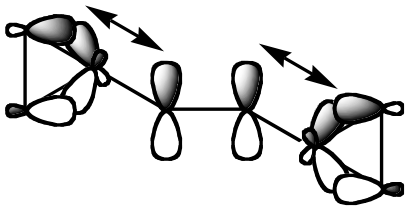
The steric interaction as described above should not be effective for the (*E*)-isomers. WENDER et al. showed examples were similar sterically congested systems were successfully transformed in the desired cycloadduct.[68]



214 **199** **215**

Scheme 53. Example of a sterically congested system in a formal [5 + 2] cycloaddition by WENDER et al.

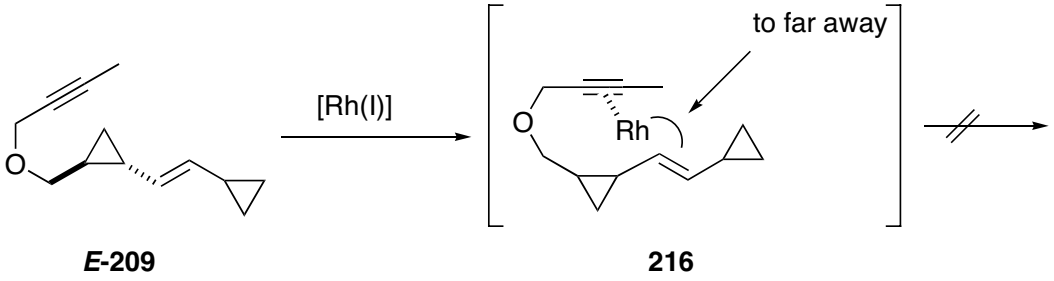
Another effect, the electronic properties of the second cyclopropane ring, might be responsible for the poor reactivity. Cyclopropanes can have a similar effect as a double bond. This would lead to a higher extent of conjugation, decrease the electron density at the double bond resulting in weaker coordination of the rhodium catalyst.



Scheme 54. Conjugation of the cyclopropane ring and the double bond.

Usually there is no need for a substituent in the 1-position for the intramolecular cocyclization. The necessary conformation should be achieved by the additional coordination with the alkyne moiety of the same molecule. For the 3rd-generation-precursor an analogous coordination seems to be a lot more difficult. As mentioned in the preliminary considerations the second cyclopropane ring introduces more rigidity. It even seems to inhibit the coordination, because the rhodium simply can not reach the vinylcyclopropane and the alkyne at the same time. Without this simultaneous

coordination the reaction is not possible. The catalyst is probably coordinated to the alkyne and not able to catalyze any addition. The starting material is re-isolated.



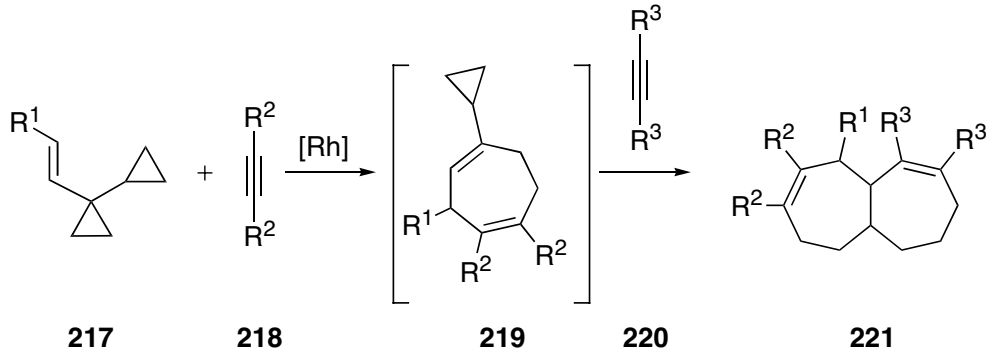
***E*-209** **216**

Scheme 55. Spacial arrangement of an intramolecular precursor with the catalyst.

1.4. The 4th-generation-precursor

1.4.1. Introduction

As outlined in the introduction there is another possibility of attaching a second cyclopropane ring: in the 1-position of the first cyclopropane ring. The first [5 + 2] cocyclization would result in another vinylcyclopropane, suitable for the second [5 + 2] cocyclization which would open an easy access to bicyclic[5.5.0]undecane ring systems (Scheme 56).



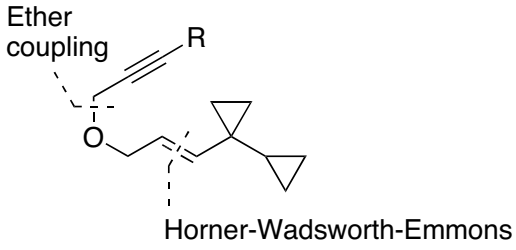
Scheme 56. Possible double [5 + 2] cocyclization cascade reaction.

An intramolecular and an intermolecular version is thinkable, too. In the first case all components might be added at the same time. The selectivity has to be controlled by the different rates to be expected for the first – the intramolecular – and the following intermolecular [5 + 2] cocyclization. In the intermolecular case the two alkyne components probably have to be added sequential if there is not a considerable difference in reactivity.

1.4.2. Preparation of the precursor

The strategy for the synthesis of the 4th-generation-precursor followed the methodology described in the previous chapter for the 1st–3rd-generation-precorsors. The bicyclopropyl unit will be attached by the HORNER-WADSWORTH-EMMONS reaction to form the vinyl-bicyclopropyl moiety. Reduction to the allylic alcohol and coupling with a propargylic bromid will furnish an intramolecular precursor **222** (Scheme 57).

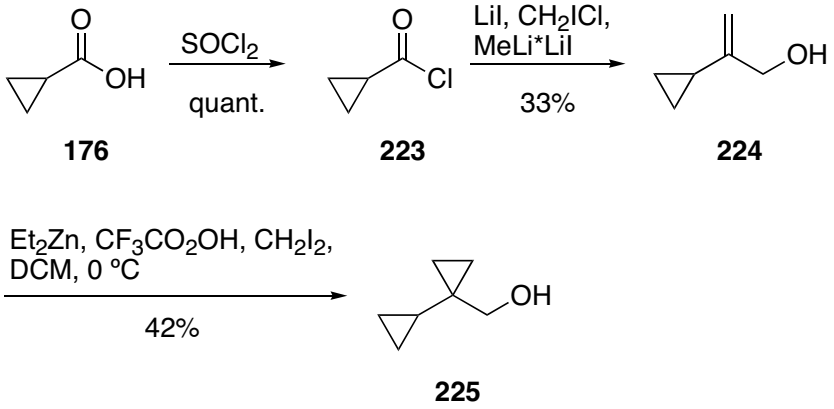
1.4.2.1. Synthesis of the bicyclopropyl unit The synthesis of the bicyclopropyl unit starts from the known allylalcohol **224**, prepared from cyclopropanecarbonyl



222

Scheme 57. Retro-synthetic analysis.

chloride (**223**).[108] Cyclopropanation with Et_2Zn, CH_2I_2 and CF_3CO_2H yielded the desired bicyclopropyl-1-yl-methanol (**225**) (Scheme 58).

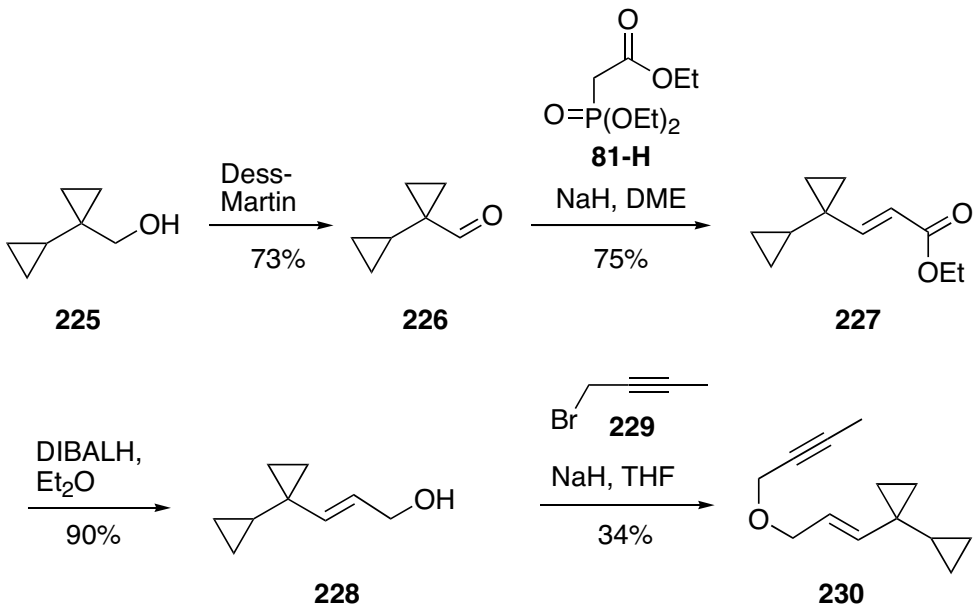


176 **223** **224**

225

Scheme 58. Synthesis of the bicyclopropane unit.

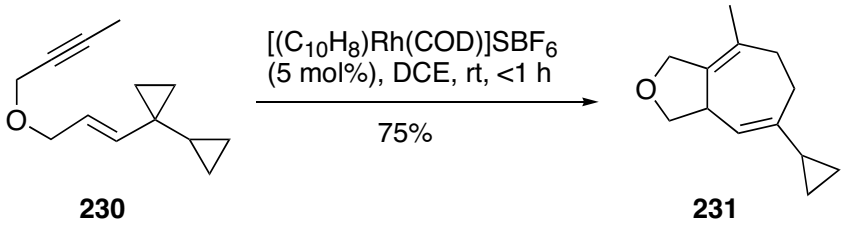
1.4.2.2. Attachment of the vinyl portion and assembly of the whole precursor Following the retro-synthetic analysis, the vinyl portion was set up by the HORNER-WADSWORTH-EMMONS reaction in excellent yield after its oxidation of the alcohol **225** to the aldehyde **226** (Scheme 59). The resulting ester **227** was altered to the corresponding alcohol **228** which can already be used as an intermolecular precursor. Reduction with $LiAlH_4$ reduced not only the ester but also partially the double bond. However, the use of DIBALH generated the allylic alcohol **228** as expected and treatment of **228** with NaH and bromide **229** yielded the desired intramolecular precursor **230** (Scheme 59).



Scheme 59. Assembly of the whole precursor **230**.

1.4.3. Results of cocyclization

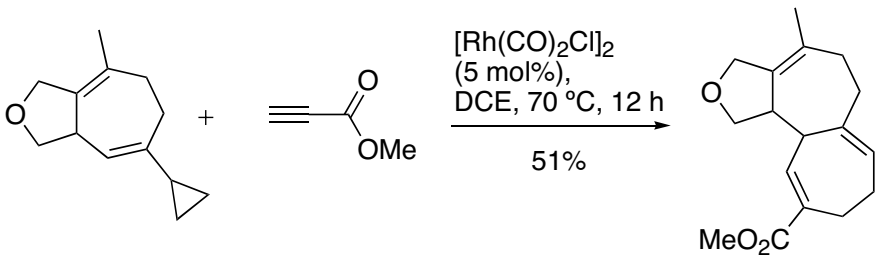
1.4.3.1. Intramolecular version With the necessary precursor in hand the intramolecular formal $[5+2]$ cycloaddition was tested. In less then one hour (the reaction was checked the first time after one hour and the TLC showed full conversion) $[(C_{10}H_8)Rh(COD)]SBF_6$ gave the desired $[5+2]$ cycloadduct in 75% yield, basically as a spot-to-spot reaction by TLC.



Scheme 60. Intramolecular formal $[5+2]$ cycloaddition.

After the establishment of the intramolecular $[5+2]$ cocyclization the second step – the intermolecular formal $[5+2]$ cycloaddition – had to be investigated. Propynoic acid methyl ester (**199**) was chosen as alkyne component, because it showed the best performance in the intermolecular $[5+2]$ cyclaoddition of vinylcyclopropanes

reported by WENDER et al.[67] The cycloadduct **231** was reacted with propynoic acid methyl ester (**199**) to yield the tricyclic system **232** in 51%. Usually, it seems that a substituent in the 1-position is beneficial. However, in the described cocyclization the necessary confirmation is most likely lowered in energy by the incorporation of the vinylcyclopropane in the ring system which rigidifies the structure.



231 **199** **232**

Scheme 61. Intermolecular formal [5 + 2] cycloaddition of cycloadduct **231**.

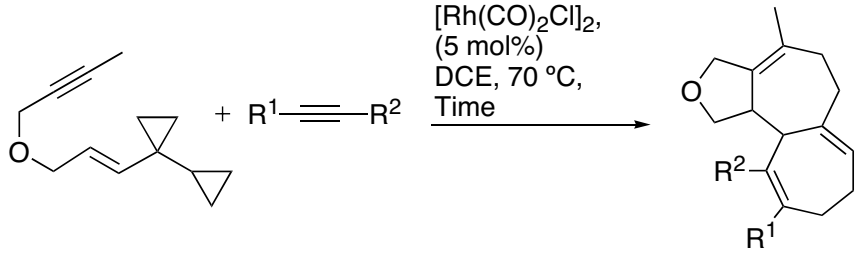
One-pot-version The reaction can also be done by adding all components in at the same time. The yield was even higher as with the sequential protocol, and it also saved one workup and purification. Unfortunately, other alkynes did not react in the same manner. Methyl propargyl ether and TMS-acetylene only gave the intramolecular [5 + 2] cycloadduct **231**. Dimethylacetylenedicarboxylate furnished **231** as well, which didn't react in an additional intermolecular cocyclisation most likely due to steric interactions (Table 7).

1.4.4. Intermolecular version

The intermolecular formal [5 + 2] cycloaddition of vinylcyclopropane **228** gave the desired seven membered ring **235** under the standard conditions ($[Rh(CO)_2Cl]_2$, DCE, 70 °) in 68% yield (Scheme 62).

In contrary to the intramolecular reaction it was not possible to push the reaction to the next formal [5 + 2] cycloaddition. Even the addition of two times six equivalents of the alkyne **199** in two portions did not help.

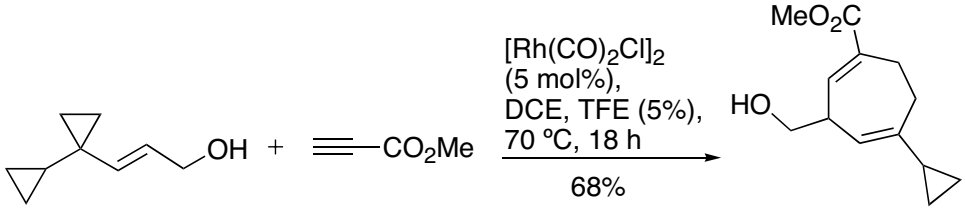
Table 7. Different alkynes in the double [5 + 2] cycloadition cascade reaction.



230 **233** **234**

Entry	R^1	R^2	Time (h)	Yield (%)
1	CO_2Me	H	18	76
2	CH_2OMe	H	24	–
3	CH_2OMe	H	24	–[a]
4	TMS	H	24	–
5	CO_2Me	CO_2Me	24	–

[a]Addition of 10% TFE.



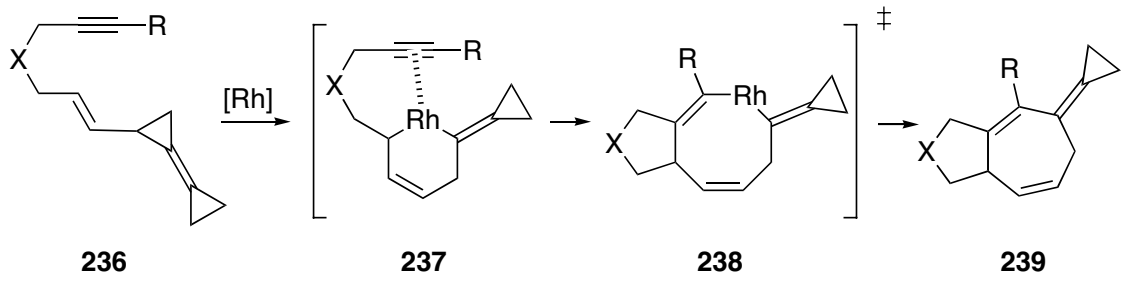
228 **199** **235**

Scheme 62. Intermolecular formal [5 + 2] cycloaddition of vinylcyclopropane **228**.

1.5. The 5th-generation-precursor

1.5.1. Introduction

Considering the synthetic strategy of the 1st-generation-precursor it is thinkable to start from bicyclopropylidene (**85**) to prepration another class of precursors containing a vinylbicyclopropylidene moiety. The ring opening of the cyclopropane ring should even be easier as a result of the additional strain introduced by the double bond. Another possibility for a course of reaction might be the addition of the metal to the bicyclopropylidene unit instead of the vinylcyclopropane moiety (Scheme 63). However, so far there is no report in the literature of a transformation of rhodium with BCP. Assuming a similar reaction pathway this new precursor would be converted to an *exo*-cyclic methylenecyclopropane attached to the seven membered ring. There are numerous different possibilities for further transformations.[109, 110]



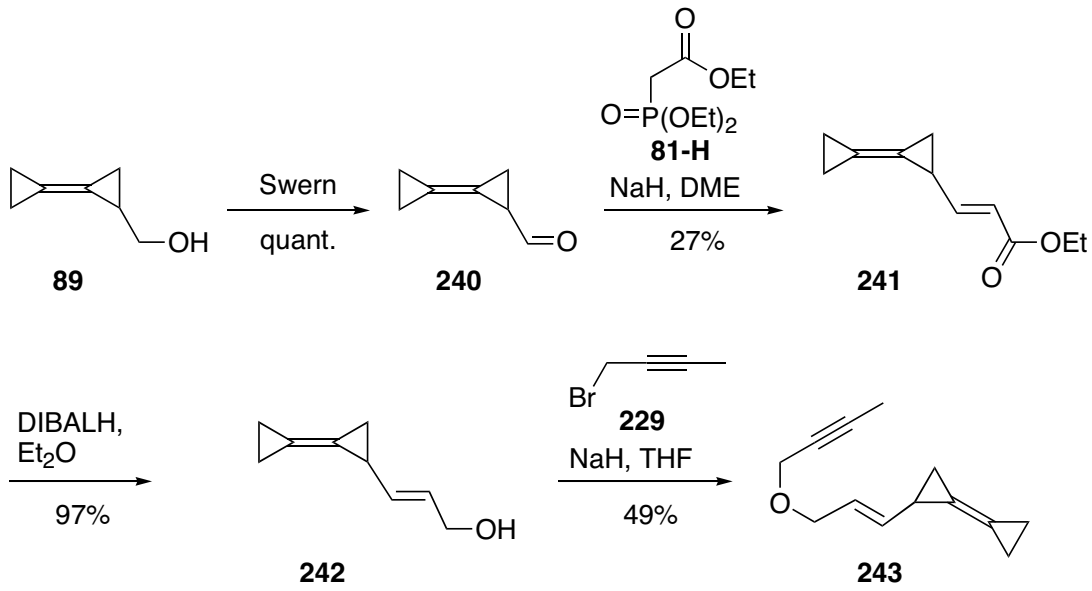
Scheme 63. Potential reaction course for a bicyclopropylidene precursor.

1.5.2. Preparation of the precursor

The preparation of the precursor started from bicyclopropyliden-2-yl-methanol (**89**) and was done analogous to the 1st-, 2nd-, 3rd- and 4th-generation-precursors. The SWERN oxidation, followed by the HORNER-WADSWORTH-EMMONS reaction of **81-H** and aldehyde **240** yielded the ester **241**. Reduction with DIBALH and ether coupling afforded the desired 2-(3-but-2-ynyloxy-propenyl)-bicyclopropylidene (**243**) (Scheme 64).

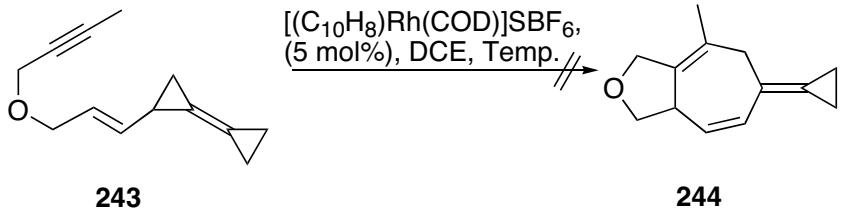
1.5.3. Results of cocyclization

The precursor **243** was subjected to $[(C_{10}H_8)Rh(COD)]SbF_6$, in DCE, but only minimal conversion was observed after 24 h at room temperature. An increase of the



Scheme 64. Assembly of the precursor **243**.

reaction temperature to 70 °C led to decomposition of the starting material (Scheme 65).



Scheme 65. Attempt of cocyclization at rt and 70 °C.

The bicyclopropylidene unit seems to have totally different electronic properties which inhibit the insertion of rhodium for a successful cocyclization process.

1.6. Summary

Different precursors were prepared and tested in the cocyclization:

- 1st-generation-precursor:

  A second cyclopropane ring was attached to the 'regular' intramolecular [5 + 2] cocyclization precursor. In the cyloaddition the less substituted bond of the first cyclopropane ring was cleaved. Therefore a further insertion of the catalyst into the second cyclopropane ring was not possible. This result led to the design of a 2nd-generation-precursor.

- 2nd-generation-precursor:

  Apart from the second cyclopropane ring from the 1st-generation-precursor a third cyclopropanering was attached to the parent vinylcyclopropane system. By using this kind of precursor it would not matter which bond of the first cyclopropane bonds would be cleaved because one of the attached cyclopropanes would always be in the right arrangement to make an insertion possible. Even for this precursor no insertion could be observed. The [5 + 2] cycloadduct was isolated in nearly 70% yield

- 3rd-generation-precursor:

  To achieve the 3rd-generation-precursor the bicylopropyl unit was abandoned in favor for a 1,2-bis-cyclopropylethene element. Both cyclopropane rings might benefit from conjugation with the double bond. This feature was paid for with a higher rigidity in the precursor which was probably the reason why in most cases nearly no reaction was observed and only starting material isolated. Besides the more crowded environment around the double bond, which may make a coordination more difficult, electronic considerations by means of conjugation might also inhibit the cocyclization.

- 4th-generation-precursor:

  With the synthesis of the 4th-generation-precurser a new efficient way to synthesize bicyclo[5.5.0]undecane building blocks could be established. Unfortunately, until now only one alkyne, propionic acid methyl ester (**199**), gave the desired bicycle in satisfactory yield. For other alkynes and in the case of the intermolecular reaction the process stops after the first formal [5 + 2] cycloaddition.

Nevertheless, the vinylcyclopropane moiety may be used for other transformations. Furthermore, it exhibits in addition to the other precursors an elegant way to prepare seven membered rings with cyclopropyl substitution as a new synthetic tool for the preparation of analogous of natural products.

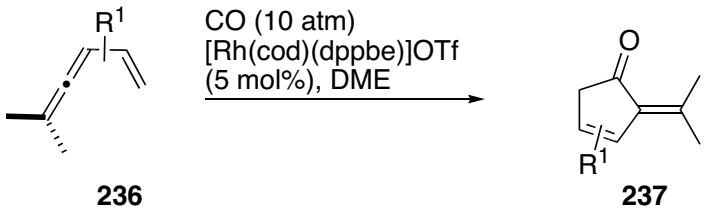
- 5th-generation-precursor:

  The 5th-generation-precursor has a special structural feature: the bicyclopropylidene unit. The idea to obtain a new methylenecyclopropanecycloheptadiene after a $[5+2]$ cocyclization with a handle for further transformation could not be realized. The precursor showed only sluggish reactivity at rt and decomposed at 70 °C.

2. First intermolecular Rh-catalyzed cocyclization of Vinylcyclopropanes with Allenes

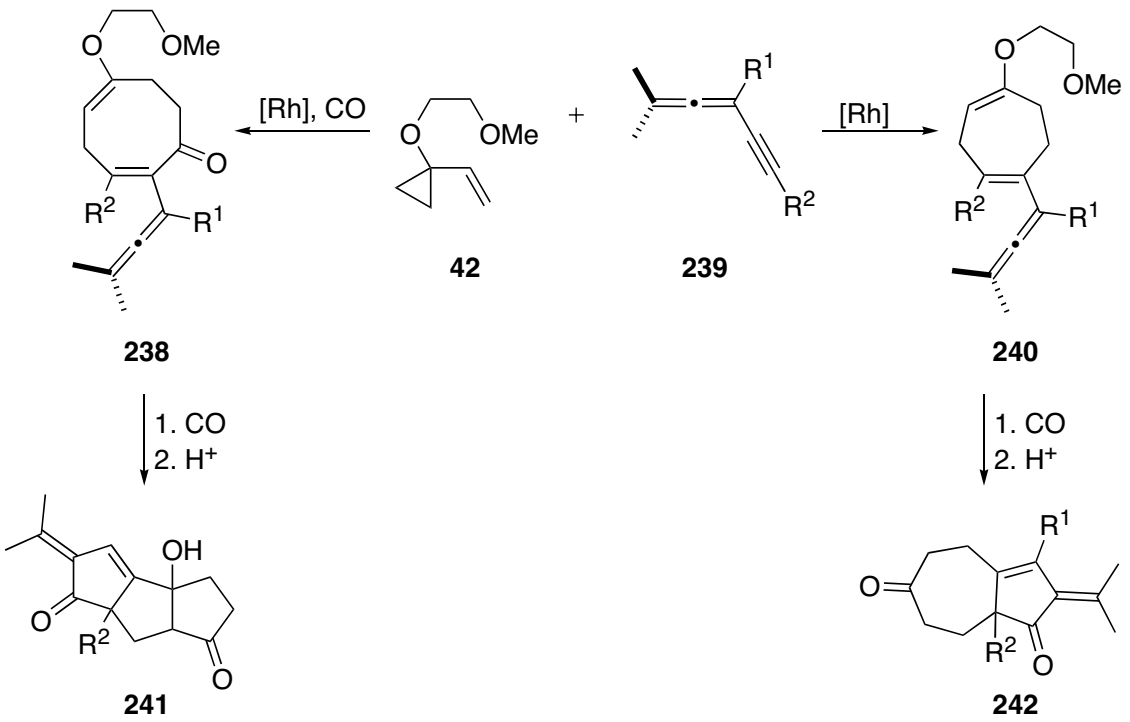
As outlined in the introduction the *inter*molecular [5 + 2] cocyclization reaction is still limited to alkynes. It is only in intramolecular cocyclization reactions where alkenes or allenes showed satisfying performance. All attempts to use other partners in the intermolecular [5 + 2] cocyclization reaction failed, even allenes showed no reaction. The different reactivity of alkynes and allenes could be used to apply alleneynes in [5 + 2] cocyclizations and do sequential reactions. After the reaction with the alkyne moiety the allene would give an additional handle for further functionalization and transformations of the resulting vinylallene.

In 1999 for example Ito et al. reported a new catalytic carbonylative [4 + 1] cocyclization of vinylallenes (Scheme 66).[111, 112]



Scheme 66. [4 + 1] cocyclization developed by Ito et al.

This reaction might be applicable to the system resulting from the [5 + 2] cocyclization of a vinylcyclopropane with an alleneyne to form a bicyclic ring system. Besides the regular [5 + 2] cocyclization, a [5 + 2 + 1] cocyclization reaction under an atmosphere of CO may be conceivable. This would make the synthesis of tricyclic ring systems **241** doable in an extremly efficient way (Scheme 67). Ito et al. used rhodium as a catalyst. This opens the possibility of running both steps in one pot with the same catalyst as a domino-sequence.



Scheme 67. Proposed reaction pathways of $[5+2]$+$[4+1]$ cocyclizations.

The primary goals for this project can be summarized as follows:

- Establishment of a general synthesis of alleneynes.
- Testing the compatibility of alleneynes with the $[5+2]$ cocyclization reported by WENDER et al.
- In the case of the anticipated reactivity pattern, the exploration of a following $[4+1]$ reaction.

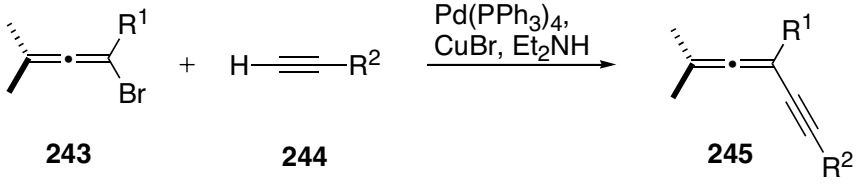
2.1. Alleneynes

2.1.1. Synthesis of starting materials

Two major strategies were applied to prepare alleneynes: Direct SONOGASHIRA coupling of bromoallenes with alkynes and palladium catalyzed coupling of propargyl chlorides with alkynes.[113,114]

2.1.1.1. Preparation of alleneynes by the SONOGASHIRA coupling The bromoallenes were prepared according to literature by reacting propargyl alcohols with HBr and by the CLAISEN rearrangment of 1-bromo-3-(1-ethoxy-vinyloxy)-3-methyl-but-1-yne.[115] In most cases the SONOGASHIRA coupling gave the desired alleneyne in good yield (Table 8). The synthesis of a terminal alkyne was accomplished by the STILLE coupling (Table 8, entry 5).

Table 8. Substrates and results.



243 **244** **245**

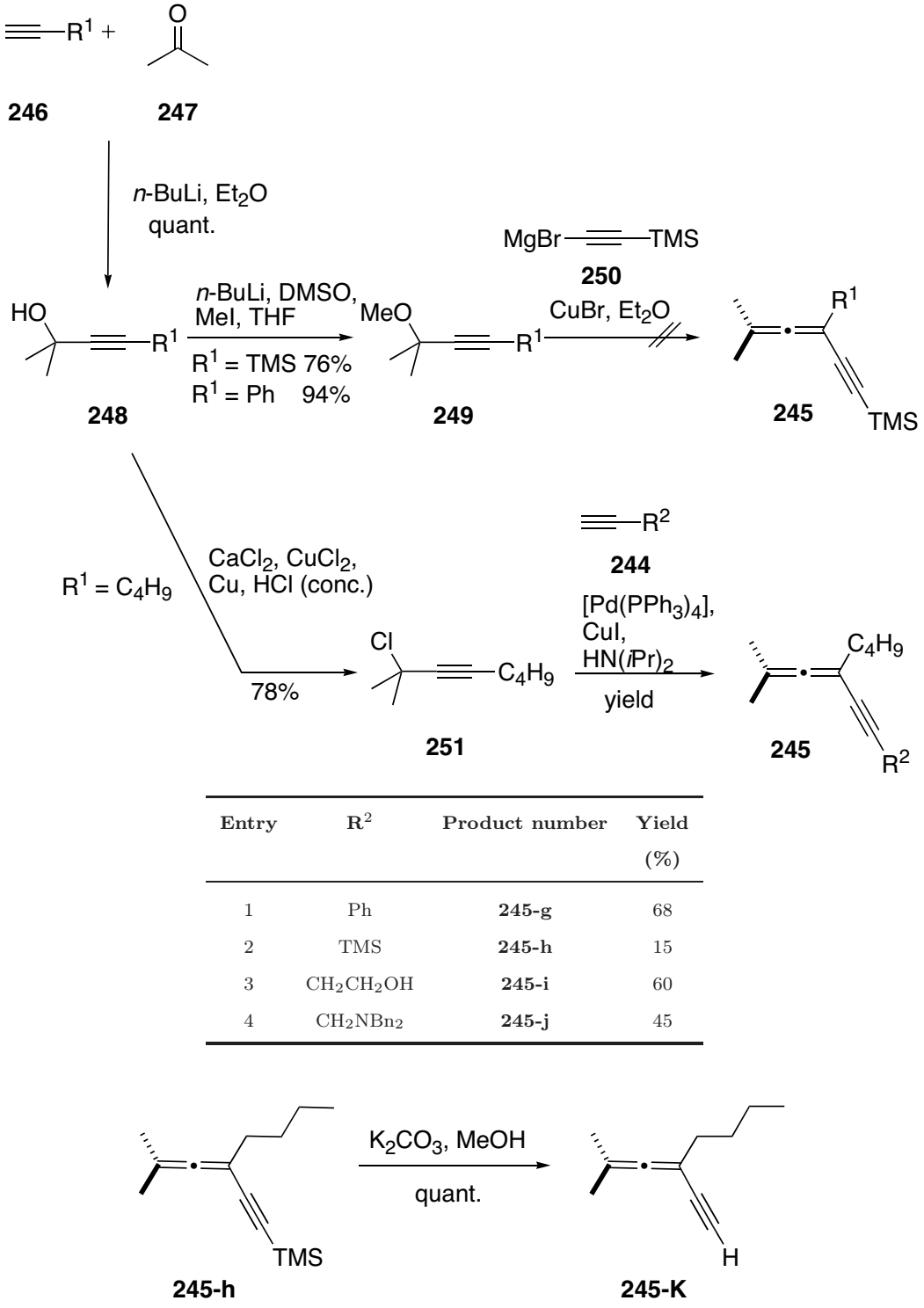
Entry	R^1	R^2	Product number	Yield (%)
1	H	TMS	**245-a**	53
2	H	Ph	**245-b**	84
3	H	CO_2Me	**245-c**	–
4	H	CH_2OMe	**245-d**	71
5	CH_2CO_2Et	H	**245-e**	54[a]
6	CH_2CO_2Et	Ph	**245-f**	69

[a] STILLE coupling

2.1.1.2. Preparation of alleneynes by palladiumcatalyzed coupling of propargyl chlorides First attempts to couple a TMS-acetylene GRIGNARD **250** copermediated to a 3-methoxy-propyne **249** failed. The second, yet more successful method started from propargyl chlorides **251**, which were also prepared according to literature from 1-hexyne by addition of acetone (**247**), followed by an exchange of the alcohol functionality with Cl.[113,116] Palladiumcatalyzed coupling gave the desired product. The small alkyl-chain was chosen to minimize sterical problems (Table 9).

Deprotection of the TMS-acetylene **245-h** was done by stirring the compound in a saturated solution of K_2CO_3 in MeOH to give the desired terminal alkyne in quantitative yield.

Table 9. Substrates and results.



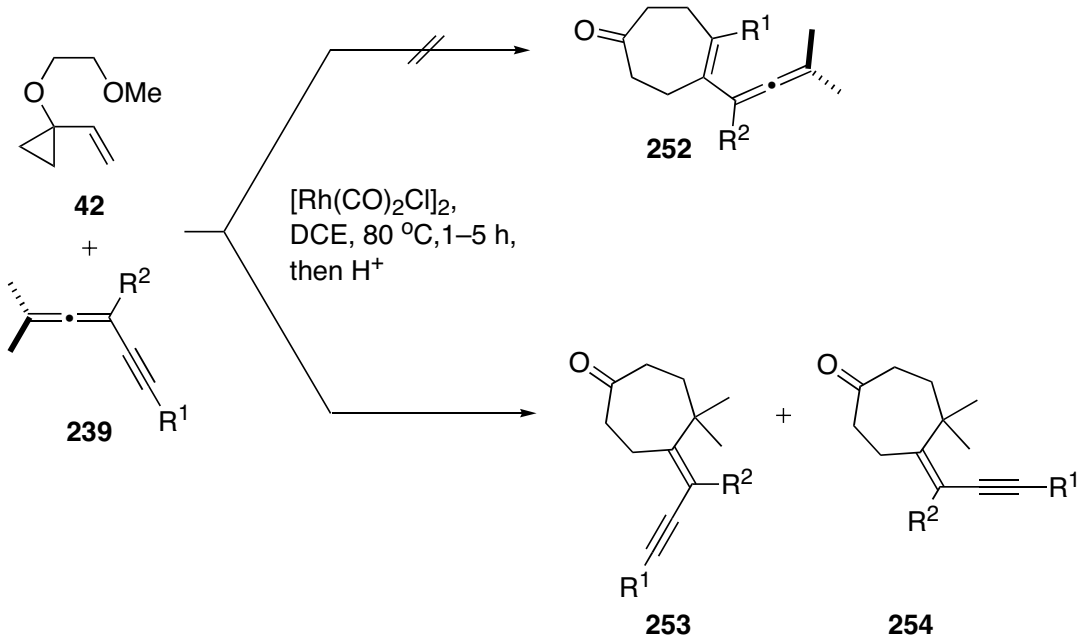
Entry	R^2	Product number	Yield (%)
1	Ph	**245-g**	68
2	TMS	**245-h**	15
3	CH_2CH_2OH	**245-i**	60
4	CH_2NBn_2	**245-j**	45

Scheme 68. Deprotection of TMS-acetylene **245-h**.

2.1.2. Results of the cocyclization

With the alleneynes available the first cocyclizations were done. Two products were obtained with the right molecular mass but the NMR-data did not fit to the desired allenocycloheptene (Scheme 69).

Interestingly, vinylcyclopropane **42** did not react with the alkyne, but selective with the *exo*-double bond of the allene. *This exhibits the first intermolecular rhodium-catalyzed [5 + 2] cocyclization with a double bond.*

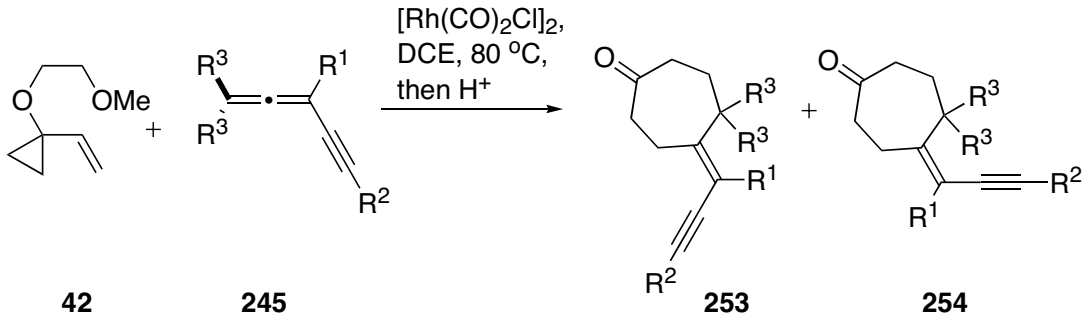


Scheme 69. Unprecedented reactivity of the allenemoiety in a [5 + 2] cocyclization reaction.

2.1.2.1. Subsitution at the alleneyne After the elucidation of the structure (see discussion of spectral data 2.4.2) and with this novel reactivity of alleneynes the compatibility of different substituents had to be tested. A variety of alleneynes was prepared according to the synthetic strategies outlined above. The results of their application in the formal [5 + 2] cycloaddition with 1-(2-methoxy-ethoxy)-1-vinyl-cyclopropane (**42**) are summarized in Table 10.

Most alleneynes reacted in good yield. Terminal alkynes in the alleneyne seemed to impede the reactivity. No reaction could be observed. Even after 24 h (Table

Table 10. Different substituents.



42 **245** **253** **254**

Entry	$\mathbf{R^1}$	$\mathbf{R^2}$	$\mathbf{R^3}$	**Time (h)**	**Yield (%)(253:254)**
1	H	TMS	Me	1.0	95 (1:2)
2	H	Ph	Me	1.0	83 (1:2)
3	H	CH_2OMe	Me	5.0	45 (1:1)
4	CH_2CO_2Et	H	Me	24	No reaction
5	CH_2CO_2Et	Ph	Me	1.0	92 (1:2)
6	C_4H_9	Ph	Me	3.0	80 (2:3)
7	C_4H_9	TMS	Me	1.0	80 (2:5)
8	C_4H_9	CH_2CH_2OH	Me	1.0	65 (1:1.2)
9	C_4H_9	CH_2NBn_2	Me	1.0	22 (1:2)
10	C_4H_9	H	Me	36	No reaction
11	H	Ph	H	36	Decomposition

10, entry 4) resp. 36 h (Table 10, entry 10) only starting material was detected in the GC/MS along with some decomposition. alleneyne **245-l** in (Table 10, entry 11) with its terminal allene functionality decomposed under usual cyclization conditions (80 °C). Despite conducting the reaction at room temperature no turnover occured. Heating to 40 °C led to decomposition of the alleneyne yet again. The reason for this observation is probably the low stability of penta-3,4-dien-1-ynyl-benzene (**245-l**) unlike all the other alleneynes tested. It changed color from colorless to dark red upon being at room temperature under air for 15 minutes.

Other functionalities like TMS, Ph, alkyl or ester were well tolerated. A methoxy group (Table 10, entry 3), a free alcohol (Table 10, entry 8) or even an amine (Table 10, entry 9) could form the desired cycloadduct. Especially the last three functional groups were of interest, because the enhanced reactivity of alleneynes in formal [5 + 2] cycloaddition reactions can be rationalized by a coordinating effect of the alkyne moiety with the rhodium catalyst. As a matter of fact, if substrates with lone electron pairs free for coordination were to be used the reaction might be inhibited. The lower yields for OMe or NBn_2 could be explained by this effect. Interestingly, the free alcohol, though featuring a lone pair at the oxygen atom was converted to the desired cycloadduct in good yield.

2.2. Other allenes

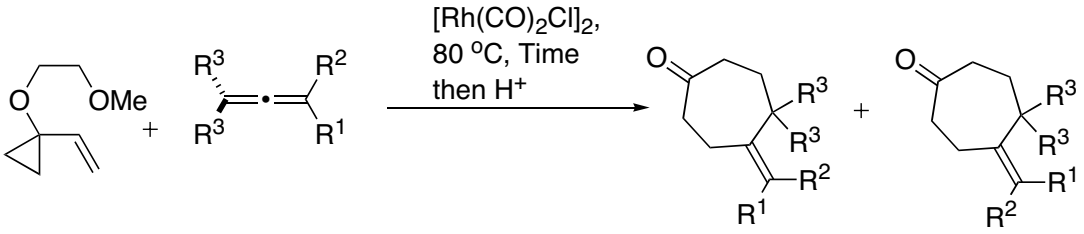
After succeeding with the alleneynes a closer look at allenes in general was undertaken. Different allenes were prepared and tested in the [5 + 2] cocyclization.

2.2.1. Results of the cocyclization

Table 11 shows the results of Rh catalyzed [5 + 2] cocyclization reactions with different allenes, which were prepared according to literature procedures.[113] As a first substrate 2-methyl-4-phenyl-buta-2,3-diene (**255-a**) was chosen. It corresponds to entry 2 in Table 10, which gave the desired cycloadduct in good yield. However, in this case after 36 h no cycloadduct was detected. In the case of alleneynes the alkyne moiety might function as a coordination group. Phenyl would not be able to have the same effect. Therefore 1-methoxypropa-1,2-diene (**255-b**) was tested (Table 11, entry 2), but again no reaction was observed. As mentioned above activation by coordination might be the cause for the unexpected reactivity of alleneynes. Another reason could originate from the electronic properties of the alleneynes, hence

allenobromide **255-c**, allenene **255-d**, allenonitrile **255-e** and allenoester **255-f** were chosen for following attempts. It were only the nitrile group and the styrene moiety that seemed to have a similar effect as an alkyne and made a reaction possible. This result strengthens the assumption that special coordinating properties are necessary. Interestingly allenoesters did not react in the same fashion. The ability of the esterfunctionality to coordinate with rhodium seems to be insufficient to enable the reaction.

Table 11. Results of allenes in Rh catalyzed [5 + 2] cocyclization.



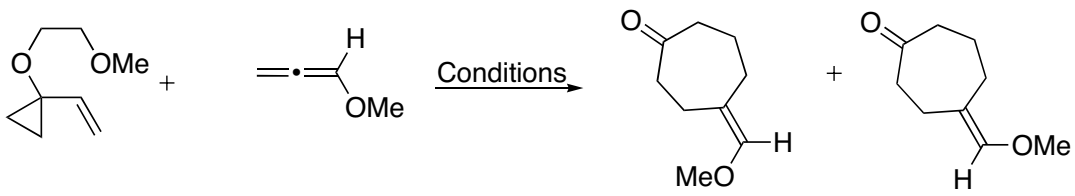
42 **255** **256** **257**

Entry	R^1	R^2	R^3	Time (h)	Yield (%) (256:257)
1	Ph	H	Me	36	No reaction
2	OMe	H	H	36	No reaction
3	Br	H	Me	1.0	Decomposition
4	CH=CHPh	H	Me	1.0	69 (2:1)
5	CN	H	Me	1.0	99 (2:3)
6	CO_2Et	Me	Me	36	No reaction

Screening of cocyclization conditions The use of allenoethers like **255-b** would be very intriguing, because positive results with these substrates would be structural related to enolethers, which are easily accessible (Table 11, entry 2). Therefore 1-methoxy-propa-1,2-diene (**255-b**) was chosen for screening different cocyclization conditions. Results are summerized in Table 12.

Entry 1,3 and 7 of Table 12 refer to the catalysts usually used in the [5 + 2] cocyclization reaction, whereas the catalyst in entry 2 is used for the intermolecular Pauson-Khand reaction. Murakami et al. employed similar catalysts in their

Table 12. Attempts towards a [5 + 2] cocyclization reaction of 1-methoxypropa-1,2-diene (**255-b**).



42 **255-b** **256-b** **257-b**

Entry	Catalyst	Solvent	Temp. (°C)	Time (h)	Result
1	$[Rh(CO)_2Cl]_2$	DCE	60	48	No reaction
2	$Rh(PPh_3)_2(CO)Cl$, $AgSbF_6$	DCE	60	48	No reaction
3	$Rh(PPh_3)_3Cl$, $AgSbF_6$	DCE	60	48	No reaction
4	$[Rh(COD)(CH_3CN)_2]SBF_6$	DCE	60	48	No reaction
5	[Rh(COD)(dppbe)]OTf	DCE	60	48	No reaction
6	[Rh(COD)(dppe)OTf	DCE	60	48	No reaction
7	$[Rh(CO)_2Cl]_2$	DCE	120	24	Sealed tube, decomposition, polimerisation

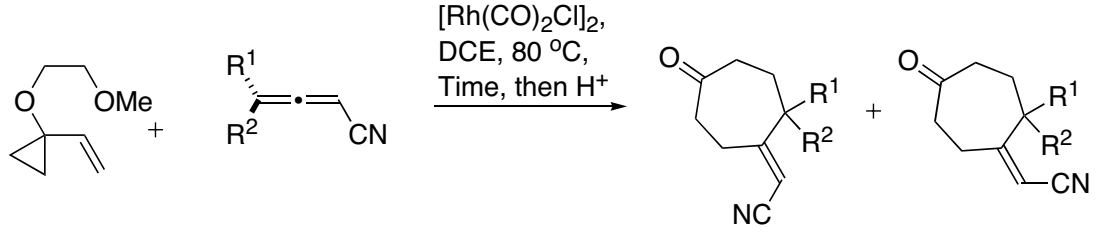
[4 + 1] cocyclization of vinylallenes,[111,112] but none of the reactions led to the product. An eventual loss of the allene was prevented by running the reaction in a high pressure flask (Table 12, entry 7). Moreover, the high pressure should facilitate the cocyclization. Unfortunately the experiment yielded only decomposed or polymerized material (GC/MS).

Analyzing the color of the reaction mixture a stable Rh-allene complex, which does not participate in a further reaction, is most likely. This was confirmed by literature, which refers to the formation of stable Rh-allene complexes.[117]

Allenonitriles – different substitution Besides other functional groups different substitution patterns of allenonitriles were assayed. The results of the cocyclizations are outlined in Table 13.

The unsubstituted allenonitrile **258-a** did not give any cycloadduct. During the reaction a white precipitate was formed. This may be an evidence for polymerization, which is known in literature for unsubstituted allenes (Table 13, entry 2) It is

Table 13. Different allenonitriles.



42 **258** **259** **260**

Entry	R^1	R^2	Time (h)	Yield (%) (259:260)
1	Me	Me	1.0	99 (2:3)
2	H	H	36	No reaction
3	H	Me	1.0	52 (1:2)
4	$CH_2CH_2CH_2CH_2CH_2$		1.0	99 (5:2)[a]

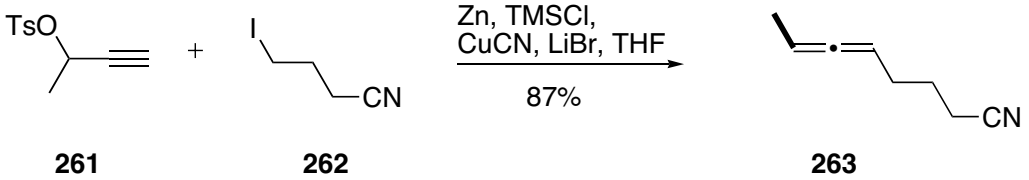
also known that already one single substituent is sterically too demanding to allow polymerization. This was confirmed by the reaction of penta-2,3-dienenitrile (**258-b**), which gave the desired cycloadducts **259-b** and **260-b** in moderate yield (52%) (Table 13, entry 3). Even sterically more encumbered allenonitriles did reacted (Table 13, entry 4). Actually, the higher steric demand enhanced the performance and led to the desired product in nearly quantitative yield.

Different tetherlengths between allene and nitrile Until now the coordinating group was always located directly next to the allene. In the following survey different tetherlenghts between allene and nitrile were explored.

The syntheses of the compounds with 0–2 carbon tethers are known in literature. Octa-5,6-dienenitrile (**263**) was prepared from 4-iodo-butyronitrile (**262**) and toluene-4-sulfonic acid 1-methyl-prop-2-ynyl ester (**261**).

The results of the cycoaddition are summarized in Table 14.

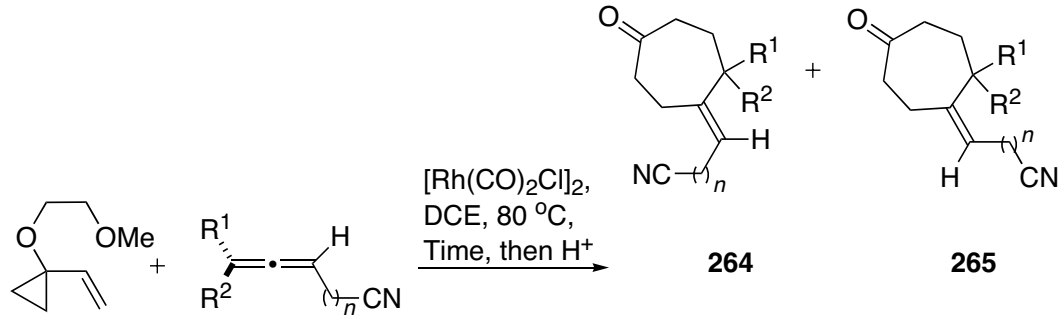
Interestingly enough conjugation of the coordinating group with the allene did not seem to be necessary. Allenonitriles with a spacer of 1-3 carbon atoms still reacted in the same yield. The longer the spacer, though, the more reaction with the *endo*-double bond of the allene moiety took place. The ratio of *endo* to *exo* in entry 4 was nearly 1:1 (measured by NMR).



261 **262** **263**

Scheme 70. Exemplary preparation of octa-5,6-dienenitrile (**263**).

Table 14. Different allenonitriles.



42 **263** **264** **265** **266** **267**

Entry	R^1	R^2	*n*	Time (h)	Yield (%) (264:265)
1	H	Me	0	1.0	52 (1:2)[a]
2	H	Me	1	1.0	56 (1:1.4)[b]
3	H	Me	2	1.0	58[c]
4	H	Me	3	2.0	58[d]

[a]Isomers are not assigned yet.
[b]Isomers are not assigned yet. – Reaction with the *endo*-double bond was observed, too (8%).
[c]Different isomers could not be separated by column chromatography, reaction with *endo*- and *exo*-double bond was observed.
[d]= c, but ratio of the reaction with *endo*- and *exo*-double bond of 1:1.

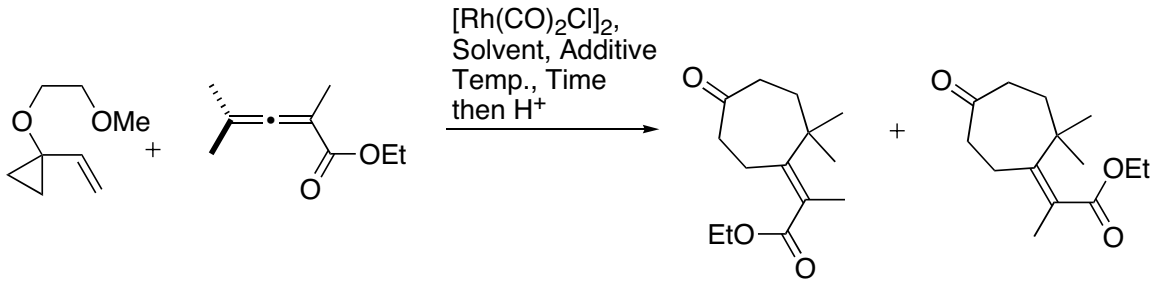
2.3. Nitriles as additives

The experiments with spaced allenonitriles showed that there does not seem to be a direct interaction between the coordinating group and the reacting allene. That suggests that there is the possibility of adding an 'external' nitrile to modify the catalyst in a similar way as a coordination group in alleneynes and allenonitriles.

2.3.1. Allenoester

Allenoester **255-f** did not show any reaction under the standart [5 + 2] conditions (1 mol% catalyst, DCE, 80 °C). Acetonitrile was tested as the simplest nitrile with concentrations from 0.01 equivalents to the use as solvent. The reactions were carried out with 10 mol% of catalyst. The control experiment, however, showed that even without any nitriles as additives a reaction with 10% yield could be observed. Generally all yields are significantly higher with additives. The results are summarized in Table 15. An increase in temperature also enhanced the reactivity and strengthens the hypothesis of a relatively stable allene-Rh complex (Table 15, entry 7).

Table 15. Nitriles as additives in the reaction of allenoester **255-f** with VCP **42**.



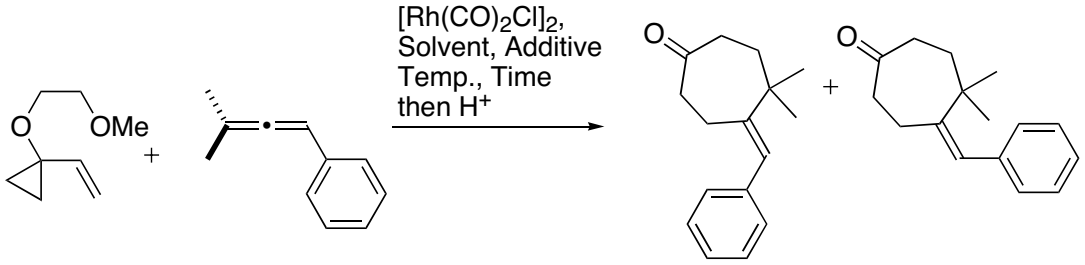
42 **255-f** **256-f** **257-f**

Entry	Catalyst loading (mol%)	Additive	Solvent	Temp. (°C)	Time (h)	Yield (%)
1	2	–	DCE	80	36	No reaction
2	10	CH_3CN (1 eq.)	DCE	80	24	17
3	10	CH_3CN (solv.)	DCE	80	24	Decomposition
4	10	CH_3CN (0.01èq.)	DCE	80	24	16
5	10	PhCN (1èq.)	DCE	80	24	14
6	10	–	DCE	80	24	9
7	1	–	TCE	110	24	15

2.3.2. Phenylallene

Phenylallene (**255-a**) was selected as a second substrate to test the possibility of activation by adding nitriles. The allenoester with its carbonyl group has still a potential to assist in the reaction, phenylallene (**255-a**) should not exhibit such coordinating function. However, running the reaction with 10 mol% of rhodium led again to formation of the desired cycloadduct. The conversion of **255-a** with VCP **42** with a catalyst loading of 1 mol% could significantely be increased independent from the added nitrile. Just fumarnitrile and tetracyanoethene reacted with the substrates under the reaction conditions. Unfortunately, it has not been possible to assign a structure yet (Table 16).

