Macrocycles by Ring-Closing Metathesis

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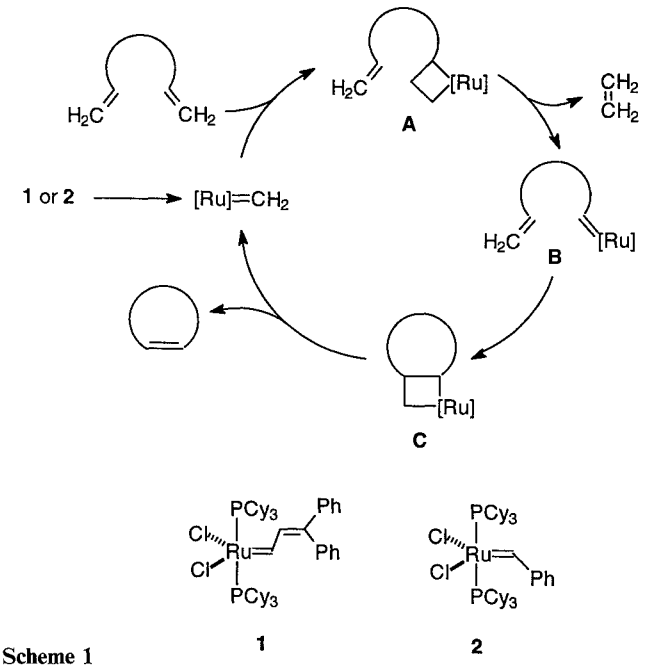
The ruthenium carbene complexes **1** and **2** (0.05–5 mol%) catalyse highly efficient macrocyclization reactions of 1,ω-dienes by ring-closing metathesis (RCM). Key parameters for successful RCM are (i) the presence of a functional group which serves as a relay entity that assembles the reacting sites, (ii) an appropriate distance between this polar group and the alkenes to be metathesized, and (iii) low steric congestion near the double bonds. Contrary to previous assumptions, however, the ring size formed and the conformational predisposition of the substrates for ring closure turned out to be of minor importance. These aspects are illustrated by some straightforward syntheses of macrocyclic lactones, lactams, ethers and ketones, including the musk odored perfume ingredients Exaltolide, Exaltone and Arova 16, of the macrolide recifeiolide **(24)**, as well as of the alkaloids epilachnene **(40)** and its homologue 9-propyl-10-azacyclododecan-12-olide **(39)**, which are active principles of the defense secretions of the pupae of the mexican beetle *Epilachnar varivestis*.

The ruthenium complexes **1** and **2** developed by Grubbs et al. are exceedingly useful precatalysts for alkene metathesis.[1] They owe their high performance and excellent tolerance towards polar functional groups to a well-balanced electronic and coordinative unsaturation of their Ru(2+) center. Among the many applications of these and related carbene species to organic synthesis and polymer chemistry, ring-closing metathesis (RCM) of 1,ω-dienes with formation of cycloalkenes is particularly noteworthy.[2,3] This reaction which is generally believed to proceed via a sequence of formal [2+2] cycloaddition/cycloreversion steps (Scheme 1) is rapidly evolving into a routine tool for the synthesis of 5-, 6- and 7-membered carbo- and heterocycles.[2]

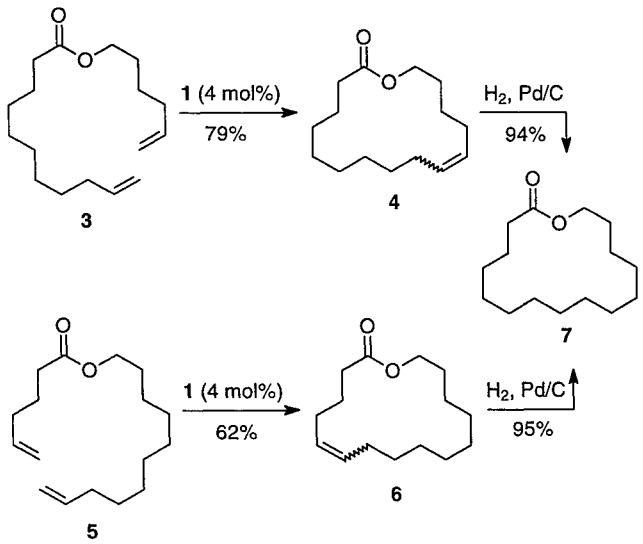
In contrast, the relevance of RCM for the formation of medium and large rings has been perceived only recently. Thus, it has been shown that RCM very well applies to substrates devoid of any conformational constraints and must be considered to be among the most efficient entries into macrocycles provided that the site of ring-closure is properly chosen.[4–6] These preliminary results together with some very recent applications of RCM to the synthesis of macrocyclic antibiotics[5,7–9] render previous assumptions obsolete that macrocyclizations by RCM do require substrates that are conformationally predisposed for ring-closure.[2] We now disclose a full account of our work in this area which may help to assess RCM in a more rational way for retrosynthetic planning. Finally, we show that **1** or **2** convert into very stable and performant catalysts which give ample room for optimizing the total turnover number of a given transformation.

Olfactory Macrocycles

Since RCM inevitably cuts one molecule into two, sufficient entropic bias for ring-closure should be gained, provided that the enthalpic term of a given transformation is small. This can be expected to be the case for the cyclization of flexible dienes to conformationally equally



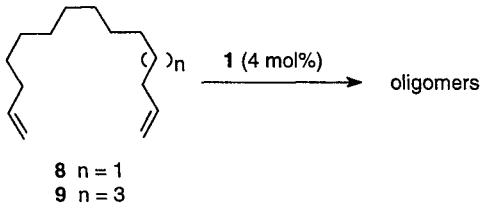
Scheme 1



Scheme 2

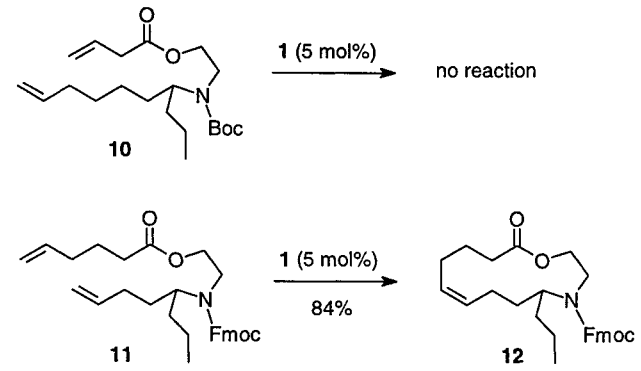
flexible macrocycles. Although alkene metathesis in general is a reversible process, the formation of e.g. ethylene as the cut-off byproduct will thereby evaporatively drive the conversion and hence prevent unfavorable equilibria.

We reasoned that these chemical incentives may convey macrocyclization reactions and have used a set of simple substrates as an appropriate testing ground. As shown in Scheme 2, the slow combination of CH_2Cl_2 solutions of carbene **1** (4 mol %) and ester **3**, readily prepared from commercially available 10-undecenoyl chloride and hex-5-en-1-ol, provided the 16-membered ring **4** in 79 % isolated yield ($E:Z = 46:54$). Under the same conditions ester **5** cyclized to lactone **6** ($E:Z = 77:23$) with similar ease. Hydrogenation of these unsaturated macrolides provided 15-pentadecanolide **7** (Exaltolide),[4] a musk-odored component of the root oil of *Archangelica officinalis* which is used as a valuable perfumery ingredient.[10]

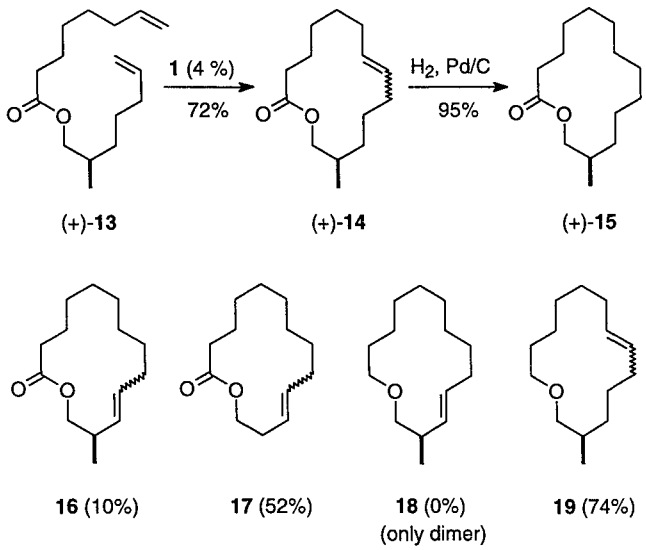


Scheme 3

However, these smooth conversions are in striking contrast to the resistance of unfunctionalized dienes of similar length towards cyclization (Scheme 3)! Thus, neither tetradeca-1,13-diene **(8)** nor hexadeca-1,15-diene **(9)** led to cyclic monomers to any appreciable extent on exposure to **1** in the same dilution regime. Therefore, it must be