Table 16. Nitriles as additives in the reaction of phenylallene **255-a** with VCP **42**.

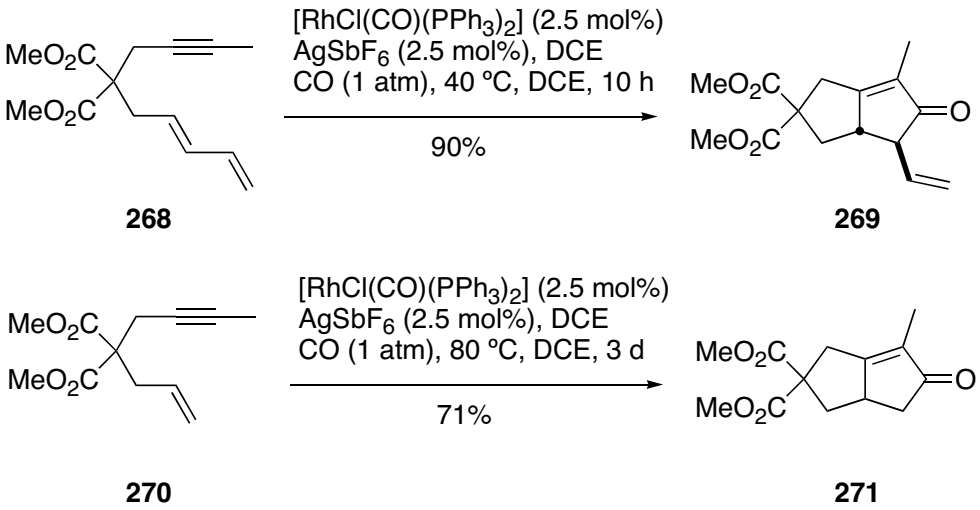


42 **255-a** **256-a** **257-a**

Entry	Catalyst loading (mol%)	Additive	Solvent	Temp. (°C)	Time (h)	Conversion (%)
1	2	–	DCE	80	36	No reaction
2	10	–	DCE	80	48	12
3	1	CH_3CN (1eq.)	DCE	80	48	8
4	1	PhCN (1eq.)	DCE	80	48	5
5	1	CH_2CHCN (1eq.) (1eq.)	DCE	80	48	8
6	1	CNCH=CHCN	DCE	80	48	Other product
7	1	$CN_2C=CCN_2$ (1eq.)	DCE	80	48	Other product
8	1	$CNCH_2CH_2CN$ (1eq.)	DCE	80	48	7

2.4. Alkenes

After realizing the necessity of a coordinating group in order to make the reaction successful, alkenes were tested. As illustrated above vinylallenes showed good reactivity in [5 + 2] cocyclization reactions. If alleneynes undergo cycloaddition reactions with VCP **42**, dienes might be able to react in the same way. This enhancement of reactivity was also observed in the case of the rhodium-catalyzed PAUSON-KHAND reactions.[118] In that case it was possible to dramatically accelerate the reaction. Some substrates did only react with the assistance of a second alkene.



Scheme 71. Enhancement of reactivity by dienes in PAUSON-KHAND reactions.

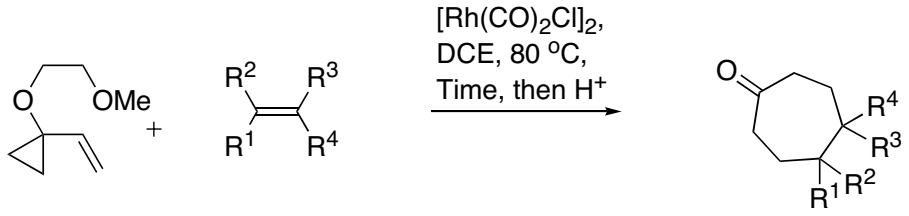
Another alkene, that may have suitable coordination features is acrylonitrile. Experiments with spaced allenonitriles proof, that the selectivity of the reaction is highly dependent on the possible arrangement in the transition state of the catalyst. This is the reason why the nitrile functionality in acrylonitrile might be too close to the reactive site. Taking these considerations onboard, a spacer might solve this problem – thinkable are simple, flexible alkyl tethers or more rigid aromatic bridges. One promising candidate to test the last assumption made above, which was subjected to the [5 + 2] conditions, is *ortho*-cyanostyrene (**272-f**). The different spacer between alkene and nitrile might make the reaction possible. Fumarnitrile was considered to enable the reaction by a possible double coordination of both nitrile functionalities instead of one nitrile and one allene double bond. If the extraordinary reactivity of allenonitriles is, at least partially, due to their electron withdrawing properties, simi-

lar substituents in electronegativity and electronwithdrawing properties like Cl may have a good chance reacting in a cocyclization process. CRAMER investigated the coordination of a varierty of olefines with Rh(I) complexes. He observed a stabilization effect of electronegative groups. [119] Another possibility of increasing reactivity is to add strain to a doublebond. For these reasons norbornene (**272-d**) was also chosen as substrate.

2.4.1. Results of the cocyclization

All substrates mentioned above were subjected to the usual [5 + 2] cocyclization conditions. Unfortunately none of these substrates reacted in the desired fashion (Table 17). During the [5 + 2] cocyclization reaction the color usually changed from yellow to brown/black. However, in most cases of the reaction with olefins the reaction stayed yellow or orange the whole course. This speaks for a stable Rh-complex, which can not participate in desired catalytic reaction.

Table 17. Cyclization attempts of alkene precursors.

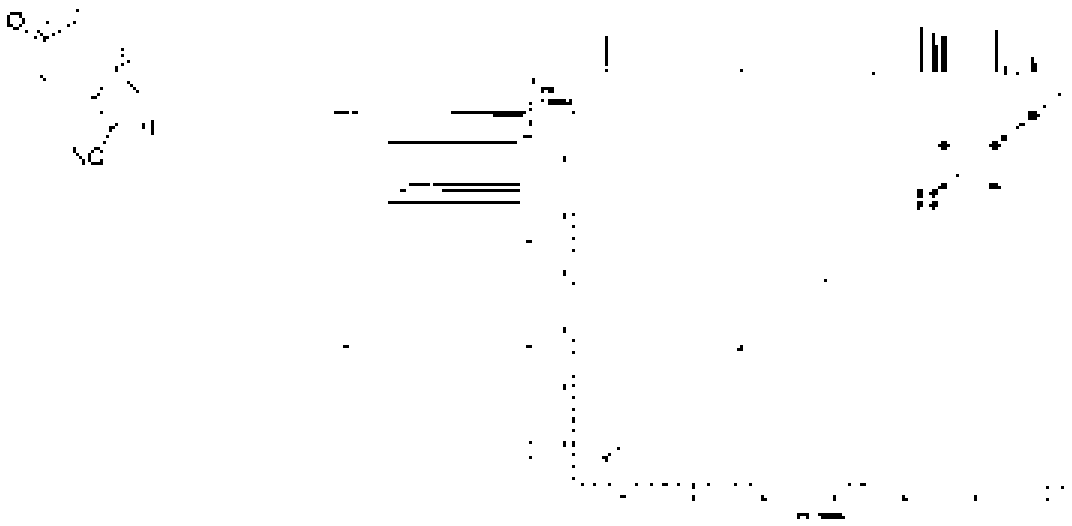


42 **272** **273**

Entry	R^1	R^2	R^3	R^4	Time (h)	Result
1	$CCH_3{=}CH_2$	Me	H	H	36	Decomposition
2	CN	H	H	H	36	No reaction
3	Cl	H	H	Cl	36	Decomposition
4	Norbornene				36	No [5 + 2]
5	CN	H	CN	H	36	No reaction
6	*o*-CNPh	H	H	H	36	No reaction

2.4.2. Disscussion of the spectral data

To elucidate and assign the structure of the two isomers of the cocyclization extensive NMR-data was collected. The outcome of the reaction was assigned by ^{1}H-, ^{13}C-, COSY-, HSQC-, HMBC- and NOE-NMR studies, exemplary demonstrated for the cycloadducts of the reaction of vinylcyclopropane **42** and 4-methyl-penta-2,3-dienenitrile (**255-e**). 2-H and 3-H, resp. 6-H and 7-H showed a strong correlation in the COSY-NMR. The absolute assignment was done by HSQC- and HMBC-NMR, exemplary shown in Scheme 73 for isomer **256-e**.

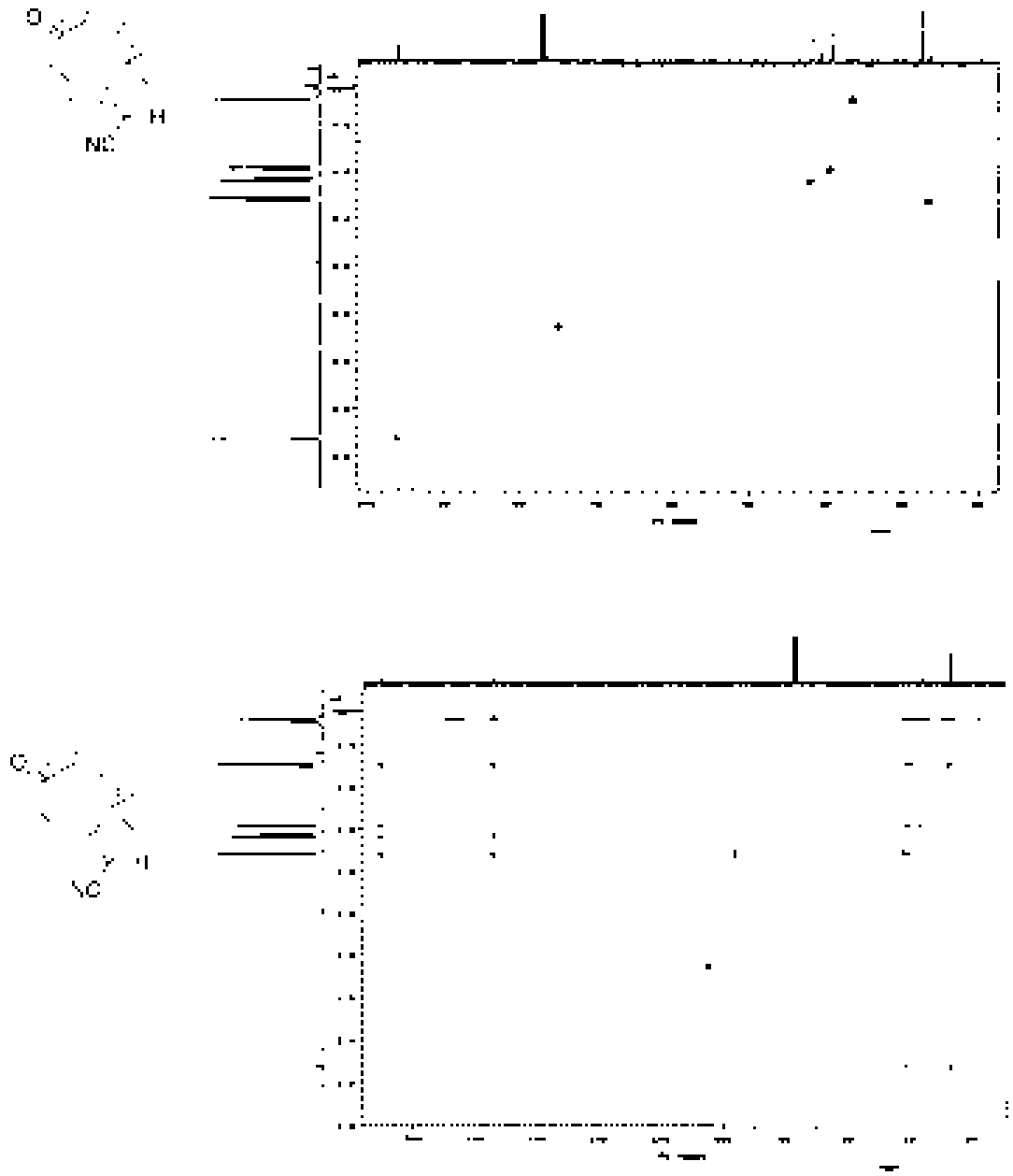


Scheme 72. COSY-NMR.

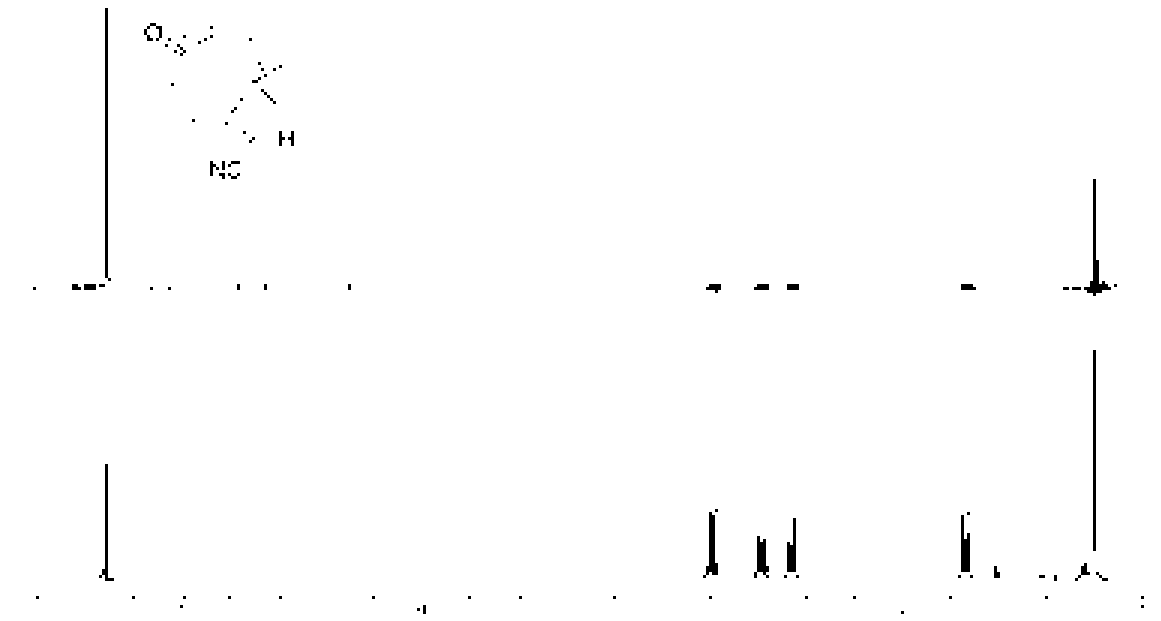
The two isolated isomers can be rationalized as (*E*)- and (*Z*)-isomers. The mapping to the corresponding structure was done by 1D-NOE. For the isomer **256-e**, when irradiated on the vinyl-H, a strong NOE-signal was detected with C-6, while the other isomer, **257-e**, showed a strong NOE-signal with the two methyl groups (Scheme 74 and 75). In addition the alkyne moiety was also proven by IR.

^{1}H- and ^{13}C-NMR of all other compounds show similar signals and correspond in 2D-NMR, too.

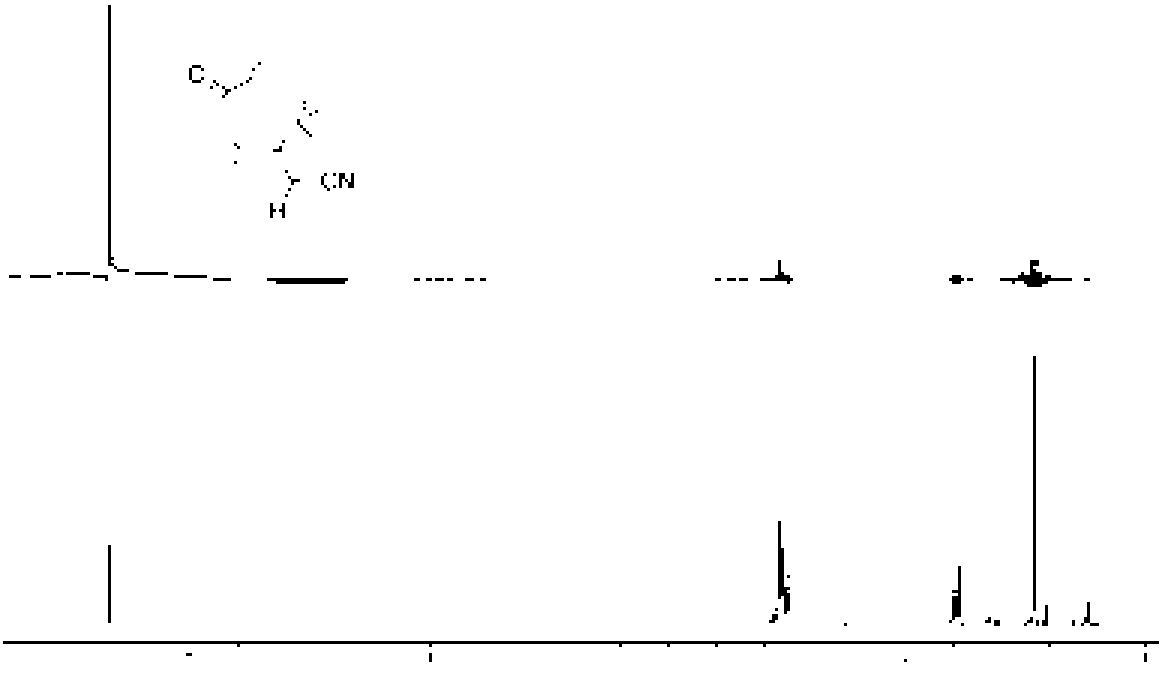
To entirely ensure the assigned structure, the two isomers of 4-4-dimethyl-5-[3-(trimethyl-silanyl)-prop-2-ynylidene]-cycloheptanone (**253-a**) and (**254-a**) were re-



Scheme 73. HSQC- and HMBC-NMR.

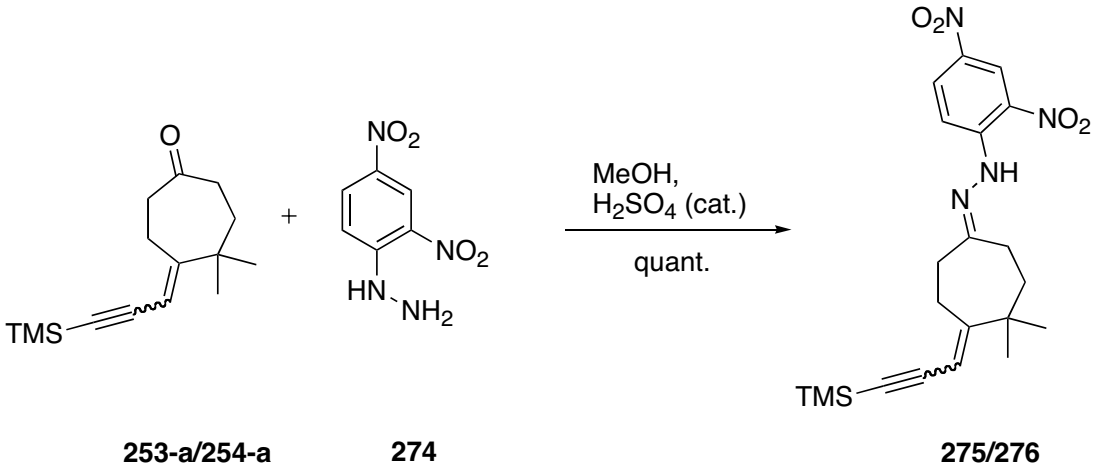


Scheme 74. 1D-NOE-NMRspectra of **256-e**.



Scheme 75. 1D-NOE-NMRspectra of **257-e**.

acted with (2,4-dinitro-phenyl)-hydrazine (**274**) to transform these compounds in crystaline substances. Unfortunately up to now no crystals suitable for X-ray analysis could be obtained.



Scheme 76. Reaction of 4,4-dimethyl-5-[3-(trimethyl-silanyl)-prop-2-ynylidene]-cycloheptanone (**253-a**) and (**254-a**) with (2,4-dinitro-phenyl)-hydrazine (**274**).

2.5. [5 + 2 + 1] Cocyclization of alleneynes

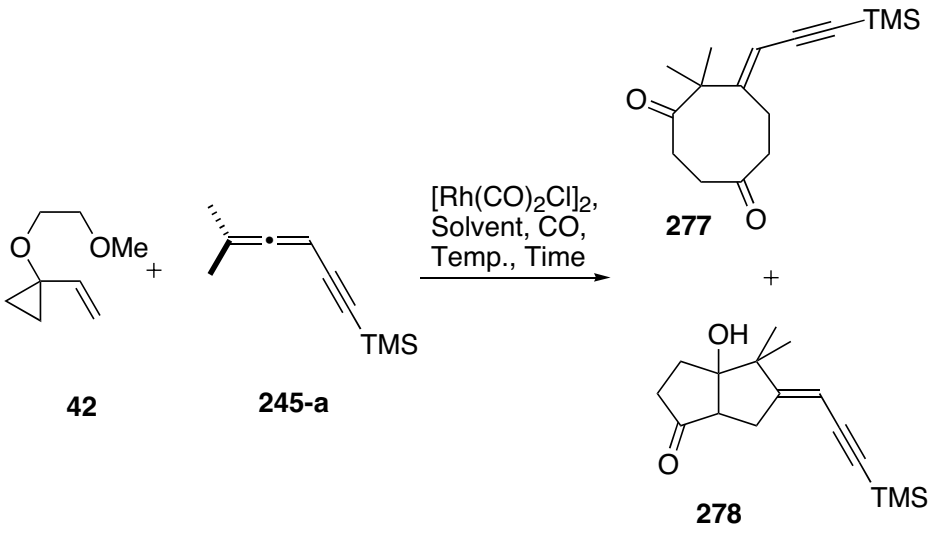
WENDER et al. already showed the possibility of incorporating CO during the cocyclization by running the reaction under a CO atmosphere as mentioned in the introduction. In order to check the possible analogy between alkynes and allenes trimethyl-(5-methyl-hexa-3,4-dien-1-ynyl)-silane (**245-a**) was reacted with vinylcyclopropane **42** under an atmosphere of CO. Different solvents were screened. The best result was achieved, like in the alkyne case, with dioxane at 60 °C and $[Rh(CO)_2Cl]_2$ as catalyst. Besides the desired bicyclo[3.3.0]octane the 'non-closed' eight membered ring was isolated. The results are summerized in Table 18.

When the vinylcyclopropane **42** or trimethyl-(5-methyl-hexa-3,4-dien-1-ynyl)-silane (**245-a**) were treated with CO and $[Rh(CO)_2Cl]_2$ in dioxane for 24 h at 60 °C, no reaction was observed. After additing the second reaction partner the cocyclization proceeded smoothly. Due to an increase the CO pressure to 2 atm the yield was boosted to 94% (GC, 89% isolated). The reaction time was much longer and the ratio of **277** to **278** changed from 1:2.2 to 1:1.3.

Interestingly only the two isomers shown in Table 18 could be isolated. The structural assignment was again done by extensive NMR-studies. A NOE-signal of the vinyl-H with the *gem*-dimethyl proved the conformational correlation.

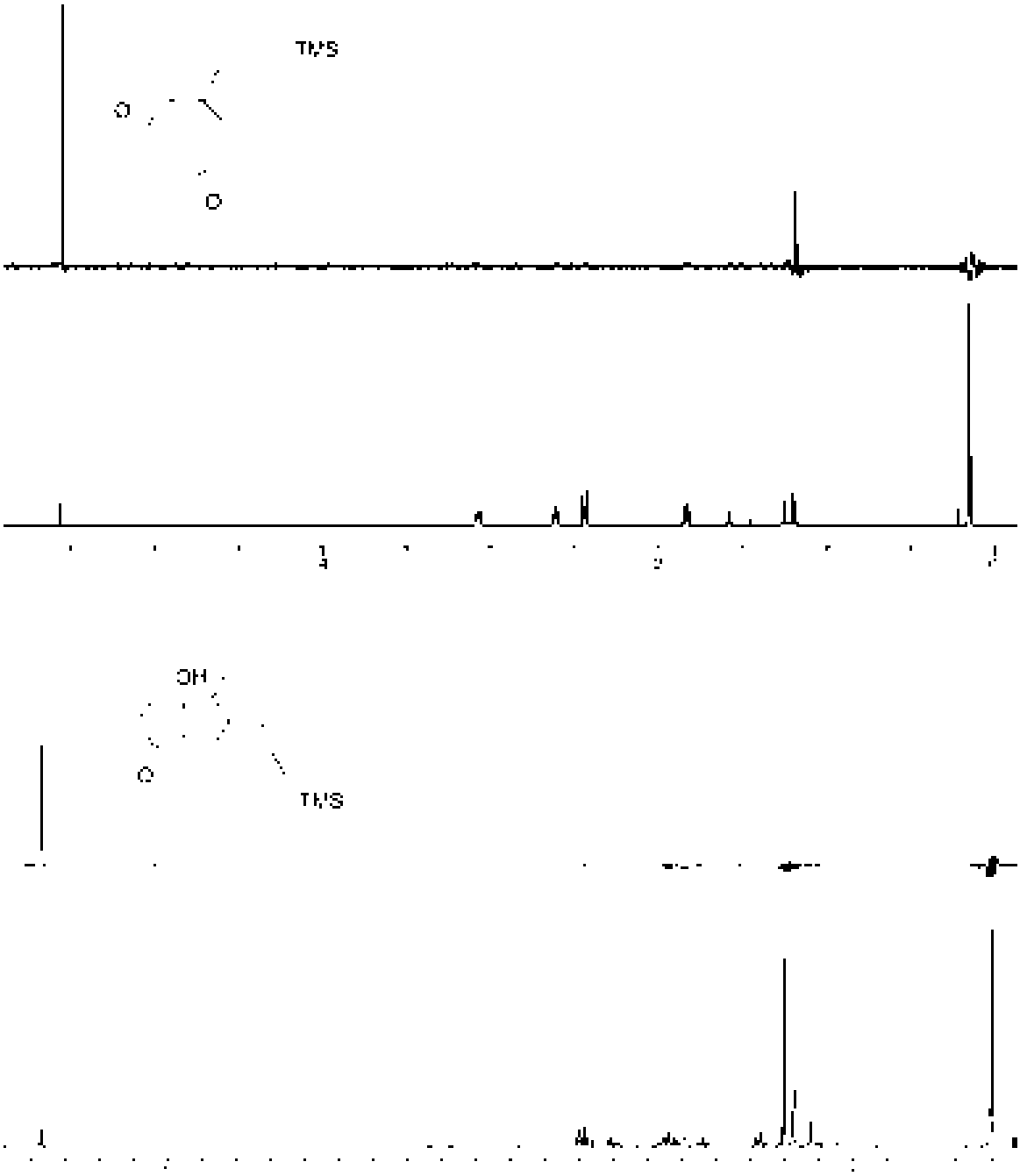
Noteworthy even is that no activation by means of a carbonyl group is necessary as in the case published by WENDER et al. This underlines, together with its higher reaction rate compared to the [5 + 2 + 1] cocyclization reaction with alkynes, the enhanced reactivity of alleneynes.

Table 18. Solvent study in the [5 + 2 + 1] cocyclization reaction of alleneyne **245-a** with VCP **42**.



Entry	Solvent	CO Pressure (atm)	Temp. (°C)	Time (h)	[5 + 2 + 1][a] (%)	[5 + 2][a] (%)
1	DCE	1.0	80	1.0	–	92
2	DCE	1.0	RT	72	8	–
3	DCE	1.0	50	1.0	45	8
4	Acetone	1.0	50	24	48	46
5	THF	1.0	50	1.0	72	7
6	Dioxane	1.0	60	1.0	88 (62)	7
7	Toluene	1.0	60	1.0	63	5
8	TCE	1	60	1.0	42	11
9	Dioxane	2.0	60	15.0	94 (88)	–

[a]GC yield (isolated yield)



Scheme 77. 1D-NOE-NMR spectrum of **277** and **278**.

2.6. Mechanistic studies

To elucidate the reaction mechanism or to improve the reaction different aspects were investigated:

- Catalyst loading
- Isomeric ratio
- Different catalysts
- Temperature

All parameters were investigated in the reaction of trimethyl-(5-methyl-hexa-3,4-dien-1-ynyl)-silane (**245-a**) and 1-(2-methoxy-ethoxy)-1-vinyl-cyclopropane (**42**).

2.6.1. Catalyst loading

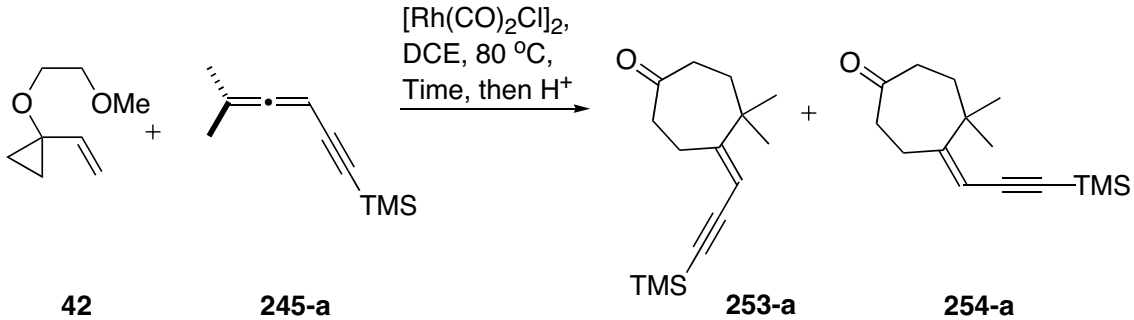
The reaction of trimethyl-(5-methyl-hexa-3,4-dien-1-ynyl)-silane (**245-a**) and 1-(2-methoxy-ethoxy)-1-vinyl-cyclopropane (**42**) was done with catalyst loadings from 2 mol% rhodium (1 mol% of $[Rh(CO)_2Cl]_2$) down to 0.1 mol% rhodium. The results are summarized in Table 19. With 2 mol% rhodium the reaction occured after 20 min, whereas with 1 mol% and 0.5 mol% the reaction still proceeded, but at a much slower pace. There was no reaction observed by GC at a catalyst loading of 0.1 mol% rhodium, not even after 48 h. Therefore a catalyst loading of 1 mol% of $[Rh(CO)_2Cl]_2$ is recommended to avoid long reaction times.

2.6.2. Ratio of isomers during the reaction course

The ratio of the two isomers was followed by GC during the course of the reaction. At all times the ratio stayed a little bit above 1:2. This observation points to a kinetically controlled mechanism (Scheme 78).

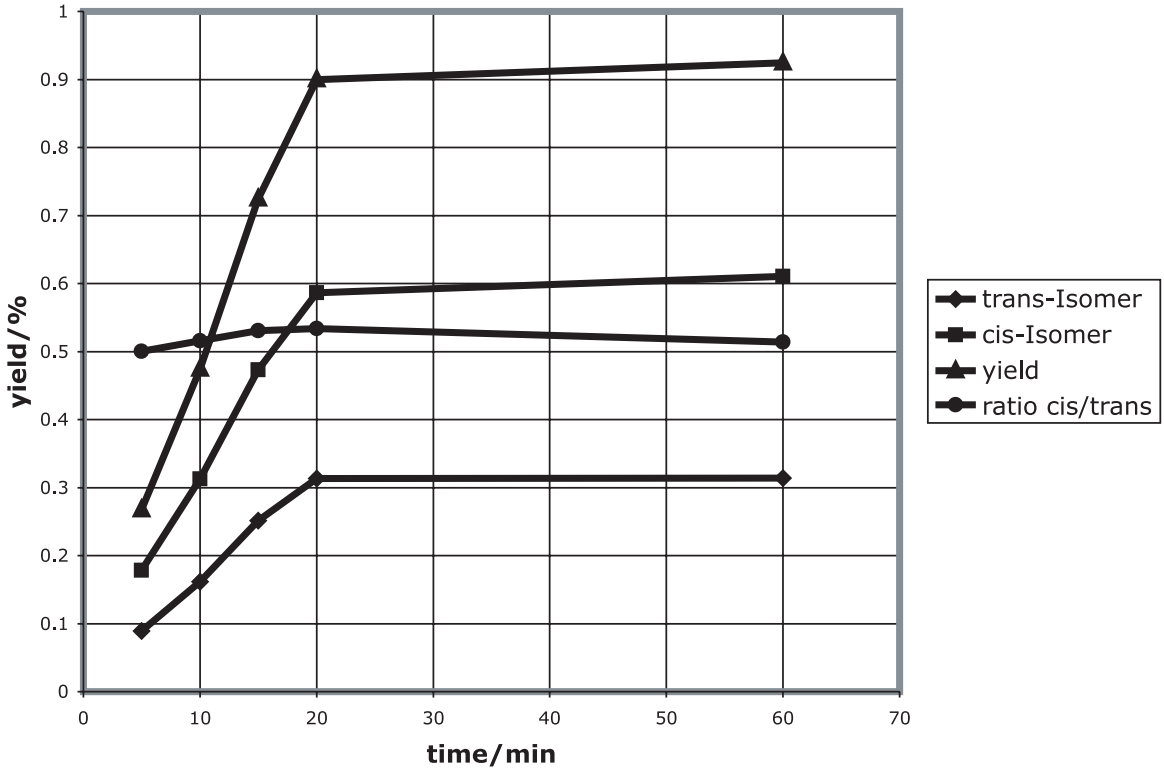
The two hydrolyzed isomers **253-a** and **254-a** were resubjected to the reaction conditions ($[Rh(CO)_2Cl]_2$, DCE, 80 °C, 1 h), but no isomerisation was observed. Even though partial hydrolization of the enol to the ketone occured during the reaction, total conversion to the keto-form was achieved by adding 1% HCl in EtOH after the reaction. Therefore it might be possible that only the enol-form, which is initially formed before hydrolization, is able to isomerize. To check this hypothesis the crude

Table 19. Variation of catalyst loading.



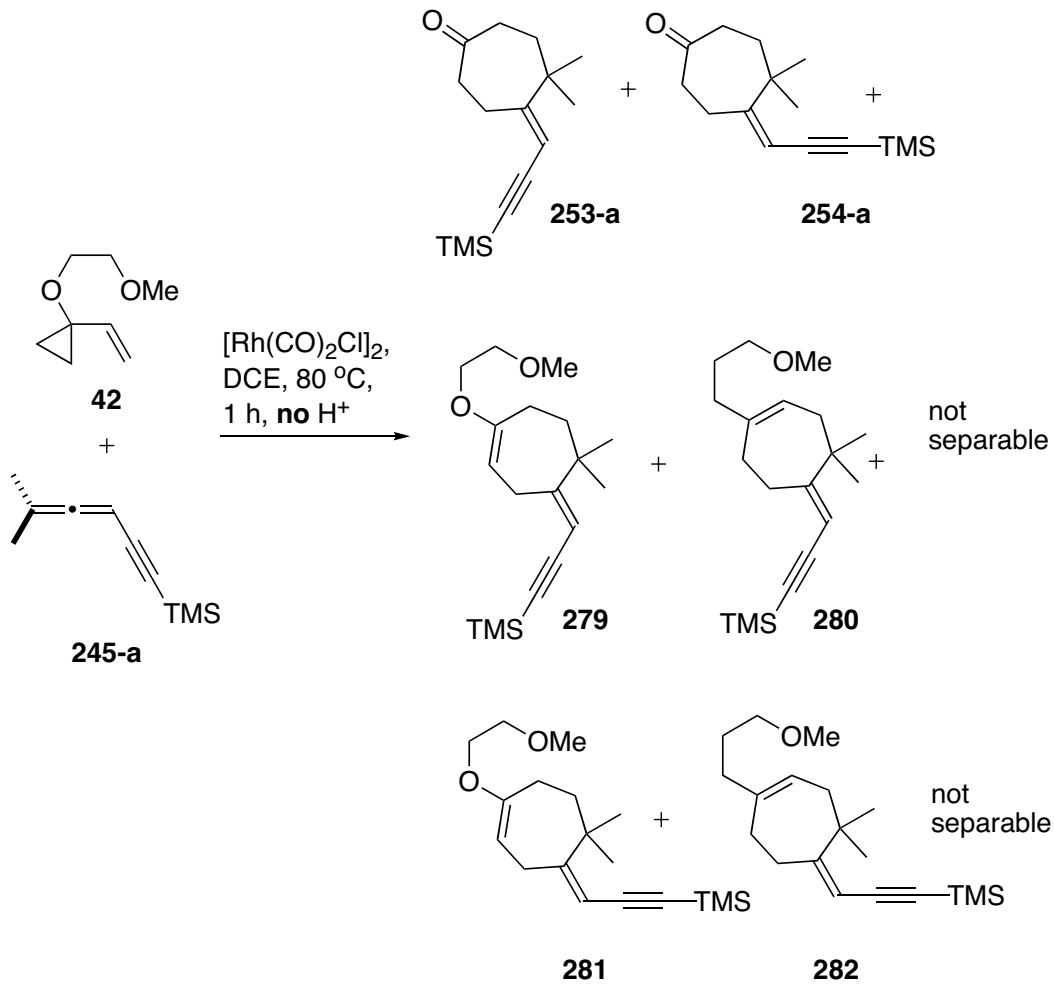
42 **245-a** **253-a** **254-a**

Entry	Catalyst loading (mol%)	20 min (%)	1.0 h (%)	20 h (%)	48 h (%)
1	2.0	90	92	–	–
2	1.0	–	47	96	–
3	0.5	–	7	12	30
4	0.1	–	0	0	0

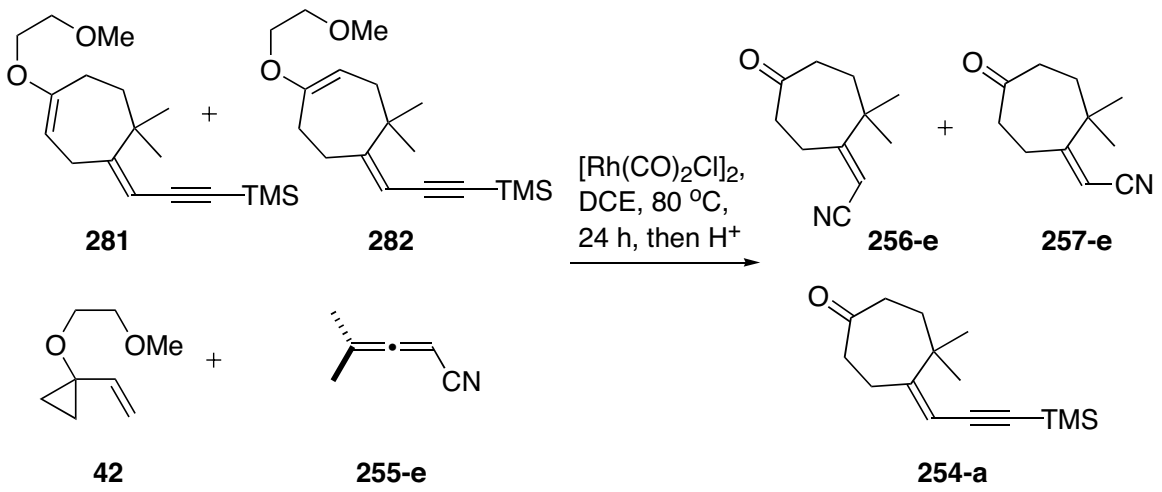


Scheme 78. Isomeric ratio during the course of the reaction.

reaction mixture was chromatographed before hydrolyzation. As expected a mixture of the two isomers of the keto-form and the four possible isomers of the enolform were isolated. The two (*E*)- resp. (*Z*)-enolisomers were resubjected to the reaction conditions along with 4-methyl-penta-2,3-dienenitrile (**255-e**) to ensure the same reaction conditions. The nitrile **255-e** was chosen, because it was easily separable from the other reaction products by flash column chromatography. However, no isomerization was observed. This proved that no post-reaction isomerization took place.



Scheme 79. [5 + 2] cocyclization without acidic work up.



Scheme 80. Experiment to test post-reaction isomerization.

2.6.3. Different catalysts

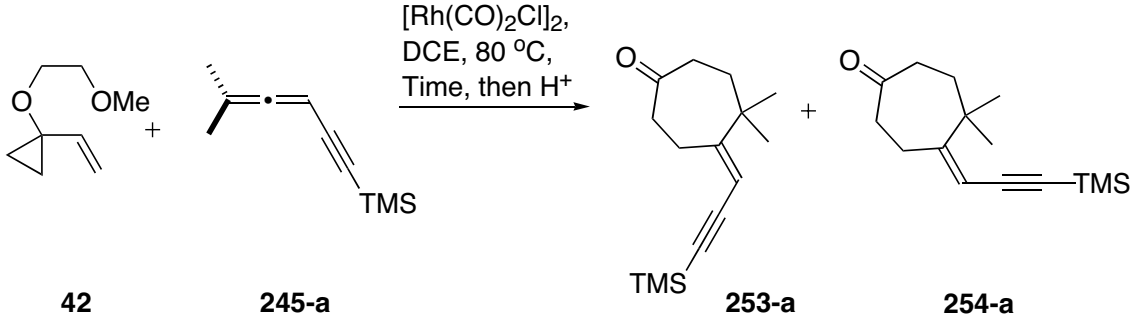
Under standard conditions ($[Rh(CO)_2Cl]_2$, DCE, 80 °C) two isomers were obtained. By modifying the catalyst the ratio might be shifted to one or the other side. To test this hypothesis different catalysts were tested. The results are summarized in Table 20.

Best results were obtained with $Rh(PPh_3)_2(CO)Cl/AgSbF_6$. Only one isomer was detected by GC. Unfortunately the reaction was much slower. After two days only approximately 30% of product were formed. This result led to the conclusion, that CO as ligand seemed to play an important role. Second, the formation of the isomers might also be dependent on the steric bulk of the environment around the metal.

2.6.4. Temperature and solvent dependence

To see if the ratio of isomers was temperature dependent the reaction was conducted at different temperatures and with different solvent systems. The reaction time of 1h was not optimized. It was expected that TFE would enhance the reactivity, hence this reaction was checked after 15 min and showed almost complete conversion with only a slight loss of yield. But even at room temperature the ratio of the two isomers was basically 1:2. The reaction was stopped after 5.5 h. At that time some starting material was still remaining.

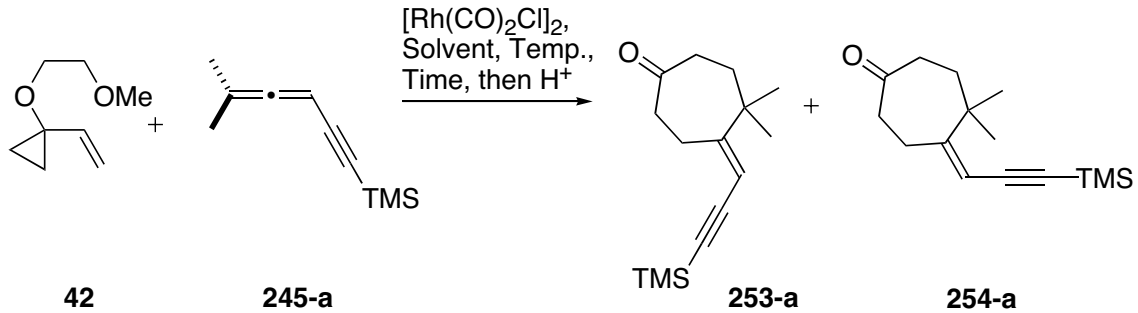
Table 20. Different catalysts in the [5 + 2] cocyclization (yields determined by GC).



42 **245-a** **253-a** **254-a**

Entry	Catalyst	4 h (%)	20 h (%)	42 h (%) (253-a:254-a)
1	$[Rh(dppbe)Cl]_2$	0	0	1.5 (1:2)
2	[Rh(COD)(dppbe)]OTf	0	0	0
3	[Rh(COD)(dppe)OTf	0	0	0
4	$Rh(PPh_3)_3Cl/AgSbF_6$	0	0	15 (1:8)
5	$Rh(PPh_3)_2(CO)Cl/AgSbF_6$	10 (0:1)	20 (0:1)	29 (0:1)
6	$[Rh(COD)(CH_3CN)_2]SBF_6$	0	3 (2:3)	20 (1:2)
7	$[Rh(CH_2CH_2)Cl]_2$	0	0	0
8	$[CpRh(CNCH_3)_3]PF_6$	0	0	0

Table 21. Temperature dependence.



42 **245-a** **253-a** **254-a**

Entry	Solvent	Temp. (°C)	Time (h)	Yield (%) (253-a:254-a)
1	DCE	80	1.0	95 (1:2)
2	DCE, TFE (10 %)	80	0.25	84 (1:2)
3	DCE	RT	5.5	25 (1:2)[a]

[a]GC/MS still showed starting material.

2.6.5. Discussion of a possible mechanism

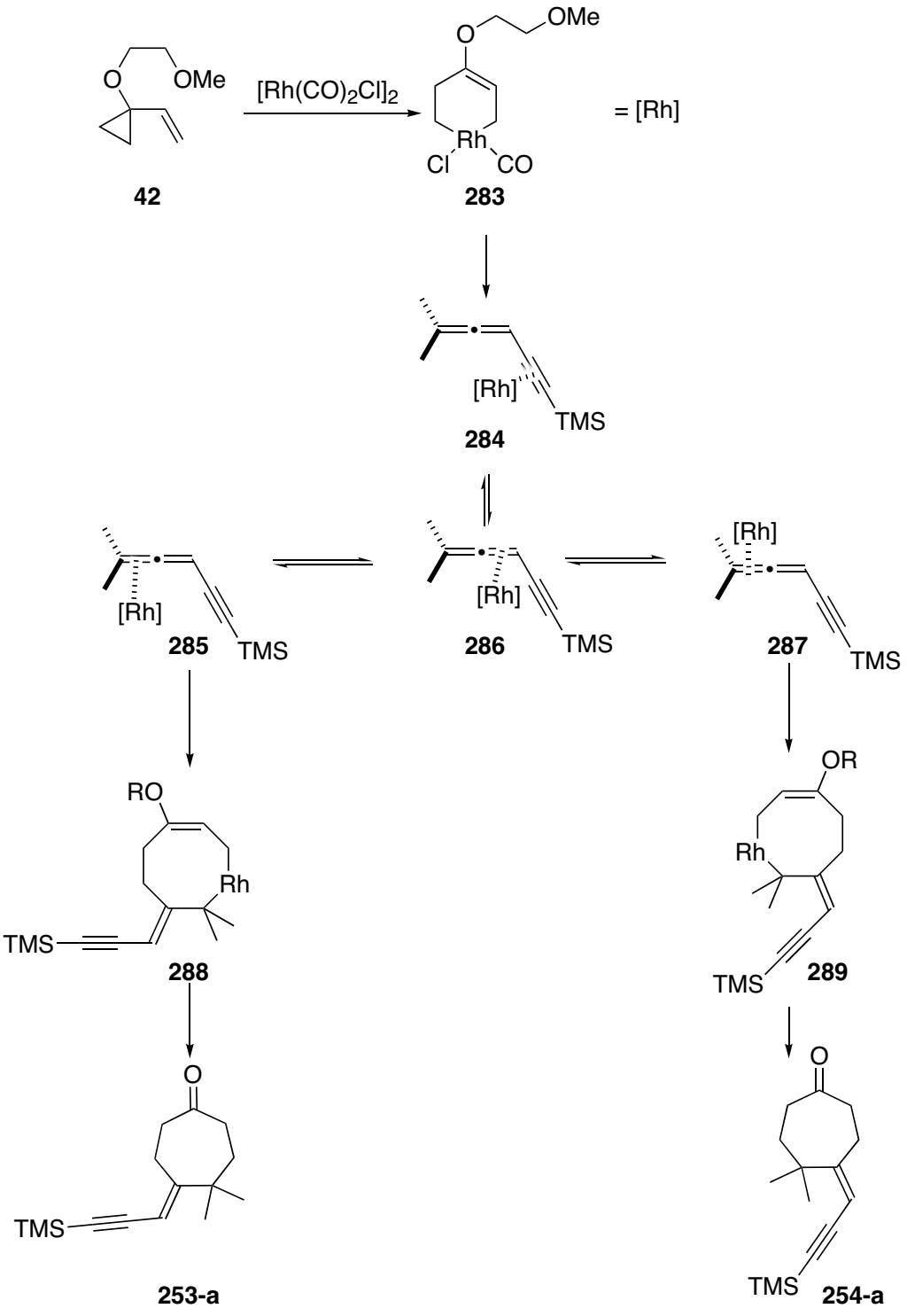
A first hypothesis is based on the initial coordination of the rhodium with the triple bond **286**, followed by a migration of the rhodium to the *exo*-double bond of the allene **285** or **287**. The isomeric ratio is determined by the steric bulk of the ligand field. This corresponds with the result that $Rh(PPh_3)_2(CO)Cl/AgSbF_6$ gave only one isomer. This mechanism does not answer the question why the reaction takes place selectively at the *exo*-double bond of the allene. Furthermore it does not explain the reactivity of the allenonitriles with a spacer between allene and nitrile.

A second mechanism assumes a two-fold coordination of the allene and the coordination group **291**. This explains, why 'normal' allenes do not work and why the spacer-allenonitriles reacted in that specific fashion. The longer the spacer the easier the rhodium can coordinate to both double bonds of the allene. But this mechanism can not justify the isomeric ratio. Looking at the intermediates a reversed ratio would be more likely.

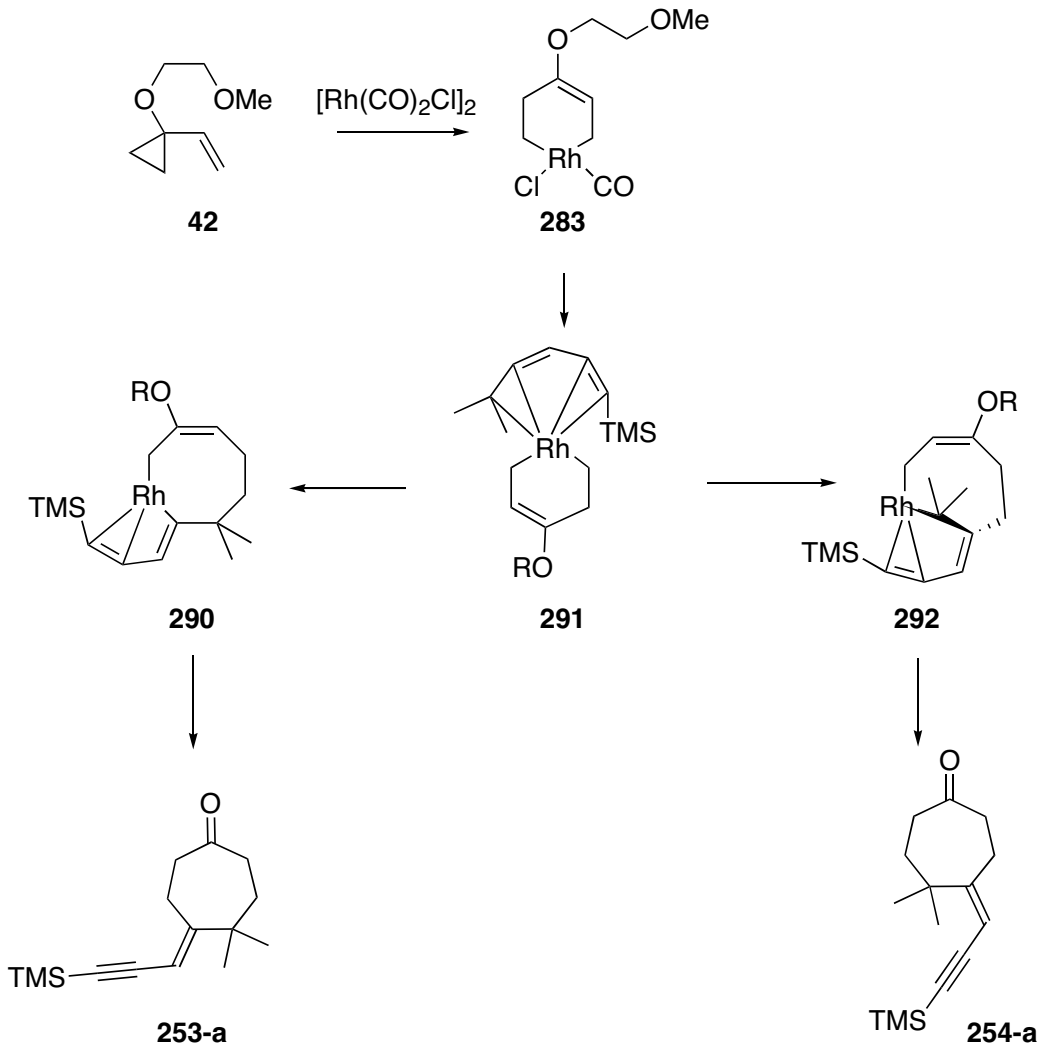
The reactivity of phenylallene **255-a** and allenoester **255-f** suggests that allenes are a rather good ligands for rhodium. The reaction stops after the catalyst is consumed – the yield corresponds with the catalyst loading. Furthermore a bright yellow or orange color during the whole course of the reaction supports the idea of a stable complex. This can be confirmed in literature.[120,121] Therefore the presence of an additional coordination group in the substrate might not help with the coordination but with the release of the rhodium after the cyloaddition to bring it back into the catalytic cycle. The exact mechanism still remains a topic of controversity.

2.7. Summary

The first intermolecular $[5+2]$ cocyclization with allenes was achieved. Essential for the reaction is a coordinating group like alkyne, alkene or nitrile. Allenes without an activation like alleno ester **255-f** or phenylallene **255-a** reacted only with a stoichiometric amount of catalyst. The yield corresponded with the amount of catalyst. The additional coordinating group should not be in conjugation. If the coordinating group is adjacent to the allenemoiety the reaction takes place selectively with the *exo*-double bond of the allene. With increasing spacerlength between the allene and the coordinating group more reaction with the *endo*-double bond was observed. A variety of substituents was tolerated. Only if there is no substituent on the alkyne or the allene moiety the reaction is inhibited. In addition, a variety of alkenes were



Scheme 81. Possible Mechanism I.



Scheme 82. Possible Mechanism II.

tested, but none of them reacted in the desired [5 + 2] fashion. It was also possible to show that alleneynes reacted in the known [5 + 2 + 1] reaction in good yields. The reported condition (dioxane, 60 °C) worked best in this case, too. An increase in CO pressure enhanced the total yield to 94%. Two different mechanism to explain the extraordinary reactivity of alleneyens in the [5 + 2] cocyclization were discussed.

C. Experimental

1. General

Air and moisture sensitive reactions were carried out in oven-dried (150 °C) glassware sealed with rubber septa under a positive pressure of dry nitrogen or dry argon from a manifold, unless otherwise indicated. Similarly sensitive liquids and solutions were transferred via syringe or stainless steel cannula. Reactions were stirred with oven-dried, Teflon®-coated magnetic stir bars, or Teflon®/glass stir vanes attached to a mechanical stirrer if indicated.

Reactions run at room temperature (rt) refers to a temperature range of 22–28 °C. Elevated temperatures were achieved by partial immersion of the reaction vessel into silicone oil baths. The temperature was controlled using a variable autotransformer and measured externally as the temperature of the oil bath unless otherwise indicated. Reduced temperatures were achieved by partial immersion of the reaction vessel into cold baths. A temperature of 0 °C was achieved with an ice/water bath; –78 °C was achieved with a dry ice/acetone bath. The temperature was measured externally as the temperature of the cold bath unless otherwise indicated.

Organic solutions were concentrated in vacuo using a rotary evaporator with a membrane pump. Residual solvents were removed from nonvolatile samples on a vacuum line with a pressure of 0.1–2 mmHg. Glassware that was base-washed was soaked overnight in a solution of potassium hydroxide and wet isopropanol. The glassware was then rinsed with deionized water and oven-dried (150 °C).

1.1. Reagents and Solvents

Unless otherwise indicated, reagents and solvents were purchased and used without further purification, with the following exceptions. $[Rh(CO)_2Cl]_2$ was purchased from Strem Chemical Co. and stored at –20 °C under nitrogen. Ether and THF were distilled from a sodium-benzophenone ketyl under nitrogen, or pre-dried over 1/16″bead 4 Å molecular sieves and passed through a column of activated alumina under a pres-

sure of dry nitrogen. Toluene was distilled from sodium under nitrogen prior to use, or predried over 1/1″bead 4 Å molecular sieves and passed through a column of activated alumina under a pressure of dry nitrogen. CH_2Cl_2 was distilled from calcium hydride under nitrogen, or pre-dried over 1/1″bead 4 Å molecular sieves and passed through a column of activated alumina under a pressure of dry nitrogen. 1,2-Dichloroethane (DCE) and 1,1,2,2-tetrachloroethane (TCE) were purchased anhydrous and stored over activated molecular sieves.
The concentration of alkyllithium solutions was determined by titration of a solution of 2,2,2′-trimethylpropionanilide in THF or DME.[122]

1.2. Chromatography

Analytical TLC was performed with 0.25 mm silica gel 60F plates with 254 nm fluorescent indicator from Merck. Plates were visualized by ultraviolet light and treatment with acidic *p*-anisaldehyde stain followed by gentle heating. Chromatographic purification of products was accomplished by flash column chromatography, as described by Still et al.[123] on E. Merck silica gel 60, 230–400 mesh. Solvent was eluted at a flow rate of approximately two inches/min with 2–9 pounds of nitrogen pressure. Analytical Gas Chromatography (GC) was performed using a Hewlett Packard HP 6890 Series GC with a 5% phenyl dimethylpolysiloxane capillary column.

1.3. Physical and Spectroscopic Measurments

Nuclear magnetic resonance (NMR) spectra were measured on a Varian INOVA 500 (^{1}H at 500 MHz, ^{13}C at 125 MHz), Varian Mercury 400 (^{1}H at 400 MHz, ^{13}C at 100 MHz), Varian Gem-300 (^{1}H at 300 MHz, ^{13}C at 75 MHz) or Bruker AM 250 (^{1}H at 250 MHz, ^{13}C at 62.9 MHz), magnetic resonance spectrometer. Data for ^{1}H NMR spectra are reported as chemical shifts in parts-permillion (ppm) downfield from a tetramethylsilane internal standard (0 ppm) or the residual solvent peak (7.26 for $CHCl_3$). The following abbreviations are used to describe spin multiplicity: s = singlet; brs = broad singlet; d = doublet; t = triplet; q = quartet; dd = doublet of doublets; dt = doublet of triplets; dq = doublet of quartets; tt = triplet of triplets; tq = triplet of quartets; ddd = doublet of doublet of doublets; ddt = doublet of doublet of triplets; m = multiplet. Coupling constants (J) are reported in Hertz (Hz). Data for ^{13}C NMR spectra are reported as chemical shifts in ppm based on the middle peak of the solvent peak (77.0 for $CDCl_3$) and were recorded with complete

heterodecoupling. Short cuts for the assignment of the signals: *c*Pr = cyclopropyl, Ph = phenyl, Ar = aryl, *c*Hex = cyclohexyl, * = exchangeable signals. Infrared spectra were recorded on a Perkin-Elmer 1600 Series or Perkin-Elmer Spectrum BX Fourier transform spectrometer (FTIR) and are reported in wavenumbers (cm^{-1}). High-resolution mass spectra (HRMS) were recorded at the NIH regional mass spectrometry facility at the University of California, San Francisco. Reported mass values are with error limits of ±13 millimass units.

1.4. Preparation of known compounds

The following compounds were prepared according to literature procedures: 3-Cyclopropyl-2-methyl-acrylic acid ethyl ester and 3-cyclopropyl-acrylic acid ethyl ester according to JORGENSON,[124] bicyclopropyliden-2-yl-methanol according to DE MEIJERE,[125] bicyclopropylidene-2-carbaldehyde according to DE MEIJERE,[126] 2-(3'-bromo-allyloxy)-tetrahydro-2*H*-pyran, 2-(3'-bicyclopropyl-2'-yl-allyloxy)-tetrahydro-2*H*-pyran, 3-bicyclopropyl-2-yl-prop-2-en-1-ol and *trans*-2-formyl-cyclopropanecarboxylic acid methyl ester according to LÖHR,[127] (*Z*)-dicyclopropylethylene according to KNOKE,[128] 2-cyclopropyl-prop-2-en-1-ol according to BERLUENGA,[129] trimethyl-(5-methyl-hexa-3,4-dien-1-ynyl)-silane according to WANG,[130] (5-methyl-hexa-3,4-dien-1-ynyl)-benzene according to JEFFERY,[131] (3-methoxy-3-methyl-but-1-ynyl)-benzene, (3-methoxy-3-methyl-but-1-ynyl)-trimethyl-silane, 4-methyl-penta-2,3-dienenitrile, 3-cyclohexylidene-acrylonitrile and penta-2,3-dienenitrile according to BRANDSMA,[113] 2-vinyl-benzonitrile according to WIPF,[132] 5-butyl-7-methyl-octa-5,6-dien-3-yn-1-ol according to GUEUGNOT,[133] 2,4-dimethyl-penta-2,3-dienoic acid ethyl ester according to TROST,[115] bromovinylidene-cyclohexane according to LOEFSTEDT,[134] (3-methyl-buta-1,2-dienyl)-benzene according to RUITENBERG,[135] (5-methyl-hexa-1,3,4-trienyl)-benzene according to PASTO,[136] 3-iodo-propionitrile, 4-iodo-butyronitrile according to YASUI[137] and 5-methyl-hex-4-enenitrile according to JANSEN.[138]

2. General procedures

General Procedure (GP 1): $LiAlH_4$ (287 mg, 7.03 mmol) was suspended in Et_2O (20 mL). The ester (10.0 mmol) was added at 0 °C. The mixture was refluxed over night. After cooling to 0 °C water (0.3 mL) was added and stirring continued for 15 min. Then KOH (15%, 0.3 mL) was added and again stirred for 15 min, followed by the addition of water (0.9 mL). The suspension was stirred at rt until it turned white. The precipitate was filtered off and extensively washed with Et_2O. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (Et_2O in pentane eluant).

General Procedure (GP 2): The ester (1.00 mmol) was dissolved in dry Et_2O or THF (20 mL). DIBALH (1.2 M in toluene, 2.5 mL, 3.00 mmol) was added at –78 °C. The mixture was stirred at that temperature for 1.5 h. Sodiumpotassiumtartrate (sat., 15 mL) was added and the mixture was stirred over night at rt. The aqueous layer was extracted with Et_2O (20 mL, 2 times). Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (Et_2O in pentane eluant).

General Procedure (GP 3): An oven dried, septum capped, 2-neck flask, equipped with a reflux condenser under a positive pressure of argon, was charged with NaH (60% in mineraloil, 44.0 mg, 1.10 mmol) and anhydrous THF (5 mL). The alcohol was added to this suspension (1.00 mmol). The mixture was heated to 50 °C and stirred over night. After cooling to 0 °C the propargyl bromide (1.50 mmol) was added and the reaction mixture stirred for 2 h at rt. The reaction was quenched with NH_4Cl solution (sat., 10 mL). The aqueous layer was extracted with Et_2O (15 mL, 3 times). The combined organic layers were dried over $MgSO_4$ and the solvent removed under reduced pressure. The crude product was purified by flash column chromatography.

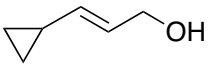
General Procedure (GP 4): An oven dried, septum capped SCHLENK flask under a positive pressure of argon, was charged with catalyst (5.00 μmol) and anhydrous DCE (1 mL). To this was added the cyclization precursor (100 μmol). The test tube was placed in an oil bath preheated to 75–80 °C. The reaction was monitored by TLC. The crude reaction mixture was purified by flash column chromatography.

General Procedure (GP 5): An oven dried SCHLENK flask under a positive pressure of argon, was charged with 2-chloro-2-methyl-octa-3-yne (**251**) (159 mg, 1.00 mmol) and di-*iso*-propylamine (3 mL). Ar was bubbled through the solution for 15 min. Then $Pd(PPh_3)_4$ (58.0 mg, 50.0 μmol) was added and the resulting mixture stirred for 5 min, before subsequently the acetylene (1.20 mmol mmol) and CuI (19.0 mg, 100 μmol) were added. The reaction was stirred at rt for 2 h. After diluting with Et_2O/pentane (1:1, 20 mL) the mixture was washed with NH_4Cl (sat., 10 mL, 2 times), dried over $MgSO_4$ and concentrated under reduced pressure. The residue was purified by flash column chromatography.

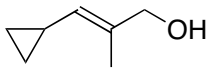
General Procedure (GP 6): An oven dried, septum capped, 16 x 100 mm, disposable, borosilicate glass test tube, under a positive pressure of argon, was charged with $[Rh(CO)_2Cl]_2$ (1.9 mg, 5.00 μmol) and anhydrous DCE (2 mL). To this was added vinylcyclopropane **42** (142 mg, 1.00 mmol), followed by addition of the alkyne (1.20–1.30 mmol). The test tube was placed in an oil bath preheated to 80 °C. The reaction was monitored by TLC. Upon completion, the initially pale yellow solution turned dark red in color. The reaction mixture was treated with 1% HCl in EtOH (0.2 mL) and stirred open to the atmosphere until TLC indicated that the hydrolysis was complete, typically 15–30 min. For the larger scale reactions addition of water (1 equiv.) accelerated the hydrolysis. The resultant mixture was filtered through a short pad of silica gel (Et_2O eluant) and concentrated in vacuo. The residue was purified by flash column chromatography.

3. Exploration of the Rh-catalyzed [5+2] cycloaddition with vinylbicyclopropyls

3.1. 1st-Generation precursors



trans-*3-Cyclopropyl-prop-2-en-1-ol* (**118**) According to GP 1, 3-cyclopropyl-(*E*)-acrylic acid ethyl ester (10.0 g, 71.3 mmol) and $LiAlH_4$ (1.90 mg, 50.1 mmol) were allowed to react in dry Et_2O (250 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yielded 6.30 g of **118** (90%) as colorless oil. – The analytical data correspond to those reported in literature.[141]



*3-Cyclopropyl-2-methyl-prop-2-(*E*)-en-1-ol* According to GP 1, 3-cyclopropyl-2-methyl-(*E*)-acrylic acid ethyl ester (**94**) (2.00 g, 13.0 mmol) and $LiAlH_4$ (347 mg, 9.14 mmol) were allowed to react in dry Et_2O (50 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yielded 1.31 g of 3-cyclopropyl-2-methyl-prop-2-(*E*)-en-1-ol (90%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3321 cm^{-1} (O–H), 3080 (*c*Pr–H), 3003 (C–H), 2917 (C–H), 2861 (C–H), 1674 (C=C), 1429, 1130, 1014 (C–O), 949 (H–C=C–H), 896, 867, 809. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.25–0.38 (m, 2 H, *c*Pr-H), 0.67–0.78 (m, 2 H, *c*Pr-H), 1.40–1.55 (m, 1 H, *c*Pr-H), 1.76 (s, 3 H, C=CCH_3), 1.85 (bs, 1 H, O*H*), 3.97 (s, 2 H, CH_2OH), 4.78 (d, ^3J = 7.2 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 6.72 (*c*Pr-C), 9.78 (*c*Pr-C), 13.97 (C=CCH_3), 68.72 (CH_2OH), 130.54 (vinyl-C), 133.18 (vinyl-C). – MS (70 eV), *m/z* (%): 112 (84) [M^+], 97 (67) [M^+ – CH_3], 95 (18) [M^+ – OH], 81 (66) [M^+ – CH_2OH], 79 (100) [M^+ – CH_3 – OH – H], 77 (38), 71 (41) [M^+ – *c*Pr], 67 (39), 58 (45) [M^+ – CH*c*Pr], 55 (80) [CH*c*Pr$^+$ + H], 53 (51), 43 (90), 41 (98) [*c*Pr$^+$]. – $C_7H_{12}O$ (112.17).

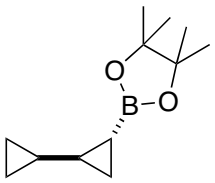
trans-*Bicyclopropyl-2-yl-methanol* (**90**) Lithium (567 mg, 81.8 mmol) was dissolved in liquid NH_3 (500 mL) at −78°C. The solution was stirred for 1 h. Bicyclopropylidenylmethanol (**89**) (3.00 g, 27.3 mmol) in Et_2O (40 mL) was added. After stirring for 4 h at that temperature the reaction was quenched with MeOH (15 mL) in Et_2O (80 mL), and NH_3 was evaporated over night. The residue was dissolved in water (50 mL) and extracted with Et_2O (70 mL, 3 times). Drying over

$MgSO_4$ and evaporation of the solvent gave the crude mixture which was purified by flash column chromatography (33% Et_2O in pentane eluant) affording 2.50 g of the product **90** as colourless oil (82%). – The analytical data correspond to those reported in literature.[139]

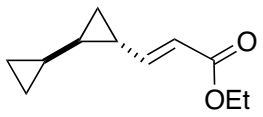
trans-*Bicyclopropyl-2-carbaldehyde* (**112**) DESS-MARTIN-periodinane (4.82 g, 11.4 mmol) was suspended in dry DCM (60 mL). *trans*-Bicyclopropyl-2-yl-methanol (**90**) (850 mg, 7.58 mmol) was added and the resulting mixture stirred for 2 h at rt. After deluting with Et_2O (40 mL) the solution was washed with NaOH (1 M, 100 mL, 2 times). Drying over $MgSO_4$ and evaporation gave the crude product. Purification by flash column chromatography (12% Et_2O in pentane eluant) yielded 743 mg of **112** (89%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3083 cm^{-1} (*c*Pr–H), 3006 (C–H), 2827 (C–H), 2729 (OC–H), 1709 (C=O), 1458, 1432, 1353, 1321, 1236, 1169, 1106, 1048, 1020, 891, 825. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.02–0.22 (m, 2 H, *c*Pr-H), 0.29–0.56 (m, 2 H, *c*Pr-H), 0.84–0.96 (m, 2 H, *c*Pr-H), 1.18–1.25 (m, 1 H, *c*Pr-H), 1.48–159 (m, 1 H, *c*Pr-H), 1.60–175 (m, 1 H, *c*Pr-H), 9.00 (d, ^3J = 6.8 Hz, 1 H, C*H*O). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.71 (*c*Pr-C), 3.83 (*c*Pr-C), 11.27 (*c*Pr-C), 12.99 (*c*Pr-C), 25.00 (*c*Pr-C), 29.41 (*c*Pr-C), 200.94 (*C*HO). – DCI-MS (200 eV, NH_3), *m/z* (%): 238 (5) [2 M + NH_4^+], 128 (80) [M + NH_4^+], 111 (100) [M + H^+]. – Cal. C 76.33, H 9.15; found C 76.19, H 8.96.

2-(2-Cyclopropyl-vinyl)-4,4,5,5-tetramethyl-[1,3,2]dioxaborolane (**107**) Pinacol (7.09 g, 60.0 mmol) was placed in a dry SCHLENK flask under Ar. BH_3•SMe_2 (6.14 mL, 60.0 mmol) was added at 0 °C. The resulting mixture was stirred for 3.5 h at rt. After cooling to 0 °C, cyclopropylacetylene (**146-*c*Pr**) (50% in toluene, 4.00 g, 30.0 mmol) was added and the mixture stirred over night at that temperature. The reaction was diluted with Et_2O (100 mL) and washed with NH_4Cl (sat., 75 mL, 3 times), dried over $MgSO_4$ and the solvent removed under reduced pressure. The crude product was purified by flash column chromatography (5% Et_2O in pentane eluant) to yield 3.90 g of the boronic ester **107** (67%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3084 cm^{-1} (*c*Pr–H), 2979 (C–H), 2931 (C–H), 1635 (C=C), 1457, 1406, 1383, 1327, 1272, 1228, 1144, 1107, 992, 972, 948, 846, 806, 675, 653. – ^{1}H NMR

(250 MHz, $CDCl_3$): δ = 0.48–0.55 (m 2 H, *c*Pr-H), 0.71–0.83 (m, 2 H, *c*Pr-H), 1.21 (s, 12 H, CH_3), 1.41–1.56 (m, 1 H, *c*Pr-H), 5.46 (d, ^3J = 19.0 Hz, 1 H, 1′-H), 6.07 (dd, ^3J = 19.0 Hz, ^3J = 8.5 Hz, 1 H, 2′-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 7.84 (*c*Pr-C), 17.00 (*c*Pr-C), 24.69 (CH_3), 82.85 [$C(CH_3)_2$], 107.76 (C-2′), C-1′not detectable, because of coupling with B. – MS (70 eV), *m/z* (%): 195 (7), 194 (83) [M^+], 179 (100) [$M^+ - CH_3$], 165 (65) [$M^+ - 2\ CH_3 + H$], 153 (39) [$M^+ - C(CH_3)_2 + H$], 137 (43) [$M^+ - C(CH_3)_2 - CH_3$], 136 (52), 101 (20), 95 (17), 67 (7) [*c*Pr-CH=CH], 41 (7) [*c*Pr]. – Cal. C 68.07, H 9.87; found C 68.30, H 9.57.



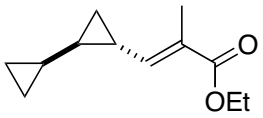
2-Bicyclopropyl-2-yl-4,4,5,5-tetramethyl-[1,3,2]dioxaborolane (**108**) 2-(2-Cyclopropyl-vinyl)-4,4,5,5-tetramethyl-[1,3,2]dioxaborolane (**107**) (2.00 g, 10.3 mmol) was added to a mixture of $Pd(OAc)_2$ (116 mg, 517 μmol) in Et_2O (100 mL). CH_2N_2, prepared from *N*-nitrosomethylurea (21.2 g, 20.6 mmol) and KOH (51 g) in a biphasic mixture of water (71 mL) and Et_2O (177 mL), was added by syringepump over 24 h. The reaction was stirred vigorously open to air, filtered though a pat of celite and the solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (5% Et_2O in pentane eluant) to yield 3.90 g of the boronic ester **108** (67%) as colorless oil. – The analytical data correspond to those reported in literature.[127]

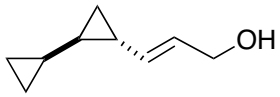


trans-*3-Bicyclopropyl-2-yl-(*E*)-acrylic acid ethyl ester* (**113-H**) NaH (60% in mineraloil, 394 mg, 9.85 mmol) was suspended in DME (20 mL). (Diethoxy-phosphoryl)-acetic acid ethyl ester (**81-H**) (2.21 g, 9.85 mmol) was added and the resulting mixture stirred for 1 h at rt. After the addition of *trans*-bicyclopropylcarboxaldehyde (**112**) (825 mg, 7.58 mmol) in DME (3 mL) the reaction was stirred for 1.5 h at rt and 30 min at 50 °C. The mixture was poured into ice water (80 mL). The aqueous layer was extracted with Et_2O (50 mL, 3 times). Drying over $MgSO_4$ and evaporation gave the crude product. Purification by flash column chromatography (12% Et_2O in pentane eluant) yielded 1.30 g of **113-H** (95%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3080 cm^{-1} (*c*Pr–H), 3004 (C–H), 2935 (C–H), 2903 (C–H), 2872 (C–H), 1717 (C=O), 1643 (C=C), 1449, 1369, 1331, 1302, 1256, 1209, 1145 (C–O), 1101, 1041, 979 (H–C=C–H), 904, 879, 835. – ^{1}H NMR (250 MHz,

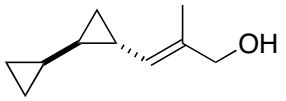
$CDCl_3$): δ = 0.01–0.13 (m, 2 H, *c*Pr-H), 0.30–0.47 (m, 2 H, *c*Pr-H), 0.66–0.88 (m, 3 H, *c*Pr-H), 1.07–1.15 (m, 1 H, *c*Pr-H), 1.26 (t, ^3J = 7.2 Hz, 3 H, CH_3), 1.28–1.39 (m, 1 H, *c*Pr-H), 4.16 (q, ^3J = 7.2 Hz, 2 H, CH_2), 5.80 (d, ^3J = 14 Hz, 1 H, vinyl-H), 6.44 (dd, ^3J = 14 Hz, ^3J = 8.7 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.41 (*c*Pr-C), 3.56 (*c*Pr-C), 11.72 (*c*Pr-C), 13.65 (*c*Pr-C), 14.27 (*C*H_3), 20.82 (*c*Pr-C), 25.04 (*c*Pr-C), 59.93 (O*C*H_2), 117.59 (vinyl-C), 153.32 (vinyl-C), 166.79 (*C*O_2Et). – MS (70 eV), *m/z* (%): 180 (1) [M^+], 151 (1) [$M^+ - C_2H_5$], 135 (1) [$M^+ - OC_2H_5$], 107 (10) [$M^+ - CO_2C_2H_5$], 91 (12), 79 (25) [*c*Pr$C_3H_2^+$], 67 (18), 53 (36), 41 (100) [*c*Pr^+]. – Cal. C 73.30, H 8.95; found C 73.21, H 8.82.

trans-*3-Bicyclopropyl-2-yl-2-methyl-(*E*)-acrylic acid ethyl ester* (**113-Me**) NaH (60% in mineraloil, 248 mg, 6.20 mmol) was suspended in DME (20 mL). 2-(Diethoxy-phosphoryl)-propionic acid ethyl ester (**81-Me**) (1.48 g, 6.20 mmol) was added and the resulting mixture stirred for 1 h at rt. After the addition of *trans*-bicyclopropylcarboxaldehyde (**112**) (525 mg, 4.77 mmol) in DME (3 mL) the reaction was stirred for 1.5 h at rt and 30 min at 50 °C. The mixture was poured into ice water (80 mL). The aqueous layer was extracted with Et_2O (50 mL, 3 times). Drying over $MgSO_4$ and evaporation gave the crude product. Purification by flash column chromatography (12% Et_2O in pentane eluant) yielded 842 mg of **113-Me** (91%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3079 cm^{-1} (*c*Pr–H), 3003 (C–H), 2930 (C–H), 2903 (C–H), 2871 (C–H), 1706 (C=O), 1642 (C=C), 1447, 1391, 1366, 1302, 1247, 1179, 1104 (C–O), 1038, 1016, 909, 755. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.03–0.17 (m, 2 H, *c*Pr-H), 0.30–0.46 (m, 2 H, *c*Pr-H), 0.63–0.92 (m, 3 H, *c*Pr-H), 1.07–1.16 (m, 1 H, *c*Pr-H), 1.26 (t, ^3J = 7.2 Hz, 3 H, C*H*$_3$), 1.28–1.42 (m, 1 H, *c*Pr-H), 1.94 (s, 3 H, C=CC*H*$_3$), 4.16 (q, ^3J = 7.2 Hz, 2 H, OC*H*$_2$), 6.12 (d, ^3J = 10 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.53 (*c*Pr-C), 3.59 (*c*Pr-C), 11.80 (*c*Pr-C), 12.42 (C=C*C*H_3), 13.40 (*c*Pr-C), 14.28 (*C*H_3), 18.16 (*c*Pr-C), 24.43 (*c*Pr-C), 60.20 (O*C*H_2), 124.70 (vinyl-C), 146.39 (vinyl-C), 168.17 (*C*O_2). – MS (70 eV), *m/z* (%): 194 (4) [M^+], 165 (4) [$M^+ - C_2H_5$], 149 (10) [$M^+ - OC_2H_5$], 139 (21), 126 (18), 121 (22) [$M^+ - CH_2CO_2C_2H_5$], 111 (23), 93 (62) [$M^+ - CH_2CO_2C_2H_5 - CCH_3 - H$], 81 (43) [$C_6H_8^+$], 79 (81) [*c*Pr$C_3H_2^+$], 67 (100) [*c*Pr$C_2H_2^+$], 55 (40) [*c*PrCH_2^+], 41 (100) [*c*Pr^+]. – Cal. C 74.19, H 9.34; found C 73.95, H 9.12.

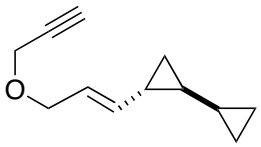




trans-*3-Bicyclopropyl-2-yl-prop-2-(*E*)-en-1-ol* (**114-H**) According to GP 1, *trans*-3-bicyclopropyl-2-yl-(*E*)-acrylic acid ethyl ester **113-H** (1.37 g, 7.58 mmol) and $LiAlH_4$ (216 mg, 5.69 mmol) were allowed to react in dry Et_2O (40 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yielded 995 mg of **114-H** (95%) as colorless oil. – The analytical data correspond to those reported in literature.[140]



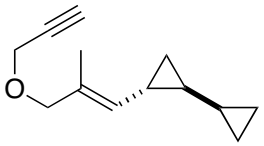
trans-*3-Bicyclopropyl-2-yl-2-methyl-prop-2-(*E*)-en-1-ol* (**114-Me**) According to GP 1, *trans*-3-bicyclopropyl-2-yl-2-methyl-(*E*)-acrylic acid ethyl ester **113-Me** (4.69 g, 24.2 mmol) and $LiAlH_4$ (645 mg, 17.0 mmol) were allowed to react in dry Et_2O (100 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yielded 2.50 g of **114-Me** (68%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3077 (*c*Pr–H), 3000 (C–H), 2914 (C–H), 2859 (C–H), 1671 (C=C), 1453, 1384, 1214, 1072, 1014 (C–O), 903, 845, 814. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.01–0.15 (m, 2 H, *c*Pr-H), 0.30–0.45 (m, 3 H, *c*Pr-H), 0.48–0.58 (m, 1 H, *c*Pr-H), 0.78–0.90 (m, 2 H, *c*Pr-H), 1.17–1.30 (m, 1 H, *c*Pr-H), 1.58 (bs, 1 H, O*H*), 1.78 (s, 3 H, C=CCH_3), 3.96 (bs, 2 H, CH_2OH), 4.80 (d, ^3J = 8.0 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.46 (*c*Pr-C), 3.30 (*c*Pr-C), 11.86 (2 C, *c*Pr-C, C=C*C*H$_3$), 13.98 (*c*Pr-C), 16.17 (*c*Pr-C), 22.59 (*c*Pr-C), 68.76 (*C*H$_2$OH), 130.03 (vinyl-C), 132.82 (vinyl-C). – MS (70 eV), *m/z* (%): 152 (23) [M^+], 165 (1) [$M^+ - CH_3$], 152 (60) [$M^+ - C_2H_4$], 134 (12) [$M^+ - OH_2$], 121 (21) [$M^+ - CH_2OH$], 105 (18) [$M^+ - OH_2 - C_2H_5$], 91 (65) [$M^+ - CH_2OH - C_2H_4$], 79 (97) [*c*PrC$_3$H$_2^+$], 67 (70), 55 (58), 43 (100), 41 (80) [*c*Pr$^+$]. – Cal. C 78.90, H 10.59; found C 79.11, H 10.75.

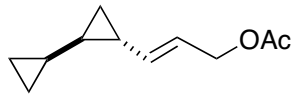


trans-*2-(3-Prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl* (**116-H**) According to GP 3, *trans*-3-bicyclopropyl-2-yl-2-methyl-prop-2-(*E*)-en-1-ol (**114-H**) (207 mg, 1.50 mmol), propargyl bromid (**115**) (80% in toluene, 334 mg, 2.25 mmol) and NaH (60% in mineraloil, 90.0 mg, 2.25 mmol) were allowed to react in THF (6 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 227 mg of **116-H** (86%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3301 cm^{-1} (C≡C–H), 3076 (*c*Pr–H), 3001 (C–H),

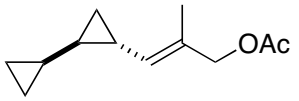
2851 (C–H), 2115 (C≡C), 1665 (C=C), 1447, 1354, 1261, 1176, 1079 (C–O), 1019, 965 (H–C=C–H), 887, 663, 632. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.00–0.21 (m, 2 H, *c*Pr-H), 0.30–0.65 (m, 4 H, *c*Pr-H), 0.78–0.98 (m, 2 H, *c*Pr-H), 1.15–1.31 (m, 1 H, *c*Pr-H), 2.43 (t, ^4J = 1.6 Hz, 1 H, C≡C-*H*), 4.01 (d, ^3J = 6.8 Hz, 2 H, OCH_2C=C), 4.18 (d, 2 H, ^4J = 1.6 Hz, OCH_2C≡C), 5.33 (dd, ^3J = 16 Hz, ^3J = 10 Hz, 1 H, vinyl-H), 5.59 (dt, ^3J = 16 Hz, ^3J = 6.8 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.38 (*c*Pr-C), 3.30 (*c*Pr-C), 11.72 (*c*Pr-C), 11.81 (*c*Pr-C), 19.73 (*c*Pr-C), 22.58 (*c*Pr-C), 56.64 (C-1), 70.25 (C-1′), 74.18 (C≡C), 79.85 (C≡C), 122.37 (vinyl-C), 139.26 (vinyl-C). – MS (70 eV), *m/z* (%): 176 (1) [M^+], 147 (1), 131 (3), 121 (17) [M^+ – $OCH_2C{\equiv}CH$], 107 (17) [M^+ – $CH_2OCH_2C{\equiv}CH$], 105 (31) [M^+ – $CH_2OCH_2C{\equiv}CH$ – 2 H], 93 (41) [M^+ – $CH_2OCH_2C{\equiv}CH$ – CH_2], 91 (72), 81 (20) [$C_6H_8{}^+$], 79 (100) [*c*Pr$C_3H_2{}^+$], 77 (40), 67 (63), 55 (60), 41 (52) [*c*Pr$^+$]. – $C_{12}H_{16}O$ (176.25).

trans-*2-(2-Methyl-3-prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl* (**116-Me**) According to GP 3, *trans*-3-bicyclopropyl-2-yl-2-methyl-prop-2-(*E*)-en-1-ol (**114-Me**) (1.00 g, 6.57 mmol), propargyl bromid (**115**) (80% in toluene, 1.95 g, 13.1 mmol) and NaH (60% in mineraloil, 578 mg, 14.5 mmol) were allowed to react in THF (30 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 750 mg of **116-Me** (60%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3306 cm^{-1} (C≡C–H), 3077 (*c*Pr–H), 3000 (C–H), 2916 (C–H), 2851 (C–H), 2116 (C≡C), 1670 (C=C), 1443, 1350, 1266, 1076 (C–O), 1016, 906, 666, 626. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.01–0.20 (m 2 H, *c*Pr-H), 0.30–0.58 (m, 4 H, *c*Pr-H), 0.81–0.94 (m, 2 H, *c*Pr-H), 1.19–1.31 (m, 1 H, *c*Pr-H), 1.77 (s, 3 H, C=CCH_3), 2.40 (t, ^4J = 1.6 Hz, 1 H, C≡C-*H*), 3.91 (s, 2 H, OCH_2C=C), 4.08 (d, ^4J = 1.6 Hz, 2 H, OCH_2C≡C), 4.86 (d, ^3J = 8.0 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.45 (*c*Pr-C), 3.30 (*c*Pr-C), 11.85 (C=CCH_3), 14.27 (*c*Pr-C), 16.28 (*c*Pr-C), 22.64 (*c*Pr-C), 56.38 (C-1), 74.00 (C≡C), 75.63 (C-1′), 79.97 (C≡C), 129.26 (vinyl-C), 133.09 (vinyl-C). – MS (70 eV), *m/z* (%): 190 (15) [M^+], 135 (42) [M^+ – $OCH_2C{\equiv}CH$], 121 (18) [M^+ – CH_2 $OCH_2C{\equiv}CH$], 119 (35), 105 (35) [M^+ – $CH_2OCH_2C{\equiv}CH$ – CH_3 – H], 93 (100) [M^+ – $CH_2OCH_2C{\equiv}CH$ – CCH_3 – H], 91 (79), 81 (46) [$C_6H_8{}^+$], 79 (61) [*c*Pr$C_3H_2{}^+$], 77 (28), 67 (17). – $C_{13}H_{18}O$ (190.28).

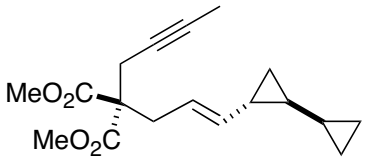




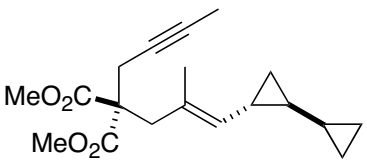
trans-*Acetic acid 3-bicyclopropyl-2-yl-allyl ester* (**120-H**) *trans*-3-Bicyclopropyl-2-yl-prop-2-(*E*)-en-1-ol (**114-H**) (3.94 g, 28.5 mmol), acetic anhydride (5.39 mL, 57.0 mmol), triethylamine (8.01 mL, 57.0 mmol) and DMAP (35.0 mg, 285 μmol) were dissolved in DCM (250 mL) and stirred for 40 min at rt. Then water (100 mL) was added and extracted with DCM (70 mL, 2 times). After drying over Na_2SO_4 and evaporation of the solvent the crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 2.72 g of **120-H** (53%) as colorless oil. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.00–0.10 (m, 2 H, *c*Pr-H), 0.25–0.56 (m, 4 H, *c*Pr-H), 0.74–0.97 (m, 2 H, *c*Pr-H), 1.12–1.30 (m, 1 H, *c*Pr-H), 2.02 (s, 3 H, COCH_3), 4.45 (d, ^3J = 6.4 Hz, 2 H, CH_2O), 5.27 (dd, ^3J = 14 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.52 (dt, ^3J = 14 Hz, ^3J = 6.4 Hz, 1H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.34 (*c*Pr-C) 3.33 (*c*Pr-C), 11.75 (*c*Pr-C), 19.78 (*c*Pr-C), 21.04 (*c*Pr-C), 22.88 (OCCH$_3$) 65.25 (CH$_2$O), 120.76 (vinyl-C), 140.13 (vinyl-C), 170.86 (OCCH$_3$). – $C_{11}H_{16}O_2$ (180.24).



trans-*Acetic acid 3-bicyclopropyl-2-yl-2-methyl-allyl ester* (**120-Me**) *trans*-3-Bicyclopropyl-2-yl-2-methyl-prop-2-(*E*)-en-1-ol (**114-Me**) (500 mg, 3.28 mmol), acetic anhydride (0.62 mL, 6.57 mmol), triethylamine (0.92 mL, 6.57 mmol) and DMAP (4.0 mg, 33 μmol) were dissolved in DCM (40 mL) and stirred for 40 min at rt. Then water (30 mL) was added and extracted with DCM (30 mL, 2 times). After drying over Na_2SO_4 and evaporation of the solvent the crude mixture was purified by flash column chromatography (12% Et_2O in pentane eluant) affording 227 mg of **120-Me** (39%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3078 cm^{-1} (*c*Pr–H), 3000 (C–H), 2877 (C–H), 1738 (C=O), 1672 (C=C), 1457, 1376, 1363, 1246 (C–O), 1224, 1028, 980, 953, 904. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.08–0.18 (m, 2 H, *c*Pr-H), 0.30–0.48 (m, 2 H, *c*Pr-H), 0.49–0.59 (m, 1 H, *c*Pr-H), 0.80–0.99 (m, 2 H, *c*Pr-H), 1.18–1.27 (m, 1 H, *c*Pr-H), 1.78 (s, 3 H, C=CCH_3), 2.06 (s, 3 H, OCCH_3), 4.41 (s, 2 H, CH_2O), 4.96 (d, ^3J = 9.4 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.45 (*c*Pr-C), 3.37 (*c*Pr-C), 11.85 (*c*Pr-C), 11.94 (C=CCH$_3$), 14.34 (*c*Pr-C), 16.42 (*c*Pr-C), 21.03 (*c*Pr-C), 22.73 (OCCH$_3$), 70.33 (CH$_2$O), 127.90 (C=CCH$_3$), 133.81 (C=CCH$_3$), 171.05 (OCCH$_3$) – DCI-MS (200 eV, NH_3), *m/z* (%): 238 (5) [M + NH_4^+], 178 (20), 161 (100). – $C_{14}H_{20}O_2$ (194.27).

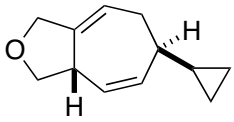


trans-*2-(3-Bicyclopropyl-2-yl-allyl)-2-but-2-ynyl-malonic acid dimethyl ester* (**121-H**) To a suspension of NaH (60% in mineraloil, 237 mg, 5.93 mmol) in THF (60 mL) was added *trans*-acetic acid 3-bicyclopropyl-2-yl-allyl ester (**120-H**) (822 mg, 4.56 mmol), 2-but-2-ynyl-malonic acid dimethyl ester (**117**) (1.09 g, 5.93 mmol) and $Pd(PPh_3)_4$ (527 mg, 456 μmol) and was stirred over night at 50 °C. The mixture was poured in brine and was extracted with Et_2O (50 mL, 3 times). After drying over $MgSO_4$ and evaporation of the solvent the crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 817 mg of **121-H** (59%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3077 cm^{-1} (*c*Pr–H), 3000 (C–H), 2953 (C–H), 2922 (C–H), 2843 (C–H), 1737 (C=O), 1664 (C=C), 1436, 1328, 1288, 1209 (C–O), 1057, 1019, 966 (H–C=C–H). – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.01–0.09 (m, 2 H, *c*Pr-H), 0.24–0.46 (m, 4 H, *c*Pr-H), 0.71–0.95 (m, 2 H, *c*Pr-H), 1.03–1.17 (m, 1 H, *c*Pr-H), 1.72 (t, ^5J = 0.7 Hz, 3 H, C≡C-CH_3), 2.65 (d, ^3J = 8.5 Hz, 2 H, 1′-H), 2.70 (d, ^5J = 0.7 Hz, 1 H, 1-H), 3.74 (s, 6 H, CO_2CH_3), 5.03–5.30 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.34 (C-4), 3.24 (*c*Pr-C), 3.47 (*c*Pr-C), 11.43 (*c*Pr-C), 11.78 (*c*Pr-C), 19.81 (*c*Pr-C), 22.53 (*c*Pr-C*, C-1*), 22.90 (*c*Pr-C*, C-1*), 35.27 (C-1′), 52.53 (CO_2CH_3), 57.55 [C(CCO$_2$Me)], 73.38 (C-3), 78.69 (C-2), 120.11 (vinyl-C), 138.68 (vinyl-C), 170.61 (CO_2Me). – DCI-MS (200 eV, NH_3), *m/z* (%): 626 (20) [2 M + NH_4^+], 322 (68) [M + NH_4^+], 305 (100) [M + H^+], 245 (12). – $C_{18}H_{24}O_4$ (304.38).



trans-*2-(3-Bicyclopropyl-2-yl-2-methyl-allyl)-2-but-2-ynyl-malonic acid dimethyl ester* (**121-Me**) *trans*-Acetic acid 3-bicyclopropyl-2-yl-2-methyl-allyl ester (**120-Me**) (227 mg, 1.17 mmol), 2-but-2-ynyl-malonic acid dimethyl ester (**117**) (237 mg, 1.29 mmol), $Pd(PPh_3)_4$ (68.0 mg, 58.5 μmol) and NaH (60% in mineraloil, 51.0 mg, 1.29 mmol) were dissolved in THF (30 mL) and stirred over night at 50 °C. The mixture was poured in brine and was extracted with Et_2O (50 mL, 3 times). After drying over $MgSO_4$ and evaporation of the solvent the crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 817 mg of the product (59%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3077 cm^{-1} (*c*Pr–H), 2999 (C–H), 2953 (C–H), 2922 (C–H), 2859 (C–H), 1737 (C=O), 1436, 1330, 1289,

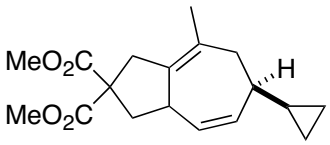
1202 (C–O), 1077, 1058, 1018, 946, 887, 818. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.00$–0.15 (m, 2 H, *c*Pr-H), 0.24–0.55 (m, 4 H, *c*Pr-H), 0.71–0.90 (m, 2 H, *c*Pr-H), 1.09–1.22 (m, 1 H, *c*Pr-H), 1.61 (s, 3 H, C=CCH_3), 1.72 (t, $^5J = 0.7$ Hz, 3 H, C≡CCH_3), 2.66–2.79 (m, 4 H, 1′-H, 1-H), 3.71 (s, 6 H, CO_2CH_3), 4.68 (d, $^3J = 8.5$ Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 2.43$ (C≡CCH$_3$), 3.27 (*c*Pr-C) 3.38 (*c*Pr-C), 11.84 (C=CCH$_3$), 16.49 (*c*Pr-C), 17.17 (*c*Pr-C), 22.61 (*c*Pr-C*, C-1*), 22.56 (*c*Pr-C*, C-1*), 41.35 (C-1′), 52.40 (CO_2CH$_3$), 57.21 [C(CO$_2$Me)$_2$], 73.73 (C-3), 78.82 (C-2), 127.41 (vinyl-C), 134.45 (vinyl-C), 170.95 (CO$_2$Me). – DCI-MS (200 eV, NH_3), *m/z* (%): 654 (8) [2 M + NH_4^+], 336 (100) [M + NH_4^+], 319 (20) [M + H^+]. – $C_{19}H_{26}O_4$ (318.41).



*6-Cyclopropyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[c]furan* (**122**)
According to GP 4, *trans*-2-(3-prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl (**116-H**) (10.0 mg, 52.6 μmol) and the catalyst [($C_{10}H_8$Rh(COD)]SbF_6 (1.5 mg, 2.63 μmol) were allowed to react in DCE (1 mL) for 24 h at rt. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 9 mg of the cycloadduct **122** (90%). – IR (film): $\tilde{\nu} = 3074$ cm^{-1} (*c*-Pr–H), 3000 (C–H), 2951 (C–H), 2842 (C–H), 1644 (C=C), 1429, 1374, 1317, 1259, 1164, 1079 (C–O), 1054, 1016, 932, 828, 716, 684. – ^{1}H NMR (300 MHz, $CDCl_3$): $\delta = 0.01$–0.18 (m, 2 H, *c*Pr-H), 0.28–0.50 (m, 2 H, *c*Pr-H), 0.69–0.81 (m, 1 H, *c*Pr-H), 1.78–1.90 (m, 1 H, 6-H), 2.01–2.18 (m, 1 H, 7-H), 2.36–2.45 (m, 1 H, 7-H), 3.45 (dd, $^2J = 10.2$ Hz, $^3J = 9.0$ Hz, 1 H, 3-H), 3.58–3.70 (m, 1 H, 3a-H), 4.21 (dd, $^2J = 9.0$ Hz, $^3J = 9.0$ Hz, 2 H, 3-H), 4.21–4.26 (m, 2 H, 1-H), 4.30–4.38 (m, 1 H, 1-H), 5.47–5.57 (m, 2 H, vinyl-H), 5.70–5.79 (m, 1 H, vinyl-H). – ^{13}C NMR (75.5 MHz, $CDCl_3$): $\delta = 3.56$ (*c*Pr-C), 3.70 (*c*Pr-C), 16.69 (*c*Pr-C), 31.85 (C-7), 40.96 (C-3a), 42.28 (C-6), 72.39 (C-3), 74.42 (C-1), 117.83 (C-4), 128.18 (C-5*, C-8*), 136.34 (C-5*, C-8*), 140.88 (C-8a). – DCI-MS (200 eV), *m/z* (%): 194 (38) [M + NH_4^+], 175 (54) [M^+ – H]. – $C_{12}H_{16}O$ (176.25).

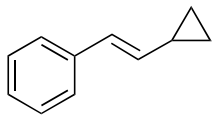
Attempt for the cyclization of trans-*2-(2-methyl-3-prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl* (**116-Me**) According to GP 4, $[C_{10}H_8)Rh(COD)]SbF_6$ (3.0 mg, 5.22 μmol) and *trans*-2-(2-methyl-3-prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl (**116-Me**) (20.0 mg, 97.9 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 16 mg of an unidentified product.

*6-Cyclopropyl-8-methyl-3,3a,6,7-tetrahydro-1*H*-azulene-2,2-dicarboxylic acid dimethyl ester* (**123**) According to GP 4, *trans*-2-(3-bicyclopropyl-2-yl-allyl)-2-but-2-ynyl-malonic acid dimethyl ester (**121-H**) (30.0 mg, 98.6 μmol) and $[(C_{10}H_8)Rh(COD)]SbF_6$ (2.8 mg, 4.93 μmol) were allowed to react in DCE (1 mL) for 1 h at rt. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 20 mg of the cycloadduct **123** (67%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3074 cm^{-1} (*c*Pr–H), 3000 (C–H), 2958 (C–H), 2924 (C–H), 2852 (C–H), 1735 (C=O), 1435, 1375, 1255, 1201 (C–O), 1165, 1071, 1018, 937, 888, 822, 741. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.00–0.15 (m, 2 H, *c*Pr-H), 0.30–0.50 (m, 2 H, *c*Pr-H), 0.57–0.75 (m, 1 H, *c*Pr-H), 1.50–2.11 (m, 4 H, 3a-H, 6-H, 7-H), 1.65 (s, 3 H, C=CCH_3), 2.45-3.02 (m, 4 H, 1-H, 3-H), 3.71 (s, 6 H, CO_2CH_3), 5.49–5.65 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 3.46 (*c*Pr-C), 3.82 (*c*Pr-C), 15.97 (*c*Pr-C), 22.48 (C=CCH_3), 38.11 (C-1*, C-3*, C-3a*, C-6*, C-7*), 39.16 (C-1*, C-3*, C-3a*, C-6*, C-7*), 39.63 (C-1*, C-3*, C-3a*, C-6*, C-7*), 41.58 (C-1*, C-3*, C-3a*, C-6*, C-7*), 43.39 (C-1*, C-3*, C-3a*, C-6*, C-7*), 52.64 (CO_2CH_3), 52.70 (CO_2CH_3), 58.39 (C-2), 128.09 (C-8), 131.31 (C-4*, C-5*), 133.78 (C-4*, C-5*), 134 52 (C-8a), 170.61 (CO_2Me). – MS (70 eV), *m/z* (%): 304 (62) [M^+], 288 (24) [M^+ – CH_3 – H], 251 (18), 244 (100) [M^+ – CO_2CH_3 – H], 228 (51) [M^+ – CO_2CH_3 – CH_3 – 2 H], 185 (95) [M^+ – 2 CO_2CH_3 – H], 169 (51) [M^+ – 2 CO_2CH_3 – CH_3 – 2 H], 143 (55) [M^+ – 2 CO_2CH_3 – *c*Pr – H], 129 (63) [M^+ – 2 CO_2CH_3 – CH_3 – *c*Pr – H], 115 (38), 91 (47), 84 (38), 59 (39), 43 (38). – $C_{18}H_{24}O_4$ (304.38).

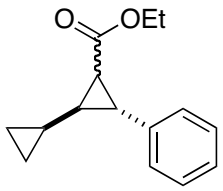


Attempt for the cyclization of trans-*2-(3-bicyclopropyl-2-yl-2-methyl-allyl)-2-but-2-ynyl-malonic acid dimethyl ester* (**121-Me**) According to GP 4, *trans*-2-(3-bicyclopropyl-2-yl-2-methyl-allyl)-2-but-2-ynyl-malonic acid dimethyl ester (**121-Me**) (20.0 mg, 62.8 μmol) and $[C_{10}H_8)Rh(COD)]SbF_6$ (1.8 mg, 3.14 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 18 mg of the starting material **121-Me**.

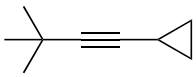
3.2. 2nd-Generation precursors



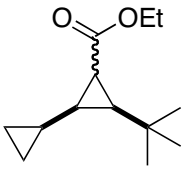
β-Cyclopropylstyrene trans-2-(2-cyclopropyl-vinyl)-4,4,5,5-tetra-methyl-[1,3,2]dioxaborolane (1.94 g, 10.0 mmol) was dissolved in benzene (50 mL). The solution was degassed by bubbeling Ar through. Iodbenzol (1.26 mL, 10.0 mmol), sodium ethanolate in ethanol (2 M, 11 mL) and $Pd(PPh_3)_2Cl_2$ (702 mg, 1.50 mmol) were added. The mixture was refluxed over night. The reaction was quenched with NaOH (3 M, 12 mL) and H_2O_2 (30%, 1.2 mL). The organic layer was washed with NaOH (3 M, 30 mL, 3 times), dried over $MgSO_4$ and the solvent evaporated. The crude mixture was purified by flash column chromatography (5% DCM in pentane eluant) affording 1.40 g of β-cyclopropylstyrene as a colourless oil (57%). – The analytical data correspond to those reported in literature.[142]



trans-*2-Cyclopropyl-3-phenyl-cyclopropylcarboxylic acid ethyl ester* β-cyclopropylstyrene (860 mg, 5.96 mmol) was dissolved in dry Et_2O (5 mL). $[Rh(OAC)_2]_2$ (132 mg, 299 μmol) was added and diazoacidic acid ethyl ester (63.0 mL, 5.99 mmol) dropped in via syringe pump over 20 h. The mixture was filtered through a pat of alox and purified by flash column chromatography (5% Et_2O in pentane eluant) affording 329 mg of *trans*-2-cyclopropyl-3-phenyl-cyclopropylcarboxylic acid ethyl ester as a colourless oil (24%). – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.20$–0.30 (m, 1 H, *c*Pr-H), 0.32–0.43 (m, 1 H, *c*Pr-H), 0.45–0.68 (m, 2 H, *c*Pr-H), 1.02–1.21 (m, 2 H, *c*Pr-H), 1.30 (t, $^3J = 7.2$ Hz, 3 H, CH_3), 2.07 (dd, $^3J = 8.0$ Hz, $^3J = 4.8$ Hz, 1 H, *c*Pr-H), 2.69 (t, $^3J = 5.6$ Hz, 1 H, *c*Pr-H), 4.20 (q, $^3J = 7.2$ Hz, 1 H, OCH_2), 7.06 (d, $^3J = 8.0$ Hz, 2 H, Ph-H), 7.17–7.31 (m, 3 H, Ph-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 4.65$ (*c*Pr-C), 5.18 (*c*Pr-C), 8.53 (*c*Pr-C), 14.30 (CH_3), 29.45 (*c*Pr-C), 31.24 (*c*Pr-C), 35.33 (*c*Pr-C), 60.43 (OCH_2), 123.53 (Ph-C), 126.06 (Ph-C), 128.36 (Ph-C), 140.30 (Ph-C), 171.59 (CO_2Et). – DCI-MS (200 eV, NH_3), *m/z* (%): 265 (18) [M + NH_3 + NH_4^+], 248 (100) [M + NH_4^+], 231 (59) [M + H^+]. – $C_{15}H_{18}O_2$ (230.31).



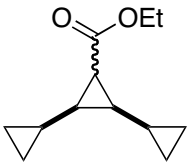
3,3-Dimethylbut-1-ynylcyclopropane (**148-*t*Bu**) 2,2-Dimethyl-7-chlorohept-3-yne (**147-*t*Bu**) (31.0 g, 195 mmol) was added to a solution of LDA (429 mmol) in THF (250 mL) at –78 °C. The mixture was warmed to rt over night. The reaction was quenched with NH_4Cl (sat.) and solvent was removed by destillation. The residue was dissolved in water and extracted with Et_2O (200 mL, 2 times). The solvent was destilled off and the product purified by destillation (70 °C at 150 mbar) to yield 13.6 g of **148-*t*Bu** (57%). – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.50–0.60 (m, 2 H, *c*Pr-H), 0.61–0.74 (m, 2 H, *c*Pr-H), 1.10–1.22 (m, 1 H, *c*Pr-H), 1.18 (s, 9 H, *t*Bu-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –5.61 [*C*(CH_3)$_3$], 8.17 (*c*Pr-C), 27.21 (*c*Pr-C), 31.33 [C(*C*H_3)$_3$], 81.45 (C≡C), 84.17 (C≡C). – MS (70 eV), *m/z* (%): 123 (6), 122 (40) [M^+], 107 (100) [$M^+ - CH_3$], 105 (22), 91 (80), 79 (42), 77 (23) [$M^+ - 3\ CH_3$]. – C_9H_{14}: 122.1095 (correct HRMS). – Cal. C 88.45, H 11.55; found C 88.69, H 11.32.



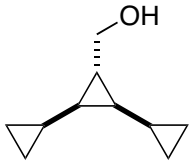
cis-*2*-tert-*Butyl-3-cyclopropylcyclopropylcarboxylic acid ethyl ester* (**150-*t*Bu**) (*Z*)-1-*tert*-Butyl-2-cyclopropylethylene (**149-*t*Bu**) (2.48 g, 20.0 mmol) was dissolved in dry Et_2O (25 mL). $[Rh(OAC)_2]_2$ (88.0 mg, 200 μmol) was added and diazoacidic acid ethyl ester (2.52 mL, 24.0 mmol) dropped in via syringe pump over 20 h. The mixture was filtered through a pat of alox and purified by flash column chromatography (2% Et_2O in pentane eluant) affording 698 mg of *cis*-2-*tert*-butyl-3-cyclopropylcyclopropyl-*cis*-carboxylic acid ethyl ester (***cis,cis,cis*-150-*t*Bu**) and 614 mg of *cis*-2-*tert*-butyl-3-cyclopropylcyclopropyl-*trans*-carboxylic acid ethyl ester (***trans,trans,cis*-150-t*Bu***) as a colourless oil (31%). – Data for ***cis,cis,cis*-150-*t*Bu**: IR (film): $\tilde{\nu}$ = 3082 cm^{-1} (*c*Pr–H), 3003 (C–H), 2956 (C–H), 2905 (C–H), 2867 (C–H), 1728 (C=O), 1481, 1462, 1405, 1382, 1261, 1180, 1150 (C–O) 1097, 1072, 1034, 971, 800. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.12–0.28 (m, 2 H, *c*Pr-H), 0.52–0.66 (m, 3 H, *c*Pr-H), 0.80–0.90 (m, 1 H, *c*Pr-H), 1.15 (s, 9 H, *t*-Bu-H), 1.18–1.30 (m, 4 H, CH_3, *c*Pr-H), 1.46–1.60 (m, 1 H, *c*Pr-H), 4.07–4.18 (m, 2 H, OC*H*$_2$). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 5.22 (*c*Pr-C), 5.72 (*c*Pr-C), 6.79 (*c*Pr-C), 14.34 (*C*H_3), 21.03 (*c*Pr-C), 30.23 (*c*Pr-C), 30.76 [C(*C*H_3)$_3$], 32.02 [*C*(CH_3)$_3$], 35.30 (*c*Pr-C), 59.84 (O*C*H_2), 171.88 (*C*O_2Et). – DCI-MS (200 eV, NH_3), *m/z* (%): 228 (100) [M + NH_4^+], 211 (83) [M + H^+]. – $C_{13}H_{22}O_2$ (210.31). – Data for ***trans,trans,cis*-150-t*Bu***: IR (film): $\tilde{\nu}$ = 3081 cm^{-1} (*c*Pr–H), 2957 (C–H), 2905 (C–H), 2868 (C–H),

1726 (C=O), 1480, 1463, 1445, 1364, 1331, 1312, 1267, 1179, 1160 (C–O) 1046, 1972. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.21–0.25 (m, 2 H, *c*Pr-H), 0.50–0.58 (m, 2 H, *c*Pr-H), 0.61–0.80 (m, 1 H, *c*Pr-H), 0.80–0.90 (m, 1 H, *c*Pr-H), 0.98–1.05 (m, 1 H, *c*Pr-H), 1.02 (s, 9 H, *t*-Bu-H), 1.19–1.32 (m, 1 H, *c*Pr-H), 1.24 (t, ^3J = 7.2 Hz, 3 H, CH_3), 4.07–4.18 (m, 2 H, OCH_2). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 6.00 (*c*Pr-C), 7.07 (*c*Pr-C), 9.00 (*c*Pr-C), 14.21 (CH_3), 22.41 (*c*Pr-C), 29.84 [C(CH_3)$_3$], 31.08 [C(CH$_3$)$_3$], 32.38 (*c*Pr-C), 39.51 (*c*Pr-C), 60.25 (OCH_2), 175.06 (CO_2Et). – DCI-MS (200 eV, NH_3), *m/z* (%): 228 (100) [M + NH_4^+], 211 (8) [M + H^+]. – $C_{13}H_{22}O_2$ (210.31).