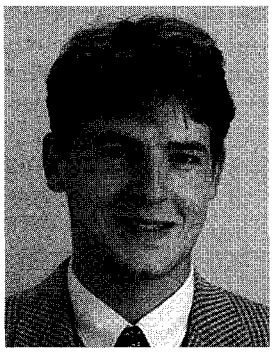
Scheme 4



Scheme 5

Biographical Sketches

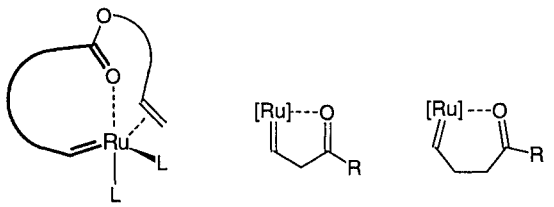
Alois Fürstner was born in 1962 in Bruck/Mur, Austria, and studied chemistry at the Technical University of Graz, Austria, where he obtained his Ph. D. in 1987 (Prof. H. Weidmann). After postdoctoral studies with Prof. W. Oppolzer at the University of Geneva, Switzerland, he finished his habilitation in organic chemistry in Graz in 1992. Since 1993 he has led a research group at the Max-Planck-Institut für Kohlenforschung, Mülheim, Germany, and is lecturer at the University of Dortmund. In 1994 he was invited professor at the Université Claude Bernard-Lyon I, France, and was awarded the Dozentenstipendium des Fonds der Chemischen Industrie. His major interests include the development of new synthetic methods with focus on organometallic reagents and catalysts, as well as their application to the synthesis of natural products.



Klaus Langemann was born in 1969 in Bad Pyrmont, Germany. He studied chemistry at the University of Bielefeld and spent one year (1993) at the University of California, Berkeley, with a fellowship of the Rotary Foundation. He finished his diploma work on studies of complexes of the siderophore nordesferriferrithiocin in 1995. Being awarded a Kekulé Stipendium of the Fonds der Chemischen Industrie, he is presently working as a graduate student in the research group of Dr. Fürstner at the Max-Planck-Institut für Kohlenforschung, Mülheim.

concluded that the presence of a polar functional group in the cyclization precursor is a pivotal parameter for successful RCM in the macrocyclic series.

Its position, however, is of similar importance. This can be deduced from a comparison of two exploratory experiments for the synthesis of azamacrolides depicted in Scheme 4. While the but-3-enoic acid derivative **10** did not cyclize at all, the corresponding hex-5-enoic acid ester **11** provided the desired 13-membered ring **12** in 84% yield as a single isomer. The notion that the proper site of ring-closure is critical for a smooth macrocyclization is confirmed by the examples of different 14-membered ring compounds shown in Scheme 5. Again, a larger distance between the heteroatoms and the alkene groups results in significantly improved yields (cf. **14** versus **16**; **18** versus **19**). These results may be interpreted in terms of chelation between the emerging ruthenium carbene and the donor atom in its vicinity: the heteroatoms most likely serve as residence sites which assemble the reactive entities within the coordination sphere of the metal and therefore strongly bias the ring-closure. However, if such a relay becomes too stable, as might be the case with 5- or 6-membered chelate structures, the catalyst is sequestered in the form of unproductive complexes.[11]



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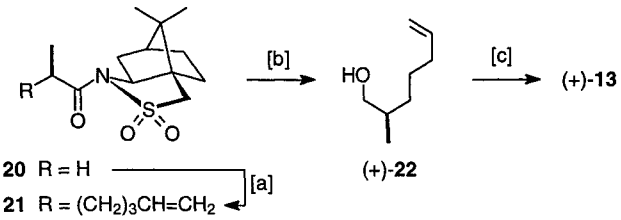
The examples shown in Scheme 5 also indicate that RCM is sensitive to steric hindrance close to the double bonds to be metathesized. Thus, the methyl branched compound **16** is formed in significantly lower yield than its truncated analogue **17**. Such a steric effect is not surprising in view of the rather space filling phosphine ligand(s) in the coordination sphere of the Ru(2+).

Hydrogenation of product (+)-**14** affords (12*R*)-(+)-12-methyl-13-tridecanolide (+)-**15**,[4] which is a minor but rather precious musk-odored component of the *Angelica* root oil.[12] Its enantiomerically pure alcohol component (+)-**22** has been prepared by alkylating *N*-propionylbornane-10,2-sultam **(20)** with 5-iodopent-1-ene followed by reduction of the resulting amide **21** with $LiAlH_4$ as depicted in Scheme 6.[13] Esterification of alcohol (+)-**22** with oct-7-enoyl chloride in the presence of DMAP affords the cyclization precursor (+)-**13** in 84% yield. As in the case of Exaltolide outlined above, this approach to a valuable fragrance clearly surpasses previous ones in terms of straightforwardness, efficiency, optical purity and overall yield.

With this information on some essential parameters for productive RCM in mind, we were able to assemble a variety of 12- to 21-membered rings from simple precursors (Table 1, Scheme 5). Since different functional groups turned out to be suitable relays, macrocyclic lactones,



Scheme 6. [a] $NaN(SiMe_3)_2$, 5-iodopent-1-ene, −78 °C → r.t., THF/HMPA, overnight; [b] $LiAlH_4$, THF, 57% (over both steps); [c] oct-7-enoyl chloride, CH_2Cl_2, DMAP, 84%.

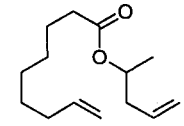
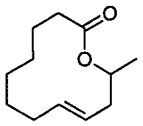
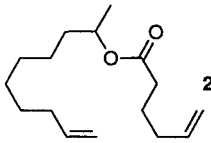
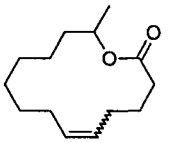
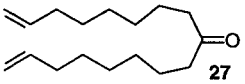
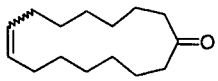
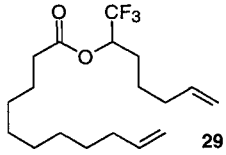
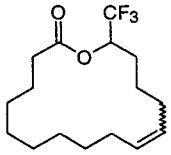
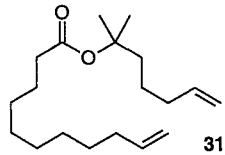
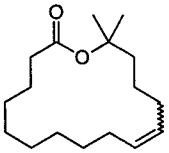
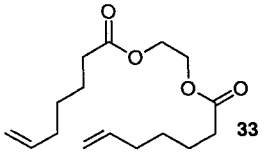
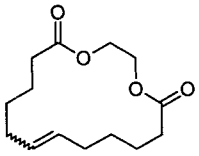
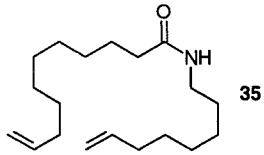
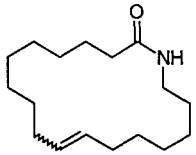
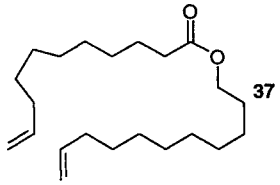
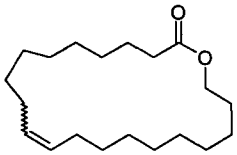
lactams, ethers and ketones can be conveniently prepared. These examples provide compelling evidence that functionalized dienes devoid of conformational constraints undergo remarkably efficient RCM under high dilution conditions (preferential final concentration ≈ 0.006–0.01 M). Furthermore, it is obvious that the ring size formed is of minor importance as can be seen from the high yielding cyclization of the 21-membered lactone **38**. Its hydrogenation under standard conditions affords 20-eicosanolide,[4] a major component of the secretion of the abdominal Dufour gland of solitary bees of the genera *Colletes* and *Halictus*.[14] These insects make their brood cells in the ground and coat them with a highly resistant waterproof polyester membrane based on 20-hydroxyeicosanoic acid and homologues thereof. 20-Eicosanolide serves as the stock form of this monomer in the gland of the bee, although it is likely to have other biological implications as well.[14]