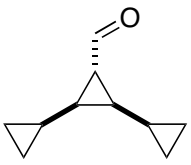
cis-*2,3-Bicyclopropylcyclopropylcarboxylic acid ethyl ester* (**150-*c*Pr**) (*Z*)-1,2-Bicyclopropylethylene (**149-*c*Pr**) (5.41 g, 50.0 mmol) was dissolved in Et_2O (25 mL). [Rh(OAc)$_2$]$_2$ (221 mg, 500 μmol) was added and diazoacidic acid ethyl ester (5.30 mL, 50.4 mmol) dropped in via syringe pump over 20 h. The mixture was filtered through a pat of alox and purified by flash column chromatography (2% Et_2O in pentane eluant) affording 1.64 g of 2,3-dicyclopropyl-*cis,cis*-cyclopropylcarboxylic acid ethyl ester (***cis,cis,cis*-150-*c*Pr**) and 2.03 g of 2,3-dicyclopropyl-*cis,trans*-cyclopropylcarboxylic acid ethyl ester (***trans,trans,cis*-150-*c*Pr**) as a colourless oil (38%). – Data for ***cis,cis,cis*-150-*c*Pr**: IR (film): $\tilde{\nu}$ = 3081 cm^{-1} (*c*Pr–H), 3002 (C–H), 2935 (C–H), 2904 (C–H), 1726 (C=O), 1437, 1402, 1381, 1354, 1151 (C–O) 1035, 971, 845. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.12–0.28 (m, 4 H, *c*Pr-H), 0.43–0.77 (m, 6 H, *c*Pr-H), 1.19–1.36 (m, 2 H, *c*Pr-H), 1.30 (t, ^3J = 7.2 Hz, 3 H, CH_3), 1.63 (t, ^3J = 8.0 Hz, 3 H, *c*Pr-H), 4.17 (q, ^3J = 7.2 Hz, 1 H, OCH_2). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.78 (*c*Pr-C), 5.27 (*c*Pr-C), 14.32 (CH_3), 21.59 (*c*Pr-C), 30.44 (*c*Pr-C), 59.70 (OCH_2), 171.88 (CO_2Et). – MS (70 eV), *m/z* (%): 194 (10) [M^+], 179 (1) [M^+ – CH_3], 165 (20) [M^+ – C_2H_5], 153 (52) [M^+ – *c*Pr], 125 (35), 121 (59) [M^+ – $CO_2C_2H_5$], 93 (50), 91 (39), 79 (100) [*c*Pr$C_3H_2^+$], 67 (55), 55 (21), 41 (23) [*c*Pr$^+$]. – $C_{12}H_{18}O_2$: 294.1307 (correct HRMS). – Cal. C 74.19, H 9.34; found C 73.92, H 9.03. – Data for ***trans,trans,cis*-150-*c*Pr**: IR (film): $\tilde{\nu}$ = 3081 cm^{-1} (*c*Pr–H), 3003 (C–H), 2905 (C–H), 1723 (C=O), 1447, 1370, 1349, 1323, 1280, 1230, 1179 (C–O), 1019, 858. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.18–0.30 (m, 4 H, *c*Pr-H), 0.41–0.61 (m, 4 H, *c*Pr-H), 0.61–0.80 (m, 2 H, *c*Pr-H), 1.15–1.35 (m, 3 H, *c*Pr-H), 1.21 (t, ^3J = 7.2 Hz, 3 H, CH_3), 4.03 (q, ^3J = 7.2 Hz, 2 H, OCH_2Et).



– ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.74 (*c*Pr-C), 4.91 (*c*Pr-C), 8.61 (*c*Pr-C), 14.17 (*C*H$_3$), 24.89 (*c*Pr-C), 31.73 (*c*Pr-C), 60.25 (O*C*H$_2$), 174.21 (*C*O$_2$). – MS (70 eV), *m/z* (%): 194 (8) [M$^+$], 179 (1) [M$^+$ – CH$_3$], 165 (12) [M$^+$ – C$_2$H$_5$], 153 (32) [M$^+$ – *c*Pr], 125 (22), 121 (39) [M$^+$ – CO$_2$C$_2$H$_5$], 93 (48), 91 (39), 79 (100) [*c*PrC$_3$H$_2^+$], 67 (57), 55 (41), 41 (32) [*c*Pr$^+$]. – $C_{12}H_{18}O_2$: 294.1307 (correct HRMS).



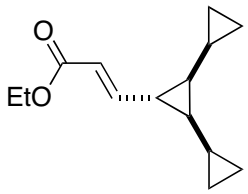
cis-*2,3-Dicyclopropyl*-trans-*cyclopropylmethanol* (**151**) According to GP 1, *cis*-2,3-dicyclopropyl-*trans*-cyclopropylcarboxylic acid ethyl ester (***trans,trans,cis*-150-*c*Pr**) (1.50 g, 7.72 mmol) and $LiAlH_4$ (214 mg, 5.64 mmol) were allowed to react in dry Et_2O (50 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yield 876 mg of **151** (75%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3078 (*c*Pr–H), 3000 (C–H), 2915 (C–H), 2868 (C–H), 1460, 1427, 1364, 1281, 1046, 1016 (C–O), 888, 823. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.11–0.22 (m, 4 H, *c*Pr-H), 0.39–0.59 (m, 6 H, *c*Pr-H), 0.67–0.78 (m, 3 H, *c*Pr-H), 1.41 (bs, 1 H, O*H*), 3.32 (t, ^3J = 4.8 Hz, 1 H, C*H*$_2$OH). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.82 (*c*Pr-C), 5.02 (*c*Pr-C), 8.88 (*c*Pr-C), 25.10 (*c*Pr-C), 25.64 (*c*Pr-C), 66.67 (*C*H$_2$OH). – MS (70 eV), *m/z* (%): 152 (1) [M$^+$], 137 (1) [M$^+$ – CH$_3$], 121 (12) [M$^+$ – OCH$_3$], 93 (79), 91 (44), 79 (90) [*c*PrC$_3$H$_2^+$], 67 (100), 55 (57), 41 (60) [*c*Pr$^+$]. – $C_{10}H_{16}O_2$: 152.1201 (correct HRMS).



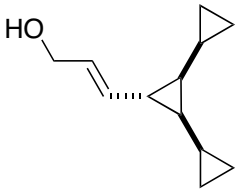
cis-*2,3-Bicyclopropyl*-trans-*cyclopropylcarboxaldehyde* (**152**) Dess-Martin-periodinane (6.00 g, 13.9 mmol) was suspended in dry DCM (50 mL). *cis*-2,3-Bicyclopropyl-*trans*-cyclopropylmethanol (**151**) (1.44 g, 9.26 mmol) was added and the resulting mixture stirred for 2 h at rt. After deluting with Et_2O (40 mL) the solution was washed with NaOH (1 M, 100 mL, 2 times). Drying over $MgSO_4$ and evaporation gave the crude product, which was purified by flash column chromatography (12% Et_2O in pentane eluant) to yield 1.32 g of **151** (94%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3081 cm^{-1} (*c*Pr–H), 3004 (C–H), 2750 (OC–H), 1688 (C=O), 1471, 1453, 1288, 1240, 1208, 1019, 892. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.21–0.37 (m, 4 H, *c*Pr-H), 0.49–0.70 (m, 4 H, *c*Pr-H), 0.70–0.96 (m, 2 H, *c*Pr-H), 1.28–1.42 (m, 2 H, *c*Pr-H), 1.62 (q, ^3J = 4.8 Hz, 1 H, *c*Pr-H), 9.09 (d, ^3J = 4.8 Hz, 1 H, C*H*O). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.95 (*c*Pr-C), 5.15 (*c*Pr-C), 32.81 (*c*Pr-C), 35.70

(*c*Pr-C), 200.82 (*C*HO). – MS (70 eV), *m/z* (%): 125 (30), 124 (25), 123 (24), 121 (20) [M^+ – CHO], 97 (27), 93 (41), 91 (33), 79 (100) [$cPrC_3H_2^+$], 67 (36), 55 (20), 41 (28) [cPr^+]. – $C_{10}H_{14}O$ (150.22).

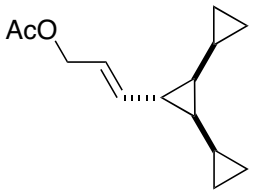
cis-*2,3-Bicyclopropyl*-trans-*cyclopropyl-propenic acid ethyl ester* (**153**) NaH (60% in mineraloil, 104 mg, 2.60 mmol) was suspended in DME (10 mL). (Diethoxy-phosphoryl)-acetic acid ethyl ester (**81-H**) (582 mg, 2.60 mmol) was added and the resulting mixture stirred for 1 h at rt. After the addition of *cis*-2,3-bicyclopropyl-*trans*-cyclopropylcarboxaldehyde (**152**) (300 mg, 2.00 mmol) in DME (3 mL) the reaction was stirred for 1.5 h at rt and 30 min at 50 °C. The mixture was poured into ice water (50 mL). The aqueous layer was extracted with Et_2O (30 mL, 3 times). Drying over $MgSO_4$ and evaporation gave the crude product, which was purified by flash column chromatography (12% Et_2O in pentane eluant) to yield 388 mg of **153** (88%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3080 cm^{-1} (*c*Pr–H), 3002 (C–H), 2957 (C–H), 2926 (C–H), 2853 (C–H), 1715 (C=O), 1642 (C=C), 1463, 1368, 1299, 1260, 1206, 1139 (C–O), 1045, 1018, 977 (H–C=C–H), 882, 855. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.17–1.26 (m, 4 H, *c*Pr-H), 0.43–0.62 (m, 4 H, *c*Pr-H), 0.71–0.92 (m, 5 H, *c*Pr-H), 1.28 (t, ^3J = 7.2 Hz, 3 H, CH_3), 4.15 (q, ^3J = 7.2 Hz, 2 H, OCH_2), 5.78 (d, ^3J = 14 Hz, 1 H, vinyl-H), 6.42 (dd, ^3J = 14 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.76 (*c*Pr-C), 4.99 (*c*Pr-C), 8.98 (*c*Pr-C), 14.30 (CH_3), 26.87 (*c*Pr-C), 32.33 (*c*Pr-C), 59.93 (OCH_2), 117.21 (vinyl-C), 153.47 (vinyl-C), 166.88 (CO_2Et). – DCI-MS (200 eV, NH_3), *m/z* (%): 458 (21) [2 M + NH_4^+], 238 (100)[M + NH_4^+], 221 (21) [M + H^+]. – $C_{14}H_{20}O_2$ (220.31).



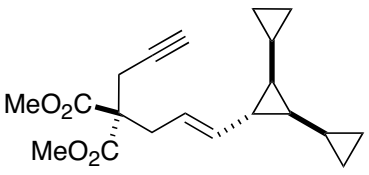
cis-*2,3-Bicyclopropyl*-trans-*cyclopropyl-prop-2-(*E*)-enol* (**154**) According to GP 2, *cis*-2,3-bicyclopropyl-*trans*-cyclopropyl-propenic acid ethyl ester (**153**) (1.54 g, 7.01 mmol) and DIBALH (1.2 M in toluene, 17.5 mL, 21.0 mmol) were allowed to react in THF (50 mL). The crude mixture was purified by flash column chromatography (20% Et_2O in pentane eluant) affording 850 mg of **154** (68%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3340 cm^{-1} (O–H), 3078 (*c*Pr–H), 3001 (C–H), 2919 (C–H), 2865 (C–H), 1666 (C=C), 1461, 1427, 1358, 1283, 1089, 1017 (C–O), 961 (H–C=C–H), 871, 814. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.10–0.22



(m, 4 H, *c*Pr-H), 0.38–0.67 (m, 8 H, *c*Pr-H), 1.02–1.10 (m, 1 H, *c*Pr-H), 1.58 (bs, 1 H, O*H*), 4.01 (bs, 2 H, CH_2OH), 5.19 (dd, ^3J = 14 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.56 (dt, ^3J = 14 Hz, ^3J = 4.8 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.68 (*c*Pr-C), 4.83 (*c*Pr-C), 25.43 (*c*Pr-C), 29.63 (*c*Pr-C), 63.64 (*C*H_2OH), 125.65 (vinyl-C), 136.82 (vinyl-C). – DCI-MS (200 eV, NH_3), *m/z* (%): 196 (4) [M + NH_4^+], 178 (20) [M – H_2O + NH_4^+], 161 (100). – $C_{12}H_{18}O$ (178.27).



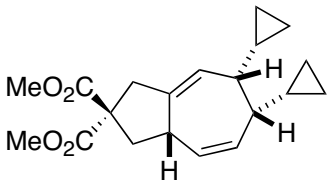
cis-2,3-*Bicyclopropyl*-trans-*cyclopropyl-prop-2-(*E*)-enol-acetate* (**155**) *cis*-2,3-Bicyclopropyl-*trans*-cyclopropyl-prop-2-(*E*)-enol (**154**) (850 mg, 4.74 mmol), acetic anhydride (0.90 mL, 9.48 mmol), triethylamine (1.31 mL, 9.48 mmol) and DMAP (6.0 mg, 47.4 μmol) were dissolved in DCM (50 mL) and stirred for 40 min at rt. Then water (30 mL) was added and extracted with DCM (30 mL, 2 times). After drying over Na_2SO_4 and evaporation of the solvent, the crude mixture was purified by flash column chromatography (12% Et_2O in pentane eluant) affording 778 mg of **155** (75%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3079 cm^{-1} (*c*Pr–H), 3002 (C–H), 2945 (C–H), 2880 (C–H), 1740 (C=O), 1665 (C=C), 1382, 1363, 1244 (C–O), 1226, 1030, 960 (H–C=C–H), 886. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.08–0.22 (m, 4 H, *c*Pr-H), 0.38–0.68 (m, 8 H, *c*Pr-H), 1.02–1.10 (m, 1 H, *c*Pr-H), 2.06 (s, 3 H, OCCH_3), 4.43 (d, ^3J = 6.4 Hz, 2 H, CH_2O), 5.26 (dd, ^3J = 14 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.52 (dt, ^3J = 14 Hz, ^3J = 6.4 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.71 (*c*Pr-C), 4.85 (*c*Pr-C), 21.05 (*c*Pr-C), 25.62 (*c*Pr-C), 29.79 (OC*C*H_3), 65.33 (*C*H_2O), 120.40 (vinyl-C), 140.10 (vinyl-C), 170.87 (O*C*CH_3). – DCI-MS (200 eV, NH_3), *m/z* (%): 238 (5) [M + NH_4^+], 178 (20), 161 (100). – $C_{14}H_{20}O_2$ (220.31).



cis-*2,3-Bicyclopropyl*-trans-*cyclopropyl-prop-2-(*E*)-enyl-malonate* (**157**) To a suspension of NaH (60% in mineraloil, 283 mg, 7.06 mmol) in dry THF (50 mL) was added *cis*-2,3-bicyclopropyl-*trans*-cyclopropyl-prop-2-(*E*)-enol acetate (**155**) (778 mg, 3.53 mmol), prop-2-ynylmalonate (**156**) (1.20 g, 7.06 mmol) and $Pd(PPh_3)_4$ (408 mg, 353 μmol) and it was stirred over night at 50 °C. The mixture was poured into brine and was extracted with Et_2O (50 mL, 3 times). After drying over $MgSO_4$

and evaporation of the solvent the crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 809 mg of **157** (69%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3306 cm^{-1} (C≡C–H), 3079 (*c*Pr–H), 3000 (C–H), 2954 (C–H), 2843 (C–H), 1737 (C=O), 1662 (C=C), 1436, 1327, 1285, 1213 (C–O), 1055, 1010, 964 (H–C=C–H), 889, 646. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.11–0.21 (m, 4 H, *c*Pr-H), 0.39–0.61 (m, 6 H, *c*Pr-H), 0.63–0.75 (m, 2 H, *c*Pr-H), 0.94–1.03 (m, 1 H, *c*Pr-H), 1.99 (t, ^4J = 2.0 Hz, 1 H, C≡C-*H*), 2.65 (d, ^3J = 6.4 Hz, 2 H, 1′-H), 2.66 (d, ^4J = 2.0 Hz, 1 H, 1-H), 3.71 (s, 6 H, CO_2CH_3), 5.03–5.21 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.70 (*c*Pr-C) 4.84 (*c*Pr-C), 22.61 (C-1), 25.55 (*c*Pr-C), 29.50 (*c*Pr-C), 35.33 (C-1′), 52.64 (CO_2CH_3), 57.23 [$C(CO_2Me)$], 71.26 (C-3), 78.94 (C-2), 119.37 (vinyl-C), 139.14 (vinyl-C), 170.26 (CO_2Me). – DCI-MS (200 eV, NH_3), *m/z* (%): 678 (9) [2 M + NH_4^+], 348 (100) [M + NH_4^+], 331 (20) [M + H^+]. – Cal. C 72.70, H 7.93; found C 72.42, H 7.68.

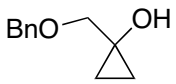
*6,7-Dicyclopropyl-3,3a,6,7-tetrahydro-1*H-*azulene-2,2-dicarboxylic acid dimethyl ester* (**158**) According to GP 4, *cis*-2,3-bicyclopropyl-*trans*-cyclopropyl-prop-2-(*E*)-enyl-malonate (**157**) (30 mg, 98.8 μmol) and the catalyst [($C_{10}H_8$)Rh(COD)]SbF_6 (2.6 mg, 4.54 μmol) were allowed to react in DCE (1 mL) for 24 h at 70 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 24 mg of the cycloadduct **158** (80%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3075 cm^{-1} (*c*Pr–H), 3001 (C–H), 2953 (C–H), 2847 (C–H), 1736 (C=O), 1435, 1253, 1203, 1163, 1072, 1017, 951, 887, 823, 733. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.01–0.11 (m, 4 H, *c*Pr-H), 0.31–0.50 (m, 4 H, *c*Pr-H), 0.87–1.05 (m, 2 H, *c*Pr-H), 1.61–1.79 (m, 2 H, 6-H, 7-H), 2.02 (dd, ^2J = 11.8 Hz, ^3J = 11.8 Hz, 1 H, 3-H), 2.63 (dd, ^2J = 11.8 Hz, ^3J = 7.9 Hz, 1 H, 3-H), 2.99 (s, 2 H, 1-H), 3.71 (s, 3 H, CO_2CH_3), 3.72 (s, 3 H, CO_2CH_3), 5.44–5.70 (m, 3 H, vinyl-H) . – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 3.45 (*c*Pr-C), 4.33 (*c*Pr-C), 4.60 (*c*Pr-C), 13.77 (*c*Pr-C), 39.84 (C-1*, C-3*, C-3a*, C-6*, C-7*), 41.10 (C-1*, C-3*, C-3a*, C-6*, C-7*), 41.23 (C-1*, C-3*, C-3a*, C-6*, C-7*), 46.63 (C-1*, C-3*, C-3a*, C-6*, C-7*), 46.95 (C-1*, C-3*, C-3a*, C-6*, C-7*), 52.64 (CO_2CH_3), 58.41 (C-2), 126.08 (C-8), 134.26 (2 C, C-4, C-5), 155.85 (C-8a), 171.86 (CO_2Me), 172.05 (CO_2Me). – MS (70 eV), *m/z* (%): 330 (27) [M^+], 270 (24) [M^+ – CO_2CH_3 – H], 262 (23), 227



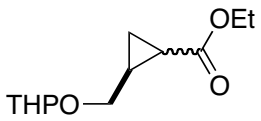
(16), 215 (30), 211 (38) [M^+ – 2 CO_2CH_3 – H], 203 (68), 189 (24) [M^+ – CO_2CH_3 – 2 *c*Pr], 169 (30) [M^+ – 2 CO_2CH_3 – *c*Pr – H], 155 (44), 143 (50) [M^+ – 2 CO_2CH_3 – *c*Pr –C_2H_4 – H], 129 (63) [M^+ – 2 CO_2CH_3 – 2 *c*Pr – H], 115 (58), 91 (100) [M^+ – $(CH_2)_2C(CO_2CH_3)_2$ – 2 *c*Pr + H], 59 (81) [$CO_2CH_3^+$], 41 (90) [*c*Pr^+]. – $C_{18}H_{24}O_4$ (330.41).

3.3. 3rd-Generation precursors

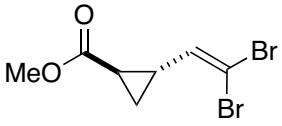
3.3.1. Intramolecular Cyclization



1-Benzyloxymethyl-cyclopropanol (**170**) Benzyloxy-acetic acid methyl ester (**169**) (1.80 g, 100 mmol) was dissolved in THF (20 mL). Ti(O*i*Pr)$_4$ (3.54 mL, 12.0 mmol) was added, followed by ethylmagnesium bromide (2.7 M in Et_2O, 8.89 mL, 24.0 mmol) via syringe pump over 1 h. The solution was stirred over night. The reaction was quenched with water (2 mL) and stirred open to air until the black color turned white. $MgSO_4$ was added and the mixture filtered through a pad of celite. Evaporation of the solvent and purification by flash column chromatography (50% Et_2O in pentane eluant) gave 280 mg of the product (16%) as a colorless oil . – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.51–0.60 (m, 2 H, *c*Pr-H), 0.79–0.88 (m, 2 H, *c*Pr-H), 1.85 (bs, 1 H, O*H*), 3.56 (s, 2 H, *c*Pr-CH_2), 4.60 (s, 2 H, Ph-CH_2), 7.28–7.39 (m, 5 H, Ph-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –0.57 (*c*Pr-C), 11.61 (*c*Pr-C), 65.28 (*c*Pr-*C*H$_2$), 73.09 (Ph-*C*H$_2$), 126.93 (Ph-C), 127.59 (Ph-C), 127.72 (Ph-C), 128.50 (Ph-C). – $C_{11}H_{14}O_2$ (178.23).

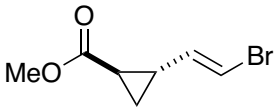


Attempt for the preparation of trans-*2-(tetrahydro-pyran-2-yloxymethyl)-cyclopropanecarboxylic acid ethyl ester* (**181**) $[Rh(OAc)_2]_2$ (137 mg, 310 μmol) was suspended in DCM (30 mL), followed by the addition of 2-allyloxy-tetrahydro-pyran (**180**) (8.82 g, 62.0 mmol). Diazo acidic acid ethyl ester (7.26 mL, 69.0 mmol) was added via syringe pump over 20 h at 0 °C. The mixture was filtered through a pad of silica. Evaporation of the solvent and purification by flash column chromatography (5% Et_2O in pentane eluant) gave a mixture of both isomers, which were not separable by column chromatography.

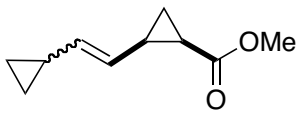


trans-*2-(2,2-Dibromo-vinyl)-cyclopropanecarboxylic acid methyl ester* (**201**) To a solution of tetrabromomethane (8.18 g, 15.6 mmol) in dry DCM (30 mL) was added triphenylphosphine (5.17 g, 15.6 mmol), dissolved in dry DCM (30 mL), at 0 °C. After stirring for 1 h at that temperature *trans*-2-formyl-cyclopropanecarboxylic acid methyl ester (**101**) (1.00 g, 7.80 mmol), dissolved in dry

DCM (50 mL), was slowly added. The reaction was stirred for 1 h at 0 °C and 1 h at rt. The mixture was filtered through a pad of silica, eluated with 25% Et_2O in pentane. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was essentially pure by NMR and was directly used in the next reaction. – IR (film): $\tilde{\nu}$ = 3013 cm^{-1} (*c*Pr–H), 2951 (C–H), 1727 (C=O), 1440, 1396, 1324, 1271, 1206, 1174, 1091, 1026, 929, 860, 788, 736. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.01–1.10 (m, 1 H, *c*Pr-H), 1.43–1.59 (m, 1 H, *c*Pr-H), 1.74–1.83 (m, 1 H, *c*Pr-H), 2.19–2.31 (m, 1 H, *c*Pr-H), 3.72 (s, 3 H, CO_2CH_3), 5.84 (d, ^3J = 7.9 Hz, 1 H, $CHCBr_2$). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 15.04 (*c*Pr-C), 21.12 (*c*Pr-C), 29.10 (*c*Pr-C), 52.05 (CO_2CH_3), 89.28 ($CHCBr_2$), 137.89 ($CHCBr_2$), 172.77 (CO_2CH_3). – MS (70 eV), *m/z* (%): 286 (4), 284 (10) [M^+], 282 (4), 253 (10) [$M^+ - OCH_3$], 242 (22), 205 (39), 203 (41) [M^+ – Br], 173 (20) [$M^+ - OCH_3$ – Br], 171 (18), 146 (54), 145 (38), 144 (57) [$M^+ - CO_2CH_3$ – Br], 143 (39), 115 (20), 117 (21) [$CHCH{=}CBr^+$], 96 (15), 79 (16), 65 (100) [$M^+ - CO_2CH_3$ – 2 Br], 59 (82) [$CO_2CH_3^+$]. – Cal. C 29.61, H 2.84; found C 29.78, H 2.67.



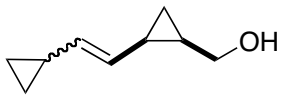
Attempt for the preparation of trans-*2-(2-bromo-vinyl)-cyclopropanecarboxylic acid methyl ester* (**202**) A mixture of *trans*-2-(2,2-dibromo-vinyl)-cyclopropanecarboxylic acid methyl ester (**201**) (2.21 g, 7.80 mmol), diethylphosphite (1.99 mL, 15.5 mmol) and triethylamine (2.19 mL, 15.6 mmol) were stirred at 0 °C for 4 h. The mixture was diluted with pentane (50 mL), washed with brine and water (50 mL, 2 times). The organic layer was dried over $MgSO_4$ and the solvent evaporated. Column chromatography (15% Et_2O in pentane eluant) gave only starting material.



cis-*2-(2-Cyclopropyl-vinyl)cyclopropanecarboxylic acid methyl ester* To a suspension of cyclopropylmethyl-triphenylphosphonium bromide (**178**) (1.57 g, 3.94 mmol) in THF (25 mL) was slowly added *n*-BuLi (2.38 M in hexane, 1.66 mL, 3.94 mmol) at –78 °C. After stirring for 1 h at rt *trans*-2-formyl-cyclopropanecarboxylic acid methyl ester (***cis*-103**) (500 mg, 3.90 mmol) was slowly added. The reaction was stirred for 1 h at rt. The mixture was diluted with pentane and filtered through a pad of silica. Drying over $MgSO_4$ and

evaporation of the solvent gave the crude product, which was purified by column chromatography (10% Et_2O in pentane eluant) affording 231 mg of the product as a mixture of *cis*-2-(2-cyclopropyl-vinyl)cyclopropanecarboxylic acid methyl ester in a ratio of *E*:*Z* of 1:2.4 (NMR), which were not separable by column chromatography (36%). – IR (film): $\tilde{\nu}$ = 3083 cm^{-1} (*c*Pr–H), 3005 (C–H), 2952 (C–H), 1729 (C=O), 1439, 1383, 1201, 1167 (C–O), 961 (H–C=C–H), 938, 907, 812, 791. – Data for the (*Z*)-isomer: ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.30–0.38 (m, 2 H, *c*Pr-H), 0.70–0.81 (m, 2 H, *c*Pr-H), 1.11–1.27 (m, 2 H, *c*Pr-H), 1.56–1.72 (m, 1 H, *c*Pr-H), 1.90–2.02 (m, 1 H, *c*Pr-H), 2.19–2.32 (m, 1 H, *c*Pr-H), 3.67 (s, 3 H, CO_2CH_3), 4.84 (t, ^3J = 10 Hz, 1 H, vinyl-H), 5.23 (t, ^3J = 10 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 7.08 (*c*Pr-C), 9.89 (*c*Pr-C), 14.69 (*c*Pr-C), 19.73 (*c*Pr-C), 20.79 (*c*Pr-C), 51.59 (CO_2CH_3), 124.29 (vinyl-C), 136.11 (vinyl-C), 172.56 (CO_2CH_3). – Data for the (*E*)-isomer: ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.30–0.38 (m, 2 H, *c*Pr-H), 0.61–0.70 (m, 2 H, *c*Pr-H), 1.11–1.27 (m, 2 H, *c*Pr-H), 1.30–1.41 (m, 1 H, *c*Pr-H), 1.80–92 (m, 2 H, *c*Pr-H), 3.67 (s, 3 H, CO_2CH_3), 5.17 (dd, ^3J = 10 Hz, ^3J = 16 Hz, 1 H, vinyl-H), 5.49 (m, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 6.64 (*c*Pr-C), 13.74 (*c*Pr-C), 14.22 (*c*Pr-C), 20.50 (*c*Pr-C), 24.10 (*c*Pr-C), 51.59 (CO_2CH_3), 124.17 (vinyl-C), 136.23 (vinyl-C), 172.56 (CO_2CH_3). – MS (70 eV), *m/z* (%): 167 (5), 166 (48) [M^+], 151 (4) [$M^+ - CH_3$], 138 (9), 107 (40) [$M^+ - CO_2Me$], 91 (92), 79 (100), 67 (37), 59 (30) [CO_2Me^+], 41 (59) [cPr^+]. – Cal. C 72.26, H 8.49; found C 72.27, H 8.32.

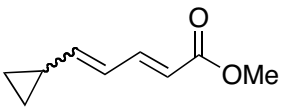
cis-*[2-(2-Cyclopropyl-vinyl)-cyclopropyl]-methanol* (**179**)



According to GP 2, *cis*-2-(2-cyclopropyl-vinyl)-cyclopropanecarboxylic acid methyl ester (229 mg, 1.38 mmol) and DIBALH (1.2 M in toluene, 3.44 mL, 4.13 mmol) were allowed to react in dry THF (15 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 193 mg of the product as a mixture of ***E*-179** and ***Z*-179** in a ratio of 1:2.4 (NMR), which were not separable by column chromatography (36%). – IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3080 (*c*Pr–H), 3002 (C–H), 2927 (C–H), 2875 (C–H), 1430, 1041 (CH_2–O), 1017, 956, 938, 810. – Data for ***Z*-179**: ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.30–0.40 (m, 3 H, *c*Pr-H), 0.76–0.81 (m, 2 H, *c*Pr-H), 0.98–1.09 (m, 1 H, *c*Pr-H), 1.20–1.42 (m, 2 H, *c*Pr-H), 1.63–1.79 (m, 2 H, *c*Pr-H, O*H*), 1.80–1.95 (m, 1 H, *c*Pr-H), 3.40–3.51 (m, 1 H, CH_2OH), 3.69–3.81 (m, 1 H, CH_2OH), 4.84 (t, ^3J = 10 Hz, 1 H, vinyl-H),

5.07 (t, ^3J = 10 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 6.96 (*c*Pr-C), 10.01 (*c*Pr-C), 12.20 (*c*Pr-C), 14.04 (*c*Pr-C), 20.74 (*c*Pr-C), 63.81 (CH_2OH), 126.04 (vinyl-C), 136.15 (vinyl-C). – Data for the ***E*-179** : ^{1}H NMR (250 MHz, $CDCl_3$); δ = 0.30–0.40 (m, 3 H, *c*Pr-H), 0.61–0.70 (m, 2 H, *c*Pr-H), 0.85–0.93 (m, 1 H, *c*Pr-H), 1.20–1.42 (m, 2 H, *c*Pr-H), 1.63–1.79 (m, 2 H, *c*Pr-H, O*H*), 3.40–3.51 (m, 1 H, CH_2OH), 3.69–3.81 (m, 1 H, CH_2OH), 5.10 (dd, ^3J = 23 Hz, ^3J = 10 Hz, 1 H, vinyl-H), 5.33 (dd, ^3J = 23 Hz, ^3J = 10 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 6.56 (*c*Pr-C), 10.59 (*c*Pr-C), 13.72 (*c*Pr-C), 18.12 (*c*Pr-C), 20.46 (*c*Pr-C), 63.29 (CH_2OH), 125.40 (vinyl-C), 135.57 (vinyl-C). – MS (70 eV), *m/z* (%): 138 (19) [M^+], 120 (4) [$M^+ - H_2O$], 107 (16) [$M^+ - CH_2OH$], 91 (38), 79 (100), 67 (35), 53 (17), 41 (39). – $C_9H_{14}O$ (138.21).

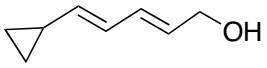
*5-Cyclopropyl-penta-(*E*)-2,4-dienoic acid methyl ester* (**186**)

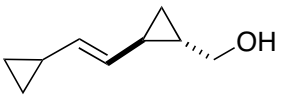


To a suspension of NaH (60% in mineraloil, 780 mg, 19.5 mmol) in dry THF (20 mL) was dropwise added a solution of 4-(diethoxy-phosphoryl)-but-2-enoic acid methyl ester (**183**) (4.61 g, 19.5 mmol) in THF (5 mL) at 0 °C. The mixture was stirred for 30 min at that temperature. Then, cyclopropylcarboxaldehyde (**184**) (1.12 mL, 15.0 mmol) in THF (5 mL) was added. After stirring for 1 h at 0 °C and 1 h at rt the mixture was poured into a mixture of HCL (1 M) and Et_2O. The layers were separated and the aqueous layer was extracted with Et_2O (50 mL). The combined organic phases were washed with water (50 mL), $NaHCO_3$ (sat., 50 mL) and brine (50 mL). Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (5% Et_2O in Pentane) to yield 1.38 g of ***E*-186** (61%) and 53.0 mg of ***Z*-186** (2%). – Data for ***Z*-186**: IR (film): $\tilde{\nu}$ = 3086 cm^{-1} (*c*Pr–H), 3009 (C–H), 2954 (C–H), 2904 (C–H), 1723 (C=O), 1661 (C=C), 1437, 1308, 1274, 1201, 1174, 1028, 978 (H–C=C–H), 826. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.50–0.59 (m, 2 H, *c*Pr-H), 0.85–0.95 (m, 2 H, *c*Pr-H), 1.52–1.65 (m, 1 H, *c*Pr-H), 3.73 (s, 3 H, CO_2CH_3), 5.49 (d, ^3J = 12 Hz, 1 H, vinyl-H), 5.52 (dd, ^3J = 16 Hz, ^3J = 7.9 Hz, 1 H, vinyl-H), 6.50 (t, ^3J = 12 Hz, 1 H, vinyl-H), 7.49 (dd, ^3J = 16 Hz, ^3J = 12 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 8.45 (*c*Pr-C) 14.90 (*c*Pr-C), 50.96 (CO_2CH_3), 113.62 (C-5), 124.46 (C-4), 145.29 (C-3), 150.16 (C-2), 167.04 (CO_2CH_3). – MS (70 eV), *m/z* (%): 153 (5), 152 (33) [M^+], 137 (20) [$M^+ - CH_3$], 121 (18) [$M^+ - OCH_3$], 111 (19), 93 (95) [$M^+ - CO_2CH_3$], 91 (100),

77 (98), 65 (40), 53 (32), 41 (38) [*c*Pr$^+$]. – $C_9H_{12}O_2$ (152.19). – Data for ***E*-186**: IR (film): $\tilde{\nu}$ = 3086 cm^{-1} (*c*Pr–H), 3009 (C–H), 2955 (C–H), 2906 (C–H), 1726 (C=O), 1661 (C=C), 1437, 1309, 1274, 1200, 1173, 1100, 1030, 978 (H–C=C–H). – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.50–0.59 (m, 2 H, *c*Pr-H), 0.85–0.95 (m, 2 H, *c*Pr-H), 1.48–1.59 (m, 1 H, *c*Pr-H), 3.73 (s, 3 H, CO_2CH_3), 5.59 (dd, ^3J = 14 Hz, ^3J = 7.9 Hz, 1 H, vinyl-H), 5.75 (d, ^3J = 14 Hz, 1H, vinyl-H), 6.26 (dd, ^3J = 16 Hz, ^3J = 12 Hz, 1 H, vinyl-H), 7.20 (dd, ^3J = 16 Hz, ^3J = 12 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 8.35 (*c*Pr-C) 14.90 (*c*Pr-C), 51.34 (CO_2CH_3), 117.35 (C-5), 125.73 (C-4), 145.09 (C-3), 155.34 (C-2), 167.83 (CO_2CH_3). – MS (70 eV), *m/z* (%): 153 (5), 152 (33) [M$^+$], 137 (20) [M$^+$ – CH_3], 121 (23) [M$^+$ – OCH_3], 111 (19), 93 (100) [M$^+$ – CO_2CH_3], 91 (82), 77 (65), 65 (18), 53 (10), 41 (17) [*c*Pr$^+$]. – $C_9H_{12}O_2$ (152.19).

5-Cyclopropyl-penta-2,4-dien-1-ol (**188**) According to GP 2, 5-cyclopropyl-penta-(*E*,*E*)-2,4-dienoic acid methyl ester (***E*-186**) (1.38 g, 9.09 mmol) and DIBALH (1.2 M in toluene, 22.7 mL, 27.3 mmol) were allowed to react in dry Et_2O (100 mL). The crude mixture was purified by flash column chromatography (40% Et_2O in pentane eluant) affording 1.13 g of **188** (quant.) as colorless oil. – IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3082 (*c*Pr–H), 3004 (C–H), 2927 (C–H), 2866 (C–H), 1725, 1685 (C=C), 1656 (C=C), 1628, 1456, 1428, 1386, 1172, 1090 1047, 1021, 985 (H–C=C–H), 949, 859, 809. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.38–0.44 (m, 2 H, *c*Pr-H), 0.73–0.85 (m, 2 H, *c*Pr-H), 1.38–1.50 (m, 2 H, *c*Pr-H, O*H*), 4.13 (t, ^3J = 6.3 Hz, 2 H, CH_2OH), 5.22 (dd, ^3J = 14 Hz, ^3J = 8.7 Hz, 1 H, vinyl-H), 5.70 (dt, ^3J = 14 Hz, ^3J = 6.3 Hz, 1 H, vinyl-H), 6.05–6.21 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 7.36 (*c*Pr-C) 14.04 (*c*Pr-C), 63.60 (CH_2OH), 126.95 (C-5), 128.48 (C-4), 131.91 (C-3), 139.39 (C-2). – MS (70 eV), *m/z* (%): 125 (7), 124 (100) [M$^+$], 109 (8) [M$^+$ – CH_3], 95 (22), 93 (50) [M$^+$ – CH_2OH], 91 (82), 79 (70), 77 (65), 67 (60), 55 (38), 41 (54) [*c*Pr$^+$]. – Cal. C 77.38, H 9.74; found C 77.14, H 9.48.



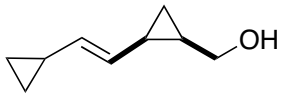


[2-(2-Cyclopropylvinyl)-cyclopropyl]-methanol (***trans*-190**) Method a) Diiodomethane (1.95 mL, 24.2 mmol) was added to a mixture of diethylzink (1.23 mL, 12.0 mmol) and DME (1.25 mL, 12.0 mmol) in DCM (20 mL) at –10 °C. After stirring for 20 min 5-cyclopropyl-penta-2,4-dien-1-ol (**188**) (500 mg, 4.03 mmol) in DCM (5 mL) was added. The mixture was stirred at –10 °C over night. NH_4Cl (sat., 10 mL) was added, followed by HCl (1 M, 10 mL). It was diluted with Et_2O (20 mL) and the organic layer was successively washed with Na_2SO_3 (sat., 20 mL), NaOH [2 M, containing 1% H_2O_2 (30%), 20 mL], NH_4Cl (sat., 20 mL) and brine (20 mL), dried over $MgSO_4$ and concentrated. Purification by flash column chromatography (50% Et_2O in pentane eluant) yielded 111 mg of **190** (20%) and 143 mg [1.1′;2′,1″]tercyclopropan-2″-yl-methanol (**192**) (23%). – Data for **190**: IR (film): $\tilde{\nu} = 3320$ cm^{-1} (O–H), 3080 (*c*Pr–H), 3002 (C–H), 2946 (C–H), 2915 (C–H), 1868 (C–H), 1663 (C=C), 1456, 1427, 1054 (C–O), 1015, 953, 887, 865, 809. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.25$–0.34 (m, 2 H, *c*Pr-H), 0.50–0.71 (m, 4 H, *c*Pr-H), 1.01–1.12 (m, 1 H, *c*Pr-H), 1.19–1.38 (m, 2 H, *c*Pr-H), 1.78 (bs, 1 H, O*H*), 3.45 (m, 2 H, CH_2OH), 4.99–5.17 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 6.37$ (*c*Pr-C) 11.33 (*c*Pr-C), 13.45 (*c*Pr-C), 19.44 (*c*Pr-C), 22.62 (*c*Pr-C), 66.40 (*C*H_2OH), 129.76 (vinyl-C), 132 36 (vinyl-C). – MS (70 eV), *m/z* (%): 138 (8) [M$^+$], 120 (3) [M$^+$ – H_2O], 107 (18) [M$^+$ – C_2OH], 105 (22), 91 (42), 79 (100), 67 (38), 53 (11), 41 (27) [*c*Pr$^+$]. – $C_9H_{14}O$ (138.21). – Data for **192**: IR (film): $\tilde{\nu} = 3320$ cm^{-1} (O–H), 3077 (*c*Pr–H), 2999 (C–H), 2915 (C–H), 2869 (C–H), 1458, 1426, 1310, 1039 (C–O), 1013, 871, 819. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = -0.02$–0.03 (m, 2 H, *c*Pr-H), 0.04–0.20 (m, 2 H, *c*Pr-H), 0.21–0.35 (m, 4 H, *c*Pr-H), 0.40–0.83 (m, 5 H, *c*Pr-H), 1.40 (bs, 1 H, O*H*), 3.40 (m, 2 H, CH_2OH). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 6.37$ (*c*Pr-C) 2.73 (*c*Pr-C), 2.99 (*c*Pr-C), 8.38 (*c*Pr-C), 11.96 (*c*Pr-C), 17.67 (*c*Pr-C), 18.45 (*c*Pr-C), 18.71 (*c*Pr-C), 19.59 (*c*Pr-C), 66.93 (*C*H_2OH). – MS (200 eV, DCI, NH_3), *m/z* (%): 170 (21) [M + NH_4^+], 152 (50) [M – H_2O + NH_4^+], 135 (100), 121 (19). – $C_{10}H_{16}O$ (152.23).

Method b) In a 50 mL Schlenk flask were placed 2-(2-Cyclopropyl-vinyl)-benzo-[1,3,2]dioxaborole (**200**) (150 mg, 806 μmol), *trans*-(2-iodo-cyclopropyl)-methanol (***trans*-198**) (79.0 mg, 399 μmol), K_2CO_3 (166 mg, 1.29 mmol), $Pd(OAc)_2$ (9.0 mg, 40.1 μmol), triphenylphosphine (52.0 mg, 198 μmol), *n*Bu_4NCl (222 mg, 799 μmol), DMF (12 mL) and water (4 mL). The mixture was degased by bubbling Ar through

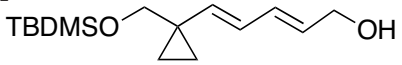
the solution in a sonicator. The reaction was then stirred at 90 °C for 4 h. The mixture was diluted with Et_2O and washed with water and brine. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (50% Et_2O in pentane eluant) to yield 30 mg of ***trans*-190** (54%).

cis-*[2-(2-Cyclopropyl-(*E*)-vinyl)-cyclopropyl]-methanol* (***cis*-190**) 2-(2-Cyclopropyl-vinyl)-benzo[1,3,2]dioxaborole (**200**) (930 mg, 5.00 mmol), *cis*-(2-iodo-cyclopropyl)-methanol (***cis*-198**) (500 mg, 2.53 mmoll), K_2CO_3 (1.04 g, 7.50 mmol), $Pd(OAc)_2$ (56.0 mg, 249 μmol), triphenylphosphine (328 mg, 1.25 mmol), nBu$_4$NCl (1.39 g, 5.00 mmol), DMF (40 mL) and water (13 mL) were placed in a 100 mL SCHLENK flask. The mixture was degased by bubbling Ar through the solution in a sonicator. The flask was then stirred at 90 °C over night. The mixture was diluted with Et_2O and washed with water and brine. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (40% Et_2O in pentane eluant) to yield 30 mg of ***cis*-190** (9%). – IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3079 (*c*Pr–H), 3001 (C–H), 2926 (C–H), 2852 (C–H), 1602 (C=C), 1514, 1470, 1370, 1257, 1190, 1015 (C–O), 956 (H–C=C–H), 745. – ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.25–0.40 (m, 2 H, *c*Pr-H), 0.60–0.78 (m, 2 H, *c*Pr-H), 0.82–1.01 (m, 2 H, *c*Pr-H), 1.20–1.60 (m, 3 H, *c*Pr-H), 1.90 (bs, 1 H, O*H*), 3.41–3.56 (m, 1 H, CH_2OH), 3.65–3.80 (m, 1 H, CH_2OH), 5.10 (dd, ^3J = 16 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.30 (dd, ^3J = 16 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H). – ^{13}C NMR (50 MHz, $CDCl_3$): δ = 6.51 (*c*Pr-C) 5.59 (*c*Pr-C), 10.62 (*c*Pr-C), 13.72 (*c*Pr-C), 18.15 (*c*Pr-C), 20.41 (*c*Pr-C), 63.47 (*C*H$_2$OH), 125.33 (vinyl-C), 135.76 (vinyl-C). – MS (70 eV), *m/z* (%): 138 (3) [M$^+$], 120 (2) [M$^+$ – OH$_2$], 110 (100) [M$^+$ – C$_2$H$_4$], 105 (22) [M$^+$ – CH$_2$OH – 2 H], 91 (43), 79 (74) [*c*PrC$_3$H$_2^+$], 67 (20), 53 (14), 41 (27) [*c*Pr$^+$]. – C$_9$H$_{14}$O (138.21).

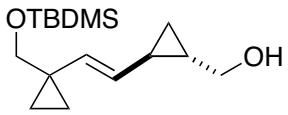


*5-[1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-2(*E*),4-dienoic acid methyl ester* (**187**) To a suspension of NaH (60% in mineraloil, 260 mg, 6.50 mmol) in dry DME (20 mL) was dropwise added 4-(diethoxy-phosphoryl)-but-2-enoic acid methyl ester (**183**) (1.54 g, 6.50 mmol), dissolved in DME (5 mL), at 0 °C. The mixture was

stirred for 30 min at that temperature. Then, cyclopropanecarbaldehyde **185** (750 g, 3.50 mmol) in DME (5 mL) was added. After stirring for 1 h at 0 °C and 1 h at rt the mixture was poured into a mixture of HCL (1 M) and Et_2O. The layers were separated and the aqueous layer was extracted with Et_2O. The combined organic phases were washed with water, $NaHCO_3$ (sat.) and brine. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product which was purified by flash column chromatography (5% Et_2O in Pentane) to yield 662 mg of ***E*-187** (67%) and 32 mg of ***Z*-187** (3%). – Data for ***Z*-187**: IR (film): $\tilde{\nu} = 3082$ cm^{-1} (*c*Pr–H), 3008 (C–H), 2955 (C–H), 2929 (C–H), 2887 (C–H), 2856 (C–H), 1722 (C=O), 1635 (C=C), 1602 (C=C), 1469, 1435, 1307, 1269, 1167, 1092 (C–O), 1000, 837, 777, 711, 668. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.02$ (s, 6 H, Si(CH_3)$_2$*t*Bu), 0.58–0.62 (m, 2 H, *c*Pr-H), 0.78–0.83 (m, 2 H, *c*Pr-H), 0.87 (s, 9H, Si(CH$_3$)$_2$*tBu*), 3.51 (s, 2 H, CH_2OSi), 3.77 (s, 3 H, CO$_2$CH_3), 5.82 (d, $^3J = 16$ Hz, 1 H, vinyl-H), 5.90 (d, $^3J = 10$ Hz, 1 H, vinyl-H), 6.15 (t, $^3J = 10$ Hz, 1 H, vinyl-H), 7.83 (dd, $^3J = 16$ Hz, $^3J = 10$ Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = -5.43$ [Si(*C*H$_3$)$_2$*t*Bu], 11.35 (*c*Pr-C), 18.28 [Si(CH$_3$)$_2$*C*(CH$_3$)$_3$], 22.63 (*c*Pr-C), 25.82 [Si(CH$_3$)$_2$C(*C*H$_3$)$_3$], 51.41 (CO$_2$*C*H$_3$), 68.40 (*C*H$_2$OSi), 121.22 (C-5), 129.59 (C-4), 141.33 (C-3), 141.72 (C-2), 167.49 (*C*O$_2$Me). – MS (70 eV), *m/z* (%): 295 (1) [M$^+$ – H], 265 (3) [M$^+$ – 2 CH$_3$], 253 (18), 239 (80) [M$^+$ – *t*Bu + H], 207 (11) [M$^+$ – *t*Bu – 2 Me – H], 179 (8) [M$^+$ – TBDMS – H], 151 (28) [M$^+$ – CH$_2$OTBDMS + H], 105 (37), 89 (89), 75 (100), 73 (75), 59 (30), 41 (17) [*c*Pr$^+$]. – $C_{16}H_{28}O_3Si$ (296.48). – Data for ***Z*-187**: IR (film): $\tilde{\nu} = 3084$ cm^{-1} (*c*Pr–H), 3006 (C–H), 2956 (C–H), 2929 (C–H), 2887 (C–H), 2856 (C–H), 1724 (C=O), 1639 (C=C), 1469, 1434, 1390, 1357, 1306, 1266, 1171, 1138, 1084 (C–O), 1041, 999, 939, 836, 776, 667. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.02$ (s, 6 H, Si(CH_3)$_2$*t*Bu), 0.69–0.75 (m, 2 H, *c*Pr-H), 0.87–0.92 (m, 11 H, *c*Pr-H, Si(CH$_3$)$_2$*tBu*), 3.62 (s, 2 H, CH_2OSi), 3.75 (s, 3 H, CO$_2$CH_3), 5.76 (d, $^3J = 16$ Hz, 1 H, vinyl-H), 5.88 (d, $^3J = 16$ Hz, 1 H, vinyl-H), 6.20 (dd, $^3J = 16$ Hz, $^3J = 8.7$ Hz, 1 H, vinyl-H), 7.21 (dd, $^3J = 16$ Hz, $^3J = 8.7$ Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = -5.38$ [Si(*C*H$_3$)$_2$*t*Bu], 13.34 (*c*Pr-C), 18.26 [Si(CH$_3$)$_2$*C*(CH$_3$)$_3$], 24.60 (*c*Pr-C), 25.82 [Si(CH$_3$)$_2$C(*C*H$_3$)$_3$], 51.37 (CO$_2$*C*H$_3$), 66.23 (*C*H$_2$OSi), 117.80 (C-5), 124.74 (C-4), 145.58 (C-3), 148.71 (C-2), 167.80 (*C*O$_2$Me). – MS (70 eV), *m/z* (%): 296 (1) [M$^+$], 253 (28), 239 (100) [M$^+$ – *t*Bu + H], 207 (7) [M$^+$ – *t*Bu – 2 Me – H], 179 (8) [M$^+$ – TBDMS – H], 151 (30) [M$^+$ – CH$_2$OTBDMS + H], 105 (37), 89 (76), 75 (78), 59 (20), 41 (10) [*c*Pr$^+$]. – $C_{16}H_{28}O_3Si$ (296.48).

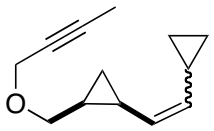
*5-[1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-(*E,E*)-2,4-dien-1-ol* (**189**) 

According to GP 3, 5-[1-(*tert*-butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-(*E,E*)-2,4-dienoic acid methyl ester (***E*-187**) (662 mg, 2.34 mmol) and DIBALH (1.2 M in toluene, 5.86 mL, 7.03 mmol) were reacted in dry Et_2O (40 mL). The crude mixture was purified by flash column chromatography (40% Et_2O in pentane eluant) affording 1.13 g of **189** (quant.) as colorless oil. – IR (film): $\tilde{\nu}$ = 3340 cm^{-1} (O–H), 3082 (*c*Pr–H), 3005 (C–H), 2956 (C–H), 2929 (C–H), 2887 (C–H), 2856 (C–H), 1687 (C=C), 1656 (C=C), 1630 (C=C), 1469, 1254, 1087, 987 (H–C=C–H), 835, 776. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.02 (s, 6 H, $Si(CH_3)_2tBu$), 0.56–0.63 (m, 2 H, *c*Pr-H), 0.71–0.95 (m, 2 H, *c*Pr-H), 0.93 (s, 9 H, $Si(CH_3)_2tBu$), 1.40 (bs, 1 H, O*H*), 3.62 (s, 2 H, CH_2OSi), 4.15 (bs, 2 H, CH_2OH), 5.56 (d, ^3J = 16 Hz, 1 H, vinyl-H), 5.66–5.78 (m, 1 H, vinyl-H), 6.03–6.28 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –5.35 [$Si(CH_3)_2tBu$], 12.14 (*c*Pr-C), 18.31 [$Si(CH_3)_2C(CH_3)_3$], 23.70 (*c*Pr-C), 25.87 [$Si(CH_3)_2C(CH_3)_3$], 63.55 (CH_2OH), 66.74 (CH_2OSi), 124.60 (C-5), 126.19 (C-4), 132.23 (C-3), 138.89 (C-2). – MS (70 eV), *m/z* (%): 268 (1) [M^+], 253 (1) [$M^+ - CH_3$], 211 (15) [$M^+ - tBu$], 165 (6) [$M^+ - tBu - CH_2OH$], 151 (5) [$M^+ - tBu - CH_2O - CH_3$], 131 (8), 119 (15), 105 (13) [$M^+ - OCH_2TBDMS - OH - H$], 91 (43) [$M^+ - OCH_2TBDMS - CH_2OH - H$], 75 (100), 59 (8), 41 (17) [cPr^+]. – Cal. C 67.11, H 10.51; found C 67.14, H 10.32.