Some other products shown in Table 1 also deserve mentioning. Thus, hydrogenation of the dilactone **34**, which has a very pleasent odor of its own, affords a synthetic musk Arova 16,[15] while hydrogenation of ketone **28** leads to the famous fragrance Exalton (cyclopentadecanone).[16] Compounds **30** and **32** are non-natural analogues of hexadecane-15-olide, a precious odorant from the essential oils of *Ferula galbaniflua* and *F. rubicaulis*,[17] in which the methyl substituent of the natural product is replaced by either a trifluoromethyl or a *gem*-dimethyl group. The (5*Z*,13*S*)-isomer of the 14-membered lactone **26** is a synergist of the aggregation pheromone of the flat grain beetle *Cryptoletes pusillus*.[18] Finally, RCM gave ready access to recifeiolide **24**, a naturally occurring 12-membered macrolide isolated from the fungus *Cephalosporium recifei*.[19] Compound (*E*)-**24** was readily separated from its stereoisomer by flash chromatography using silica impregnated with $AgNO_3$.[20] These examples amply demonstrate the scope of this macrocyclization reaction. The ready accessibility of all precursors, the low number of steps, the compatibility with various functional groups, the great flexibility in structural terms and the excellent overall yields all deserve particular emphasis. All syntheses can be considered as highly atom economical,[21] with ethylene formed by RCM being essentially the only "waste" product.

Catalyst and Catalyst Loading

The reactions mentioned above have been carried out using 2–5 mol% of **1** for convenience of handling of this

Table 1. Macrocycles by RCM. All reactions were carried out with **1** (2–5 mol%) in refluxing CH_2Cl_2 unless stated otherwise.

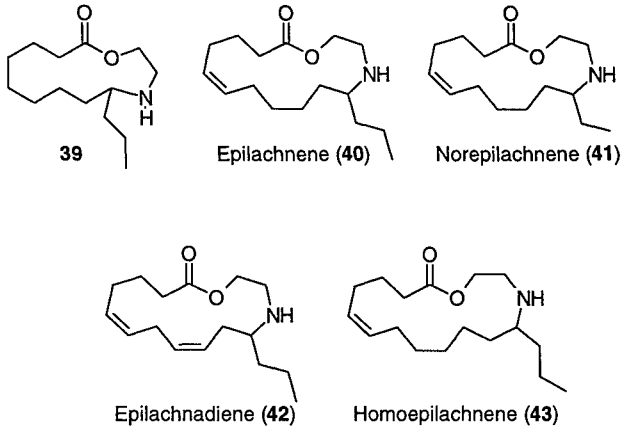
Substrate	Product	Yield (%)	$Z:E$[a]
 **23**	 **24**[19]	80 77[c]	1 : 4.7 1 : 3.3
 **25**	 **26**[18]	71[b]	2.2 : 1
 **27**	 **28**	72	1 : 4.6
 **29**	 **30**	80	1 : 5.9
 **31**	 **32**	72[b]	1 : 7.0
 **33**	 **34**	87	1 : 3.0
 **35**	 **36**	83 80[d]	1 : 2.2
 **37**	 **38**	71[b]	1 : 1.4[e]

[a] Determined by GC.
[b] At room temperature rather than at reflux.
[c] In toluene at 80 °C; pure (*E*)-**24** was obtained in 58 % yield by separating the isomers by flash chromatography on $AgNO_3$-impregnated silica gel.[20]
[d] Using 0.05 mol% of the catalyst.
[e] Stereochemical assignment may be interchanged.

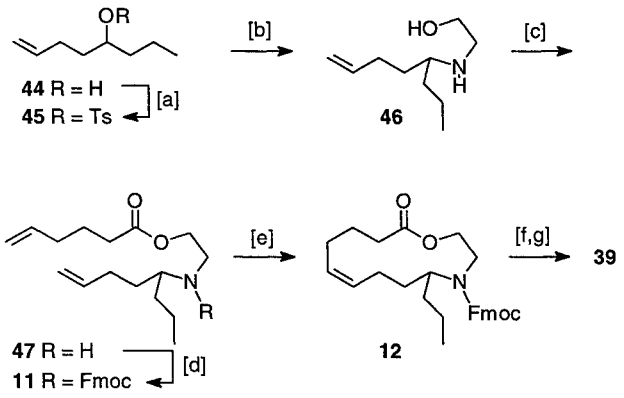
complex. However, these numbers must not be mistaken for the lowest possible catalyst loading. In order to probe this important aspect, the cyclization of amide **35** to lactam **36** has been carried out in refluxing CH_2Cl_2 with 5 mol % and with as little as 0.05 mol % of **1**.[22] Although the reaction time was significantly increased in the latter case, the yield of **36** was essentially the same in both runs (cf. Table 1). This example features the excellent stability and performance of such ruthenium based catalysts and holds promise for further optimization. It should also be noted that carbene complexes **1** and **2** show similar application profiles since the propagating, catalytically active species formed in situ from either precatalyst is the same (cf. Scheme 1). The only difference lies in the accessibility of these complexes as well as in the initiation period.[1]

Synthesis of Azamacrolides

The series of homologous azamacrolides **39**–**43** discovered in 1993 in the defense secretion of the pupae of the Mexican beetle *Epilachnar varivestis* constitutes a rather unique family of alkaloids (Figure).[23,24] They are the first examples of naturally occurring macrolides containing a basic nitrogen atom in the tether without ring contraction being observed; moreover, they prove for the first time that insects in the pupal state can defend themselves by chemical means.



Figure



Scheme 7. [a] 4-Tosyl chloride, CH_2Cl_2, pyridine, 0 °C → r.t., 6 h, 93%; [b] ethanolamine, reflux, 60 h, 84%; [c] hex-5-enoic acid, 4-TsOH (1.05 eq.), toluene, Dean–Stark, 5 h, 76%; [d] 9-fluorenylmethyl chloroformate, $NaHCO_3$, THF/H_2O, 4.5 h, 90%; [e] **1** (5 mol%), CH_2Cl_2, r.t., 84%; [f] H_2 (1 atm), Pd/C (5%), EtOAc, 4 h; [g] aq Bu_4NF, THF, 10 min, 83% (over both steps).

We felt that these macrocycles are ideally suited for assembly via RCM. Our first target was compound **39**, which constitutes a minor component of the pupal secretions.[23] Its synthesis is shown in Scheme 7. Reaction of but-3-enylmagnesium bromide with butanal in diethyl ether gives alcohol **44** (78%), which after tosylation is treated with ethanolamine to afford compound **46**. Subsequent azeotropic esterification with hex-5-enoic acid in the presence of >1 equiv of TsOH (in order to ensure quantitative protonation of the amine) proceeds smoothly and provides diene **47** as a first candidate for RCM. Unfortunately, **47** as well as the ammonium salt thereof (**47** · HCl) failed to cyclize under the standard reaction conditions outlined above. However, the *N*-Fmoc derivative **11** (Fmoc = 9-fluorenylmethoxycarbonyl), on treatment with catalytic amounts of **1** in CH_2Cl_2 at room temperature, cyclized smoothly affording the 13-membered alkene **12**. Hydrogenation of the double bond followed by *N*-deprotection with aqueous Bu_4NF led to the target in excellent overall yield.

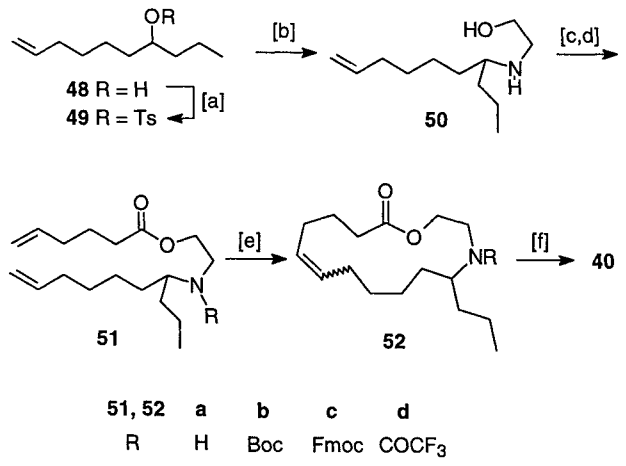
Lactone **12** was obtained as a single isomer, which was assigned to be (*Z*) on the basis of its spectroscopic properties.[25] Although this result was somewhat unexpected with regard to the *E*:*Z*-ratios previously obtained (cf. Table 1), it encouraged us to pursue the synthesis of the major secretion component epilachnene **40** containing a *Z*-alkene moiety by a similar sequence of reactions (Scheme 8). Starting from hex-5-en-1-ylmagnesium bromide and butanal as the substrates and closely following the sequence of reactions outlined above, a series of suitable diene substrates **(51a–d)** bearing different *N*-protecting groups was prepared. All of them cyclized readily on exposure to catalytic amounts of **1** (Table 2). This includes even the ammonium salt **51a** · HCl, although its smaller homologue **47** · HCl had failed to react under identical conditions. However, a mixture of both isomers of **52a–d** was invariably obtained in a roughly 2:1 ratio, with the (*E*)-alkene predominating. This ratio was found to be essentially independent of the *N*-protecting group, the temperature and the solvent in the cyclization reaction. Epilachnene as well as its (*E*)-isomer could be obtained in pure form after HPLC separation of the isomeric mixture of **52c**, followed by deprotection with aqueous Bu_4NF.

Table 2. Preparation of differently protected epilachnene derivatives by RCM. The reactions were carried out using **1** (5 mol%) in CH_2Cl_2 at room temperature under high dilution conditions.

Entry	Substrate	*E*:*Z*[a]	Product (Yield)
1	**51a**[b]	2:1	**52a** (83%)
2	**51b**	2:1	**52b** (89%)
3	**51c**	2:1	**52c** (89%)
4	**51d**	[c]	**52d** (91%)

[a] As determined by GC after *N*-deprotection.
[b] Substrate **51a** was cyclized as ammonium chloride after protonation with HCl in THF.
[c] Not determined, since attempted *N*-deprotection results in the opening of the lactone ring.

These examples shed light on a very fundamental aspect of macrocycle synthesis by RCM. We are neither in control of the configuration of the newly formed double bond, nor are we presently able to predict it properly. Even more seriously, small structural variations can alter the stereochemical outcome significantly (cf. **12** versus **52**). If the cycloreversion of a metallacyclobutane is a concerted process, the *E*:*Z*-ratio obtained reflects the configuration of the bicyclic intermediate of type **C** (Scheme 1) which is determined in the preceding cyclo-



Scheme 8. [a] 4-Tosyl chloride, CH_2Cl_2, pyridine, 0 °C → r.t., 24 h, 91 %; [b] ethanolamine, reflux, THF, 72 h, 85 %; [c] hex-5-enoic acid, 4-TsOH (1.05 eq.), toluene, Dean–Stark, 5 h, 80 %; [d] *N*-protection: **51b** (R = Boc): $(Boc)_2O$, Et_3N, 89 %; **51c** (R = Fmoc): 9-fluorenylmethyl chloroformate, $NaHCO_3$, THF/H_2O, 4 h, 92 %; **51d** (R = $COCF_3$): trifluoroacetic acid anhydride, pyridine, 94 %; [e] **1** (5 mol%), CH_2Cl_2 r.t., cf. Table 2; [f] *N*-deprotection: **52b → 40** (R = Boc): CF_3COOH, THF, 20 min, 86 %; **52c → 40** (R = Fmoc): aq Bu_4NF, THF, 5 min, 89 %.

addition step **(B→C)**. More details on the actual structure of such intermediates must be gathered before a general solution for the inherently difficult but preparatively most important problem of controlling the stereochemistry of the cycloalkene formed can be envisaged.

All reactions were carried out under Ar in predried glassware using Schlenk techniques. $Cl_2Ru(PCy_3)_2 = CHCH = CPh_2$ **(1)** was prepared from 3,3-diphenylcyclopropene according to the literature procedure.[1] The solvents were dried by distillation over the drying agent indicated and were stored and transferred under Ar: CH_2Cl_2 (CaH_2), toluene (Na/K alloy). Flash chromatography: Merck silica gel 60 (230–400 mesh) or Alox (Macherey & Nagel, Al_2O_3 90, neutral, 70–250 mesh) as indicated with hexane/EtOAc in various proportions as the eluent. Instrumental Analyses: NMR: spectra were recorded on a Bruker AC 200, AMX 300, AMX 400 or DMX 600 spectrometer in $CDCl_3$. Chemical shifts (δ) are listed in ppm relative to tetramethylsilane, coupling constants (J) are given in Hz. IR: Nicolet FT-7199, wavenumbers in cm^{-1}. MS: Finnigan MAT 8200 (70 eV). HRMS: Finnigan MAT 95 (70 eV). Optical rotation measurements: Jasco DIP-360 polarimeter in CH_2Cl_2 using a 5 cm path length quartz cell at the temperature stated. Mps were measured on a Gallenkamp apparatus (uncorrected). Elemental analyses: Dornis & Kolbe, Mülheim. Substrates: Commercially available compounds were used as received. Tetradeca-1,13-diene **(8)** (Aldrich) was purchased, hexadeca-1,15-diene **(9)** was prepared according to a literature procedure.[26] The unsaturated esters and amides were obtained by azeotropic esterifications (toluene, 4-TsOH) or by acylation of the corresponding alcohols (amine) with the appropriate acid chloride in CH_2Cl_2/pyridine under standard conditions. Spectroscopic data of the starting materials thus prepared are compiled in Table 3.

Unsaturated Macrocycles via RCM; Typical Procedure:

Solutions of the diene (0.5 mmol) and of the ruthenium carbene **1** (14 mg, 0.015 mmol, 3 mol %) in CH_2Cl_2 each (30 mL) were simultaneously added dropwise to CH_2Cl_2 (30 mL) over a period of ≈ 20 h at r.t. or at reflux (cf. Tables 1 and 2). After stirring the mixture for another 12 h at that temperature, the solvent was removed in vacuo and the residue purified by flash chromatography with hexane/EtOAc in various proportions as the eluent. This afforded analytically pure compounds (GC > 95 %), the spectroscopic data of which are compiled in Tables 4 and 5.

(*R*)-2-Methylhept-6-en-1-ol [(+)-22]:

A solution of *N*-propionylbornane-10,2-sultam **20**[13] (500 mg, 1.84 mmol) in THF (10 mL) was added dropwise over a period of 10 min to a solution of sodium hexamethyldisilazide (440 mg, 2.4 mmol) in THF (10 mL) at −78 °C. Stirring was continued for 1 h at that temperature prior to the addition of 5-iodopent-1-ene (1.082 g, 5.52 mmol) dissolved in HMPA (5 mL). After stirring for 4 h at −78 °C, the reaction was allowed to warm to r.t. overnight and then quenched with aq sat. NH_4Cl (50 mL). A standard extractive workup followed by flash chromatography (hexane/EtOAc 5:1) afforded **21** as a colorless syrup (600 mg). This material, dissolved in Et_2O (10 mL), was added dropwise at 0 °C to a suspension of $LiAlH_4$ (200 mg, 5.31 mmol) in Et_2O (10 mL) and the mixture was stirred at that temperature for 2 h. Quenching with wet Et_2O and aq sat. NH_4Cl followed by a standard extractive workup and flash chromatography (hexane/EtOAc 2:1) afforded the alcohol (+)-**22** as a colorless syrup (134 mg, 57 %), $[\alpha]_D^{23} = +10.4$ ($c = 14$, CH_2Cl_2).

^1H NMR (200 MHz, $CDCl_3$): $\delta = 5.75$ (ddt, 1 H, $J = 17.0$, 10.3, 6.6 Hz), 4.97–4.86 (m, 2 H), 3.40 (dd, 1 H, $J = 10.5$, 5.8 Hz), 3.37 (dd, 1 H, $J = 10.5$, 6.4 Hz), 2.04–1.92 (m, 2 H), 1.77 (s, 1 H), 1.63–0.92 (m, 5 H), 0.85 (d, 3 H, $J = 6.7$ Hz).

^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 138.9$, 114.4, 68.2, 35.6, 34.0, 32.6, 26.3, 16.5.

The spectroscopic data are in accordance with those reported in the literature.[27]

Oct-7-en-4-ol (44):

A solution of 4-bromobut-1-ene (6.0 g, 44.4 mmol) in Et_2O (20 mL) was added dropwise to a suspension of Mg turnings (1.215 g, 50 mmol) activated by two drops of 1,2 dibromoethane in the same solvent (10 mL) at such a rate as to maintain a gentle reflux. After stirring for 1 h, a solution of butanal (2.884 g, 40 mmol) in Et_2O (20 mL) was added to the Grignard reagent formed and stirring was continued for 2 h at r.t. Sat. aq NH_4Cl (40 mL) was added, the product was extracted with Et_2O (3 × 50 mL) and the combined organic phases were dried (Na_2SO_4), filtered and evaporated. Flash chromatography (hexane/EtOAc 10:1) afforded compound **44** as a colorless liquid (4.02 g, 78 %).