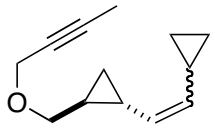
trans-*(2-{2-[1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-(*E*)-vinyl}-cyclopropyl)-methanol* (**191**) 

Diiodomethane (0.634 mL, 7.86 mmol) was added to a mixture of diethylzink (0.403 mL, 3.93 mmol) and DME (0.408 mL, 3.93 mmol) in DCM (8 mL) at –10 °C. After stirring for 20 min this solution was added to 5-[1-(*tert*-butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-(*E,E*)-2,4-dien-1-ol (**189**) (400 mg, 1.57 mmol) in DCM (20 mL). The mixture was stirred at –10 °C over night. NH_4Cl (sat.) was added, followed by HCl (1 M). It was diluted with Et_2O and the organic layer was successively washed with Na_2SO_3 (sat.), NaOH [2 M, containing 1% H_2O_2 (30%)], NH_4Cl (sat.) and brine, dried over $MgSO_4$ and concentrated. Purification by flash column chromatography (50% Et_2O in pentane eluant) yielded 108 mg of **191** (24%) and 245 mg starting material **189** (58%). – IR (film): $\tilde{\nu}$ = 3350 cm^{-1} (O–H), 3077 (*c*Pr–H), 3002 (C–H), 2956 (C–H), 2929 (C–H), 2887

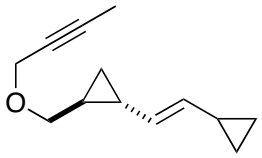
(C–H), 2856 (C–H), 1468, 1387, 1360, 1254, 1107, 1054 (C–O), 1011, 960 (H–C=C–H), 836, 775, 666. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.01 (s, 6 H, Si(CH_3)$_2$*t*Bu), 0.45–0.50 (m, 2 H, *c*Pr-H), 0.52–0.65 (m, 4 H, *c*Pr-H), 0.86 (s, 9 H, Si(Me)$_2$C(CH_3)$_3$), 1.03–1.15 (m, 1 H, *c*Pr-H), 1.20–1.33 (m, 1 H, *c*Pr-H), 1.39 (bs, 1 H, O*H*), 3.40–51 (m, 2 H, CH_2OH), 3.55 (s, 2 H, CH_2OSi), 5.00 (dd, ^3J = 15 Hz, ^3J = 8.4 Hz, 1 H, vinyl-H), 5.38 (d, ^3J = 15 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –5.73 [Si(*C*H$_3$)$_2$*t*Bu], 11.13 (*c*Pr-C), 11.45 (*c*Pr-C), 18.36 [Si(Me)$_2$*C*(CH$_3$)$_3$], 19.75 (*c*Pr-C), 22.77 (*c*Pr-C), 23.25 (*c*Pr-C), 25.92 [Si(Me)$_2$C(*C*H$_3$)$_3$], 66.45 (*C*H$_2$OH), 67.17 (*C*H$_2$OSi), 129.61 (vinyl-C), 131.82 (vinyl-C). – DCI-MS (200 eV, NH_3), *m/z* (%): 300 (100) [M + NH_4^+], 283 (10) [M + H^+], 168 (7), 151 (28). – $C_{16}H_{30}O_2Si$ (282.49).



trans-*1-But-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane* (**208**) According to GP 3, *trans*-[2-(2-cyclopropyl-*E*-vinyl)-cyclopropyl]-methanol (**179**) (154 mg, 1.11 mmol), bromo-2-butyne (**229**) (230 mg, 1.73 mmol) and NaH (60% in mineraloil, 48.0 mg, 1.19 mmol) were allowed to react in THF (5 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 112 mg of the product as a mixture of ***E*-208** and ***Z*-208** in a ratio of 1:2.4 (NMR), which were not separable by column chromatography (54%). – Data for ***Z*-208**: IR (film): $\tilde{\nu}$ = 3079 cm^{-1} (*c*Pr–H), 3004 (C–H), 2963 (C–H), 2920 (C–H), 2854 (C–H), 2210 (C≡C), 1708, 1308, 1261, 1080 (C–O), 1019, 939, 795. – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.25–0.40 (m, 3 H, *c*Pr-H), 0.70–0.78 (m, 2 H, *c*Pr-H), 0.99–1.07 (m, 1 H, *c*Pr-H), 1.23–1.38 (m, 1 H, *c*Pr-H), 1.60–1.76 (m, 1 H, *c*Pr-H), 1.79–1.90 (m, 1 H, *c*Pr-H), 1.82 (t, ^5J = 1.0 Hz, 3 H, 4-H), 3.42–3.55 (m, 2 H, 1′-H), 4.10 (q, ^5J = 1.0 Hz, 2 H, 1-H), 4.80 (t, ^3J = 10 Hz, 1 H, vinyl-H), 5.00 (t, ^3J = 10 Hz, 1 H, vinyl-H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 3.63 (C-4), 6.99 (*c*Pr-C), 7.08 (*c*Pr-C), 9.99 (*c*Pr-C), 12.32 (*c*Pr-C), 14.35 (*c*Pr-C), 17.46 (*c*Pr-C), 58.24 (C-1′), 70.08 (C-1), 75.33 (C-3), 82.17 (C-2), 126.12 (vinyl-C), 135.49 (vinyl-C). – MS (70 eV), *m/z* (%): 190 (2) [M^+], 175 (1) [M^+ – CH_3], 160 (5), 145 (30), 131 (20), 119 (16), 105 (23), 91 (50), 79 (100), 67 (31), 53 (80) [$CH_2C{\equiv}CCH_3^+$], 41 (24) [*c*Pr^+]. – $C_{13}H_{18}O$ (190.28).

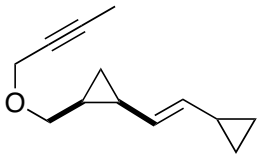


trans-*1-But-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane* (**209**) According to GP 3, *trans*-[2-(2-cyclopropyl-vinyl)-cyclopropyl]-methanol (***trans*-179**) (154 mg, 1.11 mmol), bromo-2-butyne (**229**) (230 mg, 1.73 mmol) and NaH (60% in mineraloil, 48.0 mg, 1.19 mmol) were allowed to react in THF (5 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 112 mg of the product as a mixture of ***E*-209** and ***Z*-209** in a ratio of 1:2.4 (NMR), which were not separable by column chromatography (54%). – Data for the ***Z*-209**: ^{1}H NMR (300 MHz, $CDCl_3$0: δ = 0.27–0.35 (m, 2 H, *c*Pr-H), 0.58–0.65 (m, 1 H, *c*Pr-H), 0.71–0.78 (m, 3 H, *c*Pr-H), 1.00–1.12 (m, 1 H, *c*Pr-H), 1.58–1.75 (m, 2 H, *c*Pr-H), 1.82 (t, ^5J = 1.0 Hz, 3 H, 4-H), 3.30–3.45 (m, 2 H, 1′-H), 4.10 (q, ^5J = 1.0 Hz, 2 H, 1-H), 4.73 (m, 2 H, vinyl-H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 3.61 (C-4), 7.00 (*c*Pr-C), 7.04 (*c*Pr-C), 9.94 (*c*Pr-C), 12.40 (*c*Pr-C), 16.08 (*c*Pr-C), 19.98 (*c*Pr-C), 57.94 (C-1′), 72.92 (C-1), 75.20 (C-3), 82.28 (C-2), 130.30 (vinyl-C), 133.02 (vinyl-C). – MS (70 eV), *m/z* (%): 190 (1) [M^+], 175 (1) [$M^+ - CH_3$], 145 (25), 131 (18), 119 (16), 105 (25), 91 (50), 79 (100), 67 (31), 53 (90) [$CH_2C{\equiv}CCH_3^+$]. – $C_{13}H_{18}O$ (190.28).

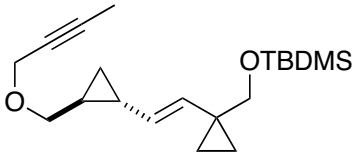


trans-*1-But-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane* (***E*-209**) According to GP 3, *trans*-[2-(2-cyclopropyl-*E*-vinyl)-cyclopropyl]-methanol (**190**) (106 mg, 767 μmol), bromo-2-butyne (**229**) (158 mg, 1.19 mmol) and NaH (60% in mineraloil, 48.0 mg, 1.20 mmol) were allowed to react in THF (5 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 114 mg of ***E*-209** (78%) as a colorless oil and 21 mg of starting material (20%). – IR (film): $\tilde{\nu}$ = 3080 cm^{-1} (*c*Pr–H), 3003 (C–H), 2920 (C–H), 2854 (C–H), 2242 (C≡C), 1708, 1357, 1255, 1083, 1020, 954, 810. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.24–0.35 (m, 2 H, *c*Pr-H), 0.58–0.69 (m, 4 H, *c*Pr-H), 0.99–1.11 (m, 1 H, *c*Pr-H), 1.18–1.39 (m, 2 H, *c*Pr-H), 1.83 (t, ^5J = 1.0 Hz, 3 H, 4-H), 3.28–3.45 (m, 2 H, 1′-H), 4.10 (q, ^5J = 1.0 Hz, 2 H, 1-H), 5.00 (m, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 3.58 (C-4), 6.39 (*c*Pr-C), 11.59 (*c*Pr-C), 13.47 (*c*Pr-C), 19.51 (*c*Pr-C), 19.64 (*c*Pr-C), 57.94 (C-1′), 72.96 (C-1), 75.15 (C-3), 82.24 (C-2), 129.75 (vinyl-C), 132.36 (vinyl-C). – MS (70 eV), *m/z* (%): 190 (1) [M^+], 175 (1) [$M^+ - CH_3$], 145 (25), 131 (18), 119 (16), 105 (25), 91 (50), 79

(100), 67 (31), 53 (90) [$CH_2C{\equiv}CCH_3^+$]. – $C_{13}H_{18}O$ (190.28).



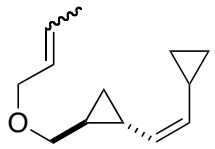
cis-*1-But-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane* (***E*-208**) According to GP 3, *cis*-[2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropyl]-methanol (***cis*-190**) (50.0 mg, 362 μmol), bromo-2-butyne (**229**) (96.0 mg, 724 μmol) and NaH (60% in mineraloil, 29.0 mg, 724 μmol) were allowed to react in THF (2 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 16 mg of ***E*-208** (23%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3077 cm^{-1} (*c*Pr–H), 3003 (C–H), 2921 (C–H), 2855 (C–H), 1446, 1357, 1261, 1134, 1082 (C–O), 1019, 954, 808. – ^{1}H NMR (200 MHz, $CDCl_3$): δ = 0.20–0.32 (m, 4 H, *c*Pr-H), 0.49–0.64 (m, 2 H, *c*Pr-H), 0.75–0.90 (m, 1 H, *c*Pr-H), 1.18–1.38 (m, 1 H, *c*Pr-H), 1.40–1.55 (m, 1 H, *c*Pr-H), 1.79 (t, ^5J = 1.0 Hz, 3 H, 4-H), 3.36–3.50 (m, 2 H, 1′-H), 4.00–4.15 (m, 2 H, 1-H), 5.04 (dd, ^3J = 23 Hz, ^3J = 14 Hz, 1 H, vinyl-H), 5.25 (dd, ^3J = 23 Hz, ^3J = 14 Hz, 1 H, vinyl-H). – ^{13}C NMR (50.3 MHz, $CDCl_3$): δ = 3.62 (C-4), 6.49 (*c*Pr-C), 6.54 (*c*Pr-C), 10.34 (*c*Pr-C), 14.18 (*c*Pr-C), 17.35 (*c*Pr-C), 18.28 (*c*Pr-C), 58.20 (C-1′), 69.70 (C-1), 75.35 (C-3), 82.14 (C-2), 125.69 (vinyl-C), 135.05 (vinyl-C). – DCI-MS (200 eV, NH_3), *m/z* (%): 208 (100) [M + NH_4^+], 191 (7) [M + H^+], 156 (5), 138 (8), 121 (24). – $C_{13}H_{18}O$ (190.28).



trans-tert-*Butyl-1-[2-(2-but-2-ynyloxymethyl-cyclopropyl)-(*E*)-vinyl]-cyclopropylmethoxy-dimethyl-silane* (**210**) According to GP 3, bromo-2-butyne (**229**) (76.3 mg, 574 μmol), *trans*(2-{2-[1-(*tert*-butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-(*E*)-vinyl}-cyclopropyl)-methanol (**191**) (108 mg, 382 μmol) and NaH (60% in mineraloil, 24.0 mg, 600 μmol) were allowed to react in THF (3 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 13 mg of **210** (10%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3078 cm^{-1} (*c*Pr–H), 3002 (C–H), 2956 (C–H), 2928 (C–H), 2887 (C–H), 2855 (C–H), 1470, 1387, 1358, 1255, 1087 (C–O), 961, (H–C=C–H), 937, 837, 775, 667. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.01 (s, 6 H, $Si(CH_3)_2tBu$), 0.41–0.50 (m, 2 H, *c*Pr-H), 0.51–0.65 (m, 3 H, *c*Pr-H), 0.85 (s, 9 H, $Si(CH_3)_2tBu$), 0.90–1.30 (m, 3 H, *c*Pr-H), 1.82 (t, ^5J = 1.0 Hz, 3 H, $C{\equiv}CCH_3$), 3.38 (dd, ^2J = 16 Hz, ^3J = 8.0 Hz,

2 H, *c*PrCH_2O), 3.55 (s, 2 H, CH_2OSi), 4.09 (q, ^5J = 1.0 Hz, 2 H, C≡CCH_2O), 5.00 (dd, ^3J = 16 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.38 (d, ^3J = 16 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –5.31 [Si(CH_3)$_2$*t*Bu], 3.61 (C-4), 11.09 (*c*Pr-C), 11.73 (*c*Pr-C), 18.36 [Si(CH_3)$_2$*C*(CH_3)$_3$], 19.61 (*c*Pr-C), 19.93 (*c*Pr-C), 23.23 (*c*Pr-C), 25.92 [Si(CH_3)$_2$C(*C*H$_3$)$_3$], 57.98 (C-1), 67.10 (C-1′), 73.01 (*C*H$_2$OSi), 75.19 (C-3), 82.27 (C-2), 129.61 (vinyl-C), 131.80 (vinyl-C). – MS (70 eV), *m/z* (%): 334 (1) [M$^+$], 319 (4) [M$^+$ – CH_3], 305 (17) [M$^+$ – 2 CH_3 + H], 277 (43) [M$^+$ – *t*Bu], 264 (15) [M$^+$ – CH_3C≡CCH_2O – H], 249 (14) [M$^+$ – CH_3C≡CCH_2O – CH_3 – H], 224 (18), 223 (20), 207 (43) [M$^+$ – CH_3C≡CCH_2O – *t*Bu – H], 183 (36), 157 (29), 133 (38), 105 (43), 91 (57), 75 (100), 53 (47). – $C_{20}H_{34}O_2Si$ (334.57).

Cyclization attempt of cis-*1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane* (**208**) According to GP 4, $[Rh(CO)_2Cl]_2$ (3.1 mg, 79.7 μmol) and *cis*-1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane (**208**) (30.0 mg, 157 μmol) were allowed to react in DCE (1 mL) for 24 h at 70 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 10 mg of the starting material (33%) and 5 mg of *cis*-1-but-2-enyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane (17%). – Data for *cis*-1-but-2-enyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane: IR (film): $\tilde{\nu}$ = 3080 cm^{-1} (*c*Pr–H), 3002 (C–H), 2961 (C–H), 2925 (C–H), 2855 (C–H), 1261, 1085 (C–O), 1017, 939, 808. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.30–0.38 (m, 3 H, *c*Pr-H), 0.72–0.81 (m, 2 H, *c*Pr-H), 1.00–1.14 (m, 1 H, *c*Pr-H), 1.24–1.42 (m, 1 H, *c*Pr-H), 1.66 (d, ^3J = 6.0 Hz, 3 H, 4-H), 1.68–1.79 (m, 1 H, *c*Pr-H), 1.80–1.96 (m, 1 H, *c*Pr-H), 3.45 (d, ^3J = 7.9 Hz, 2 H, 1′-H), 4.04 (d, ^3J = 6.6 Hz, 2 H, 1-H), 4.81 (t, ^3J = 10 Hz, 1 H, vinyl-H), 5.01 (t, ^3J = 10 Hz, 1H, vinyl-H), 5.57–5.72 (m, 2 H, 2-H, 3-H). – $C_{13}H_{20}O$ (192.30).



Cyclization attempt of trans-emph1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane (**209**) According to GP 4, *trans*-1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane (**209**) (9.0 mg, 47 μmol) and $[Rh(CO)_2Cl]_2$ (0.9 mg, 2.4 μmol) were allowed to react in DCE (1 mL) for 24 h at 70 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 5 mg of starting material (56%).

Cyclization attempt of trans-*1-but-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane* (***E*-209**) According to GP 4, *trans*-1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane (***E*-209**) (30.0 mg, 157 μmol) and $[Rh(CO)_2Cl]_2$ (3.0 mg, 7.7 μmol) were allowed to react in DCE (1 mL) for 24 h at 70 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 21 mg of starting material (70%).

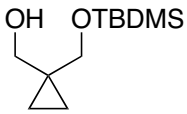
Cyclization attempt of trans-1-*but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane* (**209**) $[Rh(PPh_3)_3Cl]$ (7.4 mg, 8.0 μmol) and AgOTf (2.0 mg, 7.9 μmol) were stirred in dry toluene (1 mL) for 5 min at rt. Then, *trans*-1-but-2-ynyloxymethyl-2-(2-cyclopropyl-vinyl)-cyclopropane **209** (15 mg, 79 μmol) was added and the mixture stirred at 70 °C. The starting material was consumed after 24 h h by TLC. No identifiable product could be isolated by flash column chromatography (10% Et_2O in pentane eluant).

Cyclization attempt of cis-*1-but-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane* (***E*-208**) According to GP 4, *cis*-1-but-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane (***E*-208**) (10.0 mg, 52.6 μmol) and $[Rh(CO)_2Cl]_2$ (1.0 mg, 2.57 μmol) were allowed to react in DCE (1 mL) for 10 h at 75 °C. No identifiable product could be isolated by flash column chromatography (10% Et_2O in pentane eluant).

Cyclization attempt of trans-tert-*butyl-1-[2-(2-but-2-ynyloxymethyl-cyclopropyl)-(*E*)-vinyl]-cyclopropylmethoxy-dimethyl-silane* (**210**) According to GP 4, *trans-tert*-butyl-1-[2-(2-but-2-ynyloxymethyl-cyclopropyl)-(*E*)-vinyl]-cyclopropylmethoxy-dimethyl-silane (**210**) (12.0 mg, 35.9 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 18.0 μmol) were allowed to react in DCE (1 mL) for 24 h at 70 °C. No identifiable product could be isolated by flash column chromatography (10% Et_2O in pentane eluant).

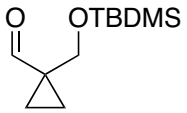
3.3.2. Intermolecular Cyclization

*[1-(*tert-*Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-methanol* (**205**)



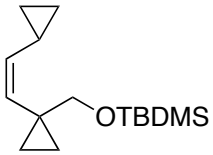
To a suspension of NaH (60% in mineraloil, 1.57 g, 39.2 mmol) in dry THF (100 mL) was added dropwise (1-hydroxymethyl-cyclopropyl)-methanol (**204**) (4.00 g, 39.2 mmol), dissolved in dry THF (20 mL), at 0 °C. The mixture was stirred at rt for 1 h. Then *tert*-butyldimethylsilylchlorid (6.00 g, 39.6 mmol), dissolved in dry THF (30 mL), was added and the resulting solution stirred over night. The mixture was diluted with Et_2O (200 mL) and washed subsequently with K_2CO_3 (10%) (2 times) and brine. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (33% Et_2O in pentane eluant) affording 6.70 g of **205** (79%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3350 cm^{-1} (O–H), 3078 (*c*Pr–H), 3005 (C–H), 2958 (C–H), 2929 (C–H), 2889 (C–H), 2857 (C–H), 1469, 1390, 1254, 1088 (C–O), 1030, 939, 836, 777, 667. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.03 (s, 6 H, Si(CH_3)$_2$*t*Bu), 0.42–0.47 (m, 2 H, *c*Pr-H), 0.50–0.54 (m, 2 H, *c*Pr-H), 0.87 (s, 9 H, Si(CH$_3$)$_2$*tBu*), 2.75 (bs, 1 H, O*H*), 3.56 (s, 2 H, CH_2OSi), 3.62 (s, 2 H, CH_2OH). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = –5.53 [Si(*C*H$_3$)$_2$*t*Bu], 8.69 (*c*Pr-C), 18.17 [Si(CH$_3$)$_2$*C*(CH$_3$)$_3$], 23.81 (*c*Pr-C), 25.82 [Si(CH$_3$)$_2$C(*C*H$_3$)$_3$], 69.65 (*C*H$_2$OH*, *C*H$_2$OSi*), 70.17 (*C*H$_2$OH*, *C*H$_2$OSi*). – DCI-MS (200 eV, NH_3), *m/z* (%): 234 (100) [M + NH_4^+], 217 (90) [M+ H^+]. – Cal. C 61.05, H 11.18; found C 61.28, H 11.00.

*1-(*tert-*Butyl-dimethyl-silanyloxymethyl)-cyclopropanecarbaldehyde* (**185**)

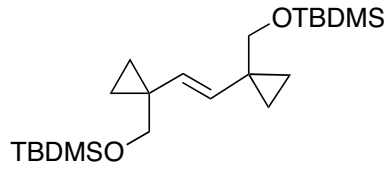


Oxalylchlorid (1.35 mL, 15.5 mmol) was dissolved in DCM (20 mL). DMSO (2.35 mL, 33.1 mmol), dissolved in DCM (5 mL), was added dropwise at –78 °C. The mixture was stirred at that temperature for 30 min. [1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-methanol (**205**) (2.66 g, 12.3 mmol), dissolved in DCM (3 mL), was added at –78 °C and the resulting solution stirred for 30 min. Triethylamine (9 mL) was added and the mixture warmed to rt, followed by addition af water (50 mL). The organic layer was washed subsequently with HCL (1 M), $NaHCO_3$ (sat.) and water. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 2.19 g of **185** (83%) as a colorless oil. – IR (film): $\tilde{\nu}$ = 3016 cm^{-1}

(*c*Pr–H), 2955 (C–H), 2931 (C–H), 2887 (C–H), 2858 (C–H), 2742 (OC–H), 1596 (OC–H), 1800, 1693 (C=O), 1468, 1432, 1361, 1325, 1256, 1199, 1103 (C–O), 1008, 940, 907, 838, 778, 669. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.03$ (s, 6 H, $Si(CH_3)_2tBu$), 0.87 (s, 9 H, $Si(CH_3)_2tBu$), 1.16 (s, 4 H, *c*Pr-H), 3.91 (s, 2 H, CH_2OSi), 9.00 (s, 1 H, CHO). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = -5.52$ [$Si(CH_3)_2tBu$], 11.17 (*c*Pr-C), 18.20 [$Si(CH_3)_2C(CH_3)_3$], 25.76 [$Si(CH_3)_2C(CH_3)_3$], 33.92 (*c*Pr-C), 61.01 (CH_2OSi), 201.58 (CHO). – MS (70 eV), *m/z* (%): 173 (42), 157 (43) [M^+ – *t*Bu], 127 (10) [M^+ – *t*Bu – 2 CH_3], 105 (9), 101 (26) [M^+ – TBDMS + 2 H], 84 (27) [M^+ – OTBDMS + H], 75 (100), 59 (8), 49 (18). – $C_{11}H_{22}O_2Si$ (214.37).



tert-*Butyl-[1-(2-cyclopropyl-vinyl)-cyclopropylmethoxy]-dimethyl-silane* (**206**) To a suspension of cyclopropylmethyl-triphenyl-phosphonium bromide (**178**) (1.20 g, 3.02 mmol) in THF (25 mL) was slowly added *n*-BuLi (1.6 M in hexane, 1.89 mL, 3.02 mmol) at –78 °C. After stirring for 1 h at rt 1-(*tert*-butyl-dimethyl-silanyloxymethyl)-cyclopropanecarbaldehyde (**185**) (643 mg, 3.00 mmol) was slowly added. The reaction was stirred for 1 h at rt, diluted with pentane and filtered through a pad of silica. Drying over $MgSO_4$ and evaporation of the solvent gave the crude product, which was purified by column chromatography (10% Et_2O in pentane eluant) affording 594 mg of **206** as a colorless oil (36%). – IR (film): $\tilde{\nu} = 3081$ cm^{-1} (*c*Pr–H), 3005 (C–H), 2957 (C–H), 2929 (C–H), 2888 (C–H), 2856 (C–H), 1649 (C=C), 1470, 1254, 1095 (C–O), 1018, 939, 837, 775. – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.02$ (s, 6 H, $Si(CH_3tBu)_2$), 0.26–0.35 (m, 2 H, *c*Pr-H), 0.55–0.61 (m, 2 H, *c*Pr-H), 0.62–77 (m, 4 H, *c*Pr-H), 0.90 (s, 9 H, $SiMe_2C(CH_3)_3$), 1.86 (m, 1 H, *c*Pr-H), 3.58 (s, 2 H, CH_2OSi), 4.78 (t, $^3J = 8.0$ Hz, 1 H, vinyl-H), 5.43 (d, $^3J = 8.0$ Hz, 1Ḣ, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = -5.34$ [$Si(CH_3)_2tBu$], 6.99 (*c*Pr-C), 10.38 (*c*Pr-C), 10.48 (*c*Pr-C), 18.37 [$SiMe_2C(CH_3)_3$], 21.36 (*c*Pr-C), 25.91 [$SiMe_2C(CH_3)_3$], 67.82 (CH_2OSi), 128.64 (vinyl-C), 138.45 (vinyl-C). – MS (70 eV) (*m/z*): 252 (3) [M^+], 237 (4) [M^+ – CH_3], 223 (4) [M^+ – 2 CH_3 + H], 209 (4) [M^+ – 3 CH_3 + 2 H], 195 (44), 139 (8), 91 (14), 79 (10) [C_6H_7], 77 (12), 75 (100) [$OSi(CH_3)_2$ + H], 73 (35) [Si*t*Bu$^+$], 67 (10), 59 (13) [$Si(CH_3)_2{}^+$ + H]. – $C_{15}H_{28}OSi$: 252.1909 (correct HRMS).

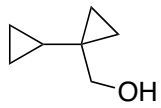


*1,2-(*E*)-Bis-(1-methyl(*tert*-butyl-dimethylsiloxy)cyclopropyl)ethene* (**207**) DME (25 mL) was added carefully to $TiCl_3$ (4.00 g, 25.9 mmol), followed by lithium (360 mg, 51.8 mmol) in little portions. The mixture was gently refluxed over night. After cooling to rt, 1-(*tert*-butyl-dimethyl-silanyloxymethyl)-cyclopropanecarbaldehyde (**185**) (500 mg, 2.33 mmol), dissolved in DME (4 mL), was added in one portion. The reaction was stirred 2 h at rt and then refluxed over night. The black suspension was cooled to rt, diluted with pentane (50 mL) and filtered through a pad of silica, eluated with pentane and Et_2O. Evaporation of the solvent and flash column chromatography gave 85 mg of **207** (19%). – ^{1}H NMR (250 MHz, $CDCl_3$): $\delta = 0.02$ (s, 12 H, $Si(CH_3)_2tBu$), 0.46–0.52 (m, 4 H, *c*Pr-H), 0.63–0.70 (m, 4 H, *c*Pr-H), 0.89 (s, 18 H, $Si(CH_3)_2tBu$), 3.59 (s, 4 H, CH_2OSi), 5.35 (s, 2 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta =$ –5.34 [$Si(CH_3)_2tBu$], 10.99 (*c*Pr-C), 18.33 [$Si(CH_3)_2C(CH_3)_3$], 23.21 (*c*Pr-C), 25.89 [$Si(CH_3)_2C(CH_3)_3$], 66.96 (CH_2OSi), 130.57 (vinyl-C). – MS (200 eV, DCI, NH_3), *m/z* (%): 415 (100) [M + NH_4^+], 282 (20), 265 (9), 207 (6), 133 (17). – $C_{22}H_{44}O_2Si_2$ (396.75).

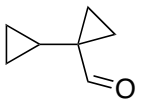
Cocyclization attempt of tert-*butyl-[1-(2-cyclopropyl-(*Z*)-vinyl)-cyclopropylmethoxy]-dimethyl-silane* (**206**) with propionic acid methyl ester (**199**) According to GP 4, *tert*-butyl-[1-(2-cyclopropyl-(*Z*)-vinyl)-cyclopropylmethoxy]-dimethyl-silane (**206**) (50 mg, 200 μmol), propionic acid methyl ester (**199**) (0.022 mL, 240 μmol) and $[Rh(CO)_2Cl]_2$ (3.9 mg, 10 μmol) were allowed to react in DCE (1 mL) for 24 h at 75 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 31 mg of starting material (62%).

Cocyclization attempt of *1,2-(*E*)-bis-(1-methyl(*tert*-butyl-dimethylsiloxy)cyclopropyl)ethene* (**207**) with propionic acid methyl ester (**199**) According to GP 4, 1,2-(*E*)-bis-(1-methyl(*tert*-butyl-dimethylsiloxy)cyclopropyl)ethene (**207**) (10.0 mg, 25.0 μmol), propionic acid methyl ester (**199**) (2.5 mg, 30.0 μmol) and $[Rh(CO)_2Cl]_2$ (0.5 mg, 1.29 μmol) were allowed to react in DCE (0.5 mL) for 24 h at 75 °C. The crude mixture was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 7 mg of starting material (70%).

3.4. 4th-Generation precursor



1-(Cyclopropyl)cyclopropylmethanol (**225**) To a solution of diethyl zink (1.51 mL, 14.7 mmol) in DCM (5 mL) was slowly added trifluoracidic acid (1.14 mL, 14.7 mmol) in DCM (5 mL) at 0 °C. After stirring for 20 min at that temperature diiodomethane (1.19 mL, 14.7 mmol) in DCM (5 mL) was added and stirred for another 20 min. 2-Cyclopropylprop-2-enol (**224**) (655 mg, 6.67 mmol) in DCM (5 mL) was added and the resulting mixture stirred for 30 min at rt. The reaction was quenched with NH_4Cl (sat.) and the aqueous layer was extracted with DCM. The combined organic phases were washed with $NaHCO_3$, water and brine. Drying over Na_2SO_4 and evaporation of the solvent gave the crude product, which was purified by flash column chromatography (33% Et_2O in pentane eluant) to yield 315 mg of **225** (42%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3315 cm^{-1} (O–H), 3078 (*c*Pr–H), 3006 (C–H), 2917 (C–H), 2869 (C–H), 1467, 1425, 1392, 1261, 1033 (C–O), 936, 907, 840, 820. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.08–0.03 (m, 2 H, *c*Pr-H), 0.17–0.38 (m, 6 H, *c*Pr-H), 1.09–1.23 (m, 1 H, *c*Pr-H), 1.77 (bs, 1 H, O*H*), 3.48 (s, 2 H, CH_2OH). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 1.62 (*c*Pr-C), 7.26 (*c*Pr-C), 12.43 (*c*Pr-C), 23.20 (*c*Pr-C), 70.86 (*C*H_2O). – MS (70 eV), *m/z* (%): 112 (1) [M^+], 97 (7) [M^+ – CH_3], 93 (7), 84 (20) [M^+ – C_2H_4], 83 (40) [M^+ – C_2H_5], 81 (50) [M^+ – C_2OH], 79 (100) [*c*Pr-C_3H_2], 67 (35), 55 (78). – $C_7H_{12}O$ (112.17).



1-(Cyclopropyl)cyclopropylcarboxaldehyde (**226**) To a suspension of Dess-Martin-periodinane (1.75 g, 4.12 mmol) in DCM (30 mL) was added 1-(cyclopropyl)cyclopropylmethanol (**225**) (300 mg, 2.67 mmol) and the resulting mixture stirred for 2 h at rt. After deluting with Et_2O (40 mL) it was washed with NaOH (1 M, 100 mL, 2 times). Drying over $MgSO_4$ and evaporation gave the crude product, which was purified by flash column chromatography (12% Et_2O in pentane eluant) to yield 214 mg of **226** (73%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3084 cm^{-1} (*c*Pr–H), 3013 (C–H), 2965 (C–H), 2960 (C–H), 2593 (OC–H), 1685 (C=O), 1419, 1319, 1292, 1205, 1161, 1018, 965, 859, 821. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.03–0.02 (m, 2 H, *c*Pr-H), 0.42–0.55 (m, 2 H, *c*Pr-H), 0.68–0.80 (m, 2 H, *c*Pr-H), 0.93–1.07 (m, 2 H, *c*Pr-H), 1.32–144 (m, 1 H, *c*Pr-H), 8.98 (s, 1 H, C*H*O). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 1.89 (*c*Pr-C), 8.84 (*c*Pr-C), 11.45 (*c*Pr-C), 33.34 (*c*Pr-C), 202.86 (*C*HO). – MS (70 eV), *m/z* (%): 97 (19), 93 (8), 83

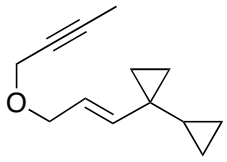
(29) [$M^+ - C_2H_3$], 81 (100) [M^+ – CHO], 80 (40), 79 (59) [*c*Pr-$C_3H_2^+$], 67 (30), 53 (31), 41 (27) [*c*Pr^+]. – $C_7H_{10}O$ (110.15).

*3-Bicyclopropyl-1-yl-(*E*)-acrylic acid ethyl ester* (**227**) To a suspension of NaH (60% in mineraloil, 94.0 mg, 2.34 mmol) in DME (10 mL) was added (diethoxy-phosphoryl)-acetic acid ethyl ester (**81-H**) (525 mg, 2.34 mmol) and the resulting mixture stirred for 1 h at rt. After the addition of 1-(cyclopropyl)cyclopropylcarboxaldehyde (**226**) (200 mg, 1.82 mmol) in DME (3 mL) the reaction was stirred for 1.5 h at rt and 30 min at 50 °C. The mixture was poured into ice water (50 mL) and the aqueous layer was extracted with Et_2O (30 mL, 3 times). Drying over $MgSO_4$ and evaporation gave the crude product, which was purified by flash column chromatography (12% Et_2O in pentane eluant) to yield 242 mg of **227** (75%) as colorless oil. – IR (film): $\tilde{\nu} = 3082$ cm^{-1} (*c*Pr–H), 3008 (C–H), 2981 (C–H), 1715 (C=O), 1642 (C=C), 1367, 1327, 1308, 1262, 1234, 1198, 1161 (C–O), 1041, 987 (H–C=C–H), 937, 837. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.01–0.06 (m, 2 H, *c*Pr-H), 0.40–0.51 (m, 2 H, *c*Pr-H), 0.63–0.74 (m, 4 H, *c*Pr-H), 1.15–1.27 (m, 1 H, *c*Pr-H), 1.28 (t, $^3J = 7.2$ Hz, 3 H, CH_3), 4.19 (q, $^3J = 7.2$ Hz, 2 H, OCH_2), 6.09 (d, $^3J = 14$ Hz, 1 H, vinyl-H), 6.56 (d, $^3J = 14$ Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): $\delta = 2.22$ (*c*Pr-C), 12.16 (*c*Pr-C), 13.11 (*c*Pr-C), 14.29 (*C*H_3), 23.70 (*c*Pr-C), 59.99 (O*C*H_2), 117.07 (vinyl-C), 157.44 (vinyl-C), 167.14 (*C*O_2Et). – MS (70 eV), *m/z* (%): 180 (1) [M^+], 165 (1) [$M^+ - CH_3$], 152 (60) [$M^+ - C_2H_4$], 135 (12) [$M^+ - OC_2H_5$], 107 (100) [$M^+ - CO_2C_2H_5$], 91 (43), 79 (97) [*c*Pr-C_3H_2], 67 (10), 53 (13), 41 (11) [*c*Pr]. – Cal. C 73.30, H 8.95; found C 73.53, H 8.82.

1-Cyclopropyl-cyclopropyl-3-prop-2-enol (**228**) Method a) According to GP 1, 3-bicyclopropyl-1-yl-(*E*)-acrylic acid ethyl ester (**227**) (242 mg, 1.34 mmol) and $LiAlH_4$ (36.0 mg, 942 μmol) were allowed to react in Et_2O (30 mL). Purification by flash column chromatography (33% Et_2O in pentane eluant) yielded 51 mg of **228** (28%) and 27 mg of the saturated analog of **228** as a byproduct (14%). – Data for **228**: IR (film): $\tilde{\nu} = 3330$ cm^{-1} (O–H), 3078 (*c*Pr–H), 3004 (C–H), 2939 (C–H), 2868 (C–H), 1665 (C=C), 1466, 1421, 1093, 1048, 1016 (C–O), 965 (H–C=C–H), 822. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –

0.05–0.02 (m, 2 H, *c*Pr-H), 0.33–0.55 (m, 6 H, *c*Pr-H), 1.10–1.24 (m, 1 H, *c*Pr-H), 1.45 (bs, 1 H, O*H*), 4.13 (d, ^3J = 4.8 Hz, 1 H, CH_2OH), 5.39 (d, ^3J = 14 Hz, 1 H, vinyl-H), 5.87 (dt, ^3J = 14 Hz, ^3J = 4.8 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.07 (*c*Pr-C), 11.41 (*c*Pr-C), 13.23 (*c*Pr-C), 22.12 (*c*Pr-C), 63.95 (*C*H_2OH), 125.09 (vinyl-C), 140.73 (vinyl-C). – DCI-MS (200 eV, NH_3), *m/z* (%): 276 (8) [2 M – H_2O + NH_4^+], 156 (9) [M + NH_4^+], 138 (53) [M – H_2O + NH_4^+], 121 (100) [M – H_2O + H^+]. – $C_9H_{14}O$ (138.21). – Data for the saturated analog: IR (film): $\tilde{\nu}$ = 3330 cm^{-1} (O–H), 3076 (*c*Pr–H), 3003 (C–H), 2939 (C–H), 2870 (C–H), 1467, 1421, 1065, 1048, 1014 (C–O), 926, 821. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –1.01–(–0.02) (m, 2 H, *c*Pr-H), 0.05–0.20 (m, 4 H, *c*Pr-H), 0.21–0.37 (m, 2 H, *c*Pr-H), 0.97–1.09 (m, 1 H, *c*Pr-H), 1.32–48 (m, 2 H, 3-H, O*H*), 1.70–1.82 (m, 2 H, 2-H), 3.66 (t, ^3J = 6.4 Hz, 1 H, 1-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 1.96 (*c*Pr-C), 9.19 (*c*Pr-C), 14.24 (*c*Pr-C), 19.96 (*c*Pr-C), 30.24 (C-3), 35.83 (C-2), 63.34 (*C*H_2OH). – DCI-MS (200 eV, NH_3), *m/z* (%): 175 (10) [M + NH_3 + NH_4^+], 158 (100) [M + NH_4^+], 141 (61) [M + H^+]. – $C_9H_{16}O$: (140.22).

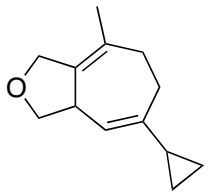
Method b) According to GP 2, *cis*-2-(2-cyclopropyl-vinyl)-cyclopropanecarboxylic acid ethyl ester (**227**) (800 mg, 4.44 mmol) and DIBALH (1.2 M in toluene, 11.1 mL, 13.3 mmol) were allowed to react in Et_2O (75 mL). The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 553 mg of **228** as a colorless oil (90%).



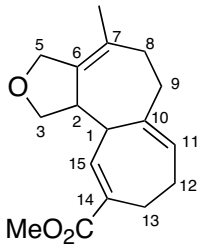
1-(3-But-2-ynyloxy-propenyl)-bicyclopropyl (**230**) According to GP 3, 1-cyclopropyl-cyclopropyl-3-prop-2-enol (**228**) (250 mg, 1.81 mmol), bromo-2-butyne (**229**) (360 mg, 2.71 mmol) and NaH (60% in mineraloil, 109 mg, 2.71 mmol) were allowed to react in THF (5 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 117 mg of **230** (34%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3078 cm^{-1} (*c*-Pr–H), 3004 (C–H), 2920 (C–H), 2850 (C–H), 2220 (C≡C), 1663 (C=C), 1446, 1354, 1262, 1136, 1075 (C–O), 1019, 966 (H–C=C–H), 926, 874, 773. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = –0.05–0.02 (m, 2 H, *c*Pr-H), 0.35–0.58 (m, 6 H, *c*Pr-H), 1.10–1.22 (m, 1 H, *c*Pr-H), 1.83 (t, ^5J = 1.0 Hz, 3 H, 4-H), 3.99 (d, ^3J = 7.8 Hz, 2 H, 1′-H), 4.10 (q, ^5J = 1.0 Hz, 2 H, 1-H), 5.40 (d, ^3J = 16 Hz, 1 H, vinyl-H), 5.78 (dt, ^3J = 16 Hz, ^3J = 7.8 Hz,

1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 2.07 (C-4), 3.60 (*c*Pr-C), 11.42 (*c*Pr-C), 13.17 (*c*Pr-C), 22.21 (*c*Pr-C), 57.42 (C-1′), 70.51 (C-1), 75.22 (C-3), 82.24 (C-2), 121.83 (vinyl-C), 142.64 (vinyl-C). – DCI-MS (200 eV, NH_3), *m/z* (%): 225 (38) [M + NH_3 + NH_4^+], 208 (41) [M + NH_4^+], 171 (82), 155 (100), 138 (97), 121 (98). – $C_{13}H_{18}O$ (190.28).

*5-Cyclopropyl-8-methyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan* (**231**) According to GP 4, 1-(3-but-2-ynyloxy-propenyl)-bicyclopropyl (**230**) (20.0 mg, 105 μmol) and the catalyst [($C_{10}H_8$)Rh(COD)]SbF_6 (3.0 mg, 5.26 μmol) were allowed to react in DCE (1 mL) for 1 h at rt. The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 15 mg of the cycloadduct **231** (75%) as colorless oil. –

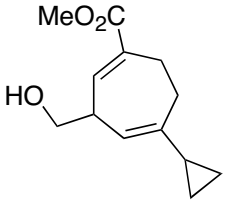


IR (film): $\tilde{\nu}$ = 3079 cm^{-1} (*c*Pr–H), 3004 (C–H), 2930 (C–H), 2852 (C–H), 1732, 1431, 1376, 1267, 1207, 1135, 1083, 1050, 1020, 912, 815, 739. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.35–0.65 (m, 4 H, *c*Pr-H), 1.30–1.41 (m, 1 H, *c*Pr-H), 1.45 (s, 3 H, C=CCH_3), 1.71–1.87 (m, 1 H, 6-H), 1.87–2.03 (m, 1 H, 6-H), 2.08–2.23 (m, 1 H, 7-H), 2.48 (t, ^3J = 12 Hz, 1 H, 7-H), 3.44 (dd, ^3J = 8.7 Hz, ^3J = 7.9 Hz, 1 H, 3-H), 3.55–3.74 (m, 1 H, 3a-H), 4.22 (dd, ^2J = 7.9 Hz, ^3J = 7.9 Hz, 2 H, 3-H), 4.22–4.43 (m, 2 H, 1-H), 5.34 (s, 1 H, vinyl-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.23 (*c*Pr-C), 4.34 (*c*Pr-C), 17.20 (*c*Pr-C), 21.03 (C=C*C*H_3), 26.65 (C-6), 31.74 (C-7), 40.34 (C-3a), 71.46 (C-3), 74.87 (C-1), 122.28 (C-4), 125.23 (C-5), 134.32 (C-8), 143.60 (C-8a). – MS (70 eV), *m/z* (%): 190 (21) [M^+], 175 (15) [M^+ – CH_3], 161 (20), 145 (30), 131 (100) [M^+ – CH_3 – CH_2OCH_2], 117 (39), 105 (50), 91 (68) [M^+ – CH_3 – CH_2OCH_2 – *c*Pr + H], 79 (22), 43 (23), 41 (20) [*c*Pr^+]. – $C_{13}H_{18}O$ (190.28).



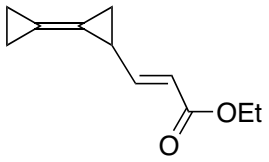
7-Methyl-4-oxa-tricyclo[8.5.0.0^{0,0}]pentadeca-6,10,14-triene-14-carboxylic acid methyl ester (**232**) Method a) According to GP 4, 5-cyclopropyl-8-methyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan (**231**) (15.0 mg, 78.8 μmol), propynoic acid methyl ester (**199**) (10.6 μg, 118 μmol) and $[Rh(CO)_2Cl]_2$ (1.5 mg, 3.94 μmol) were reacted in DCE (1 mL) for 18 h at 70 °C. The crude mixture was purified by flash column chromatography (20% Et_2O in pentane eluant) affording 11 mg of the cycloadduct **232** (51%) as colorless oil. – IR (film): $\tilde{\nu}$ = 2950 cm^{-1} (C–H), 2878 (C–H), 2829 (C–H), 1733 (C=O), 1713, 1636 (C=C), 1435, 1263, 1216, 1087, 1046, 949, 912, 819, 735. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.52 (s, 3 H, C=CCH_3), 2.00–2.19 (m, 4 H, 8-H*, 9-H*, 12-H*, 13-H*), 2.27–2.81 (m, 5 H, 2-H, 8-H*, 9-H*, 12-H*, 13-H*), 3.24–3.40 (m, 1 H, 1-H), 3.70 (s, 3 H, CO_2CH_3), 4.20–4.38 (m, 4 H, 3-H, 5-H), 5.50 (t, ^3J = 5.5 Hz, 1 H, 11-H), 6.74 (d, ^3J = 3.9 Hz, 1 H, 15-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 20.84 (C=CCH_3), 24.21 (C-1*, C-12*, C-13*), 24.87 (C-1*, C-12*, C-13*), 32.73 (C-1*, C-12*, C-13*), 39.41 (C-2*, C-8*, C-9*), 42.51 (C-2*, C-8*, C-9*), 44.08 (C-2*, C-8*, C-9*), 51.74 (CO_2CH_3), 72.37 (C-3*, C-5*), 74.76 (C-3*, C-5*), 124.09 (C-11), 125.79 (C-7), 132.00 (C-14*, C-15*), 133.17 (C-14*, C-15*), 143.68 (C-6*, C-10*), 144.46 (C-6*, C-10*), 168.15 (CO_2CH_3). – MS (70 eV), *m/z* (%): 274 (39) [M^+], 252 (26), 242 (8) [$M^+ - OCH_3 - H$], 221 (100), 215 (12) [$M^+ - CO_2CH_3$], 193 (18), 162 (10), 149 (8) [$M^+ - C_6H_9O_2$], 119 (16), 109 (25), 105 (40) [$M^+ - C_6H_9O_2 - CH_2OCH_2$], 91 (22) [$C_7H_6$], 79 (17). – $C_{13}H_{18}O$ (274.35).

Method b) According to GP 4, 1-(3-but-2-ynyloxy-propenyl)-bicyclopropyl (**230**) (10.0 mg, 62.6 μmol), propynoic acid methyl ester (**199**) (5.6 μL, 63.1 μmol) and $[Rh(CO)_2Cl]_2$ (1.0 mg, 2.63 μmol) were allowed to react in DCE (1 mL) for 18 h at 70 °C. The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 11 mg of the cycloadduct **232** (76%) as colorless oil.

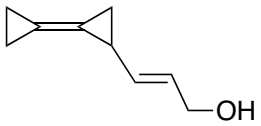


5-Cyclopropyl-3-hydroxymethyl-cyclohepta-1,4-dienecarboxylic acid methyl ester (**235**) According to GP 4, 1-cyclopropyl-cyclopropyl-3prop-2-enol (**228**) (10.0 mg, 72.4 μmol), propynoic acid methyl ester (**199**) (7.1 μL, 79.6 μmol) and $[Rh(CO)_2Cl]_2$ (1.4 mg, 3.62 μmol) were reacted in DCE (1 mL) for 18 h at 70 °C. The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 11 mg of the cycloadduct **235** (68%) as colorless oil. – IR (film): $\tilde{\nu} = 3447$ cm^{-1} (O–H), 3081 (*c*Pr–H), 3004 (C–H), 2951 (C–H), 2881 (C–H), 1710 (C=O), 1644 (C=C), 1436, 1387, 1271, 1240, 1196, 1133, 1062, 1041 (C–O), 1021, 906, 861, 814, 755. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.35–0.42 (m, 2 H, *c*Pr-H), 0.50–0.62 (m, 2 H, *c*Pr-H), 1.30–1.41 (m, 1 H, *c*Pr-H), 1.60–1.70 (m, 1 H, O*H*), 1.91–2.01 (m, 1 H, 6-H*, 7-H*), 2.22–2.36 (m, 1 H, 6-H*, 7-H*), 2.40–2.59 (m, 2 H, 6-H*, 7-H*), 3.42–3.50 (m, 1 H, 3-H), 3.61–3.78 (m, 5 H, CH_2OH, CO_2CH_3), 5.28 (d, $^3J = 2.4$ Hz, 1 H, 4-H), 6.86 (d, $^3J = 2.4$ Hz, 1 H, 2-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 4.32 (*c*Pr-C), 18.24 (*c*Pr-C), 25.05 (C-6*, C-7*), 26.68 (C-6*, C-7*), 39.76 (C-3), 51.78 (CO_2CH_3), 66.25 (CH_2OH), 120.76 (C-4), 133.50 (C-4), 142.03 (C-1*, C-5*), 143.91 (C-1*, C-5*), 168.16 (CO_2CH_3). – MS (70 eV), *m/z* (%): 221 (9) [M^+ – H], 191 (5) [M^+ – OCH_3], 177 (5), 149 (6), 131 (8) [M^+ – CO_2CH_3 – CH_2OH], 105 (7) [M^+ – CO_2CH_3 – OH – *c*Pr], 91 (19) [M^+ – CO_2CH_3 – CH_2OH – *c*Pr], 77 (12), 69 (100), 59 (17) [$CO_2CH_3^+$], 41 (63) [*c*Pr$^+$]. – $C_{13}H_{18}O$ (222.28).

3.5. 5th-Generation precursor



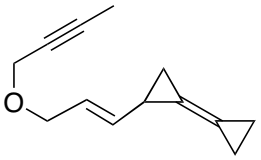
3-Bicyclopropyliden-2-yl-acrylic acid ethyl ester (**241**) To a suspension of NaH (60% in mineraloil, 1.04 g, 26.0 mmol) in DME (40 mL) was added (diethoxy-phosphoryl)-acetic acid ethyl ester (**81-H**) (5.82 g, 26.0 mmol) and the resulting mixture was stirred for 1 h at rt. After the addition of bicyclopropylidene-2-carbaldehyde (**240**) (2.16 g, 20.0 mmol) in DME (3 mL) the reaction was stirred for 1.5 h at rt and 30 min at 50 °C. The mixture was poured into ice water (80 mL). The aqueous layer was extracted with Et_2O (50 mL, 3 times). Drying over $MgSO_4$ and evaporation gave the crude product, which was purified by flash column chromatography (12% Et_2O in pentane eluant) to yield 968 mg of **241** (27%). – IR (film): $\tilde{\nu}$ = 3056 cm^{-1} (*c*Pr–H), 2982 (C–H), 2905 (C–H), 1715 (C=O), 1643 (C=C), 1448, 1369, 1301, 1258, 1232, 1177, 1139 (C–O), 1095, 1040, 978 (H–C=C–H), 939, 886, 856, 812, 753, 731. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.11–1.28 (m, 4 H, *c*Pr-H), 1.23 (t, ^3J = 7.2 Hz, 3 H, CH_3), 1.30–1.42 (m, 1 H, *c*Pr-H), 1.78–1.85 (m, 1 H, *c*Pr-H), 2.29–2.38 (m, 1 H, *c*Pr-H), 4.16 (q, ^3J = 7.2 Hz, 2 H, OCH_2), 5.80 (d, ^3J = 14 Hz, 1 H, vinyl-H), 6.51 (dd, ^3J = 14 Hz, ^3J = 8.7 Hz, 1 H, vinyl-H). – ^{13}C NMR (62.5 MHz, $CDCl_3$): δ = 3.18 (*c*Pr-C), 13.42 (*c*Pr-C), 14.23 (*C*H_3), 19.35 (*c*Pr-C), 60.00 (O*C*H_2), 113.12 (*c*Pr*C*=C*c*Pr), 113.41 (*c*Pr*C*=C*c*Pr), 118.97 (vinyl-C), 151.05 (vinyl-C), 166.60 (*C*O_2Et). – MS (70 eV), *m/z* (%): 178 (11) [M^+], 150 (7) [M^+ – C_2H_5 + H], 132 (7) [M^+ – OC_2H_5 – H], 110 (7), 105 (100) [M^+ – $CO_2C_2H_5$], 91 (12), 79 (25) [*c*Pr$C_3H_2^+$], 77 (28), 51 (15), 41 (6) [*c*Pr^+]. – Cal. C 74.13, H 7.92; found C 73.91, H 7.80.



3-Bicyclopropyliden-2-yl-prop-2-en-1-ol (**242**) According to GP 2, 3-bicyclopropyliden-2-yl-acrylic acid ethyl ester (**241**) (843 mg, 4.73 mmol) and DIBALH (1.2 M in toluene, 11.7 mL, 14.2 mmol) were allowed to react in Et_2O (100 mL). The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 628 mg of **242** as a colorless oil (97%). – IR (film): $\tilde{\nu}$ = 3326 cm^{-1} (O–H), 3046 (*c*Pr–H), 2978 (C–H), 2927 (C–H), 2864 (C–H), 1664 (C=C), 1411, 1224, 1157, 1093, 1011 (C–O), 961 (H–C=C–H), 877, 807. – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.10–1.20 (m, 5 H, *c*Pr-H), 1.53–1.62 (m, 2 H, *c*Pr-H), 2.18 (m, 1 H, O*H*), 4.04 (dd, ^3J = 6.0 Hz, ^4J = 1.2 Hz, 2 H, CH_2OH), 5.38 (ddt,

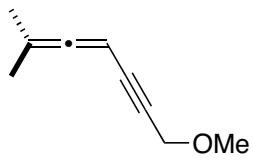
^3J = 15 Hz, ^3J = 9.0 Hz, ^4J = 1.2 Hz, 1 H, 3-H), 5.72 (dt, ^3J = 15 Hz, ^3J = 6.0 Hz, 1 H, 2-H). – ^{13}C NMR (50 MHz, $CDCl_3$): δ = 2.79 (*c*Pr-C), 3.09 (*c*Pr-C), 11.94 (*c*Pr-C), 18.48 (*c*Pr-C), 63.48 (CH_2OH), 111.81 (*c*Pr*C*=C*c*Pr), 114.11 (*c*Pr*C*=C*c*Pr), 127.78 (C-3), 134.12 (C-2). – MS (70 eV), *m/z* (%): 135 (3) [M^+ – H], 121 (10) [M^+ – OH + 2 H], 105 (58) [M^+ – CH_2OH], 91 (100) [M^+ – $CHCH_2OH$ – H], 79 (98) [M^+ – $CH{=}CHCH_2OH$], 77 (82), 65 (38), 51 (43), 41 (75) [*c*Pr^+]. – Cal. C 78.90, H 10.59; found C 79.11, H 10.75.

2-(3-But-2-ynyloxy-propenyl)-bicyclopropylidene (**243**) A dry SCHLENK flask was charged with NaH (60% in mineroil, 60.0 mg, 1.50 mmol) and THF (5 mL). To this suspension was added 3-bicyclopropyliden-2-yl-prop-2-en-1-ol (**242**) (185 mg, 1.36 mmol). The mixture was stirred for 3 h at rt. After cooling to 0 °C 1-bromo-2-butyne (**229**) (271 mg, 1.50 mmol) was added and the reaction mixture stirred for 2 h at rt. The reaction was quenched with NH_4Cl (sat., 10 mL). The aqueous layer was extracted with Et_2O (15 mL, 3 times). The combined organic layers were dried over $MgSO_4$ and the solvent removed under reduced pressure. The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 125 mg of **243** (49%) as colorless oil. – IR (film): $\tilde{\nu}$ = 3044 cm^{-1} (*c*Pr–H), 2978 (C–H), 2920 (C–H), 2851 (C–H), 2291, 2220 (C≡C), 1664 (C=C), 1444, 1410, 1355, 1262, 1232, 1137, 1106, 1072 (C–O), 1023, 960 (H–C=C–H), 875, 807, 773. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.12–1.23 (m, 5 H, *c*Pr-H), 1.58–1.64 (m, 1 H, *c*Pr-H), 1.83 (t, ^5J = 1.0 Hz, 3 H, C≡CCH_3), 2.16–2.23 (m, 1 H, *c*Pr-H), 3.97 (d, ^3J = 7.8 Hz, 2 H, OCH_2C=C), 4.08 (q, ^3J = 1.0 Hz, 2 H, OCH_2C≡C), 5.52 (dd, ^3J = 16 Hz, ^3J = 8.0 Hz, 1 H, vinyl-H), 5.64 (dt, ^3J = 16 Hz, ^3J = 7.8 Hz, 1 H, vinyl-H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 2.78 (*c*Pr-C), 2.09 (*c*Pr-C), 3.58 (C≡CCH_3), 11.99 (*c*Pr-C), 18.64 (*c*Pr-C), 57.38 (OCH_2C≡C), 69.98 (OCH_2C=C), 75.14 (C≡C), 82.27 (C≡C), 111.79 (*c*PrC=C*c*Pr), 114.06 (*c*PrC=C*c*Pr), 124.46 (vinyl-C), 125.09 (vinyl-C). – MS (70eV), *m/z* (%): 143 (2), 129 (6), 117 (10) [M^+ – $OCH_2C{\equiv}CH_3$ – 2 H], 105 (22) [M^+ – $CH_2OCH_2C{\equiv}CH_3$], 91 (46) [M^+ – $CHCH_2OCH_2C{\equiv}CH_3$], 79 (25) [$C_6H_7^+$], 77 (30), 65 (18), 53 (100) [$CH_2CCCH_3^+$], 41 (24) [*c*Pr^+]. – $C_{13}H_{16}O$ (188.27).

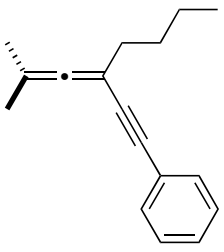


4. [5 + 2] Cycloaddition of Vinylcyclopropanes with Allenes

4.1. Starting materials



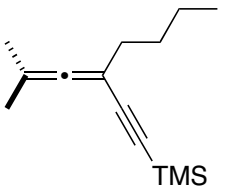
6-Methylhepta-4,5-dien-3-ynylmethylether (**245-d**) Methyl propargyl ether (**244-d**) (1.01 mL, 12.0 mmol), $Pd(PPh_3)_4$ (25.0 mg, 21.0 μmol), and CuBr (15.0 mg, 105 μmol) were dissolved in diethylamine (10 mL). After heating to 50 °C 1-bromo-3-methyl-buta-1,2-diene (**243**) (1.47 g, 10.0 mmol) was slowly added and the mixture was stirred at that temperature for 30 min. The reaction mixture was diluted with Et_2O (100 mL), washed with HCl (5%), $NaHCO_3$ (sat.), water, dried over $MgSO_4$ and the solvent was removed under reduced pressure. The crude product was purified by flash column chromatography (2% Et_2O in pentane eluant) affording 967 mg of **245-d** as a colorless oil (71%). – IR (film): $\tilde{\nu}$ = 2986 cm^{-1} (C–H), 2939 (C–H), 2845 (C–H), 2820 (C–H), 2211 (C≡C), 1995 (C=C=C), 1958 (C=C=C), 1448, 1356, 1278, 1230, 1187, 1141, 1098 (C–O), 1000, 949, 907, 789, 569. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 1.73 (d, ^5J = 1.6 Hz, 6 H, Me), 3.38 (s, 2 H, CH_2O), 3.39 (s, 3 H, OCH_3), 4.18 (d, ^5J = 1.6 Hz, 1 H, C=C=CH). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 19.88 [C=C(*C*H$_3$)$_2$], 57.60 (C≡C*C*H$_2$), 60.45 (OCH_3), 72.71 (C=C=*C*H), 80.54 (C≡C), 84.17 (C≡C), 97.80 (*C*=C=CH), 210.38 (C=*C*=CH). – Cal. C 79.37, H 8.88; found C 79.10, H 8.80.



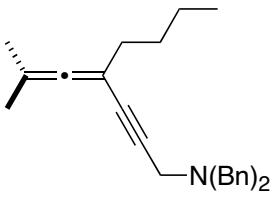
2-Methyl-4-butyl-6-phenylhexa-2,3-dien-5-yne (**245-g**) According to GP 5, 2-chloro-2-methyl-octa-3-yne (**251**) (436 mg, 2.75 mmol), $Pd(PPh_3)_4$ (150 mg, 138 μmol), CuI (52.0 mg, 275 μmol) and phenylacetylene (**244-b**) (0.36 mL, 3.30 mmol) were allowed to react in di-*iso*-propylamine (5 mL). The crude product was purified by flash column chromatography (pentane eluant) affording 420 mg of **245-g** as a colorless oil (68%). – IR (film): $\tilde{\nu}$ = 3081 cm^{-1} (Ar–H), 3056 (Ar–H), 2958 (C–H), 2931 (C–H), 2856 (C–H), 2206 (C≡C), 1950 (C=C=C), 1874 (C=C=C), 1597, 1490, 1442, 1378, 1275, 1091, 1068, 1032, 911, 755, 690, 581, 527. – ^{1}H NMR (250 MHz, $CDCl_3$): δ = 0.95 (t, ^3J = 8.0 Hz, 3 H, 4′-H), 1.30–1.60 (m, 4 H, 2′-H, 3′-H), 1.76 (s, 6 H, Me), 2.19 (t, ^3J = 8.0 Hz, 2 H, 1′-H), 7.25–7.32 (m, 3 H, Ph-H), 7.40–7.49 (m, 2 H, Ph-H). – ^{13}C NMR (62.9 MHz, $CDCl_3$): δ = 13.91 (C-4′), 20.41 [C=C(*C*H$_3$)$_2$], 21.90 (C-

2′*, C-3′*), 30.00 (C-2′*, C-3′*), 34.03 (C-1′), 86.55 (C≡C), 87.58 (C=C=*C*H), 88.98 (C≡C), 97.06 (*C*=C=CH), 123.82 (Ph-C), 127.65 (Ph-C), 128.11 (Ph-C), 131.38 (Ph-C), 206.54 (C=*C*=CH). – $C_{17}H_{20}$ (224.34).

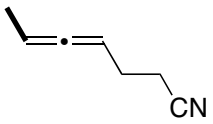
2-Methyl-4-butyl-6-(trimethylsilyl)hexa-2,3-dien-5-yne (**245-h**) According to GP 5, 2-chloro-2-methyl-octa-3-yne (**251**) (1.31 g, 8.25 mmol), $Pd(PPh_3)_4$ (476 mg, 413 μmol), CuI (156 mg, 875 μmol) and trimethylsilylacetylene (**244-a**) (1.4 mL, 9.90 mmol) were allowed to react in di-*iso*-propylamine (5 mL). The crude product was purified by flash column chromatography (pentane eluant) affording 280 mg of **145-g** as a colorless oil (15%) and 1.72 g of an unidentified byproduct. – IR (film): $\tilde{\nu}$ = 2960 cm^{-1} (C–H), 2932 (C–H), 2858 (C–H), 2145 (C≡C), 1954 (C=C=C), 1762, 1734, 1444, 1380, 1249, 1179, 1153, 1095, 1038, 882, 840, 759, 698. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.18 (s, 9 H, Si(CH_3)$_3$), 0.90 (t, ^3J = 6.8 Hz, 3 H, 4′-H), 1.28–1.48 (m, 4 H, 2′-H, 3′-H), 1.71 (s, 6 H, C=C(CH_3), 2.07 (t, ^3J = 7.6 Hz, 2 H, 1′-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 0.04 [Si(*C*H$_3$)$_3$], 13.75 (C-4′), 20.33 [C=C(*C*H$_3$)$_2$], 21.92 (C-2′*, C-3′*), 29.88 (C-2′*, C-3′*), 33.86 (C-1′), 87.57 (C≡C), 93.54 (C=C=*C*H), 97.12 (C≡C), 102.29 (*C*=C=CH), 206.93 (C=*C*=CH). – Cal. C 76.28, H 10.97; found C 75.99, H 10.88.



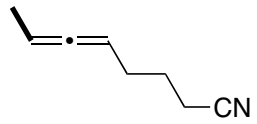
2-Methyl-4-butyl-7-hepta-2,3-dien-5-ynyl-dibenzylamine (**245-j**) According to GP 5, 2-chloro-2-methyl-octa-3-yne (**251**) (436 mg, 2.75 mmol), $Pd(PPh_3)_4$ (160 mg, 138 μmol), CuI (52.0 mg, 275 μmol), di(benzyl)propargyl amine (**244-f**) (1.43 g, 3.30 mmol) and triethylamine (0.77 mL, 5.50 mmol) were allowed to react in benzene (5 mL). The crude product was purified by flash column chromatography (pentane eluant) affording 443 mg of **245-j** as a colorless oil (45%). – IR (film): $\tilde{\nu}$ = 3400 cm^{-1}, 2908 (C–H), 2853 (C–H), 1694, 1441, 1351, 1210, 1109, 1005, 885, 833. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.82 (t, ^3J = 7.5 Hz, 3 H, 4′-H), 1.33–137 (m, 2 H, 3′-H*, 2′-H*), 1.47–151 (m, 2 H, 3′-H*, 2′-H*), 1.68 (s, 6 H, (CH_3)$_2$C=C=C), 2.09 (t, ^3J = 7.5 Hz, 2 H, 1′-H), 3.31 (s, 2 H, 7-H), 3.61 (s, 4 H, CH_2Ph), 7.15–7.25 (m, 10 H, Ar-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.03 (C-4′), 20.41 (C-3′), 21.92 [(*C*H$_3$)$_2$C=C=C], 30.08 (C-2′), 34.42 (C-1′), 42.25 (C-7), 57.59 (*C*H$_2$Ph), 82.61 (C≡C), 84.12 (C≡C), 87.24 (*C*=C=C),



96.67 (*C*=C=C), 127.04 (Ar-C), 128.39 (Ar-C), 129.12 (Ar-C), 139.03 (Ar-C), 206.32 (C=*C*=C). – MS (70 eV), *m/z* (%): 357 (7) [M^+], 314 (3) [$M^+ - C_3H_7$], 280 (3) [$M^+ - C_6H_5$], 266 (7) [M^+ – Bn], 234 (6) [$C{\equiv}CCH_2N(Bn)_2^+$], 210 (3) [$CH_2N(Bn)_2^+$], 194 (5) [$N(Bn)_2^+$], 162 (5), 119 (17), 105 (13), 91 (100) [$(CH_3O_2C{=}C{=}C\text{-}C{\equiv}C^+ + H$], 77 (8), 65 (12) [$(CH_3O_2C{=}C{=}C^+ - H$]. – $C_{26}H_{31}N$: 357.2464 (correct HRMS).



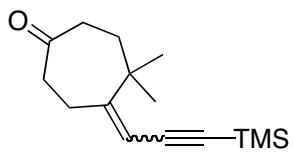
Hepta-4,5-dienenitrile (**263-2**) A suspension of zink (76.0 mg, 11.7 mmol) in THF (5 mL) was brought to reflux and cooled to rt. Then TMSCl (40.0 mg, 368 μmol) was added all at once and after stirring at rt for additional 15 min 3-iodopropylnitrile (2.00 g, 11.3 mmol) was added in one portion. The mixture was stirred at 35 °C over night, then cooled to –10 °C, and a solution of LiBr (1.42 g, 16.4 mmol) and CuCN (720 mg, 8.03 mmol) in THF (17 mL) was added dropwise keeping the temperature below 0 °C. After additional stirring for 30 min at 0 °C the mixture was cooled to –40 °C and a solution of 2-tosyloxyprop-2-yne (**261**) (1.75 g, 7.80 mmol) in THF (5 mL) was added dropwise. After warming to rt and aqueous workup the crude product was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 0.482 g of **263-2** as a colorless oil (58%). – The analytical data correspond to those reported in literature.[143]



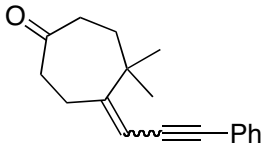
Octa-4,5-dienenitrile (**263-3**) A suspension of zink (76.0 mg, 11.7 mmol) in THF (5 mL) was brought to reflux and cooled to rt. Then TMSCl (40.0 mg, 368 μmol) was added all at once and after stirring at rt for additional 15 min 3-iodobutylnitrile (**262**) (2.16 g, 11.3 mmol) was added in one portion. The mixture was stirred at 35 °C over night, then cooled to –10 °C, and a solution of LiBr (1.42 g, 16.4 mmol) and CuCN (720 mg, 8.03 mmol) in THF (17 mL) was added dropwise keeping the temperature below 0 °C. After additional stirring for 30 min at 0 °C the mixture was cooled to –40 °C and a solution of 2-tosyloxyprop-2-yne (**261**) (1.75 g, 7.80 mmol) in THF (5 mL) was added dropwise. After warming to rt and aqueous workup the crude product was purified by flash column chromatography (10% Et_2O in pentane eluant) affording 824 mg of **263-3** as a colorless oil (87%). – IR (film): $\tilde{\nu}$ = 2946 cm^{-1} (C–H), 2856 (C–H), 2247 (C≡N), 1966 (C=C=C), 1442, 1372, 1287, 1178, 1070, 876, 706, 557. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.69–1.78 (m, 2 H,

3-H), 2.04–2.14 (m, 2 H, 4-H), 2.35 (t, ^3J = 6.8 Hz, 2 H, 2-H), 4.95–5.03 (m, 1 H, 7-H), 5.04–5.14 (m, 1 H, 5-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.66 (C-2), 16.37 (C-3), 24.80 (C-4), 27.61 (C-8), 86.94 (C-5*, C-7*), 88.35 (C-5*, C-7*), 205.28 (C-6). – DCI-MS (200 eV, NH_3), *m/z* (%): 260 (45) [2 M + NH_4^+], 156 (78) [M + NH_3 + NH_4^+], 139 (100) [M + NH_4^+], 122 (5) [M + H^+]. – C_8H_1N (121.18).

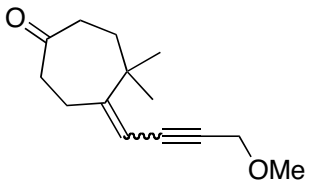
4.2. Cycloadducts



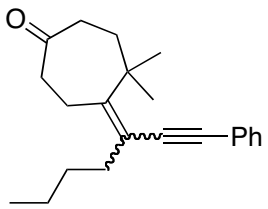
4,4-Dimethyl-5-[3-(trimethylsilanyl)-prop-2-ynylidene]-cycloheptanone (**253-a**) and (**254-a**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-a** (39.4 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.8 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (12.5% Et_2O in pentane eluant) affording 17 mg of **253-a** and 30 mg of **254-a** (95%, **253-a**:**254-a** = 1:2) as a colorless oil. – Data for **253-a**: IR (film): $\tilde{\nu}$ = 2960 cm^{-1} (C–H), 2926 (C–H), 2871 (C–H), 2138 (C≡C), 1706 (C=O), 1466, 1388, 1368, 1330, 1249, 1153, 1119, 1094, 1062, 1035, 843, 750, 699, 646. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.20 (s, 9 H, Si(CH_3)$_3$), 1.16 (s, 6 H, CH_3), 1.68–1.70 (m, 2 H, 3-H), 2.43–2.45 (m, 2 H, 2-H), 2.56–258 (m, 2 H, 6-H), 2.70–272 (m, 2 H, 7-H), 5.54 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = –0.04 [Si(CH$_3$)$_3$], 24.88 (C-6), 27.41 (CH$_3$), 36.84 (C-2), 39.59 (C-3), 39.83 (C-4), 41.94 (C-7), 99.03 (C≡C), 102.53 (C≡C), 105.48 (vinyl-C), 162.61 (C-5), 212.56 (C-1). – MS (70 eV), *m/z* (%): 249 (8), 248 (36) [M^+], 233 (47) [M^+ – CH_3], 205 (14) [M^+ – 3 CH_3 + 2 H], 177 (8), 163 (17), 159 (21) [M^+ – O – Si(CH_3)$_3$], 143 (11), 137 (10), 119 (20), 109 (12) [C-C≡CSi(CH_3)$_3^+$], 97 (9), 91 (11), 83 (14), 75 (62), 73 (100) [Si(CH_3)$_3^+$], 59 (30). – $C_{15}H_{24}OSi$: 248.1597 (correct HRMS). – Data for **254-a**: IR (film): $\tilde{\nu}$ = 2959 cm^{-1} (C–H), 2870 (C–H), 2129 (C≡C), 1705 (C=O), 1470, 1446, 1417, 1393, 1365, 1338, 1309, 1250, 1205, 1156, 1099, 1076, 1017, 934, 843, 756, 699, 674, 642. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.20 (s, 9 H, Si(CH_3)$_3$), 1.46 (s, 6 H, CH_3), 1.73–1.75 (m, 2 H, 3-H), 2.41–2.43 (m, 2 H, 2-H), 2.51–153 (m, 4 H, 6-H, 7-H), 5.57 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = –0.04 [Si(CH$_3$)$_3$], 27.61 (CH_3), 31.47 (C-6), 37.36 (C-2), 40.12 (C-3), 40.34 (C-4), 44.36 (C-7), 100.69 (C≡C), 103.67 (C≡C), 107.78 (vinyl-C), 161.14 (C-5), 211.45 (C-1). – MS (70 eV), *m/z* (%): 249 (6), 248 (26) [M^+], 233 (44) [M^+ – CH_3], 205 (12) [M^+ – 3 CH_3 + 2 H], 177 (7), 163 (17), 159 (20) [M^+ – O – Si(CH_3)$_3$], 143 (10), 137 (11), 119 (19), 109 (11) [C-C≡CSi(CH_3)$_3^+$], 83 (12), 75 (58), 73 (100) [Si(CH_3)$_3^+$]. – $C_{15}H_{24}OSi$: 248.1585 (correct HRMS).



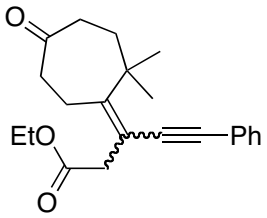
4,4-Dimethyl-5-(3-phenyl-prop-2-ynylidene)-cycloheptanone (**253-b**) and (**254-b**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-b** (40.4 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (14% Et_2O in pentane eluant) affording 15 mg of **253-b** and 24 mg mg of **254-b** (83%, **253-b**:**254-b** = 1:2) as a colorless oil. – Data for **253-b**: IR (film): $\tilde{\nu}$ = 3052 cm^{-1} (Ar–H), 2962 (C–H), 2870 (C–H), 2197 (C≡C), 1699 (C=O), 1593 (C=C), 1489, 1442, 1330, 1268, 1158, 756, 691. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.20 (s, 6 H, CH_3), 1.70–172 (m, 2 H, 3-H), 2.44–2.46 (m, 2 H, 2-H), 2.60–2.62 (m, 2 H, 6-H), 2.77–2.79 (m, 2 H, 7-H), 5.72 (s, 1 H, vinyl-H), 7.30–7.32 (m, 3 H, Ar-H), 7.39–7.41 (m, 2 H, Ar-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.93 (C-6), 27.54 (CH_3), 36.93 (C-2), 39.59 (C-3), 39.87 (C-4), 42.27 (C-7), 86.59 (C≡C), 94.07 (C≡C), 105.39 (vinyl-C), 123.49 (Ar-C), 128.03 (Ar-C), 128.31 (Ar-C), 131.27 (Ar-C), 162.04 (C-5), 212.58 (C-1). – $C_{18}H_{20}O$: 252.1518 (correct HRMS). – Data for **254-b**: IR (film): $\tilde{\nu}$ = 3033 cm^{-1} (Ar–H), 2961 (C–H), 2868 (C–H), 2192 (C–H), 1593 (C=O), 1593 (C=C), 1435, 1405, 1352, 1145, 1081, 1029, 831, 696. – ^{1}H NMR (300 MHz, $CDCl_3$): δ = 1.51 (s, 6 H, CH_3), 1.75–1.77 (m, 2 H, 3-H), 2.46–2.55 (m, 6 H, 2-H, 6-H, 7-H), 5.76 (s, 1 H, vinyl-H), 7.30–7.32 (m, 3 H, Ar-H), 7.40-7.42 (m, 2 H, Ar-H). – ^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.77 (CH_3), 31.40 (C-6), 37.24 (C-3), 40.01 (C-2), 40.22 (C-4), 44.33 (C-7), 87.34 (C≡C), 94.84 (C≡C), 107.50 (vinyl-C), 123.60 (Ar-C), 127.88 (Ar-C), 128.18 (Ar-C), 130.72 (Ar-C), 159.65 (C-5), 211.41 (C-1). – MS (70 eV) (*m/z*): 253 (21), 252 (100) [M^+], 237 (11) [M^+ – CH_3], 223 (7) [M^+ – 2 CH_3 + H], 209 (8), 195 (31), 181 (59), 167 (45), 165 (40), 152 (20), 141 (15), 128 (17) [M^+ – 2 CH_3 – Ph + H], 115 (35) [$C_9H_7^+$], 105 (8) [$C_8H_9^+$], 91 (25) [$C_7H_7^+$], 77 (20), 55 (14). – $C_{18}H_{20}O$: 252.1511 (correct HRMS).



5-(4-Methoxy-but-2-ynyl-idene)-4,4-dimethyl-cycloheptanone (**253-d**) and (**254-d**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-d** (32.6 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (14% Et_2O in pentane eluant) affording 10 mg mg of **254-d** and 8 mg of **253-d** (45%, **253-d**:**254-d** = 1:1) as a colorless oil. – Data for **254-d**: IR (film): $\tilde{\nu}$ = 2955 cm^{-1} (C–H), 2930 (C–H), 2872 (C–H), 2821 (C–H), 2205 (C≡C), 1704 (C=O), 1464, 1391, 1374, 1356, 1309, 1259, 1186, 1148, 1096, 1000, 948, 906, 868, 838, 746, 667. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.43 (s, 6 H, CH_3), 1.72–1.74 (m, 2 H, 3-H), 2.41–2.43 (m, 2 H, 2-H), 2.48–2.52 (m, 4 H, 6-H, 7-H), 3.39 (s, 3 H, OCH_3), 4.23 (d, ^5J = 2.4 Hz, 2 H, CH_2OCH$_3$), 5.57 (t, ^5J = 2.4 Hz, 1 H, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 27.87 (CH_3), 31.42 (C-6), 37.34 (C-3), 40.13 (C-2), 40.21 (C-4), 44.40 (C-7), 57.69 (CH_2O), 60.61 (OCH_3), 84.56 (C≡C), 91.03 (C≡C), 107.10 (vinyl-C), 159.99 (C-5), 211.49 (C-1). – MS (70 eV) (*m/z*): 220 (9) [M^+], 205 (16) [M^+ – CH_3], 175 (10) [M^+ – CH_2OMe], 173 (17), 163 (22), 150 (23) [M^+ – C≡CCH_2OMe – H], 149 (29), 147 (14), 145 (27), 135 (26) [M^+ – C≡CCH_2OMe – CH_3 – H], 133 (26), 131 (54), 123 (14) [M^+ – CHC≡CCH_2OMe – CH_3], 117 (58), 109 (24), 105 (61) [$C_8H_9^+$], 91 (100) [$C_7H_7^+$], 79 (41), 77 (57), 65 (36), 55 (47). – $C_{14}H_{20}O_2$: 220.1462 (correct HRMS). – Data for **253-d**: IR (film): $\tilde{\nu}$ = 2961 cm^{-1} (C–H), 2927 (C–H), 2206 (C–H), 1703 (C=O), 1464, 1356, 1260, 1186, 1154, 1096, 906, 802. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.16 (s, 6 H, CH_3), 1.67–1.69 (m, 2 H, 3-H), 2.41–2.43 (m, 2 H, 2-H), 2.53–2.55 (m, 2 H, 6-H), 2.67–2.69 (m, 2 H, 7-H), 3.39 (s, 3 H, OCH_3), 4.24 (d,^5J = 2.4 Hz, 2 H, CH_2OCH$_3$), 5.53 (t, ^5J = 2.4 Hz, 1 H, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 24.77 (C-6), 27.50 (CH_3, 36.85 (C-3), 39.54 (C-2), 39.74 (C-4), 42.23 (C-7), 57.50 (CH_2O), 60.45 (OCH_3), 83.51 (C≡C), 89.58 (C≡C), 104.83 (vinyl-C), 161.40 (C-5), 212.48 (C-1). – MS (70 eV) (*m/z*): 220 (8) [M^+], 205 (8) [M^+ – CH_3], 175 (6) [M^+ – CH_2OMe], 173 (10), 163 (11), 150 (9) [M^+ – C≡CCH_2OMe – H], 149 (47), 147 (19), 145 (15), 135 (13) [M^+ – C≡CCH_2OMe – CH_3 – H], 133 (13), 129 (100), 123 (7) [M^+ – CHC≡CCH_2OMe – CH_3], 117 (32), 112 (31), 109 (12), 105 (32) [$C_8H_9^+$], 91 (47) [$C_7H_7^+$], 79 (21), 71 (54), 65 (20), 55 (63). – $C_{14}H_{20}O_2$: 220.1458 (correct HRMS).

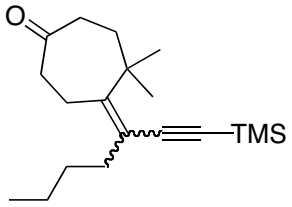


5-(1-Butyl-3-phenyl-prop-2-ynylidene)-4,4-dimethyl-cycloheptanone (**253-g**) and (**254-g**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-g** (53.8 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (14% Et_2O in pentane eluant) affording 47 mg (80%, **253-g**:**254-g** = 2:3) as a mixture of **253-g** and **254-g**, which were not separable by column chromatography, as a colorless oil. – Data for the mixture of **253-g** and **254-g**: IR (film): $\tilde{\nu}$ = 2956 cm^{-1} (C–H), 2928 (C–H), 2870 (C–H), 2192 (C≡C), 1701 (C=O), 1598 (C=C), 1489, 1466, 1442, 1249, 755, 691. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.83–0.89 (m), 1.17–1.61 (m), 1.72–1.74 (m), 2.15–2.17 (m), 2.31–2.33 (m), 2.42–2.44 (m), 2.57–2.59 (m), 2.78–2.80 (m), 7.17–7.26 (m), 7.28–7.34 (m). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 13.91, 14.20, 22.44, 22.76, 24.19, 28.02, 28.14, 28.57, 28.83, 29.09, 31.14, 31.66, 33.35, 34.95, 38.10, 38.23, 39.33, 40.37, 40.48, 40.93, 91.21, 91.47, 92.11, 95.35, 119.90, 122.60, 123.86, 124.20, 127.44, 127.94, 128.62, 130.40, 130.74, 131.12, 131.56, 151.33, 151.75, 211.67, 212.04. – MS (70 eV) (*m/z*): 309 (18), 308 (76) [M^+], 293 (15) [$M^+ - CH_3$], 265 (7), 251 (19) [$M^+ - C_4H_9$], 209 (20) [M^+ – C≡CPh – 2 H], 195 (44), 181 (38), 165 (47), 155 (27), 141 (41), 128 (46) [$C_{10}H_8^+$], 115 (61) [$C_9H_7^+$], 105 (26) [$C_8H_9^+$], 91 (100) [$C_7H_7^+$], 77 (41), 55 (25). – $C_{22}H_{28}O$: 308.2136 (correct HRMS).



3-(2,2-Dimethyl-5-oxo-cycloheptylidene)-5-phenyl-pent-4-ynoic acid ethyl ester (**253-f**) and (**254-f**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-f** (61.0 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (33% Et_2O in pentane eluant) affording 24 mg of **253-f** and 48 mg of **254-f** (92%, **253-f**:**254-f** = 1:2) as a colorless oil. – Data for **253-f**: IR (film): $\tilde{\nu}$ = 2958 cm^{-1} (C–H), 1738 (C=O), 1733 (C=O), 1703 (C=C), 1489, 1443, 1367, 1315, 1259, 1161, 1030, 757, 692. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.27 (t, ^3J = 7.2 Hz, 3 H, OCH_2CH_3), 1.33 (s, 6 H, CH_3), 1.80–1.85 (m, 2 H, 3-H), 2.50–2.54 (m, 2 H, 2-H) 2.69–2.72 (m, 2 H, 6-H), 2.88–2.92 (m, 2 H, 7-H), 3.53 (s, 2 H, CH_2CO_2), 4.19 (q, ^3J = 7.2 Hz, 2 H, OCH_2CH_3), 7.27–2.33 (m, 3 H, Ar-H), 7.33–7.39 (m, 2 H,

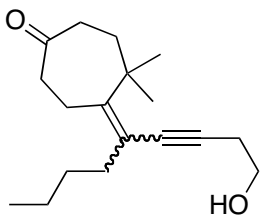
Ar-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.22 ($OCH_2\mathit{C}H_3$), 28.63 ($\mathit{C}H_3$), 29.18 (C-6), 39.22 (C-3), 39.78 (C-2), 40.16 (C-4), 41.02 (C-7), 42.75 ($\mathit{C}H_2CO_2$), 60.92 ($O\mathit{C}H_2CH_3$), 90.50 (C≡C), 92.44 (C≡C), 114.34 (vinyl-C), 123.37 (Ar-C), 128.07 (Ar-C), 128.27 (Ar-C), 131.30 (Ar-C), 155.30 (C-5), 170.91 ($\mathit{C}O_2Et$), 211.60 (C-1). – $C_{22}H_{26}O_3$: 338.1872 (correct HRMS). – Data for **254-f**: IR (film): $\tilde{\nu}$ = 2959 cm^{-1} (C–H), 2928 (C–H), 1737 (C=O), 1733 (C=O), 1704 (C=C), 1489, 1442, 1366, 1315, 1256, 1157, 1032, 757, 692. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.25 (t, ^3J = 7.2 Hz, 3 H, $OCH_2C\mathit{H}_3$), 1.53 (s, 6 H, $C\mathit{H}_3$), 1.80–1.86 (m, 2 H, 3-H), 2.50–2.54 (m, 2 H, 2-H) 2.54–2.56 (m, 4 H, 6-H, 7-H), 3.31 (s, 2 H, $C\mathit{H}_2CO_2$), 4.16 (q, ^3J = 7.2 Hz, 2 H, $OC\mathit{H}_2CH_3$), 7.27–7.31 (m, 3 H, Ar-H), 7.35–7.40 (m, 2 H, Ar-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 14.15 ($OCH_2\mathit{C}H_3$), 24.96 (C-6), 27.90 ($\mathit{C}H_3$), 37.98 (C-3), 40.28 (C-2), 41.13 (C-4), 41.24 (C-7), 42.53 ($\mathit{C}H_2CO_2$), 60.92 ($O\mathit{C}H_2CH_3$), 90.50 (C≡C), 95.85 (C≡C), 112.57 (vinyl-C), 123.67 (Ar-C), 128.08 (Ar-C), 128.27 (Ar-C), 130.83 (Ar-C), 155.19 (C-5), 170.76 ($\mathit{C}O_2Et$), 211.24 (C-1). – $C_{22}H_{26}O_3$: 338.1874 (correct HRMS).



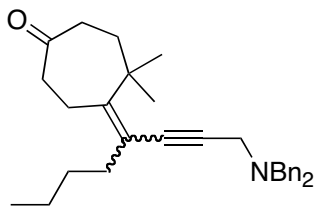
5-[1-Butyl-3-(trimethyl-silanyl)-prop-2-ynylidene]-4,4-dimethyl-cycloheptanone (**253-h**) and (**254-h**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-h** (52.9 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 mmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (5% Et_2O in pentane eluant) affording 14 mg of **253-h** and 35 mg of **254-h** (80%, **253-h**:**254-h** = 2:5) as a colorless oil. – Data for **253-h**: IR (film): $\tilde{\nu}$ = 2957 cm^{-1} (C–H), 2930 (C–H), 2872 (C–H), 2133 (C≡C), 1704 (C=O), 1464, 1249, 1100, 907, 842, 759. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 0.16 (s, 9 H, $Si(C\mathit{H}_3)_3$), 0.93 (t, ^3J = 7.2 Hz, 3H, 4″-H), 1.27 (s, 6 H, $C\mathit{H}_3$), 1.30–1.38 (m, 2 H, 3″-H*, 2″-H*), 1.50–1.57 (m, 2 H, 2H, 3″-H*, 2″-H*) 1.75–1.80 (m, 2 H, 3-H), 2.20–2.25 (m, 2 H, 1″-H), 2.44–2.52 (m, 2 H, 2-H), 2.57–2.61 (m, 2 H, 6-H), 2.77–2.82 (m, 2 H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 0.29 [$Si(\mathit{C}H_3)_3$], 14.25 (C-4″), 22.95 (C-3″), 28.84 ($\mathit{C}H_3$), 29.28 (C-6), 31.73 (C-2″), 33.25 (C-1″), 39.51 (C-4), 40.60 (C-3), 40.74 (C-2), 43.03 (C-7), 96.94 (C≡C), 107.30 (C≡C), 122.93 (vinyl-C), 153.15 (C-5), 212.94 (C-1). – $C_{19}H_{32}O$: 304.2212 (correct HRMS). – Data for **254-h**: IR (film): $\tilde{\nu}$ = 2958 cm^{-1} (C–H), 2873 (C–H), 2132 (C≡C), 1705 (C=O), 1464, 1249, 1077, 922, 904, 842, 759.

– ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 0.17$ (s, 9 H, Si(CH_3)$_3$), 0.91 (t, $^3J = 7.2$ Hz, 3 H, 4″-H), 1.27–1.33 (m, 2 H, 3″-H), 1.42 (s, 6 H, CH_3) 1.43–1.52 (m, 2 H, 2″-H), 1.75–1.79 (m, 2 H, 3-H) 2.12 (t, $^3J = 7.6$ Hz, 2 H, 1″-H) 2.45–2.52 (m, 6 H, 2-H, 6-H, 7-H). – ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = -0.27$ [Si(CH$_3$)$_3$], 14.03 (C-4″), 22.39 (C-3″), 24.11 (C-6), 27.72 (CH$_3$), 30.97 (C-2″), 34.81 (C-1″), 38.05 (C-4), 40.35 (C-3), 40.78 (C-2), 43.03 (C-7), 100.65 (C≡C), 107.19 (C≡C), 120.07 (vinyl-C), 152.23 (C-5), 211.70 (C-1). – MS (70 eV) (*m/z*): 304 (10) [M$^+$], 289 (10) [M$^+$ – CH$_3$], 247 (11) [M$^+$ – C$_4$H$_9$], 233 (6) [M$^+$ – C$_4$H$_9$ – CH$_3$ + H], 162 (11), 159 (6) 157 (6), 145 (7), 143 (6), 137 (9) [M$^+$ – CC≡CTMS – C$_4$H$_9$ – H], 133 (6), 131 (6), 119 (11) [C$_9$H$_{11}^+$], 95 (9), 83 (7), 75 (19), 73 (100). – $C_{19}H_{32}O$: 304.2217 (correct HRMS).

5-(1-Butyl-5-hydroxy-pent-2-ynylidene)-4,4-dimethyl-cycloheptanone (**253-i**) and (**254-i**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-i** (46.2 mg, 240 μmol) and [Rh(CO)$_2$Cl]$_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (30% Et_2O in pentane eluant) affording 13 mg of **253-i** and 16 mg of **254-i** (65%, **253-i**:**254-i** = 1:1.2) as a colorless oil. – Data for **253-i**: IR (film): $\tilde{\nu} = 3433$ cm^{-1} (O–H), 2960 (C–H), 2926 (C–H), 2871 (C–H), 1698 (C=O), 1461, 1362, 1338, 1260, 1046, 801. – ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 0.91$ (t, $^3J = 7.2$ Hz, 3 H, 4″-H), 1.30–1.35 (m, 2 H, 3″-H), 1.41 (s, 6 H, CH_3), 1.45–1.49 (m, 2 H, 2″-H), 1.61 (bs, 1 H, OH), 1.76–1.80 (m, 2 H, 3-H), 2.11–2.15 (m, 2 H, 1″-H), 2.46–2.51 (m, 6 H, 2-H, 6-H, 7-H), 2.64 (t, $^3J = 6.4$ Hz, 2 H, C≡C-CH_2), 3.76 (t, $^3J = 6.4$ Hz, 2 H, CH_2OH). – ^{13}C NMR (125 MHz, $CDCl_3$): $\delta = 14.08$ (C-4″), 22.49 (C-3″), 24.01 (C-6), 24.25 (C≡CCH$_2$), 27.96 (CH$_3$), 31.16 (C-2″), 35.35 (C-1″), 38.07 (C-4), 40.34 (C-3), 40.66 (C-2), 43.10 (C-7), 61.23 (CH$_2$OH), 84.27 (C≡C), 92.22 (C≡C), 119.85 (vinyl-C), 150.05 (C-5), 211.83 (C-1). – MS (70 eV), *m/z* (%): 276 (36) [M$^+$], 261 (12) [M$^+$ – CH$_3$], 246 (26) [M$^+$ – CH$_2$O], 231 (17) [M$^+$ – C$_2$H$_5$], 219 (15), 217 (14) [M$^+$ – CH$_2$O – C$_2$H$_5$], 203 (20) [M$^+$ – C$_4$H$_9$], 189 (23) [M$^+$ – CH$_2$O – C$_4$H$_9$], 175 (20) [M$^+$ – C$_2$H$_4$O – C$_4$H$_9$], 163 (17) [M$^+$ – C$_3$H$_4$O – C$_4$H$_9$], 145 (45), 137 (33) [M$^+$ – C$_5$H$_4$OH – C$_4$H$_9$], 133 (43), 131 (50), 119 (58), 105 (60), 91 (88), 77 (53) [(CH$_3$)C=C=C–C≡C$^+$ + H], 69 (43), 55 (77) [(CH$_3$)C=C=C$^+$ + H]. – $C_{18}H_{28}O_2$: 276.2090 (correct HRMS). – Data for **254-i**: IR (film): $\tilde{\nu} = 3424$ cm^{-1} (O–H), 2956 (C–H), 2928 (C–H), 2871 (C–H),



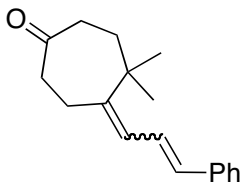
1701 (C=O), 1445, 1376, 1340, 1049. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.92 (t, ^3J = 7.2 Hz, 3 H, 4″-H), 1.27 (s, 6 H, CH_3), 1.30–1.35 (m, 2 H, 3″-H), 1.50–1.54 (m, 2 H, 2″-H), 1.58 (bs, 1 H, OH), 1.78–1.80 (m, 2 H, 3-H), 2.28–2.30 (m, 2 H, 1″-H), 2.46–2.48 (m, 2 H, 2-H), 2.58–2.62 (m, 4 H, 6-H, 7-H), 2.76 (t, ^3J = 6.4 Hz, 2 H, C≡CCH_2), 3.74 (t, ^3J = 6.4 Hz, 2 H, CH_2OH). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.04 (C-4″), 22.78 (C-3″), 23.92 (C≡CCH$_2$), 28.73 (CH$_3$), 28.78 (CH$_3$), 30.76 (C-6), 31.69 (C-2″), 33.60 (C-1″), 39.39 (C-4), 40.30 (C-3), 40.36 (C-2), 42.83 (C-7), 61.42 (CH$_2$OH), 84.16 (C≡C), 88.91 (C≡C), 122.57 (vinyl-C), 150.55 (C-5), 212.21 (C-1). – MS (70 eV), *m/z* (%): 276 (21) [M$^+$], 246 (42) [M$^+$ – CH$_2$O], 231 (27) [M$^+$ – C$_2$H$_5$], 203 (18) [M$^+$ – C$_4$H$_9$], 189 (46) [M$^+$ – CH$_2$O – C$_4$H$_9$], 175 (17) [M$^+$ – C$_2$H$_4$O – C$_4$H$_9$], 163 (12) [M$^+$ – C$_3$H$_4$O – C$_4$H$_9$], 145 (40), 137 (20) [M$^+$ – C$_5$H$_4$OH – C$_4$H$_9$], 133 (41), 131 (43), 119 (54), 105 (51), 91 (100), 77 (40) [(CH$_3$)C=C=C–C≡C$^+$ + H], 69 (26), 55 (55) [(CH$_3$)C=C=C$^+$ + H]. – C$_{18}$H$_{28}$O$_2$: 276.2083 (correct HRMS).



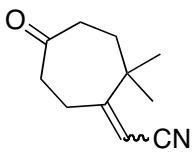
5-(1-Butyl-4-dibenzylamino-but-2-ynylidene)-4,4-dimethyl-cycloheptanone (**253-j**) and (**254-j**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allenyne **245-j** (85.8 mg, 240 μmol) and [Rh(CO)$_2$Cl]$_2$ (0.7 mg, 2.00 mmol) were allowed to react in DCE (1 mL mL). The crude mixture was purified by flash column chromatography (12.5% Et$_2$O in pentane eluant) affording 13 mg of **254-j** and 6 mg of **253-j** (22%, **253-j**:**254-j** = 1:2) as a colorless oil. – Data for **254-j**: IR (film): $\tilde{\nu}$ = 3385 cm^{-1}, 3063 (Ar–H), 3029 (Ar–H), 2956 (C–H), 2926 (C–H), 2871 (C–H), 2250 (C≡C), 1950, 1876, 1704 (C=O), 1602 (C=C), 1495, 1455, 1430, 1362, 1325, 1260, 1204, 1154, 1118, 1072, 1029, 974, 911, 804, 734, 699. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.96 (t, ^3J = 7.2 Hz, 3 H, 4″-H), 1.41 (s, 6 H, CH_3), 1.48–1.58 (m, 4 H, 2″-H, 3″-H), 1.80–1.83 (m, 2 H, 1″-H), 2.21–2.25 (m, 2 H, 2-H), 2.50–2.56 (m, 6 H, 3-H, 6-H, 7-H), 3.42 (bs, 2 H, C≡CCH_2N), 3.72 (bs, 4H, CH_2Ph), 7.24–7.28 (m, 2 H, Ar-H), 7.30–7.36 (m, 4 H, Ar-H), 7.39–7.42 (m, 4 H, Ar-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.43 (C-4″), 22.85 (C-3″), 24.33 (C-6), 28.33 (CH$_3$), 31.59 (C-2″), 35.99 (C-1″), 38.27 (C-3), 40.66 (C-4), 40.94 (C-2), 42.46 (C-7), 43.40 (C≡C-CH$_2$N), 58.05 [N(CH$_2$Ph)$_2$], 87.55 (C≡C), 91.62 (C≡C), 120.15 (vinyl-C), 127.38 (Ar-C), 128.54 (Ar-C), 129.30 (Ar-C), 139.22 (Ar-C), 169.41 (C-5), 212.09 (C-1). – MS (70 eV), *m/z* (%): 442 (3), 441 (8) [M$^+$], 426 (6) [M$^+$ – CH$_3$ – H], 398 (2) [M$^+$ – C$_3$H$_7$], 384

(5) [M^+ – C_4H_9], 364 (3) [M^+ – C_6H_5], 350 (7) [M^+ – C_7H_7], 234 (5), 222 (7), 196 (10) [$N(Bn)_2^+$], 118 (11), 91 (100) [Bn^+]. – $C_{31}H_{39}NO$: 441.3026 (correct HRMS). – Data for **253-j**: IR (film): $\tilde{\nu}$ = 3384 cm^{-1}, 3063 (Ar–H), 3029 (Ar–H), 2957 (C–H), 2926 (C–H), 2872 (C–H), 2250 (C≡C), 1950, 1876, 1704 (C=O), 1603 (C=C), 1495, 1455, 1365, 1324, 1260, 1156, 1105, 1073, 1029, 973, 911, 804, 739, 699. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.97 (t, ^3J = 7.2 Hz, 3 H, 4″-H), 1.32 (s, 6 H, CH_3), 1.40–1.44 (m, 2 H, 3″-H), 1.57–1.61 (m, 2 H, 2″-H)), 1.80–1.84 (m, 2 H, 3-H), 2.37–2.41 (m, 2 H, 1″-H), 2.52–2.56 (m, 2 H, 2-H), 2.63–2.67 (m, 2 H, 6-H), 2.86–2.90 (m, 2 H, 7-H), 3.40 (bs, 2 H, C≡CCH_2N), 3.68 (bs, 4 H, CH_2Ph) 7.22–7.28 (m, 2 H, Ar-H), 7.30–7.36 (m, 4 H, Ar-H), 7.37–7.41 (m, 4 H, Ar-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 14.13 (C-4″), 22.88 (C-3″), 28.83 (CH_3), 29.10 (C-6), 31.84 (C-2″), 33.92 (C-1″), 39.43 (C-3), 40.27 (C-4), 40.41 (C-2), 41.95 (C-7), 43.34 (C≡C-CH_2N), 57.69 [N(CH_2Ph)$_2$], 89.11 (C≡C), 91.76 (C≡C), 122.85 (vinyl-C), 127.12 (Ar-C), 128.31 (Ar-C), 129.01 (Ar-C), 135.82 (Ar-C), 174.50 (C-5), 212.37 (C-1). – MS (70 eV), *m/z* (%): 442 (2), 441 (6) [M^+], 426 (2) [M^+ – CH_3 – H], 398 (2) [M^+ – C_3H_7], 384 (3) [M^+ – C_4H_9], 364 (1) [M^+ – C_6H_5], 350 (7) [M^+ – C_7H_7], 234 (3), 222 (7), 210 (5), 196 (23) [$N(Bn)_2^+$], 118 (9), 91 (100) [Bn^+]. – $C_{31}H_{39}NO$: 441.3013 (correct HRMS).

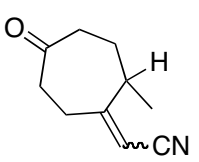
4,4-Dimethyl-5-(3-phenyl-allylidene)-cycloheptanone (**256-d**) and (**257-d**) According to GP 6, vinylcyclopropane **42** (28 mg, 200 μmol), allene **255-d** (40.8 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (1.4 mg, 4.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 35 mg (69%, **256-d**:**257-d** = 2:1) as a mixture of **256-d** and **257-d**, which were not separable by column chromatography, as a colorless oil. – Data for the mixture of **256-d** and **257-d**: IR (film): $\tilde{\nu}$ = 3023 cm^{-1} (Ar–H), 2961 (C–H), 1699 (C=O), 1594 (C=C), 1447, 1329, 1262, 1157, 962, 749, 692. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.20 (s, 6 H, **256-d**, CH_3), 1.41 (s, 6 H, **257-d**, CH_3), 1.70–1.74 (m, 2 H, **256-d**, 3-H), 1.77–1.81 (m, 2 H, **257-d**, 3-H), 2.40–2.45 (m, 2 H, **256-d**, 2-H), 2.48–2.56 (m, 8 H, **257-d**, 2-H, 6-H, 7-H + **256-d**, 6-H), 2.64–2.68 (m, 2 H, **256-d**, 7-H), 6.15 (d, ^3J = 12 Hz, 1 H, **257-d**, vinyl-H), 6.20 (d, ^3J = 11 Hz, 1 H, **256-d**, vinyl-H), 6.42 (d, ^3J = 15 Hz, 1 H, **257-d**, vinyl-H), 6.59 (d, ^3J = 15 Hz, 1 H, **256-d**, vinyl-H), 6.96 (dd, ^3J = 15 Hz, ^3J = 11 Hz, 1 H, **256-d**, vinyl-H), 7.20–7.25 (m, 2 H, **257-H**, vinyl-H, Ar-H, **256-d**,



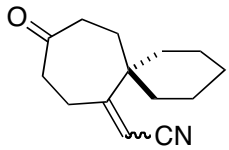
Ar-H), 7.28–7.34 (m, 4 H, **256-d** + **257-d**, Ar-H), 7.37–7.41 (m, 4 H, **256-d** + **257-d**, Ar-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 21.98, 27.82, 29.88, 32.61, 36.97, 38.57, 39.70, 39.75, 39.84, 40.23, 43.29, 44.82, 124.47, 124.57, 126.07, 126.27, 127.40, 128.58, 129.17, 132.69, 132.83, 137.55, 147.92, 148.32, 212.01, 212.47. – MS (70 eV), *m/z* (%): 255 (18), 254 (88) [M^+], 239 (23) [$M^+ - CH_3$], 197 (17), 183 (26), 169 (33), 155 (26), 141 (25), 128 (21), 115 (33), 105 (16), 91 (100) [$CHPh^+ + H$], 77 (19), 55 (16), 41 (20). – $C_{18}H_{22}O$: 254.1677 (correct HRMS).



(2,2-Dimethyl-5-oxo-cycloheptylidene)-acetonitrile (**256-e**) and (**257-e**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **255-e** (22.4 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (1.4 mg, 4.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 14 mg of **256-e** and 21 mg of **257-e** (99%, **256-e**:**257-e** = 2:3) as a colorless oil. – Data for **256-e**: IR (film): $\tilde{\nu}$ = 2965 cm^{-1} (C–H), 2920 (C–H), 2217 (C≡N), 1704 (C=O), 1614 (C=C), 1471, 1447, 1391, 1371, 1330, 1259, 1158, 1114, 1019, 980, 822. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.21 (s, 6 H, CH_3), 1.72–1.76 (m, 2 H, 3-H), 2.44–2.48 (m, 2 H, 2-H), 2.57–2.61 (m, 2 H, 6-H), 2.79–2.81 (m, 2 H, 7-H), 5.32 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 26.34 (C-6), 27.32 (*C*H_3), 36.29 (C-3), 39.26 (C-2), 40.68 (C-4), 41.82 (C-7), 96.01 (2C, C=*C*-H, C≡N), 173.95 (C-5), 210.39 (C-1). – MS (70 eV), *m/z* (%): 178 (3), 177 (18) [M^+], 162 (7) [$M^+ - CH_3$], 149 (6), 134 (8), 121 (25), 107 (35), 97 (39) [$C_6H_9O^+$], 93 (12), 91 (11), 79 (28) [$C_6H_7^+$], 68 (22), 55 (100). – $C_{11}H_{15}NO$: 177.1162 (correct HRMS). – Data for **257-e**: IR (film): $\tilde{\nu}$ = 2963 cm^{-1} (C–H), 2924 (C–H), 2214 (C≡N), 1704 (C=O), 1611 (C=C), 1470, 1446, 1395, 1369, 1341, 1260, 1156, 1116, 1013, 821. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.46 (s, 6 H, CH_3), 1.77–1.81 (m, 2 H, 3-H), 2.49–2.54 (m, 6 H, 2-H, 6-H, 7-H), 5.34 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = 27.90 (*C*H_3), 31.40 (C-6), 36.82 (C-3), 39.76 (C-2), 41.08 (C-4), 43.28 (C-7), 96.66 (2C, C=*C*-H, C≡N), 172.91 (C-5), 209.70 (C-1). – MS (70 eV), *m/z* (%): 178 (2), 177 (10) [M^+], 162 (6) [$M^+ - CH_3$], 149 (4), 134 (7), 121 (18), 120 (18), 107 (37), 97 (44) [$C_6H_9O^+$], 93 (10), 91 (10), 79 (22) [$C_6H_7^+$], 68 (22), 55 (100). – $C_{11}H_{15}NO$: 177.1149 (correct HRMS).

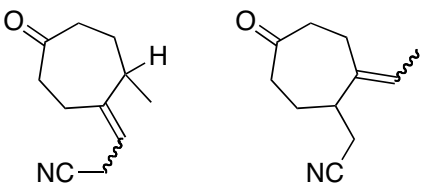


(2-Methyl-5-oxo-cycloheptylidene)-acetonitrile (**269-b**) and (**260-b**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **258-b** (19.0 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (50% Et_2O in pentane eluant) affording 17 mg (52%, **259-b**:**260-b** = 1:2) as a mixture of **259-b** and **260-b**, which were not separable by column chromatography, as a colorless oil. – Data for the mixture of **259-b** and **260-b**: IR (film): $\tilde{\nu}$ = 2921 cm^{-1} (C–H), 2252 (C≡N), 2217 (C≡N), 1703 (C=O), 1620 (C=C), 1463, 1379, 1340, 1259, 1142, 1035, 914, 881, 811, 734, 648. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.16 (d, ^3J = 6.8 Hz, 3 H, **259-b**, CH_3), 1.18 (d, ^3J = 7.2 Hz, 3 H, **260-b**, CH_3), 1.48–1.58 (m, 1 H, **259-b**, 3-H), 1.74–1.83 (m, 1 H, **260-b**, 3-H), 1.90–2.04 (m, 2 H, **259-b**, C-2, **260-b**, C-2), 2.32–2.43 (m, 3 H, **259-b**, C-2, **260-b**, C-2, C-6), 2.54–2.72 (m, 7 H, **259-b**, C-6, C-7, **260-b**, C-6, C-7), 2.82–2.90 (m, 1 H,**259-b**, C-4), 3.33–3.42 (m, 1 H, **260-b**, C-4), 5.23 (s, 1 H, **260-b**, vinyl-H), 5.24 (s, 1 H, **259-b**, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 18.79, 19.02, 27.68, 28.12, 28.31, 31.07, 38.42, 39.70, 40.88, 41.04, 41.68, 42.42, 95.68, 97.07, 116.09, 116.11, 170.97, 171.09, 210.63, 211.55. – MS (70 eV), *m/z* (%): 164 (5), 163 (60) [M^+], 135 (13) [$M^+ - C_2H_4$], 130 (16), 120 (17), 107 (24) [$M^+ - C_4H_8$], 106 (31), 79 (24) [$C_6H_7^+$], 65 (12), 55 (100) [$C_3H_3O^+$]. – $C_{10}H_{13}NO$: 163.0999 (correct HRMS).



(10-Oxo-spiro[5.6]dodec-7-ylidene)-acetonitrile (**259-c**) and (**260-c**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **258-c** (32.0 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (1.4 mg, 4.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (33% Et_2O in pentane eluant) affording 27 mg of **260-c** and 13 mg of **259-c** (99%, **259-c**:**260-c** = 2:5) as a colorless oil. – Data for **259-c**: IR (film): $\tilde{\nu}$ = 3076 cm^{-1} (C=C–H), 2931 (C–H), 2858 (C–H), 2216 (C≡N), 1704 (C=O), 1608 (C=C), 1456, 1330, 1258, 1194, 1157, 1085, 981, 918, 851, 817, 732. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.30–1.41 (m, 2 H, *c*Hex-H), 1.44–1.69 (m, 8 H, *c*Hex-H), 1.76–1.78 (m, 2 H, 3-H), 2.43–2.45 (m, 2 H, 2-H), 2.58–2.61 (m, 2 H, 6-H), 2.74–2.79 (m, 2 H, 7-H), 5.33 (s, 1 H, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 21.82 (*c*Hex-C), 25.78 (*c*Hex-C), 25.91 (*c*Hex-C), 32.54 (C-6), 34.60 (C-3), 38.44 (C-2), 41.69 (C-4), 43.33 (C-7), 96.63 (C≡N), 116.83 (vinyl-C), 173.77 (C-5), 211.02 (C-1).