^1H NMR (200 MHz, $CDCl_3$): $\delta = 5.85$ (ddt, 1 H, $J = 17.0$, 10.2, 6.6 Hz), 5.10–4.93 (m, 2 H), 3.62 (q, 1 H, $J = 5.3$ Hz), 2.25–2.09 (m, 2 H), 1.83 (s, 1 H), 1.59–1.25 (m, 6 H), 0.97–0.86 (m, 3 H).

^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 138.7$, 114.4, 71.7, 39.6, 36.5, 30.1, 18.8, 14.1.

IR (neat): $\nu = 3357$, 3079, 2997, 2959, 2932, 2873, 1641, 1456, 1416, 1379, 1126, 1069, 1026, 995, 910, 845, 642 cm^{-1}.

5-(4-Toluenesulfonyloxy)oct-1-ene (45):

Tosyl chloride (3.81 g, 20 mmol) was added in portions to a stirred solution of **44** (1.95 g, 15.22 mmol) in CH_2Cl_2 (15 mL) and pyridine (5 mL) at 0 °C. After 6 h at r.t., the reaction was quenched with H_2O (40 mL), the aqueous layer was extracted with CH_2Cl_2 (2 × 30 mL), the combined organic phases were successively washed with 10 % HCl, aq sat. $NaHCO_3$ and brine (30 mL each), dried (Na_2SO_4) and evaporated to dryness. Flash chromatography (hexane/EtOAc 20:1) afforded **45** as a colorless liquid (4.02 g, 93 %).

^1H NMR (200 MHz, $CDCl_3$): $\delta = 7.80$ (d, 2 H, $J = 8.4$ Hz), 7.33 (d, 2 H, $J = 8.5$ Hz), 5.69 (ddt, 1 H, $J = 17.6$, 9.7, 6.5 Hz), 5.00–4.90 (m, 2 H), 4.60 (quint., 1 H, $J = 6.0$ Hz), 2.44 (s, 3 H), 2.12–1.96 (m, 2 H), 1.72–1.51 (m, 4 H), 1.37–1.16 (m, 2 H), 0.82 (t, 3 H, $J = 7.2$ Hz).

^{13}C NMR (50 MHz, $CDCl_3$): $\delta = 144.4$, 137.2, 134.7, 129.7, 127.7, 115.3, 83.4, 36.2, 33.3, 28.9, 21.6, 18.0, 13.8.

UV (hexane): λ_{max} (log ε) = 224 (4.20), 262 (2.90), 268 (2.85), 273 (2.78).

IR (neat): $\nu = 3077$, 2961, 2936, 2875, 1642, 1599, 1496, 1456, 1359, 1188, 1176, 1097, 907, 816, 733, 688, 666, 576, 556 cm^{-1}.

Table 3. Characteristic Spectroscopic Data of the Dienes

Substrate	IR (cm^{-1})	^1H NMR ($CDCl_3$) δ, J (Hz)	^{13}C NMR ($CDCl_3$) resolved signals (δ)	MS (70 eV) m/z (%)
3	1738	5.88–5.70 (m, 2H), 5.05–4.91 (m, 4H), 4.07 (t, 2H, J = 6.6), 2.29 (t, 2H, J = 7.7), 2.16–1.98 (m, 4H), 1.72–1.30 (m, 16H)	173.9, 139.1, 138.3, 114.9, 114.1, 64.1, 34.4, 33.8, 33.3, 29.4, 29.3, 29.1, 29.1, 28.9, 28.1, 25.2, 25.0	266 ([M$^+$], 1), 166 (7), 148 (12), 96 (11), 82 (100)
5	1738	5.87–5.68 (m, 2H), 5.07–4.90 (m, 4H), 4.06 (t, 2H, J = 6.7), 2.31 (t, 2H, J = 7.4), 2.16–1.99 (m, 4H), 1.80–1.55 (m, 4H), 1.37–1.30 (m, 12H)	173.6, 139.1, 137.6, 115.2, 114.1, 64.4, 33.8, 33.6, 33.1, 29.5, 29.4, 29.2, 29.1, 28.9, 28.7, 25.9, 24.1	266 ([M$^+$], 2), 154 (18), 115 (47), 96 (48), 82 (50), 69 (100), 55 (97)
(+)-13[a]	1738	5.90–5.70 (m, 2H), 5.05–4.91 (m, 4H), 3.92 (dd, 1H, J = 10.7, 6.0), 3.89 (dd, 1H, J = 10.7, 6.6), 2.31 (t, 2H, J = 7.3), 2.10–1.99 (m, 4H), 1.83–1.56 (m, 3H), 1.52–1.02 (m, 8H), 0.92 (d, 3H, J = 6.8)	173.9, 138.8, 138.7, 114.5, 114.4, 69.1, 34.4, 33.9, 33.6, 32.9, 32.5, 28.6, 28.5, 26.2, 24.9, 16.9	252 ([M$^+$], < 1), 125 (19), 110 (23), 95 (23), 81 (47), 69 (97), 55 (100)
23	1735	5.87–5.65 (m, 2H), 5.13–4.90 (m, 5H), 2.41–2.18 (m, 4H), 2.09–1.99 (m, 2H), 1.77–1.51 (m, 2H), 1.45–1.25 (m, 6H), 1.21 (d, 3H, J = 6.3)	173.3, 138.9, 133.8, 117.6, 114.3, 69.7, 40.3, 34.6, 33.7, 29.0, 28.7, 25.0, 19.5	224 ([M$^+$], 2), 183 (6), 165 (5), 139 (44), 121 (59), 95 (18), 69 (100), 55 (37), 41 (53)
25	1725	5.62–5.86 (m, 2H), 4.81–5.04 (m, 4H), 2.24 (t, 2H, J = 7), 1.90–2.10 (m, 4H), 1.69, (quint., 2H, J = 7), 1.20–1.57 (m, 11H), 1.17 (s, 3H), 1.14 (s, 3H)	173.1, 138.9, 137.7, 115.2, 114.1, 70.7, 35.8, 33.9, 33.7, 33.0, 29.2, 28.9, 28.7, 25.3, 24.1, 19.9	252 ([M$^+$], 2), 138 (18), 114 (83), 110 (19), 97 (100), 83 (39), 82 (31), 80 (31), 69 (74), 68 (53), 67 (28), 55 (77), 41 (61)
27[b]	1707	5.80 (ddt 2H, J = 17.0, 10.3, 6.6), 5.02–4.90 (m, 4H), 2.38 (t, 4H, J = 7.5), 2.07–1.99 (m, 4H), 1.63–1.51 (m, 4H), 1.43–1.26 (m, 12H)	211.5, 139.0, 114.4, 42.8, 33.7, 29.1, 28.9, 28.7, 23.8	250 ([M$^+$], 11), 221 (13), 139 (38), 121 (47), 111 (73), 96 (40), 81 (28), 69 (100)
29[c]	1758	5.88–5.69 (m, 2H), 5.37–5.26 (m, 1H), 5.06–4.91 (m, 4H), 2.39 (t, 2H, J = 7.7), 2.13–2.00 (m, 4H), 1.81–1.56 (m, 4H), 1.51–1.30 (m, 12H)	172.4, 139.2, 137.5, 123.9 (q, J = 279), 115.5, 114.2, 69.2 (q, J = 32), 34.0, 33.8, 33.0, 29.3, 29.2, 29.1, 29.0	334 ([M$^+$], 40), 314 (11), 292 (11), 185 (39), 167 (29), 150 (96), 124 (51), 111 (17), 96 (46), 81 (100), 67 (55), 55 (95), 41 (69)
31	1730	5.81 (ddt, 2H, J = 17.0, 10.2, 6.6), 5.06–4.91 (m, 4H), 2.20 (t, 2H, J = 7.3), 2.10–1.99 (m, 4H), 1.79–1.70 (m, 2H), 1.61–1.45 (m, 2H), 1.42 (s, 6H), 1.39–1.29 (m, 12H)	173.2, 139.2, 138.6, 114.1, 82.0, 40.4, 35.6, 33.9, 33.8, 29.4, 29.3, 29.2, 29.1, 28.9, 26.1, 25.2, 23.3	294 ([M$^+$], 2), 279 (2), 167 (11), 149 (18), 110 (35), 95 (19), 81 (16), 69 (100), 55 (30), 41 (21)
33	1741	5.80 (ddt, 2H, J = 17.0, 10.2, 6.6), 5.06–4.93 (m, 4H), 4.28 (s, 4H), 2.34 (t, 4H, J = 7.1), 2.13–2.01 (m, 4H), 1.78–1.58 (m, 4H), 1.50–1.35 (m, 4H), 1.42 (s, 6H), 1.39–1.29 (m, 12H)	173.4, 138.4, 114.8, 62.0, 33.4, 28.3, 24.3	282 ([M$^+$], 1), 155 (100), 110 (28), 99 (31), 82 (33), 68 (15), 55 (38), 41 (19)
35	3302, 1641	5.88–5.70 (m, 2H), 5.44 (s, 1H), 5.04–4.90 (m, 4H), 3.29–3.19 (m, 2H), 2.15 (t, 2H, J = 7.0), 2.10–1.99 (m, 4H), 1.65–1.22 (m, 20H)	172.3, 139.2, 138.9, 114.3, 114.1, 39.5, 37.0, 33.8, 33.7, 29.7, 29.3, 29.1, 28.9, 28.8, 26.8, 25.9	293 ([M$^+$], 65), 252 (27), 238 (14), 224 (15), 210 (16), 196 (32), 182 (65), 169 (44), 154 (93), 149 (18), 126 (61), 112 (47), 98 (27), 86 (36), 73 (47), 69 (66), 60 (51), 55 (100), 41 (75)
37	1739	δ 5.90–5.70 (m, 2H), 4.06 (t, 2H, J = 6.7), 2.28 (t, 2H, J = 7.6), 2.08–1.98 (m, 4H), 1.65–1.55 (m, 4H), 1.41–1.30 (m, 24H)	173.4, 138.6, 113.8, 113.7, 69.9, 34.0, 33.4, 29.1, 29.0, 28.9, 28.8, 28.7, 28.7, 28.7, 28.5, 28.5, 28.3, 25.5, 24.6	336 ([M$^+$], 8), 185 (7), 167 (12), 152 (28), 124 (20), 110 (29), 96 (51), 82 (67), 69 (65), 55 (100)