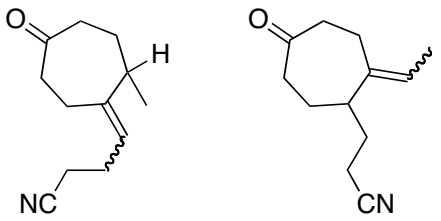
– MS (70 eV), *m/z* (%): 217 (35) [M^+], 188 (14) [$M^+ - C_2H_5$], 160 (24) [$M^+ - C_3H_5 - O$], 147 (13) $M^+ - C_5H_{10}$], 146 (17), 136 (96) [$M^+ - C_6H_9$], 132 (24), 119 (18), 118 (19), 109 (14) [$M^+ - C_5H_{10} - CHC{\equiv}N + H$], 105 (18), 96 (42), 91 (41), 82 (100) [$C_6H_{10}{}^+$], 79 (35), 77 (34), 67 (97) [$C_5H_7{}^+$]. – $C_{14}H_{19}NO$: 217.1462 (correct HRMS). – Data for **260-c**: IR (film): $\tilde{\nu} = 2931$ cm^{-1} (C–H), 2858 (C–H), 2215 (C≡N), 1704 (C=O), 1608 (C=C), 1456, 1330, 1259, 918, 816. – ^{1}H NMR (400 MHz, $CDCl_3$): $\delta =$ 1.44–1.61 (m, 6 H, *c*Hex-H), 1.62–1.65 (m, 2 H, *c*Hex-H), 1.88–1.92 (m, 2 H, *c*Hex-H), 2.18–2.22 (m, 2 H, C-3), 2.48–2.50 (m, 2 H, C-2), 2.51–2.55 (m, 4 H, C-6, C-7), 5.39 (s, 1 H, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 22.13$ (*c*Hex-C), 25.56 (*c*Hex-C), 30.25 (C-4), 30.94 (C-6), 34.86 (*c*Hex-C), 38.82 (C-3), 43.41 (C-2), 44.81 (C-7), 96.45 (C≡N), 117.14 (vinyl-C), 172.24 (C-5), 210.83 (C-1). – MS (70 eV), *m/z* (%): 217 (18) [M^+], 188 (10) [$M^+ - C_2H_5$], 160 (18) [$M^+ - C_3H_5 - O$], 147 (11) [$M^+ - C_5H_{10}$], 146 (13), 136 (68) [$M^+ - C_6H_9$], 132 (20), 119 (17), 109 (11), 105 (20), 96 (33), 91 (48), 82 (85) [$C_6H_{10}{}^+$], 77 (41), 67 (100) [$C_5H_7{}^+$]. – $C_{14}H_{19}NO$: 217.1469 (correct HRMS).



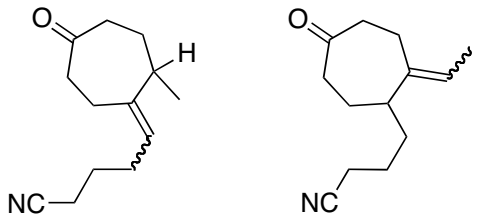
3-(2-Methyl-5-oxo-cycloheptylidene)-propionitrile (**264-1**)–(**267-1**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **263-1** (22.4 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (60% Et_2O in pentane eluant) affording 7 mg of **265-1** and 13 mg of a mixture of **264-1** and the two isomers of the *endo*-product (**266-1** and **267-1** (8%, 1:2 ratio) in total yield of 56% (ratio **265-1**:**264-1**, **266-1**, **267-1**, 1:1.4), which were not separable by column chromatography, as a colorless oil. – Data for **265-1**: IR (film): $\tilde{\nu} = 2960$ cm^{-1} (C–H), 2925 (C–H), 2871 (C–H), 2248 (C≡N), 2216, 1699 (C=O), 1456, 1339, 1260, 1140, 1104, 1030, 922, 877, 800. – ^{1}H NMR (400 MHz, $CDCl_3$): $\delta = 1.09$ (d, $^3J = 6.8$ Hz, 3 H, CH_3), 1.70–1.76 (m, 1 H, 3-H), 1.83–1.87 (m, 1 H, 3-H), 2.21–2.67 (m, 6 H, 2-H, 6-H, 7-H)), 2.87–2.96 (m, 1 H, 4-H), 3.11 (d, $^3J = 7.2$ Hz, 2 H, CH_2CN), 5.34 (t, $^3J = 7.2$ Hz, 1 H, vinyl-H). – ^{13}C NMR (100 MHz, $CDCl_3$): $\delta = 15.58$ (*C*H_2CN), 18.74 (*C*H_3), 27.73 (C-6), 28.61 (C-3), 33.93 (C-2), 40.18 (C-4), 43.74 (C-7), 88.01 (*C*≡N), 114.52 (vinyl-C), 149.42 (C-5), 212.12 (C-1). – MS (70 eV), *m/z* (%): 177 (16) [M^+], 149 (6) [$M^+ - C_2H_4$], 137 (14) [M^+ –

$CH_2C{\equiv}N$], 121 (15), 109 (33) [M^+ – $C_2H_2C{\equiv}N$ – CH_3], 107 (26), 93 (25), 79 (50) [$C_6H_7^+$], 77 (25), 67 (31), 65 (23), 55 (100) [$C_3H_3O^+$]. – $C_{10}H_{13}NO$: 177.1144 (correct HRMS). – Data for the mixture of **264-1**, **266-1**, **267-1**: IR (film): $\tilde{\nu}$ = 2957 cm^{-1} (C–H), 2925 (C–H), 2875 (C–H), 2248 (C≡N), 2215 (C≡N), 1703 (C=O), 1455, 1418, 1374, 1335, 1259, 1185, 1141, 1065, 1029, 984, 922, 880, 805. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.10 (d, ^3J = 6.8 Hz), 1.42–1.53 (m), 1.89–1.98 (m), 2.32–2.39 (m), 2.42–2.58 (m), 3.07 (dd, ^3J = 7.2 Hz, J=2.4 Hz), 5.32 (td, ^3J = 7.2 Hz, J=2.4 Hz). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 15.73, 19.43, 23.41, 31.77, 40.91, 41.42, 41.61, 112.74, 118.09, 149.13, 212.23. – MS (70 eV), *m/z* (%): 149 (9) [M^+ – C_2H_4], 132 (11), 120 (29), 109 (13) [M^+ – $C_2H_2C{\equiv}N$ – CH_3], 107 (12), 93 (27), 79 (43) [$C_6H_7^+$], 77 (40), 67 (41), 65 (29), 57 (100) [$C_4H_9^+$], 55 (72) [$C_3H_3O^+$]. – $C_{10}H_{13}NO$: 177.24.

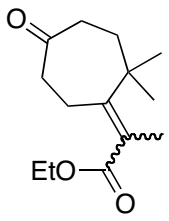
4-(2-Methyl-5-oxo-cycloheptylidene)-butyronitrile (**264-2**)–(**265-2**) and *3-(2-ethylidene-5-oxo-cycloheptyl)-propionitrile* (**266-2**)–(**267-2**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **263-2** (25.7 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (60% Et_2O in pentane eluant) affording 22 mg (58%) of a mixture of all isomers as a colorless oil. – Data for the mixture of **264-2**–**267-2**: IR (film): $\tilde{\nu}$ = 2960 cm^{-1} (C–H), 2924 (C–H), 2871 (C–H), 2245 (C≡N), 1700 (C=O), 1442, 1373, 1338, 1260, 1184, 1160, 1138, 1072, 1019, 880, 851, 801, 647. – ^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.05 (d, ^3J = 7.2 Hz), 1.08 (d, ^3J = 6.8 Hz), 1.11 (d, ^3J = 7.2 Hz), 1.41–1.49 (m), 1.63–1.94 (m), 2.00–2.66 (m), 2.95 (sex, ^3J = 6.8 Hz), 3.05 (d, ^3J = 6.0 Hz), 3.09 (d, ^3J = 6.8 Hz), 3.23 (d, ^3J = 6.4 Hz), 3.27 (d, ^3J = 6.4 Hz), 5.26 (q, ^3J = 6.4 Hz), 5.31 (t, ^3J = 6.4 Hz), 5.45 (q, ^3J = 6.4 Hz). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 16.61, 16.73, 17.57, 17.67, 18.64, 19.40, 19.65, 20.63, 23.13, 23.19, 23.35, 23.97, 24.00, 27.88, 28.30, 28.94, 29.32, 29.63, 30.67, 32.00, 33.60, 33.66, 35.59, 36.66, 40.28, 40.96, 41.79, 41.92, 42.06, 42.25, 42.81, 44.24, 119.27, 119.59, 120.93, 120.97, 131.99, 132.94, 144.36, 146.05, 146.34, 213.15. – MS (70 eV), *m/z* (%): 192 (7), 191 (36) [M^+], 176 (18) [M^+ – CH_3], 163 (40) [M^+ – C_2H_4], 151 (11) [M^+ – $CH_2C{\equiv}N$], 148 (23), 136 (25), 134 (47), 123 (53) [M^+ – $C_3H_5C{\equiv}N$], 109 (31) [M^+ – $C_3H_5C{\equiv}N$ – CH_3], 107 (29), 95 (63), 81 (75), 79 (84) [$C_6H_7^+$], 77 (54), 67 (76),



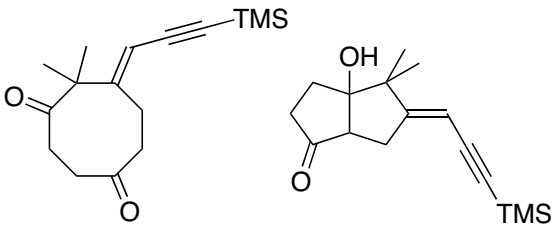
65 (33), 55 (60) [$C_3H_3O^+$]. – $C_{12}H_{17}NO$: 191.1314 (correct HRMS).



5-(2-Methyl-5-oxo-cycloheptylidene)-pentanenitrile (**264-3**)–(**265-3**) and *4-(2-ethylidene-5-oxo-cycloheptyl)-butyronitrile* (**266-3**)–(**267-3**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **263-3** (29.3 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (0.7 mg, 2.00 μmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (60% Et_2O in pentane eluant) affording 24 mg (58%) of a inseparable mixture of all isomers as a colorless oil. – Data for the mixture of**264-3**–**267-3**: IR (film): $\tilde{\nu}$ = 2933 cm^{-1} (C–H), 2868 (C–H), 2246 (C≡N), 1705 (C=O), 1462, 1456, 1428, 1374, 1337, 1258, 1211, 1157, 1136, 1107, 1079, 1032, 968, 909, 879, 820, 803, 751. –^{1}H NMR (400 MHz, $CDCl_3$): δ = 1.03 (d, ^3J = 6.8 Hz), 1.06 (d, ^3J = 6.8 Hz), 1.09 (d, ^3J = 7.2 Hz), 1.41–2.67 (m), 2.93–2.97 (m), 3.01 (d, ^3J = 6.0 Hz), 3.05 (d, ^3J = 6.4 Hz), 3.23 (d, ^3J = 6.0 Hz), 3.27 (d, ^3J = 6.4 Hz), 5.18 (q, ^3J = 6.4 Hz), 5.27 (t, ^3J = 6.0 Hz). – ^{13}C NMR (100 MHz, $CDCl_3$): δ = 16.48, 16.54, 17.03, 17.08, 18.68, 19.36, 19.75, 20.55, 23.08, 24.92, 25.11, 25.34, 25.86, 26.10, 27.24, 27.31, 27.81, 28.44, 29.10, 29.47, 29.63, 30.65, 32.28, 33.49, 34.09, 36.03, 36.60, 40.21, 40.49, 41.01, 41.87, 41.91, 42.17, 42.36, 42.94, 44.02, 114.90, 119.56, 131.47, 133.32, 144.53, 144.55, 145.58, 210.07, 212.56. – MS (70 eV), *m/z* (%): 206 (12), 205 (65) [M^+], 190 (16) [$M^+ - CH_3$], 177 (33) [$M^+ - C_2H_4$], 162 (20), 150 (16), 137 (40) [$M^+ - C_3H_6C{\equiv}N$], 134 (29), 124 (42) [$M^+ - C_4H_7C{\equiv}N$], 123 (100) [$M^+ - C_4H_7C{\equiv}N - H$], 119 (35), 109 (30) [$M^+ - C_4H_7C{\equiv}N - CH_3$], 107 (34), 95 (77), 93 (53), 81 (84), 79 (66) [$C_6H_7^+$], 77 (40), 67 (76), 65 (21), 55 (72) [$C_3H_3O^+$]. – $C_{13}H_{19}NO$: 205.1461 (correct HRMS).



2-(2,2-Dimethyl-5-oxo-cycloheptylidene)-propionic acid ethyl ester (**256-f**) According to GP 6, vinylcyclopropane **42** (28.4 mg, 200 μmol), allene **255-f** (37.0 mg, 240 μmol) and $[Rh(CO)_2Cl]_2$ (3.9 mg, 0.01 mmol) were allowed to react in DCE (1 mL). The crude mixture was purified by flash column chromatography (30% Et_2O in pentane eluant) affording 5 mg of the product (12%) as a colorless oil. – IR (film): $\tilde{\nu} = 2923$ cm^{-1} (C–H), 2853 (C–H), 1713 (C=O), 1682 (C=O), 1616 (C=C), 1462, 1404, 1377, 1261, 1200, 1101, 1064, 990, 968, 800. – ^{1}H NMR (500 MHz, $CDCl_3$): $\delta = 1.20$ (s, 3 H, C=C-CH_3), 1.30 (s, 6 H, CH_3), 1.31 (t, $^3J = 9.5$ Hz, 3 H, $CO_2CH_2CH_3$), 1.71–1.76 (m, 1 H, 3-H), 1.77–1.82 (m, 1 H, 3-H), 2.37–2.45 (m, 3 H, 2-H, 6-H), 2.48–2.2.54 (m, 2 H, 6-H, 7-H), 2.60–2.66 (m, 1 H, 7-H), 4.20 (q, $^3J = 9.5$ Hz, 2 H, $CO_2CH_2CH_3$). – MS (70 eV), *m/z* (%): 238 (13) [M^+], 223 (20) [$M^+ - CH_3$], 193 (47) [$M^+ - OC_2H_5$], 181 (43), 168 (31), 154 (47), 137 (21) [$M^+ - C_2H_3CO_2C_2H_5$], 135 (25), 125 (25),109 (21) [$M^+ - C_2H_3CO_2C_2H_5 - 2\ CH_3$], 107 (37), 95 (32), 93 (39), 81 (41), 79 (38) [$C_6H_7^+$], 77 (34), 71 (38), 69 (50), 67 (47), 59 (63), 55 (85) [$C_3H_3O^+$], 41 (100) [$OC_2H_5^+$]. – $C_{14}H_{22}O_3$: 238.1469 (correct HRMS).



5,5-Dimethyl-6-[3-(trimethyl-silanyl)-prop-2-ynylidene]-cyclooctane-1,4-dione (**277**) and *3a-Hydroxy-4,4-dimethyl-5-[3-(trimethyl-silanyl)-prop-2-ynylidene]-hexahydro-pentalen-1-one* (**278**) An oven dried, septum capped, 16 x 100 mm, disposable, borosilicate glass test tube, under a positive pressure of CO, was charged with $[Rh(CO)_2Cl]_2$ (1.9 mg, 5.00 μmol) and DCE (1 mL). To this was added vinylcyclopropane **42** (28.4 mg, 200 mmol), followed by the addition of allenyne **245-a** (39.4 mg, 240 μmol). The test tube was placed in an oil bath preheated to 80 °C. The reaction was done after 2 h, allowed to cool to rt and treated with 1% HCl in EtOH (0.2 mL) followed by stirring open to the atmosphere for 30 min. The crude mixture was purified by flash column chromatography (33% Et_2O in pentane eluant) affording 11 mg of **277** and 24 mg of **278** (62%, **277**:**278** = 1:2.2) as a colorless oil. – Data for **277**: IR (film): $\tilde{\nu}$ = 2962 cm^{-1} (C–H), 2929 (C–H), 2903 (C–H), 2163 (C≡C), 2132, 1704 (C=O), 1698 (C=C), 1458, 1445, 1422, 1367, 1346, 1304, 1250, 1176, 1131, 1074, 1044, 1030, 1001, 913, 845, 761, 701, 646. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.14 (s, 9 H, Si(CH_3)$_3$), 1.19 (s, 6 H, CH_3), 1.82–1.84 (m, 2 H, 2-H), 2.42–2.45 (m, 2 H, 3-H), 2.59–2.62 (m, 2 H, 7-H), 3.05–3.09 (m, 2 H, 8-H) 5.56 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = –0.42 [Si(CH$_3$)$_3$], 27.56 (CH$_3$), 35.72 (C-2), 36.35 (C-7), 38.91 (C-5), 42.06 (C-3), 43.14 (C-8), 100.59 (C≡C), 103.07 (C≡C), 108.86 (vinyl-C), 161.96 (C-6), 208.80 (C-1), 211.91 (C-4). – MS (70 eV), *m/z* (%): 276 (15) [M^+], 261 (17) [M^+ – CH_3], 248 (48) [M^+ – 2 CH_3 + 2 H], 219 (14), 205 (27), 163 (65) [M^+ – $C_6H_9O_2$], 130 (31), 119 (100), 97 (28), 91 (21), 85 (37), 83 (31), 75 (62), 73 (99) [$Si(CH_3)_3^+$], 71 (54), 57 (80). – $C_{16}H_{24}O_2Si$: 276.1554 (correct HRMS). – Data for **278**: IR (film): $\tilde{\nu}$ = 3419 cm^{-1} (O–H), 2959 (C–H), 2901 (C–H), 2869 (C–H), 2131 (C–H), 1739 (C=O), 1732 (C=O), 1463, 1445, 1404, 1385, 1364, 1281, 1251, 1173, 1119, 1085, 1054, 964, 902, 843, 756, 736, 670, 643. – ^{1}H NMR (500 MHz, $CDCl_3$): δ = –0.18 (s, 9 H, Si(CH_3)$_3$), 1.44 (s, 6 H, CH_3), 1.49–1.58 (m, 1H, 6-H), 1.83–1.92 (m, 1H, 6-H), 1.98 (bs, 1 H, OH), 2.00–2.16 (m, 2 H, 3-H), 2.35–2.45 (m, 1 H, 2-H), 2.51–2.64 (m, 2 H, 2-H, 6a-H), 5.55 (s, 1 H, vinyl-H). – ^{13}C NMR (125 MHz, $CDCl_3$): δ = –0.33 [Si(CH$_3$)$_3$], 27.10 (CH$_3$), 27.18 (CH$_3$), 34.85 (C-3), 37.15 (C-2), 40.92 (C-6), 43.42 (C-4), 58.44 (C-6a), 88.81 (C-3a), 101.32 (C≡C), 102.35 (vinyl-C), 102.95 (C≡C), 169.89 (C-5), 218.49 (C-1). – MS (70 eV), *m/z* (%): 276 (6) [M^+],

261 (15) [$M^+ - CH_3$], 247 (19) [$M^+ - 2\ CH_3 + H$], 220 (61), 205 (35), 163 (11), 130 (31), 119 (14), 91 (27), 83 (13), 75 (63), 73 (100) [$Si(CH_3)_3^+$], 57 (35). – $C_{16}H_{24}O_2Si$: 276.1554 (correct HRMS).

D. Conclusion and Outlook

The first part of this thesis dealt with the a new kind of precursors for transition metal-catalyzed cocyclization reactions containing a vinylbicyclopropyl unit, their synthesis and their behavior in cocyclization reactions. By introducing a second cyclopropane the catalyst might open this ring as well after insertion into the first cyclopropane ring. The 'basic' formal [5 + 2] cycloaddition reaction would be extended to a [5 + 2 + 3] cocyclization reaction to form ten-membered rings. In addition to the importance as a new synthetic tool valuable insights into the mechanism of transition metal-catalyzed cocyclization reactions of vinylcyclopropanes are gained.

A 1st-generation-precursor was designed by bringing in a second cyclopropyl substituent at the 2-position of the vinylcyclopropane. Bicyclopropylidenemethanol, prepared in two steps from bicyclopropylidene forms a starting point to make alcohol **90** by the BIRCH reduction in 84% yield. Oxidation according to the SWERN or DESS-MARTIN protocol gave aldehyde **112**, which was transformed by the HORNER-WADSWORTH-EMMONS reaction to the esters **113-H** and **113-Me**. Subsequent reduction with $LiAlH_4$ gave **114** in an overall yield of 75 to 79% (three steps). Another approach started from the vinylcyclopropane **118**, which was converted to alcohol **90** by cyclopropanation.

It is also possible to cyclopropanate the boronic ester **107** and to obtain alcohol **114-H** via the SUZUKI coupling with the THP-protected bromide **109** and subsequent deprotection in 35% yield starting from commercially available starting materials.

Finally, palladium catalyzed coupling with a 2-but-2-ynyl-malonic acid dimethyl ester respectively ether coupling with propargyl bromid gave the precursers **121** (59-66%) and **116** (54-64%).

All precursors were employed in an array of transition metal-catalyzed cocyclization reactions. The best results were obtained with $[(C_{10}H_8)Rh(COD)]SbF_6$ in DCE. Precursor **116-H** and **121-H** were smoothly converted to the cycloadducts **122** (90%) and **123** (67%) at room temperature while precursor **121-Me** showed no reaction even at elevated temperature (70°C). Precursor **116-Me** gave a different compound

to which a specific structure could not be assigned yet. [CpRu($CH_3CN)_3$] can also be used as a catalyst, but palladium and iridium, which are also known to react with vinylcyclopropanes, showed no conversion. A thorough mechanistic analysis elucidated the opening of the less substituted bond which positions the metal in a 'homocyclopropylmethyl' position to the second cyclopropane rendering the following insertion into the ring less favorable.

Considering these results, a 2nd-generation-precursor **157** was constructed, which includes a third cyclopropane ring attached to the 3-position of the vinylcyclopropane moiety. The *trans* configuration of the two cyclopropanes attached to the vinylcyclopropane was chosen on the basis of the least possible steric interaction of these cyclopropane rings with the catalyst in the proposed transition state. The synthesis started from *cis*-bicyclopropylethylene (**149-*c*Pr**). Cyclopropanation with diazoacetic acid ethyl ester gave the two diastereomers **150** in 55% yield (ratio 1:1), which were easily separated by column chromatography. Now, **150** was transformed in the same way as the 1st-generation-precursor: Reduction to alcohol **151**, followed by the DESS-MARTIN oxidation to aldehyde **152** and the HORNER-WADSWORTH-EMMONS reaction gave ester **153** in 82% from **150**. The precursor **157** was then obtained by reduction with DIBALH of **153** to alcohol **154**, acetalization and coupling with 2-prop-2-ynylmalonic acid dimethyl ester (three steps, 35%).
Under the catalysis of [($C_{10}H_8$)Rh(COD)]SbF_6 in DCE, the [5 + 2] cycloadduct **158** was obtained in 80% yield, but with the two cyclopropane rings still intact. With other Rh-catalysts only decomposition was observed, although in the course of the reaction one of the two cyclopropane rings of the 2nd-generation-precursor **157** has to end up in an cyclopropylmethyl position to the metal. Due to the fact that no insertion occurred, the special properties of the vinylcyclopropane as a whole unit seems to be essential for an insertion or the reductive elimination is more favored.

A 3rd-generation-precursor was planned with both cyclopropane rings adjacent to the double bond. With this arrangement, both rings may experience the effects of the vinylic double bond which could enable a ring expansion.
The syntheses of these 3rd-generation-precursors for an intramolecular cocyclization were achieved by different strategies: The WITTIG reaction of aldehyde ***cis*-103** with phosphonium salt **178** and subsequent reduction with DIBALH furnished alcohol **179** in an *E*:*Z* ratio of 1:2.4 in 29% overall yield. The selective preparation of the *E*-isomer was achieved by regioselective cyclopropanation of dienol **188**, obtained from

the HORNER-WADSWORTH-EMMONS reaction of cyclopropylcarboxaldehyde (**184**) and the phosphonic acid diethyl ester **183**. This strategy was also applied to the preparation of the analogous 1-substituted alcohol **191**. The method of choice to acquire *cis* or *trans* configuration selectively at the internal cyclopropane ring is the SUZUKI coupling of boronic ester **107**, and *cis*- or *trans*-2-iodocyclopropylmethanol **198**, respectively. The synthesis of the precursors **208**, **209**, ***E*-208**, ***E*-209** and **210** was then finished by ether coupling with 1-bromo-2-butyne.
Unfortunately, none of those precursors gave the desired ten-membered cycloadduct. In most cases it was possible to re-isolate starting material. These results may be rationalized by steric interactions for the *Z*-configured precursors **208** and **209**: In the s-*cis* confirmation of the vinylcyclopropane necessary for an insertion the double bond is blocked for coordination of the catalyst by the second cyclopropane ring. Another reason may be inappropriate electronic properties which result from hyper-conjugation and I-effects of the cyclopropane ring. The most plausible assumption could be the higher rigidity of the 3rd-generation-precursors. Simultaneous coordination of the catalyst to the vinylcyclopropane and the alkyne in precursors **208**-**210** is hardly possible.
Additionally, 3rd-generation-precursors **206** and**207** were tested in an intermolecular cocyclization reaction. They were assembled by the WITTIG reaction from the 1-substituted cyclopropylcarboxaldehyde **185** and the phosphonium salt **178** or via the MCMURRY coupling of **185**. However, both precursors showed no reaction with various alkynes.

A 4th-generation-precursor **230** was made from **225** in the same way as described for the 1st-generation-precursor to test the influence of a cyclopropane ring in 1-position. The cocyclization reaction with $[(C_{10}H_8)Rh(COD)]SbF_6$ in DCE gave the $[5+2]$ cycloadduct **231** in 75% yield. It can be reacted with propionic acid methyl ester in an intramolecular formal $[5+2]$ cycloaddition reaction to form **232**. These two steps can be combined in one pot to yield the tricyclic system **232** in 76%. Unfortunately it has not been possible yet to use other alkynes, which remains a goal for future works.
The intermolecular formal $[5+2]$ cycloaddition of the alcohol **228**, an intermediate in the synthesis of the intramolecular precursor was subjected to the cocyclization as well. The $[5+2]$ cycloadduct **235** was obtained in 68% yield, yet an extension to a double $[5+2]$ cocyclization has not be achieved and continues to be a research target.

By starting the synthesis from bicyclopropylidenecarboxaldehyde (**240**), a 5th-generation-precursor **243** was created. The desired cocyclization reaction would have led to cyclopropylmethylenecyclohexadienes, which could have been used for further transformations. However, no conversion was observed at room temperature with $[(C_{10}H_8)Rh(COD)]SbF_6$ in DCE. Upon heating the reaction to 70 °C decomposition of the starting material was observed.

In conclusion, the development of a variety of cyclopropyl substituted precursors and their use in transition metal-catalyzed cocyclization reactions was demonstrated. The results reveal a steric sensitivity, which can be concluded from the fact that precursors **116-Me** and **121-Me** and all 3rd-generation-precursors **208**-**210** did not show the desired cocyclization reaction.
The mechanism does probably not involve a metallacyclopentene with the metal in a cyclopropylmethyl position as a predominant intermediate, in which the catalyst could insert in the further course of the reaction, but requires the vinylcyclopropane unit as a whole for a successful insertion. Therefore, additional cyclopropanes remain untouched.
Starting from a 4th-generation-precursor gives access to structurally interesting tricyclo[8.5.0.$0^{0,0}$]pentadecane frameworks via a new intramolecular and a subsequent second intermolecular [5 + 2] cocyclization reaction cascade carried out in one pot in 76% yield.

In the second part of this thesis the formal [5 + 2] cycloaddition reaction of vinylcyclopropane **42** with allenes was investigated. Very good results were obtained with coordinating groups, like allenynes **245-a**–**j**, -enes **255-d**, and nitriles **255-e**, **258-b**–**c**. The yields of a variety of substrates range from 22 up to 99%. Various substituents are tolerated with the limitation that no terminal allene and alkyne can be used. The latter might form a stable complex with the metal catalyst leaving the starting material unchanged.
The *E*:*Z* ratio of isomers is kinetically controlled and probably dependent on the steric environment at the catalyst. Interestingly, the coordination group (C≡C, C=C, C≡N) does not have to be in conjugation to the allene moiety. Other allenes without coordinating groups as for instance allenoester **255-f** or phenylallene **255-a**, reacted only with an stoichometric amount of catalyst. All attempts to mimic the coordination group by adding an external nitrile resulted only in a minimal increase in yield. Furthermore, numerous alkenes were assayed without success.

In an atmosphere of CO allenynes react with vinylcyclopropane **42** in a [5 + 2 + 1] cocyclization reaction to yield the cyclooctadienone **277** and the bicyclo[3.3.0]octane system **278**. Noteworthy in this case is that no activating group like a carbonyl is necessary for the reaction. By increasing the CO pressure to 2 atm, the total yield went up to 94%. This increase in yield had to be paid with a longer reaction time and led to a higher amount of the eight membered ring product **277**.

These experiments represent the first transition metal-catalyzed intermolecular [5 + 2] cocyclization reaction of vinylcyclopropanes with allenes. It allows the preparation of methylenecycloheptenes in a very efficient way and includes the advantage of the possibility of further elaborations of the alkenyne moiety.

Application of this methodology in the synthesis of pharmacological active compounds may be another future goal.

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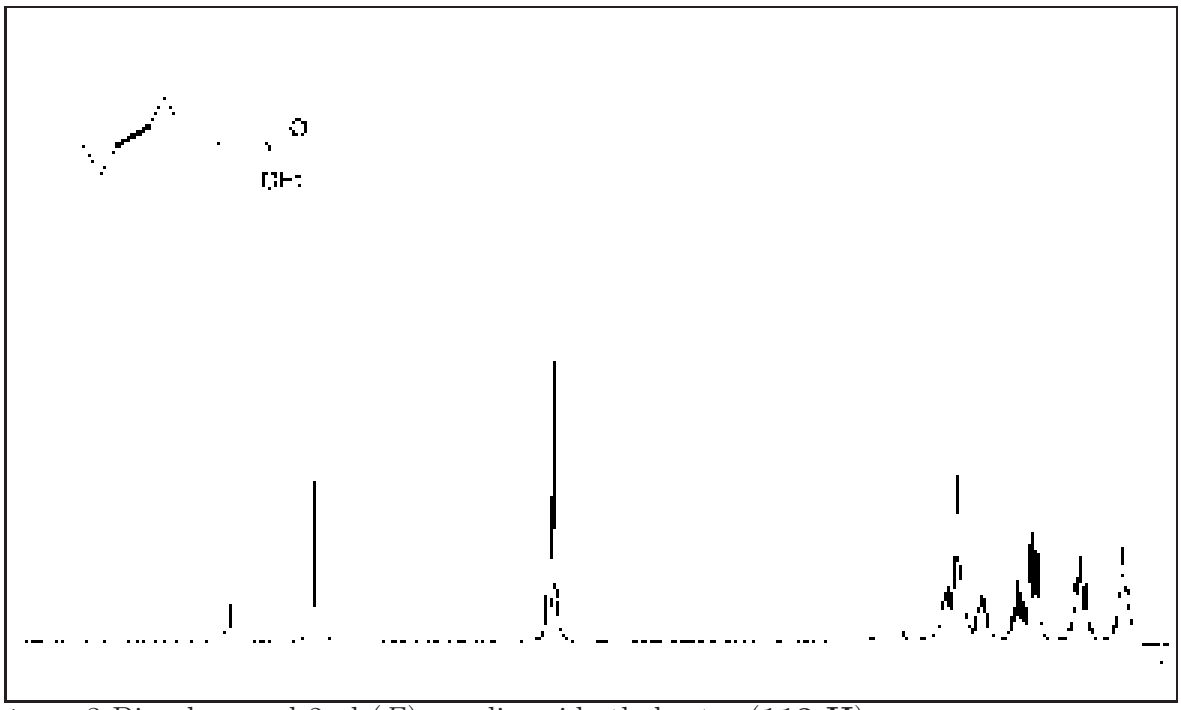
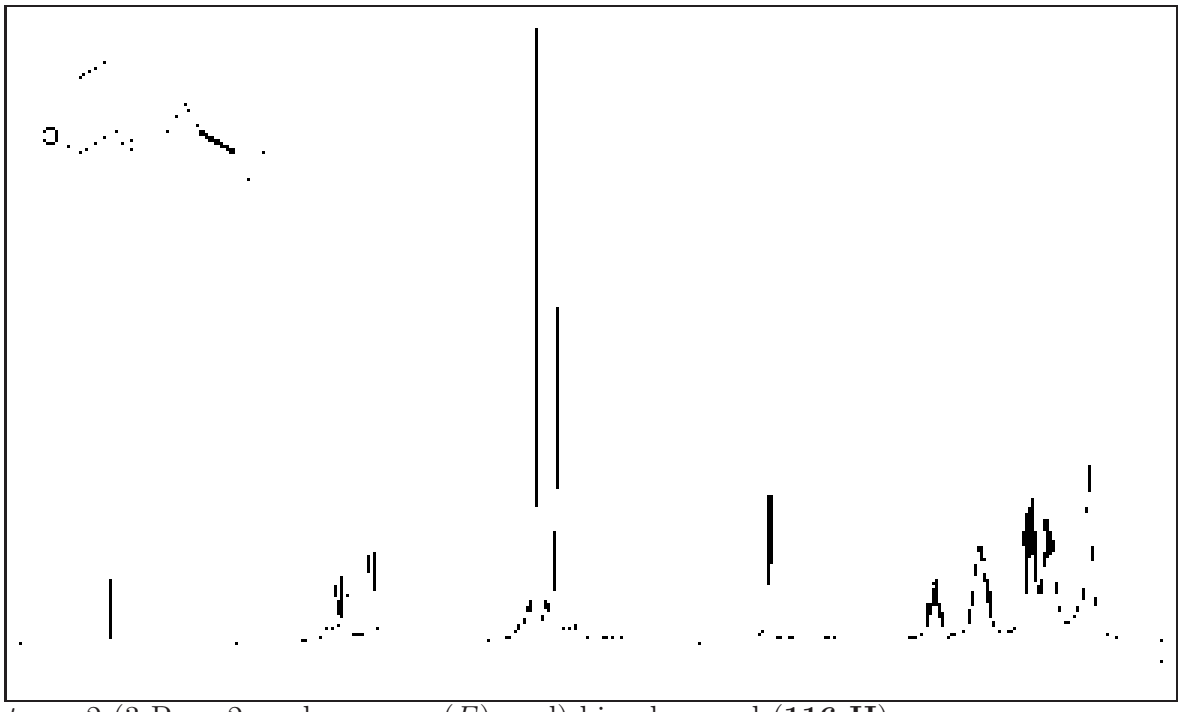
F. Spektra

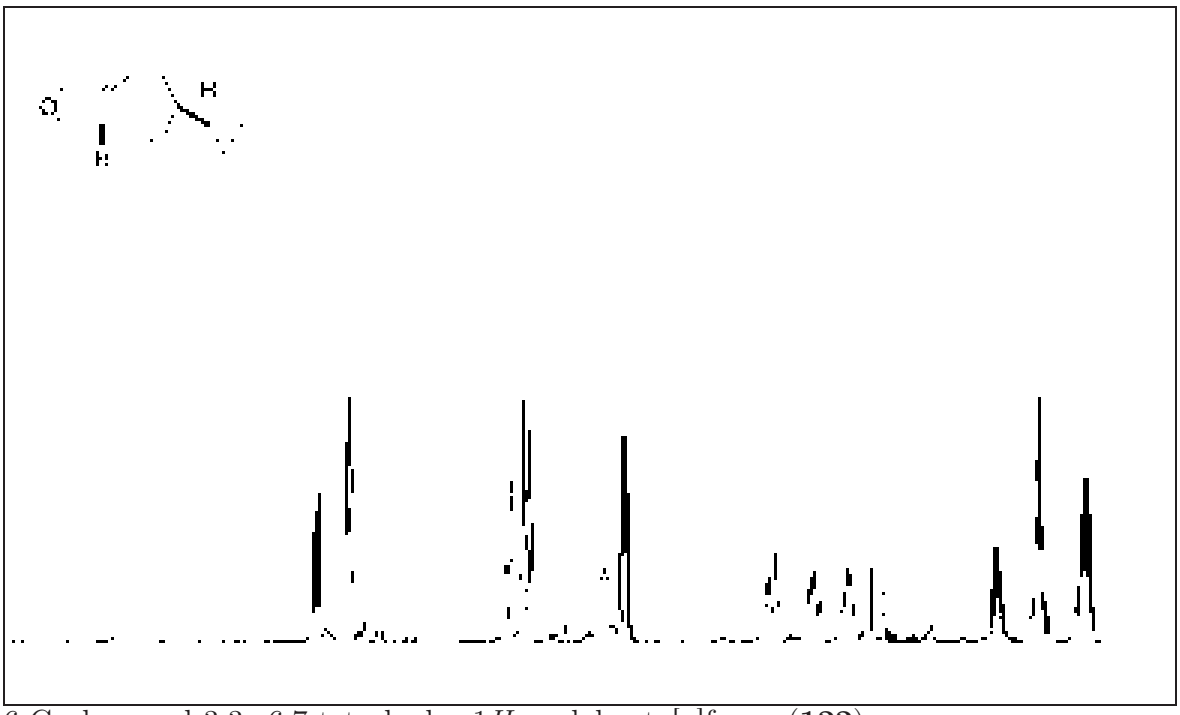
1. ^{1}H-NMR-Spectra



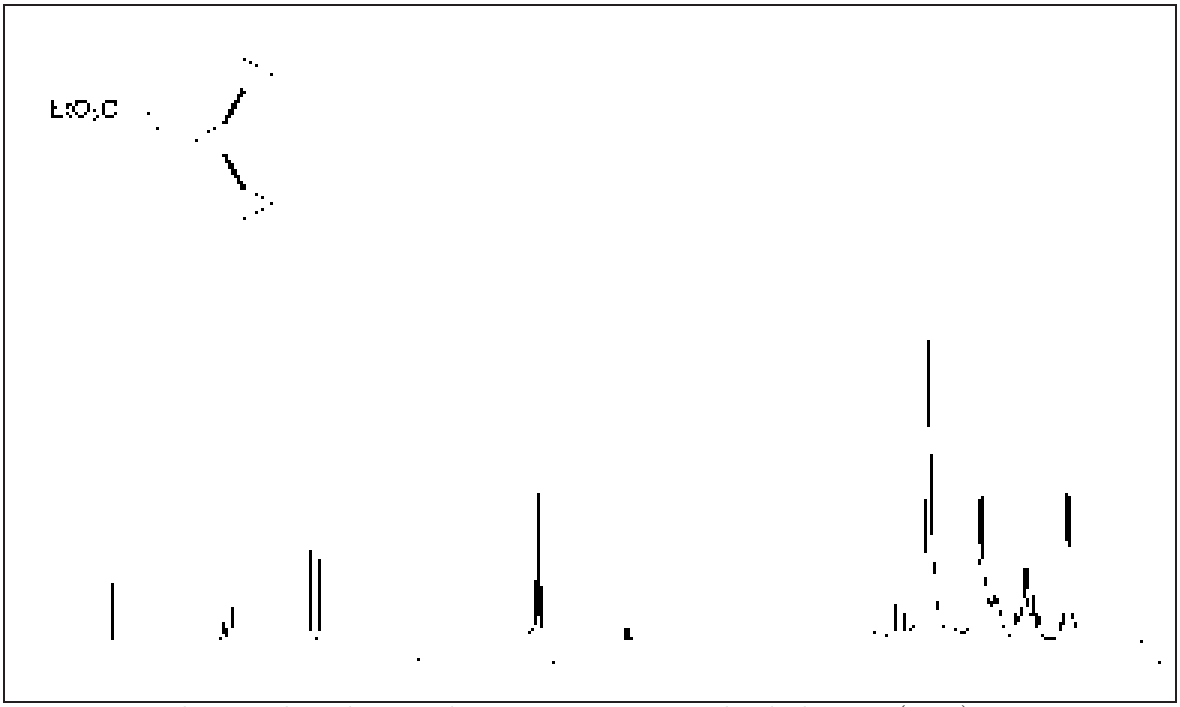
trans-3-Bicyclopropyl-2-yl-(*E*)-acrylic acid ethyl ester (**113-H**)



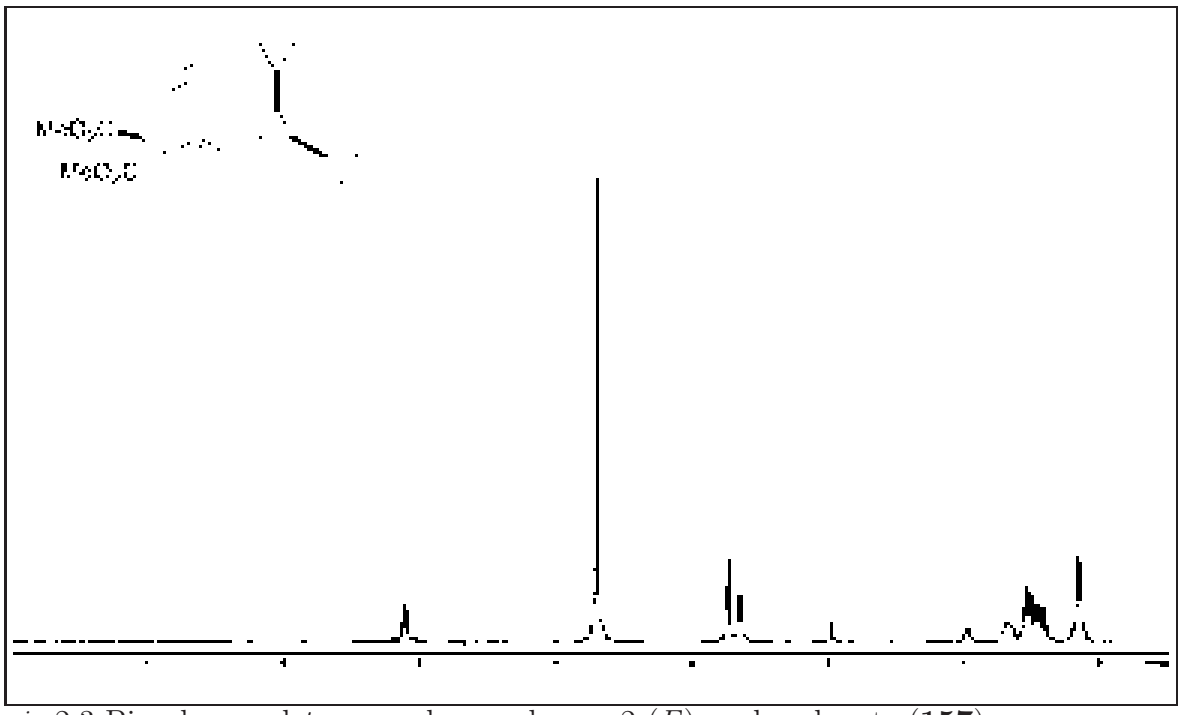
trans-2-(3-Prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl (**116-H**)



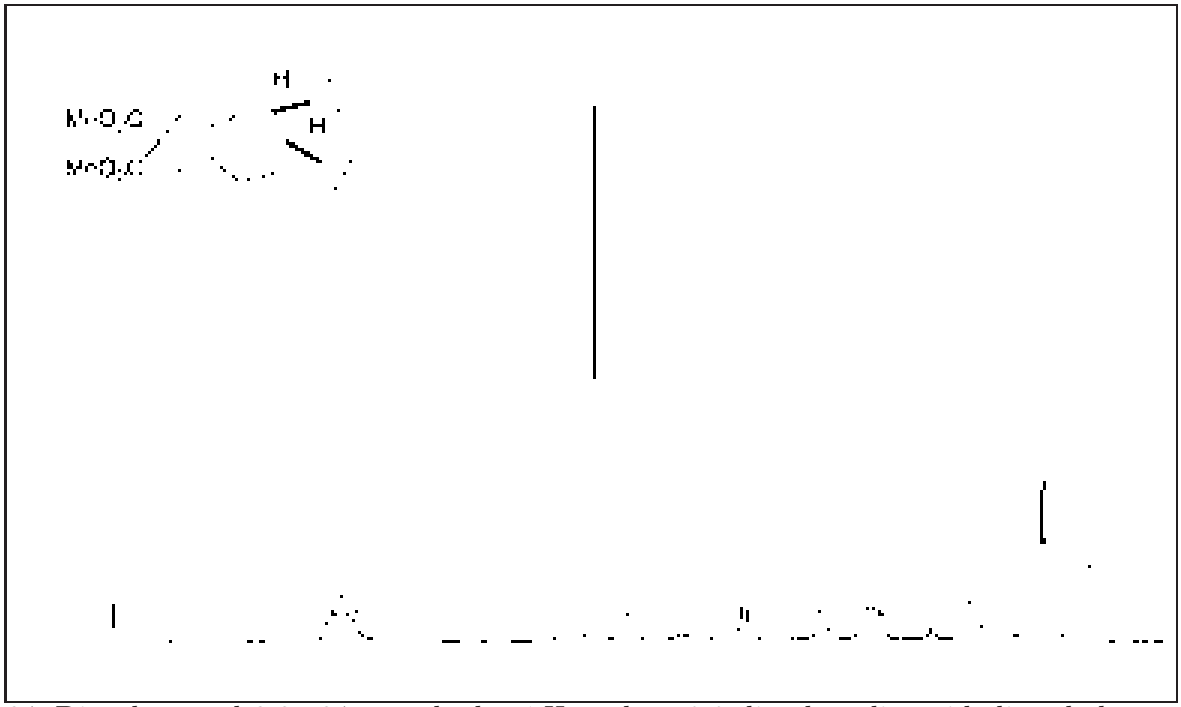
6-Cyclopropyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan (**122**)



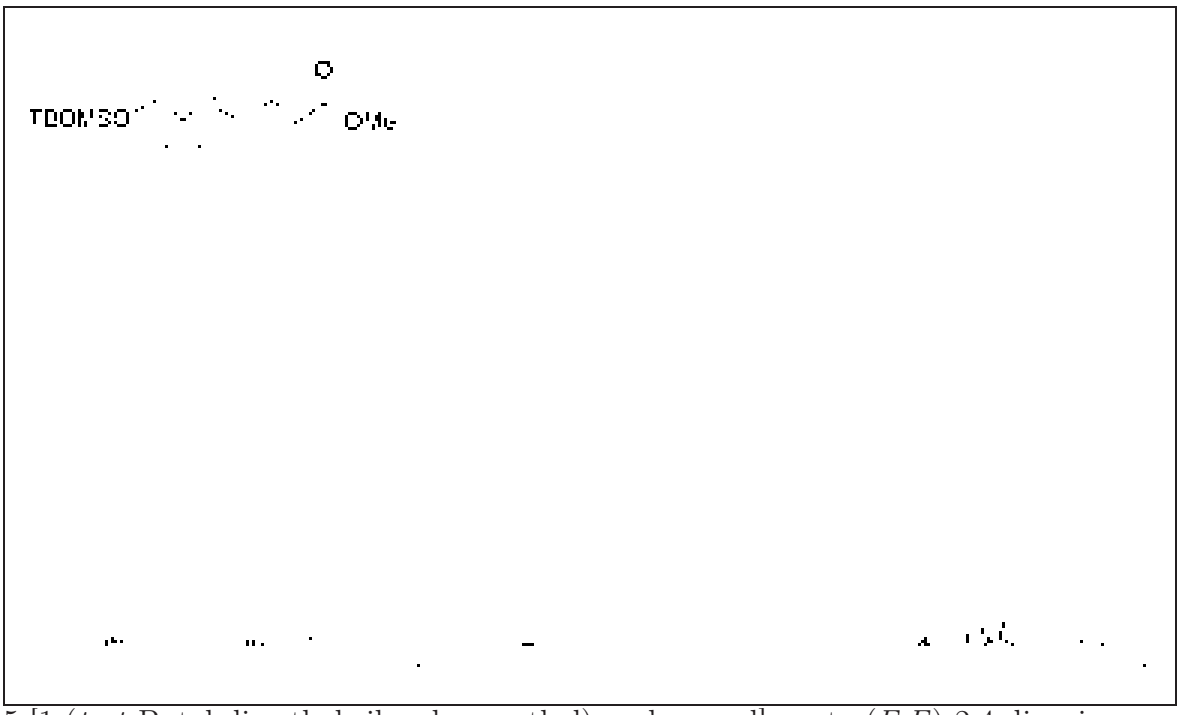
cis-2,3-Dicyclopropyl-cyclopropyl-*trans*-propenic acid ethyl ester (**153**)



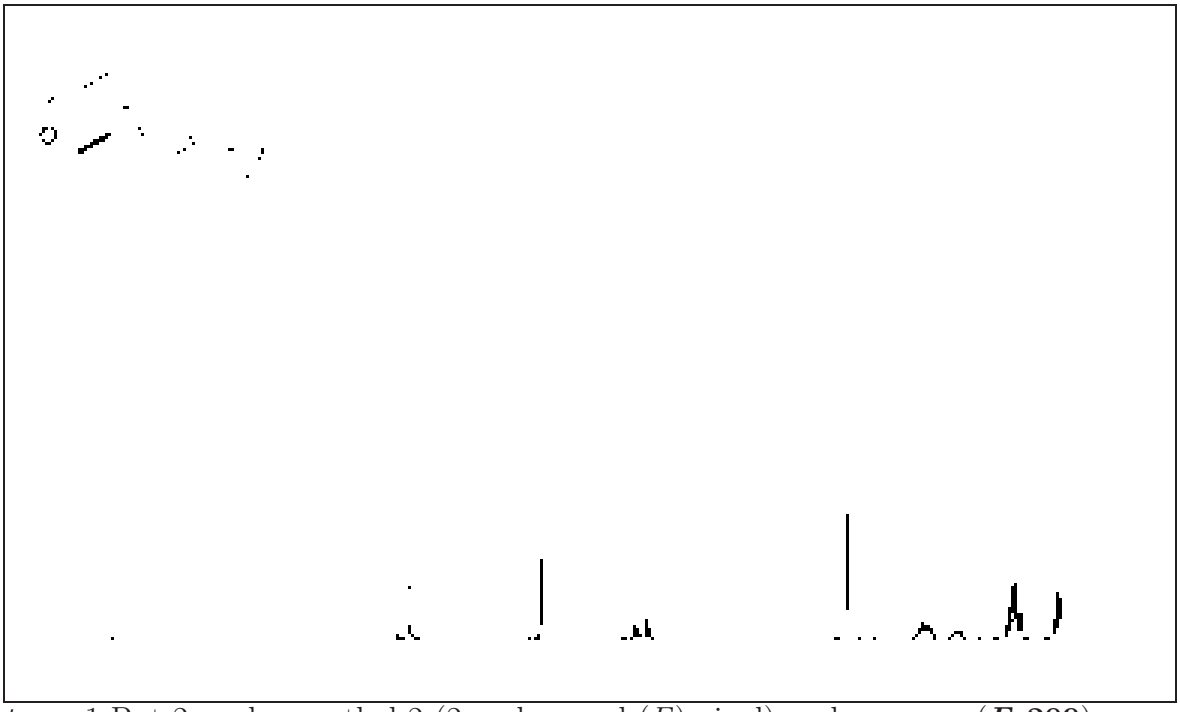
cis-2,3-Bicyclopropyl-*trans*-cyclopropyl-prop-2-(*E*)-enol-malonate (**157**)



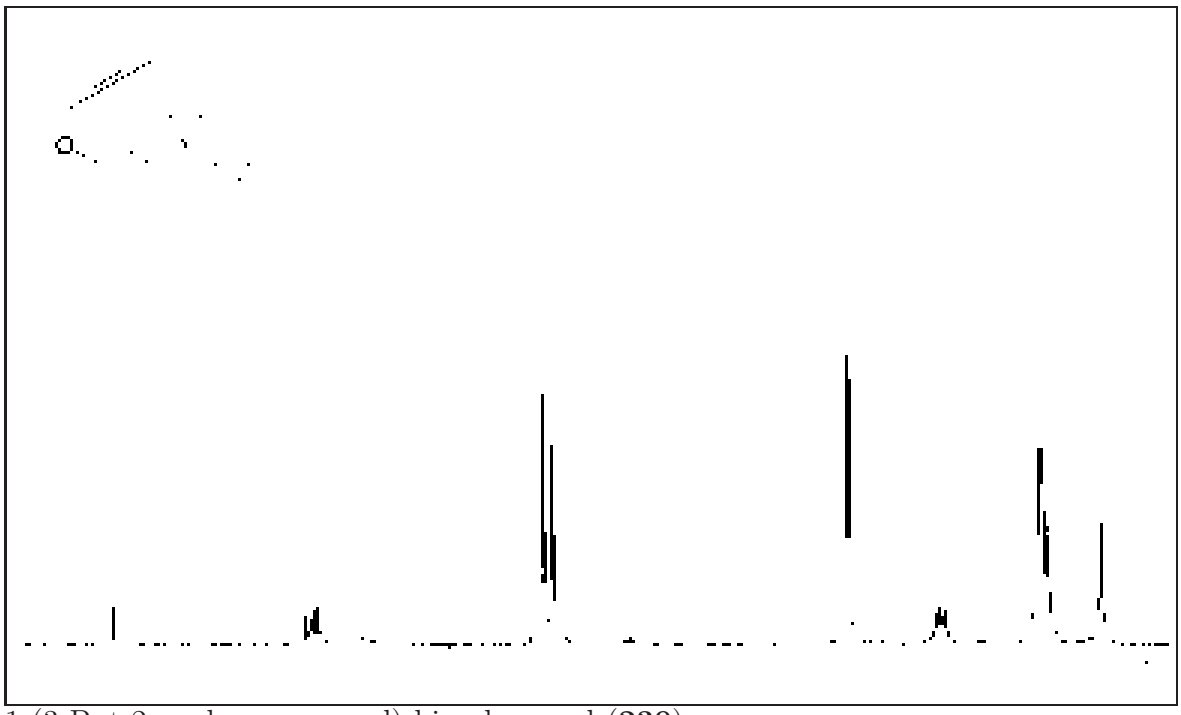
6,7-Dicyclopropyl-3,3a,6,7-tetrahydro-1*H*-azulene-2,2-dicarboxylic acid dimethyl ester (**158**)



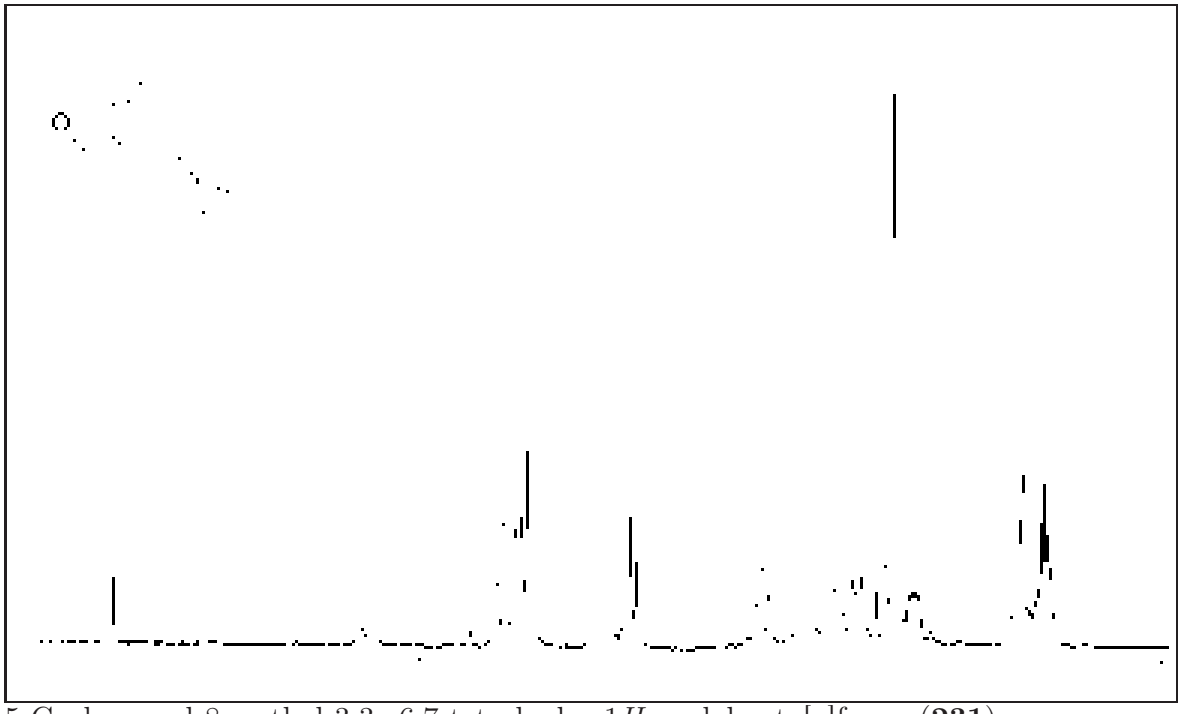
5-[1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-(*E,E*)-2,4-dienoic acid methyl ester (**187**)