[a] $[\alpha]_D^{23} = +1.42$, $[\alpha]_{546}^{23} = +1.68$ (c = 16.45); HRMS ($C_{16}H_{28}O_2$) *calcd* 252.2089, *found* 252.2078.
[b] HRMS ($C_{17}H_{30}O$) *calcd* 250.2297, *found* 250.2302.
[c] ^{19}F NMR (282 MHz, $CDCl_3$): δ −77.8 ppm.

MS (EI) m/z (rel intensity): 239 (2), 227 (3), 173 (7), 155 (73), 110 (100), 91 (78), 81 (53), 68 (47), 54 (45), 41 (18).

$C_{15}H_{22}O_3S$ (282.40): calcd C 63.80, H 7.85, S 11.35; found C 63.88, H 7.79, S 11.45.

2-(1-Propylpent-4-enylamino)ethanol (46):
A solution of 2-aminoethanol (1.83 g, 30.0 mmol) and **45** (3.8 g, 13.5 mmol) in THF (20 mL) was refluxed for 60 h. The volatiles were removed in vacuo, sat. aq $NaHCO_3$ was added and the mixture

Table 4. Spectroscopic Data of the Macrocyclic Products Formed via RCM

Product	^{1}H NMR ($CDCl_3$) δ, J (Hz)	^{13}C NMR ($CDCl_3$) (δ)
4	5.45–5.28 (m, 2H), 4.18–4.07 (m, 2H), 2.37–2.29 (m, 2H), 2.10–2.00 (m, 4H), 1.72–1.54 (m, 4H), 1.49–1.30 (m, 10H)	173.9, 131.7, 130.4, 130.1, 129.6, 64.1, 64.0, 34.7, 33.9, 32.0, 29.1, 28.4, 28.4, 28.3, 28.2, 28.1, 28.0, 27.9, 27.6, 27.2, 27.1, 26.6, 26.5, 25.4, 25.2
6	5.36–5.16 (m, 2H), 4.08 (t, 0.3H, J = 5.2), 4.05 (t, 1.7H, J = 5.3), 2.28 (t, 2H, J = 7.2), 2.09–1.92 (m, 4H), 1.71–1.55 (m, 4H), 1.28–1.24 (m, 12H)	(*E*) isomer: δ 172.6, 131.2, 128.5, 63.5, 31.1, 31.0, 29.7, 27.3, 26.9, 26.8, 26.3, 25.9, 25.2, 25.0, 22.5; (*Z*) isomer (resolved signals): δ 172.7, 130.0, 127.8, 63.3, 33.1, 26.8, 25.9, 25.8, 25.5, 25.2, 25.1, 24.5, 24.4
(+)-14	5.29–5.24 (m, 2H), 4.06 (dd, 1H, J = 10.8, 3.5), 3.81 (dd, 1H, J = 10.8, 9.2), 2.37–2.30 (m, 2H), 2.11–1.18 (m, 15H), 0.89 (d, 3H, J = 6.8)	174.0, 131.6, 131.5, 68.4, 34.9, 32.3, 31.5, 31.2, 30.2, 28.1, 26.8, 25.3, 25.1, 15.9
16	5.41–5.15 (m, 2H), 3.98 (dd, 1H, J = 10.7, 3.6), 3.76 (dd, 1H, J = 10.7, 9.1), 2.49–2.39 (m, 1H), 2.31–2.25 (m, 2H), 2.03–1.88 (m, 2H), 1.54 (m, 2H), 1.27–1.15 (m, 10H), 0.94 (d, 3H, J = 7.0)	174.0, 133.9, 130.5, 69.4, 36.2, 35.0, 31.3, 26.8, 26.2, 25.9, 23.9, 23.8, 17.0
17	5.53–5.29 (m, 2H), 4.23 (t, 0.26H, J = 5.2), 4.12 (t, 1.74H, J = 5.4), 2.41–2.32 (m, 4H), 2.04–2.00 (m, 2H), 1.65–1.56 (m, 2H), 1.34–1.21 (m, 10H)	(*E*) isomer δ 174.0, 132.9, 127.8, 64.3, 35.1, 31.9, 31.3, 26.7, 26.3, 26.0, 25.8, 24.0, 23.9; (*Z*) isomer (resolved signals) δ 173.9, 132.3, 127.2, 63.7, 33.4, 27.8, 27.6, 26.1, 25.7, 25.6, 25.3, 23.6
19	5.35–5.25 (m, 2H), 3.51–3.27 (m, 3H), 3.00 (t, 1H, J = 9.6), 2.10–1.21 (m, 16H), 1.00–0.97 (m, 1H), 0.87 (d, 0.3H, J = 6.9), 0.82 (d, 2.7H, J = 6.8)	(*E*) isomer, resolved signals δ 131.5, 75.5, 70.1, 32.9, 31.7, 31.5, 30.2, 29.2, 28.3, 26.5, 26.4, 25.5, 16.2; (*Z*) isomer (resolved signals) δ 130.2, 74.0, 69.7, 33.5, 32.6, 28.7, 28.2, 27.8, 26.9, 26.3, 25.1, 24.8, 17.4
(*E*)-24	5.32–5.27 (m, 2H), 5.17–5.14 (m, 1H), 2.38–2.14 (m, 5H), 2.05–1.92 (m, 1H), 1.87–1.77 (m, 1H), 1.56–1.42 (m, 5H), 1.24 (d, 3H, J = 6.4), 1.20–1.08 (m, 2H)	173.4, 133.5, 127.0, 68.5, 41.0, 33.0, 30.3, 24.9, 24.7, 24.2, 23.2, 20.6
26	5.41–5.30 (m, 2H), 5.07–4.88 (m, 1H), 2.46–1.19 (m, 22H)	(*Z*) isomer δ 173.4, 130.9, 128.9, 69.3, 34.7, 33.8, 27.0, 26.6, 26.2, 25.2, 25.0, 25.0, 23.3, 20.7; (*E*) isomer δ 173.6, 132.3, 129.3, 69.7, 34.4, 32.6, 32.2, 31.3, 27.4, 27.1, 26.2, 24.3, 22.5, 20.4
28	5.38–5.19 (m, 2H), 2.40 (t, 4H, J = 5.9), 2.04–2.01 (m, 4H), 1.71–1.59 (m, 4H), 1.43–1.10 (m, 12H)	(*E*) isomer δ 211.4, 130.6, 41.2, 31.4, 27.9, 27.9, 26.5, 22.6; (*Z*) isomer (resolved signals) δ 130.1, 41.2, 28.1, 27.3, 25.4, 22.8
30	5.47–5.22 (m, 3H), 2.57–2.31 (m, 2H), 2.15–1.85 (m, 4H), 1.82–1.30 (m, 16H)	(*E*) isomer, resolved signals δ 172.4, 127.2, 125.7, 123.8 (q, J = 289), 64.5 (q, J = 47), 34.2, 31.9, 31.6, 28.1, 27.8, 27.5, 25.9, 25.5, 25.3; (*Z*) isomer (resolved signals) δ 64.8 (q, J = 53), 33.3, 28.3, 28.0, 27.7, 27.6, 27.2, 26.6, 24.8
32	5.43–5.23 (m, 2H), 2.28–2.19 (m, 2H), 2.09–1.98 (m, 4H), 1.87–1.74 (m, 2H), 1.64–1.50 (m, 2H), 1.42 (s, 6H), 1.31 (m, 12H)	(*E*) isomer δ 173.0, 131.6, 130.5, 82.7, 39.4, 36.1, 32.5, 32.0, 28.3, 28.2, 27.9, 27.3, 26.3, 26.0, 25.3, 23.9; (*Z*) isomer (resolved signals) δ 130.0, 129.8, 82.4, 39.7, 34.5, 28.4, 28.0, 27.6, 27.5, 27.4, 27.0, 26.6, 26.4, 24.8, 24.7
34	5.39–5.21 (m, 2H), 4.30 (s, 1H), 4.27 (s, 3H), 2.37–2.26 (m, 4H), 2.11–2.02 (m, 4H), 1.71–1.55 (m, 4H), 1.48–1.38 (m, 4H)	(*E*) isomer δ 173.4, 131.0, 61.8, 35.1, 32.1, 28.2, 24.9; (*Z*) isomer δ 173.3, 129.8, 61.9, 34.8, 28.8, 26.8, 25.1
36	5.65 (br s, 1H), 5.49–5.22 (m, 2H), 3.35–3.21 (m, 2H), 2.22–2.14 (m, 2H), 2.10–1.98 (m, 4H), 1.64–1.17 (m, 20H)	(*E*) isomer, resolved signals δ 173.1, 130.8, 130.6, 39.0, 36.8, 31.8, 31.6, 29.2, 29.1, 28.6, 28.5, 28.1, 27.5, 27.3, 26.4, 26.1; (*Z*) isomer, resolved signals δ 173.5, 130.0, 129.9, 38.8, 37.0, 29.8, 29.6, 29.4, 28.4, 27.7, 26.8, 26.3, 26.2, 25.9
38	5.44–5.28 (m, 2H), 4.11 (td, 2H, J = 5.6, 1.7), 2.31 (t, 2H, J = 6.4), 2.03–1.98 (m, 4H), 1.68–1.58 (m, 4H), 1.45–1.23 (m, 22H)	174.0, 173.9, 130.9, 130.6, 130.1, 130.0, 64.2, 64.0, 34.8, 34.5, 32.0, 31.7, 29.5, 29.4, 29.2, 29.1, 29.1, 29.0, 29.0, 28.8, 28.7, 28.7, 28.5, 28.4, 28.0, 27.7, 26.7, 26.6, 26.2, 25.9, 25.2

extracted with Et_2O (3 × 30 mL). The combined organic phases were dried (Na_2SO_4) and evaporated to dryness. Flash chromatography (hexane/EtOAc 10:1, then MeOH) furnished **46** as a colorless syrup (1.95 g, 84%).

^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.82 (ddt, 1H, J = 17.0, 10.2, 5.6 Hz), 5.08–4.92 (m, 2H), 3.60 (t, 2H, J = 5.0 Hz), 2.76 (t, 2H, J = 4.8 Hz), 2.53 (quint., 1H, J = 5.8 Hz), 2.13–2.04 (m, 4H), 1.54–1.17 (m, 6H), 0.95–0.88 (m, 3H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.7, 114.5, 61.2, 56.4, 48.0, 36.5, 33.4, 30.1, 18.9, 14.3.

IR (neat): ν = 3310, 3204, 3078, 2957, 2871, 1641, 1458, 1377, 1332, 1062, 996, 910, 742 cm^{-1}.

MS (EI) m/z (rel intensity): 171 ([M$^+$], 0.3), 140 (18), 128 (96), 116 (100), 84 (14), 56 (12).

$C_{10}H_{21}NO$ (171.28): calcd C 70.12, H 12.36, N 8.18; found C 69.84, H 12.28, N 8.07.

2-(1-Propylpent-4-enylamino)ethyl Hex-5-enoate (47):

A mixture of hex-5-enoic acid (680 mg, 5.8 mmol), **46** (1.00 g, 5.8 mmol) and 4-TsOH · H_2O (1.12 g, 5.9 mmol) in toluene (70 mL) was refluxed in a Dean–Stark apparatus for 5 h. The solvent was removed in vacuo, the residue stirred with sat. aq $NaHCO_3$ (50 mL) for 10 min, the mixture was extracted with Et_2O (2 × 30 mL), the combined organic phases were dried (Na_2SO_4) and evaporated.

Table 5. IR- and MS Data of the Macrocyclic Products Formed via RCM[a]

Product	IR (cm^{-1})	Formula	HRMS *calcd*	*found*	MS (EI, 70 eV) *m/z* (rel. %)
4	3000, 2928, 2856, 1736, 1461, 1385, 1346, 1252, 1234, 1168, 1152, 1113, 1085, 1024, 969, 719	$C_{15}H_{26}O_2$	238.1933	238.1920	238 ([M$^+$], 20), 210 (18), 109 (17), 96 (49), 82 (100), 67 (64), 55 (64)
6	3005, 2934, 2850, 1738, 1452, 1350, 1254, 1240, 1170, 969, 714	$C_{15}H_{26}O_2$	238.1933	238.1910	238 ([M$^+$], 48), 126 (26), 110 (18), 96 (55), 82 (100), 67 (83)
(+)-**14**[b]	3024, 2929, 2856, 1734, 1461, 1444, 1378, 1341, 1252, 1206, 1168, 1148, 1116, 1007, 970, 737	$C_{14}H_{24}O_2$	224.1776	224.1755	224 ([M$^+$], 24), 109 (23), 95 (51), 81 (100), 67 (69)
16	2931, 2859, 1729, 1663, 1458, 1372, 1334, 1319, 1256, 1179, 1144, 1084, 1011, 970, 807, 703	$C_{14}H_{24}O_2$	224.1776	224.1756	224 ([M$^+$], 33), 168 (18), 150 (32), 109 (23), 95 (88), 82 (100)
17	3031, 2930, 2859, 1734, 1457, 1444, 1381, 1348, 1394, 1252, 1082, 968, 717	$C_{13}H_{22}O$			210 ([M$^+$], 41), 160 (13), 109 (18), 95 (34), 81 (58), 68 (100)
19	3025, 2926, 2851, 2790, 1460, 1443, 1377, 1368, 1353, 1121, 1088, 967, 719	$C_{14}H_{26}O$	210.1984	210.1980	210 ([M$^+$], 44), 121 (12), 109 (21), 95 (45), 81 (100), 67 (60), 55 (44)
(*E*)-**24**	2976, 2934, 2855, 1731, 1449, 1365, 1349, 1320, 1268, 1249, 1225, 1187, 1159, 1122, 1079, 1046, 976, 962, 947, 829, 762, 709	$C_{12}H_{20}O_2$	196.1463	196.1450	196 ([M$^+$], 60), 152 (34), 123 (9), 109 (20), 98 (100), 84 (21), 67 (28), 54 (30), 41 (27)
26	3000, 2930, 2857, 1732, 1653, 1460, 1414, 1374, 1345, 1293, 1246, 1206, 1172, 1132, 1107, 1042, 1022, 971, 877, 806, 719	$C_{14}H_{24}O$			224 ([M$^+$], 10), 126 (30), 95 (43), 81 (100), 67 (93), 55 (77)
28	2927, 2854, 1713, 1460, 1440, 1409, 1365, 1120, 971, 730, 702	$C_{15}H_{26}O$	222.1984	222.1939	222 ([M$^+$], 34), 165 (30), 152 (23), 125 (25), 108 (37), 98 (64), 81 (72), 67 (77)
30[c]	2930, 2857, 1755, 1461, 1442, 1398, 1367, 1284, 1236, 1179, 1129, 1096, 1046, 971, 923, 698	$C_{16}H_{25}F_3O_2$	306.1807	306.1819	306 ([M$^+$], 100), 288 (27), 268 (24), 222 (10), 152 (19), 139 (15), 98 (59), 81 (70), 67 (70), 55 (65), 41 (65)
32	2929, 2856, 1729, 1459, 1441, 1385, 1368, 1260, 1241, 1185, 1121, 1101, 967	$C_{17}H_{30}O_2$	266.2246	266.2228	266 ([M$^+$], 9), 251 (10), 210 (100), 150 (18), 136 (8), 123 (13), 109 (35), 95 (49), 82 (60), 68 (77), 55 (52), 41 (63)
34[d]	2931, 2854, 1733, 1462, 1439, 1398, 1371, 1296, 1275, 1257, 1223, 1169, 1102, 1072, 1035, 965, 874	$C_{14}H_{22}O_4$			254 ([M$^+$], 44), 236 (60), 192 (100), 164 (18), 150 (20), 136 (16), 109 (29), 98 (61), 79 (24), 67 (35), 55 (26), 41 (31)
36[e]	3300, 3085, 3003, 2923, 2849, 2684, 1639, 1552, 1461, 1434, 1360, 1267, 1243, 1193, 1123, 1082, 1026, 966, 909, 726, 610	$C_{17}H_{31}NO$			265 ([M$^+$], 100), 236 (8), 222 (12), 182 (9), 168 (11), 154 (10), 140 (11), 126 (11), 112 (13), 100 (25), 81 (25), 67 (31), 55 (52), 41 (55)
38	3001, 2926, 2854, 1737, 1462, 1385, 1348, 1252, 1236, 1175, 1117, 1090, 1066, 1030, 969, 722	$C_{20}H_{36}O_2$	308.2715	308.2720	308 ([M$^+$], 32), 290 (11), 124 (18), 110 (23), 96 (74), 82 (100)