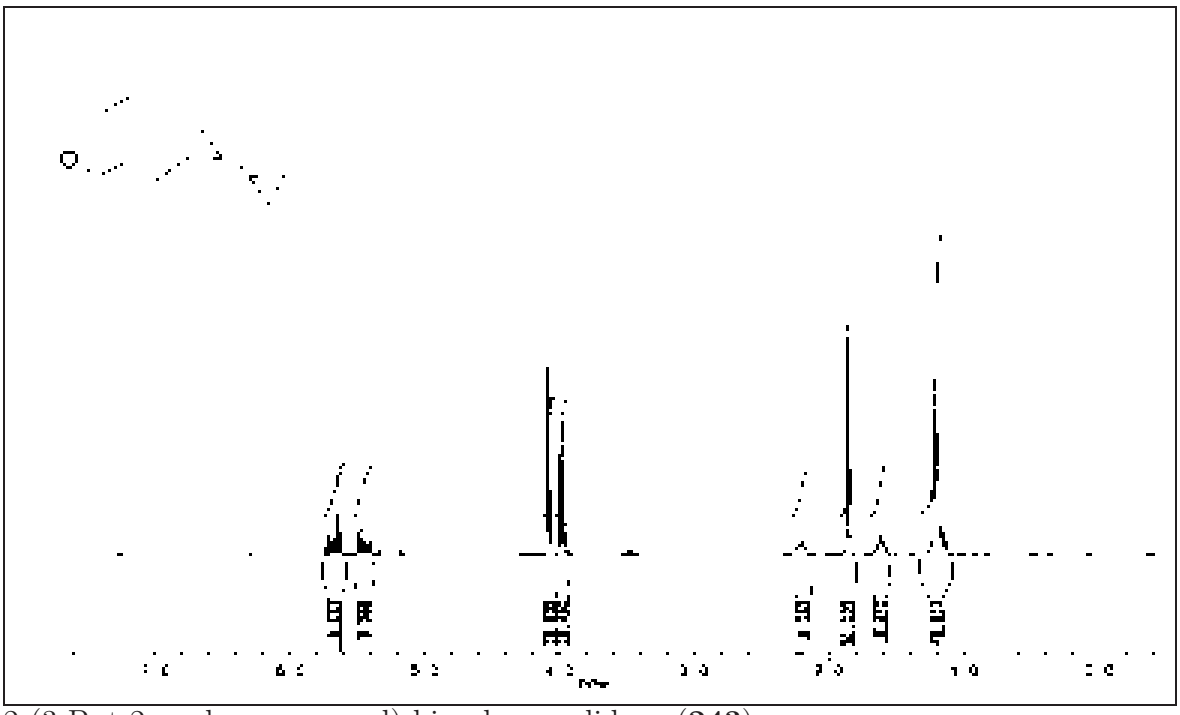
trans-1-But-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane (***E*-209**)



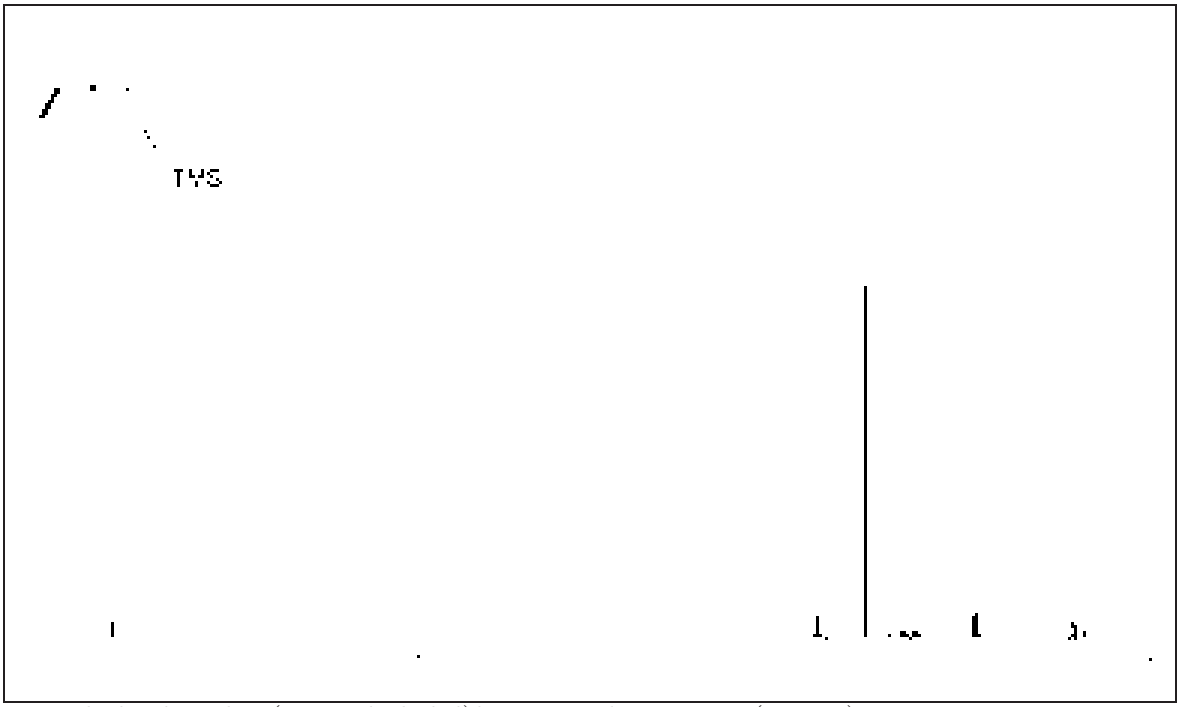
1-(3-But-2-ynyloxy-propenyl)-bicyclopropyl (**230**)



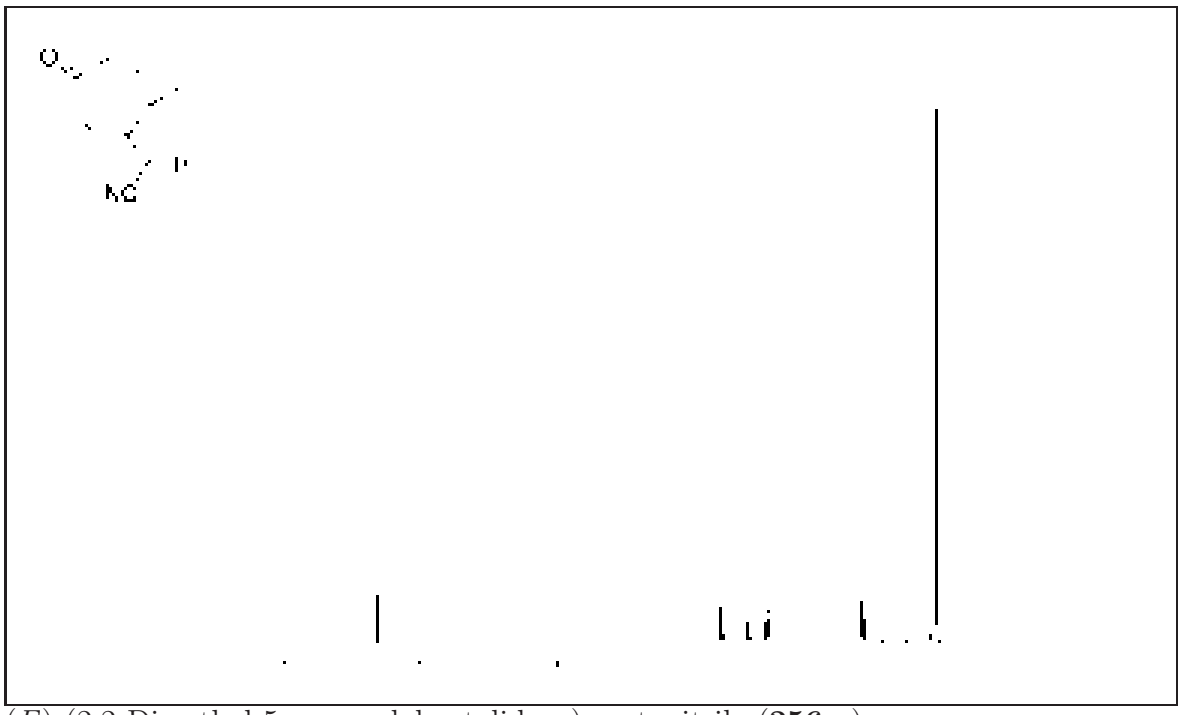
5-Cyclopropyl-8-methyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan (**231**)



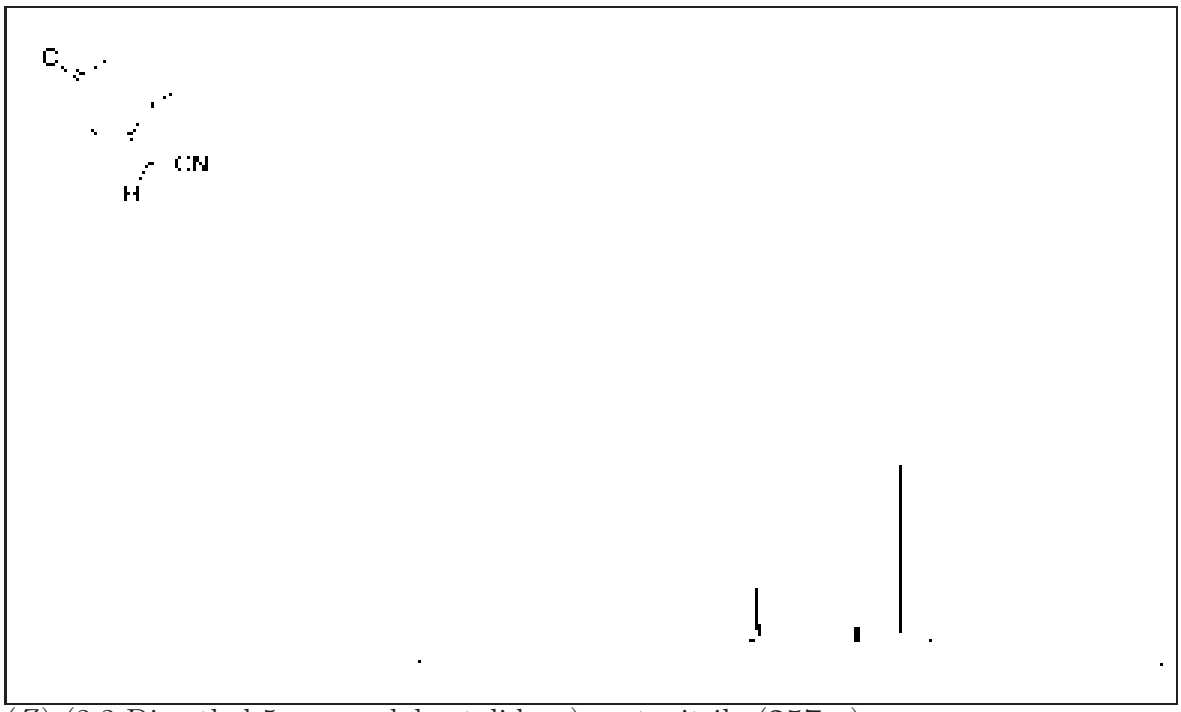
2-(3-But-2-ynyloxy-propenyl)-bicyclopropylidene (**243**)



2-Methyl-4-butyl-6-(trimethylsilyl)hexa-2,3-dien-5-yne (**245-a**)

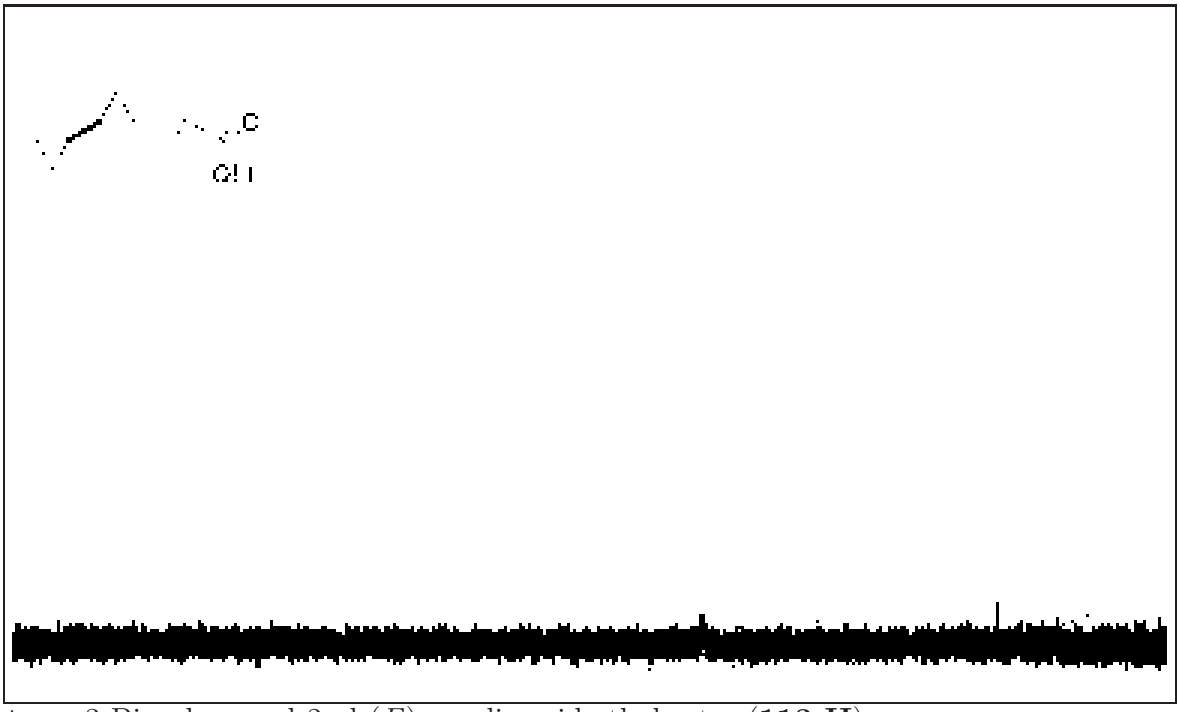


(*E*)-(2,2-Dimethyl-5-oxo-cycloheptylidene)-acetonitrile (**256-e**)

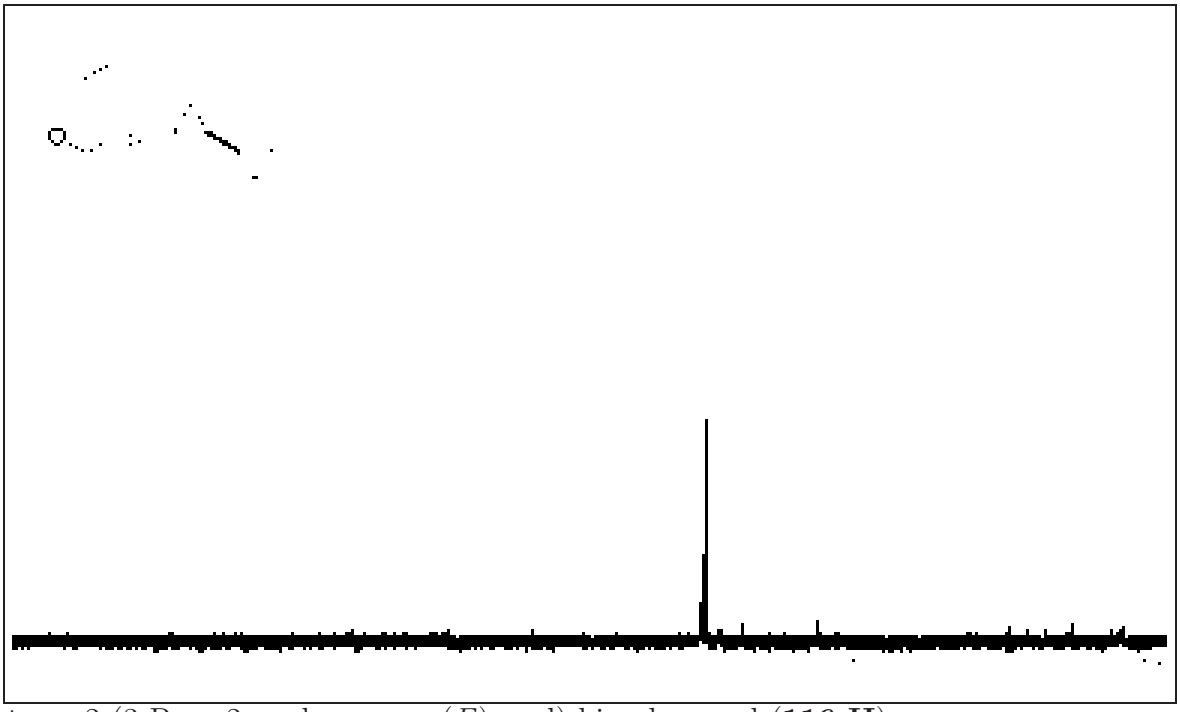


(*Z*)-(2,2-Dimethyl-5-oxo-cycloheptylidene)-acetonitrile (**257-e**)

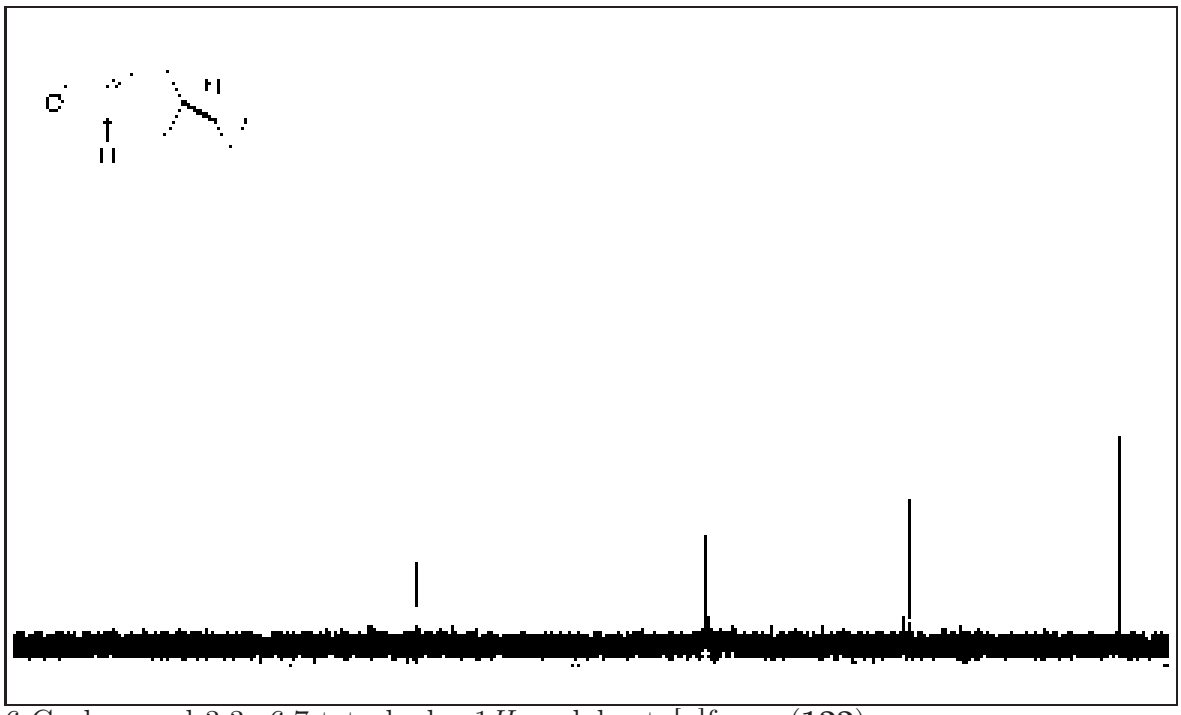
2. ^{13}C-NMR-Spectra



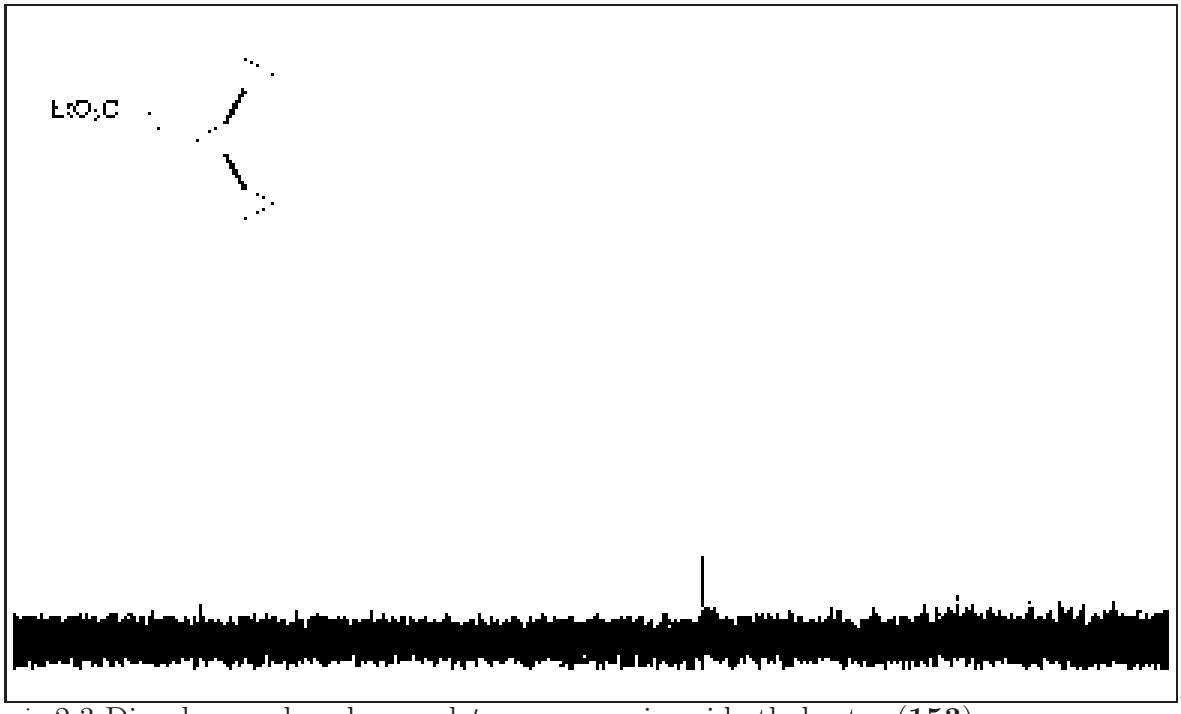
trans-3-Bicyclopropyl-2-yl-(*E*)-acrylic acid ethyl ester (**113-H**)



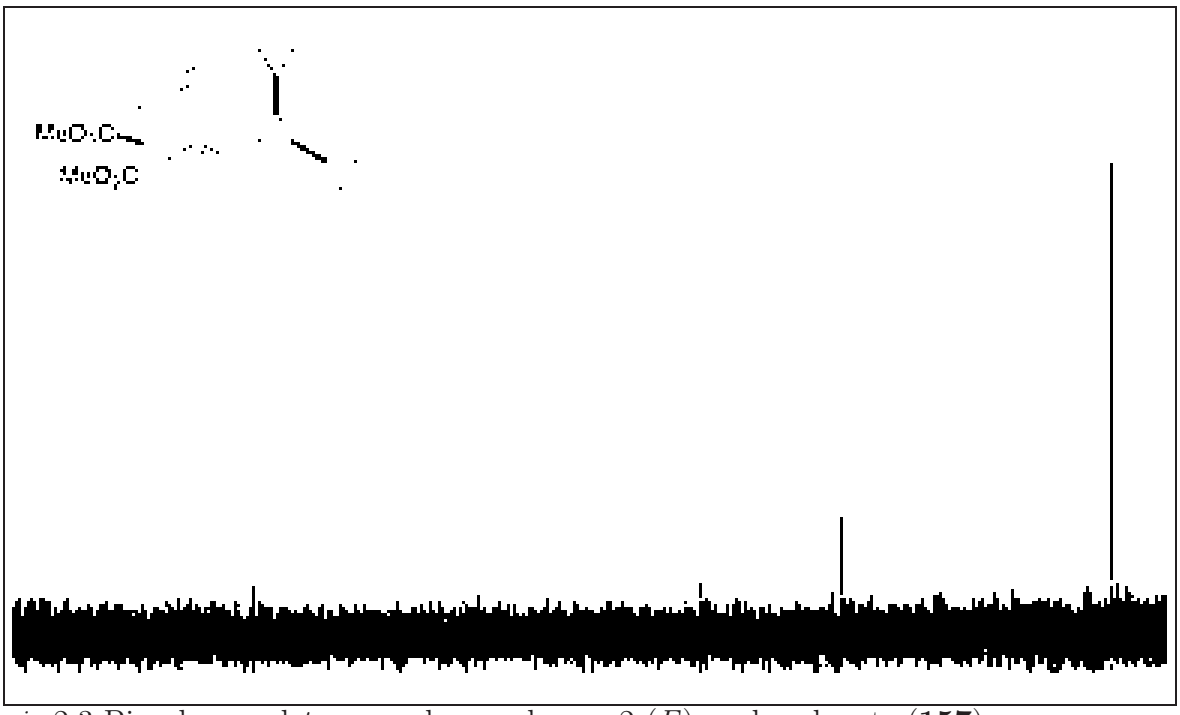
trans-2-(3-Prop-2-ynyloxy-prop-(*E*)-enyl)-bicyclopropyl (**116-H**)



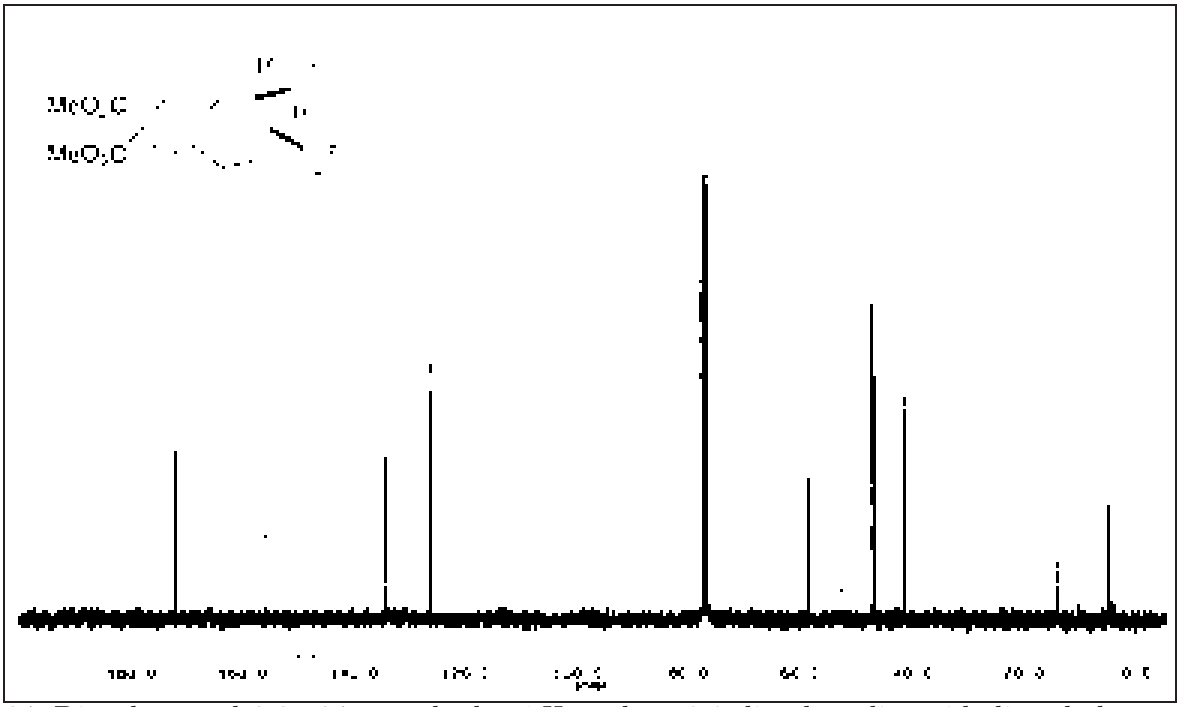
6-Cyclopropyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan (**122**)



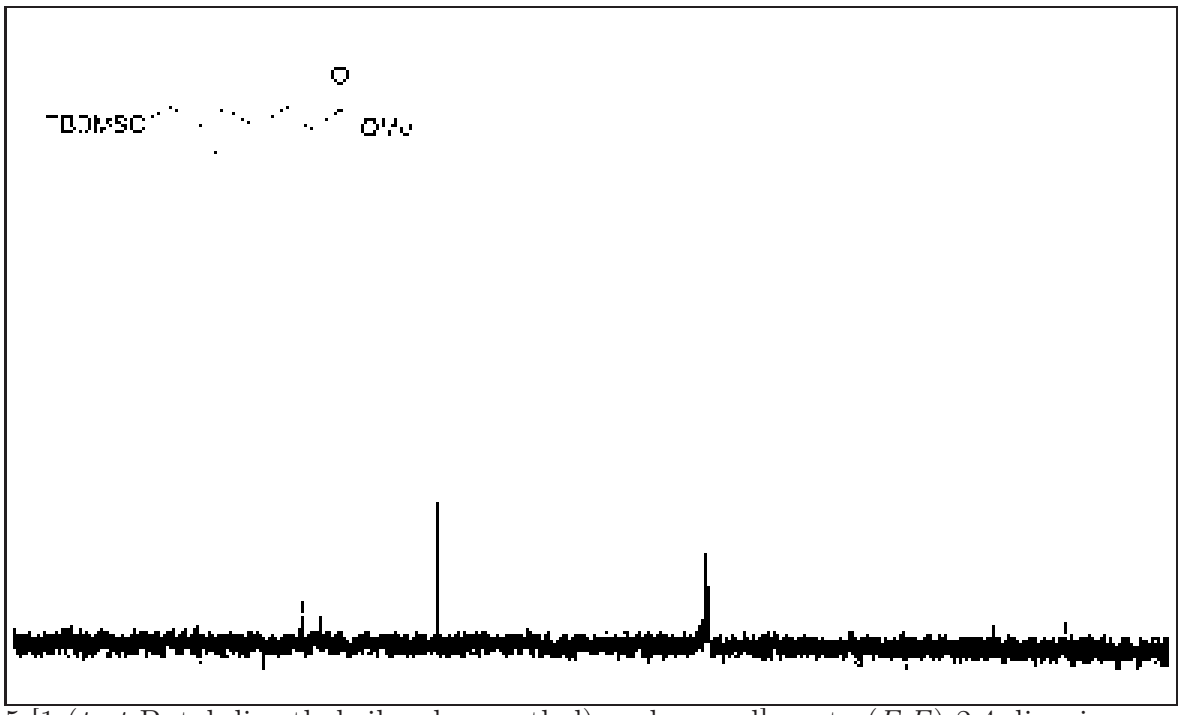
cis-2,3-Dicyclopropyl-cyclopropyl-*trans*-propenic acid ethyl ester (**153**)



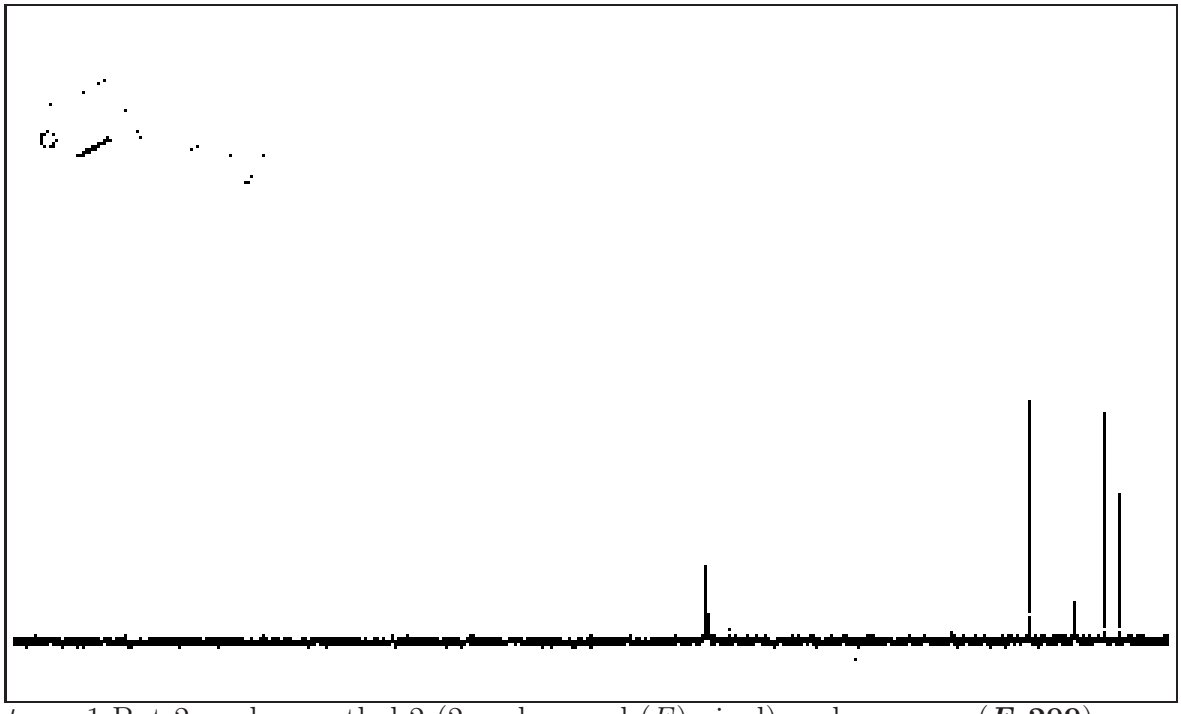
cis-2,3-Bicyclopropyl-*trans*-cyclopropyl-prop-2-(*E*)-enol-malonate (**157**)



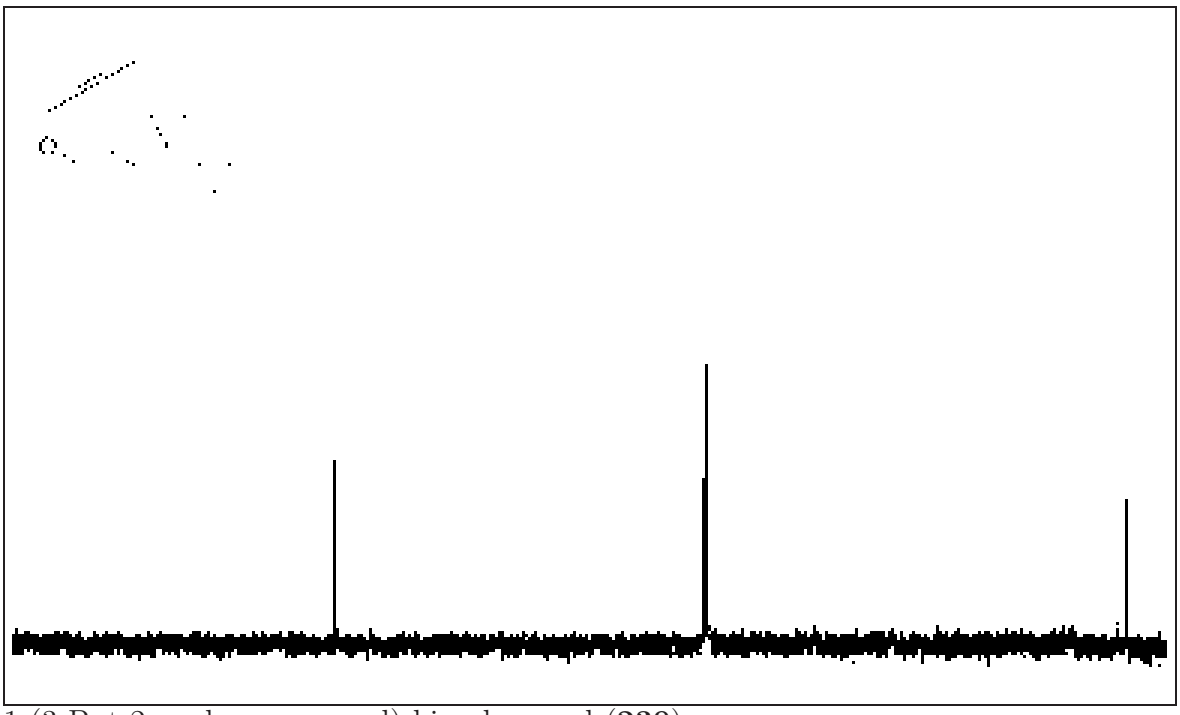
6,7-Dicyclopropyl-3,3a,6,7-tetrahydro-1*H*-azulene-2,2-dicarboxylic acid dimethyl ester (**158**)



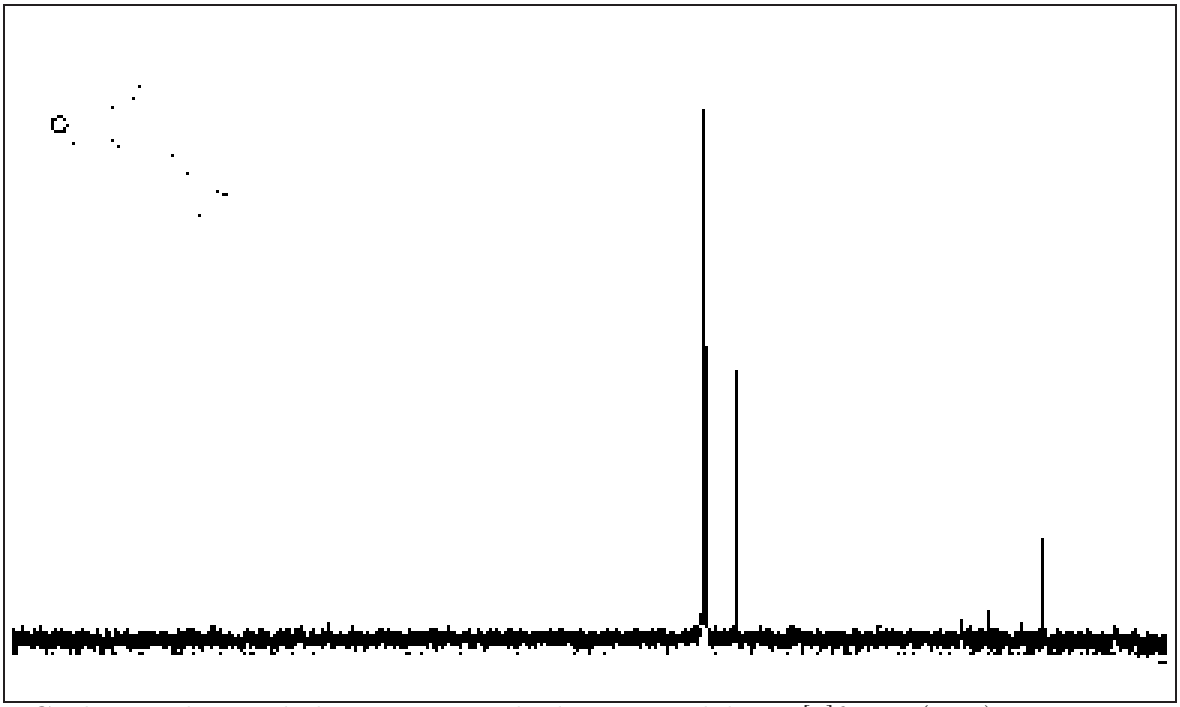
5-[1-(*tert*-Butyl-dimethyl-silanyloxymethyl)-cyclopropyl]-penta-(*E,E*)-2,4-dienoic acid methyl ester (**187**)



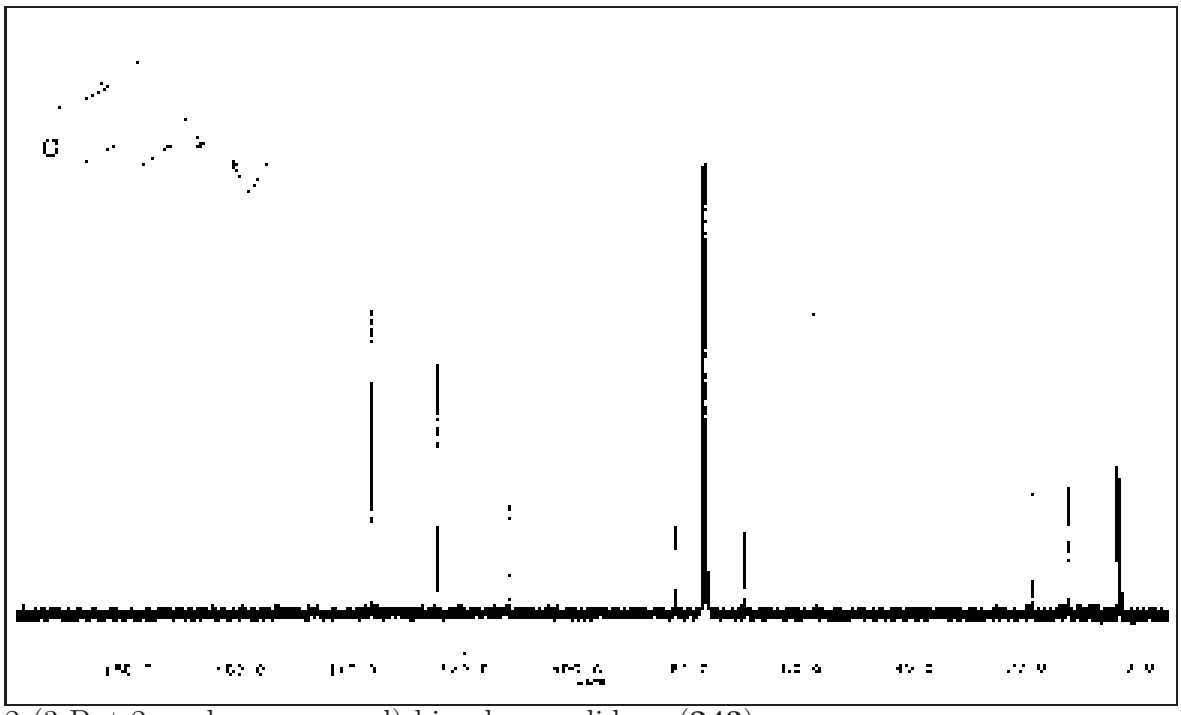
trans-1-But-2-ynyloxymethyl-2-(2-cyclopropyl-(*E*)-vinyl)-cyclopropane (***E*-209**)



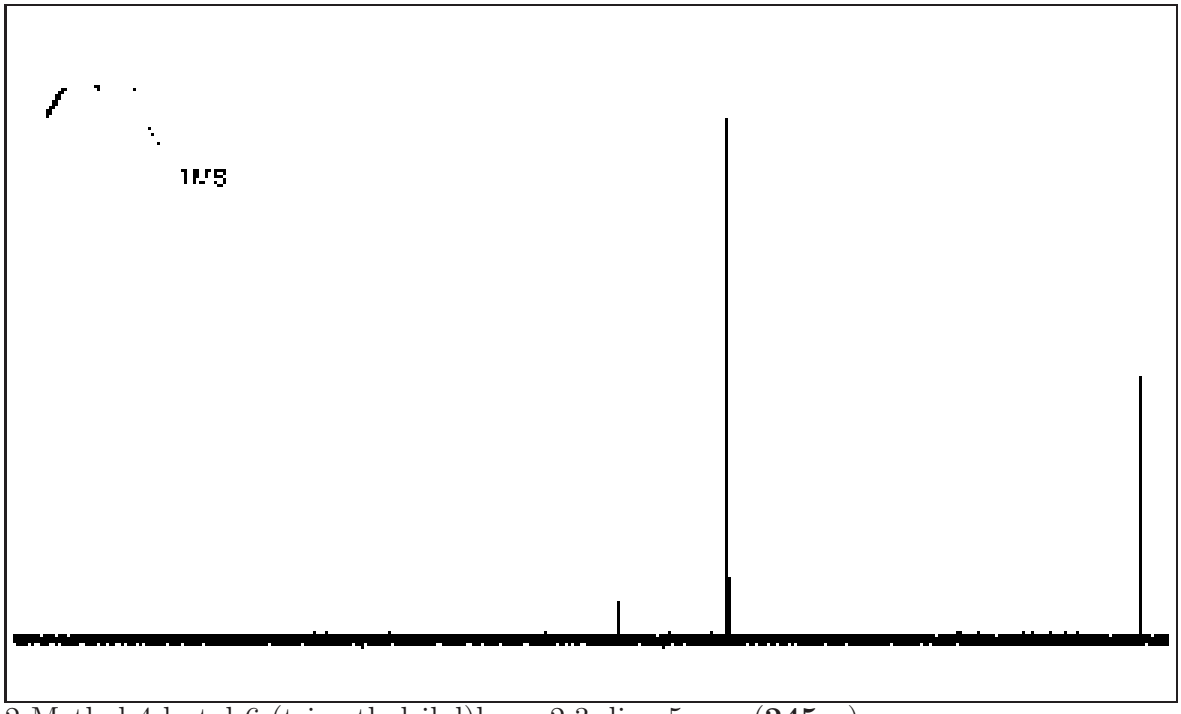
1-(3-But-2-ynyloxy-propenyl)-bicyclopropyl (**230**)



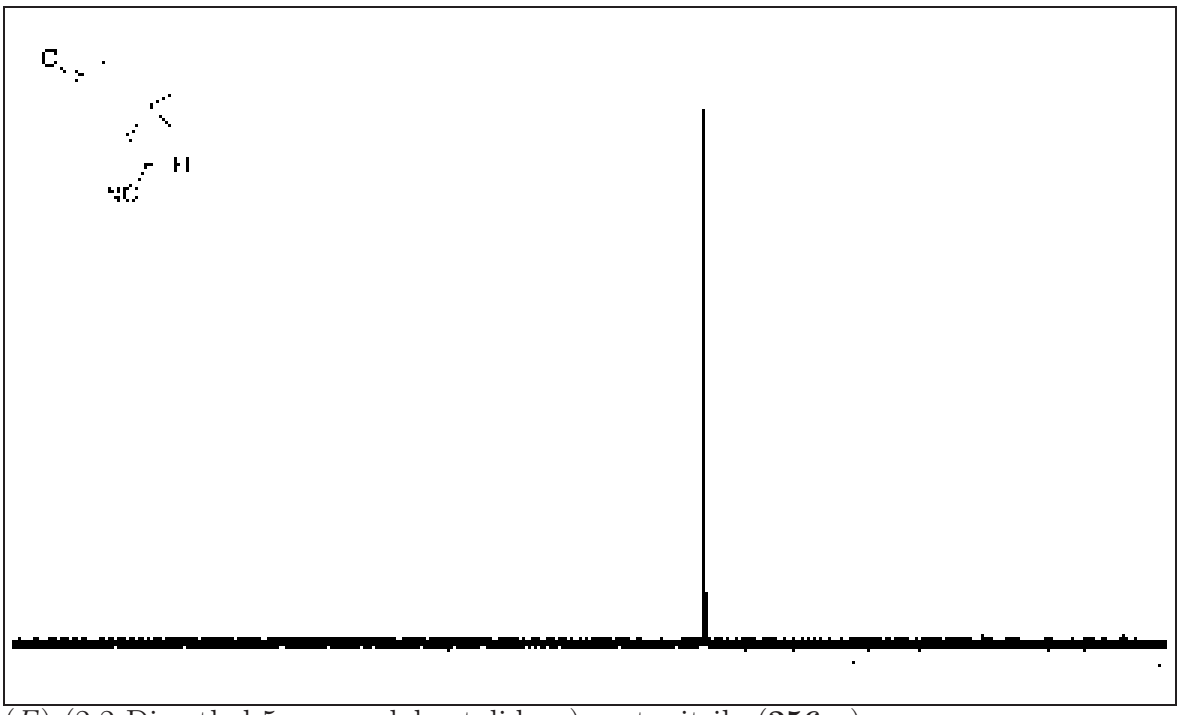
5-Cyclopropyl-8-methyl-3,3a,6,7-tetrahydro-1*H*-cyclohepta[*c*]furan (**231**)



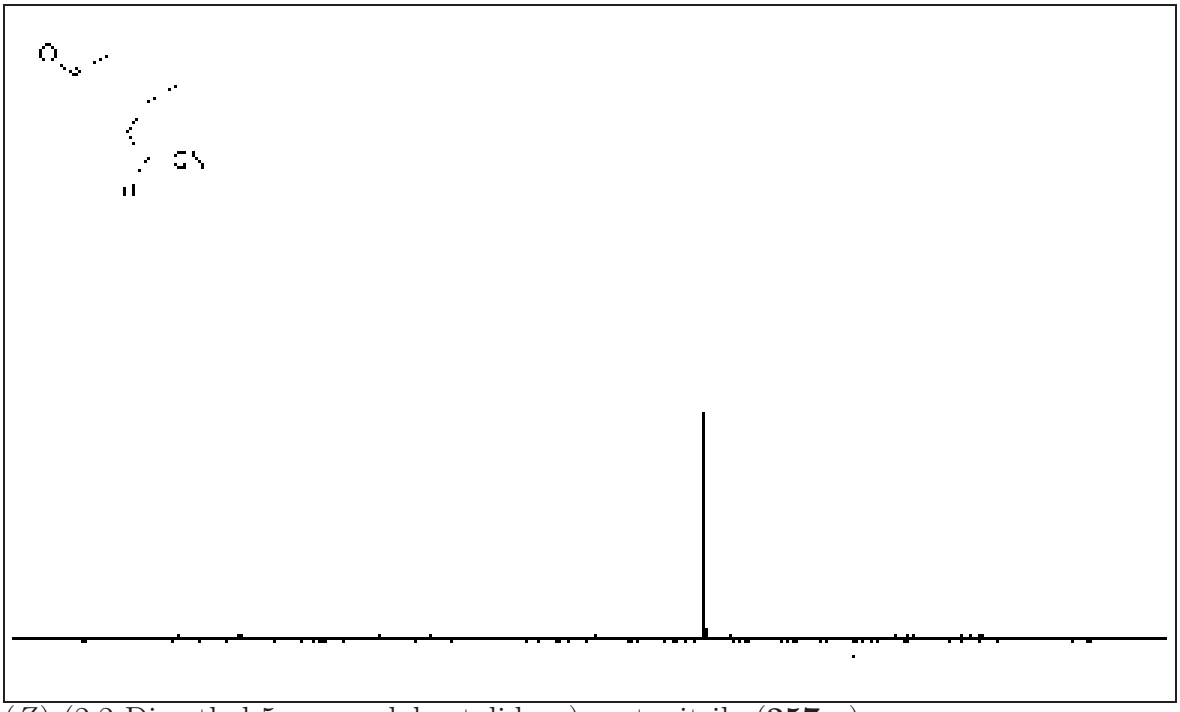
2-(3-But-2-ynyloxy-propenyl)-bicyclopropylidene (**243**)



2-Methyl-4-butyl-6-(trimethylsilyl)hexa-2,3-dien-5-yne (**245-a**)



(*E*)-(2,2-Dimethyl-5-oxo-cycloheptylidene)-acetonitrile (**256-e**)



(*Z*)-(2,2-Dimethyl-5-oxo-cycloheptylidene)-acetonitrile (**257-e**)

Acknowledgment

My thanks go to Dr. H. Frauendorf and Mrs. G. Udvarnoki for doing all the mass spectrometry, to Mr. R. Machinek and his crew for measuring NMR and to Mr. F. Hambloch for conducting the elementary analyses. I also want to express my gratitude to our secretary Mrs. G. Keil-Knepel and our technicians Stefan Beußhausen, Daniel Frank and Karsten Rauch. I have to thank the whole AdM group for the good and friendly work environment.

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For the careful proof reading of this thesis I have to thank André, Baris, Hans, Stefan, Victor and particularly Gerd, who was available until the last minutes. Without Heiko the adventure Latex would not have been possible. Thank you very much.

For all the good times outside the lab I want to show my appreciation especially to Nils and Olli, but also to Chrissi and Markus.

I am especially indebted to Prof. Dr. Paul A. Wender for giving me the opportunity to work in his lab, providing me with these exciting projects and supporting me in science and also in my future plans. I don't know how to thank the whole Wender group. I had a great time! Everybody helped me to get started and to continue working. I want to thank especially the organometallic group. This is just an incredible group of people, not only scientificly, but also it is just great to work with them. Especially Gabe for all his advice (and compounds), Travis for his never ending patience to explain things, Son for all the good times in 305 and the aisle in 365, Mitch for all the fun we had, The Champ for the good discussions about mechanism, Lars for revitalization of the Feierabendbier and all the others, Jen, Jung-Min and TJ. I also want to acknowledge Cindy and Josh for all the times we went for dinner and the other good times we had.

Without my parents I would not be where I am now. Therefore above all my thanks go to them and my whole family.

Last but not least I have to express my gratitude to my girlfriend Juliane for all her love and support in all the good and bad times. She also helped bringing this thesis in an appropriate English.

Thank you very much!

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Since 8/2001	Georg-August-University Göttingen, Germany Candidate for Ph.D. prospected graduation 7/2004
4/2003 – 12/2003	Stanford University, Stanford, USA Advisor: Prof. Paul A. Wender
10/2000 – 7/2001	Georg-August-University Göttingen, Germany Diplom, July 2001 ("excellent") in Organic Chemistry, Advisor: Prof. Armin de Meijere
9/1999 – 5/2000	Boston College, Chestnut Hill, USA Advisor: Prof. Lawrence T. Scott
4/1997 – 9/1999	Georg-August-University Göttingen, Germany Vordiplom in Chemistry ("excellent"), April 1999
EXPERIENCE (Selection):	
10/2001 – 4/2003	Georg-August-University, Göttingen, Germany Teaching assistant. Advanced labcourse in Organic Chemistry.
10/2000 – 7/2001	Georg-August-University, Göttingen, Germany Teaching assistant. Physical Chemistry for biology students.
6/2000 – 8/2000	McKinsey & Company, Germany Summer Fellow.
9/1998 – 10/1998	Laboratoire d'Analyses Medicales, Cognac, France Internship.
7/1998 – 8/1998	Apogepha Arzneimittel GmbH (Pharmaceuticals), Dresden, Germany Research Associate.
HONORS AND AWARDS:	
12/2002	"Otto-Wallach"-Award of the Department of Chemistry, Georg-August- University, Göttingen
2/2001	Ph.D. scholarship of the "Fonds des Verbandes der Chemischen Industrie" Ph.D. scholarship of the "Studienstiftung des Deutschen Volkes"
9/1999 – 5/2000	"Fulbright" scholarship
12/1997 – 7/2001	Scholarship of the "Studienstiftung des Deutschen Volkes"

Presentations and Publications

PRESENTATIONS:

8/2001 *"A New Class of Polycyclic Aromatics: Polyindenopyrenes"* Wegner H. A.; Reisch H.; de Meijere A.; Scott, L. T. 10. International Symposium on Novel Aromatics (ISNA), San Diego, USA.

5/2002 *"A New Suzuki-Heck-Type Coupling Cascade: Indeno[1,2,3]-Annelation of Polycyclic Aromatic Hydrocarbons"* Wegner, H. A.; Scott, L. T.; de Meijere, A. 5. International Symposium on Functional π-Electron Systems, Ulm/Neu-Ulm, Germany.

PUBLICATIONS:

"A New Suzuki-Heck-Type Coupling Cascade: Indeno[1,2,3]-Annelation of Polycyclic Aromatic Hydrocarbons" Wegner, H. A.; Scott, L. T.; de Meijere, A. *J. Org. Chem.* **2003**, *68*(*3*), 883–887.

"A Rational Chemical Synthesis of C_{60}" Scott, L. T.; Boorum, M. M.; McMahon, B. J.; Hagen, S.; Mack, J.; Blank, J.; Wegner, H., de Meijere, A. *Science* **2002**, *295*, 1500–1503.