[a] All compounds gave satisfactory elemental analyses: C ± 0.35, H ± 0.28.
[b] $[\alpha]_D^{23} = +31.48$, $[\alpha]_{546} = +32.24$ ($c = 5.0$, CH_2Cl_2).
[c] ^{19}F NMR ($CDCl_3$) (*E*) isomer δ −77.4; (*Z*) isomer δ −77.5.
[d] mp 46–47 °C.
[e] mp 106.5–107 °C.

Flash chromatography (Alox, hexane/EtOAc 10:1) afforded **47** as a colorless syrup (1.18 g, 76%).

^1H NMR (200 MHz, $CDCl_3$): δ = 5.89–5.68 (m, 2H), 5.07–4.93 (m, 4H), 4.16 (t, 2H, J = 5.3 Hz), 2.83 (t, 2H, J = 5.4 Hz), 2.53 (quint., 1H, J = 5.8 Hz), 2.33 (t, 2H, J = 7.6 Hz), 2.15–2.03 (m, 4H), 1.73 (d quint., 2H, J = 7.1, 1.1 Hz), 1.53–1.21 (m, 7H), 1.01–0.88 (m, 3H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 173.5, 138.8, 137.6, 115.3, 114.4, 64.3, 56.4, 45.3, 36.4, 33.5, 33.2, 33.1, 30.0, 24.1, 18.9, 14.3.

IR (neat): ν = 3453, 3350, 3078, 2957, 2931, 2872, 1739, 1641, 1459, 1377, 1245, 1170, 1108, 1027, 994, 911, 710, 640 cm^{-1}.

MS (EI) *m/z* (rel intensity): 267 ([M$^+$], 2), 238 (1), 224 (100), 212 (100), 154 (11), 141 (43), 128 (51), 116 (55), 99 (13), 84 (31), 69 (29), 55 (16), 41 (35).

HRMS ($C_{16}H_{29}NO_2$): calcd 267.2198, found 267.2183.

$C_{16}H_{29}NO_2$ (267.41): calcd C 71.87, H 10.93, N 5.24; found C 71.81, H 10.87, N 5.34.

***N*-(9-Fluorenylmethoxycarbonyl)-2-(1-propylpent-4-enylamino)ethyl Hex-5-enoate (11):**

9-Fluorenylmethyl chloroformate (310 mg, 1.2 mmol) in THF (5 mL) was added dropwise at 0 °C to a slurry of amine **47** (260 mg, 0.97 mmol) in THF (5 mL) and aq $NaHCO_3$ (10% w/w, 10 mL). After stirring for 4.5 h at that temperature, a standard extractive workup followed by final flash chromatography (hexane/EtOAc 12:1 → 10:1) afforded **11** as a colorless syrup (328 mg, 90%).

^1H NMR (200 MHz, $CDCl_3$): δ = 7.75 (d, 2H, J = 6.9 Hz), 7.58 (d, 2H, J = 7.1 Hz), 7.42–7.26 (m, 4H), 5.86–5.51 (m, 2H), 5.06–4.86 (m, 4H), 4.60 (d, 2H, J = 5.3 Hz), 4.22 (t, 1H, J = 5.1 Hz), 4.13 (t, 1H, J = 5.8 Hz), 3.96 (quint., 1H, J = 7.1 Hz), 3.77 (t, 1H, J = 6.6 Hz), 3.25 (t, 1H, J = 6.5 Hz), 3.01 (t, 1H, J = 6.7 Hz), 2.27 (td, 2H, J = 7.6, 1.6 Hz), 2.13–2.02 (m, 2H), 1.90 (quint., 1H, J = 6.6 Hz), 1.77–1.62 (m, 3H), 1.53–0.97 (m, 6H), 0.86 (t, 1.5H, J = 7.0 Hz), 0.72 (t, 1.5H, J = 6.6 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 172.9, 172.7, 156.6, 156.5, 144.1, 141.5, 138.0, 137.9, 137.7, 127.7, 127.1, 124.7, 124.6, 120.0, 115.5,

114.8, 66.6, 62.4, 62.1, 56.2, 47.7, 47.5, 41.4, 35.4, 33.4, 33.1, 32.5, 30.6, 24.0, 19.6, 14.0, 13.9.

IR (neat): ν = 3070, 2957, 2932, 2871, 1738, 1698, 1641, 1451, 1416, 1386, 1342, 1319, 1294, 1232, 1165, 1128, 1109, 1054, 995, 913, 759, 741, 621 cm^{-1}.

MS (EI) *m/z* (rel intensity): 489 ([M^+], 0.3), 178 (100).

$C_{31}H_{39}NO_4$ (489.65): calcd C 76.04, H 8.03, N 2.86; found C 75.97, H 7.99, N 2.83.

N-(9-Fluorenylmethoxycarbonyl)-5-propyl-1-oxa-4-azacyclotridec-8-en-13-one (12):

Solutions of the diene **11** (290 mg, 0.59 mmol) and the carbene complex **1** (27 mg, 0.03 mmol, 5 mol%) in CH_2Cl_2 each (30 mL) were added simultaneously to CH_2Cl_2 (30 mL) with vigorous stirring over a period of 24 h at r.t. The solvent was evaporated and the residue purified by flash chromatography (hexane/EtOAc 10:1 → 8:1) to afford compound **12** as colorless crystals (241 mg, 84%); mp 148.5–149.5 °C.

^{1}H NMR (200 MHz, $CDCl_3$, rotamers): δ = 7.77–7.70 (m, 2H), 7.59–7.56 (m, 2H), 7.41–7.23 (m, 4H), 5.49–5.32 (m, 1H), 5.19–5.07 (m, 1H), 4.78–4.47 (m, 2H), 4.24–3.47 (m, 4H), 3.09–2.74 (m, 2H), 2.35–1.89 (m, 6H), 1.65 (m, 1H), 1.46–0.69 (m, 10H).

^{13}C NMR (50 MHz, $CDCl_3$, rotamers): δ = 174.0, 157.1, 156.9, 144.9, 144.0, 143.9, 141.5, 141.4, 141.3, 131.5, 131.3, 127.6, 127.5, 127.2, 127.1, 127.0, 126.9, 124.7, 124.6, 124.5, 119.9, 119.9, 119.8, 66.4, 63.3, 62.8, 56.3, 47.6, 47.4, 41.2, 40.7, 35.8, 34.0, 32.9, 32.5, 31.5, 31.4, 25.3, 25.1, 25.0, 24.4, 24.3, 22.6, 19.3, 14.0, 13.8, 13.7.

IR (KBr): ν = 3066, 3040, 2997, 2957, 2930, 2862, 1725, 1687, 1450, 1441, 1415, 1335, 1289, 1227, 1157, 1139, 1021, 740 cm^{-1}.

MS (EI) *m/z* (rel intensity): 461 ([M^+], 0.5), 178 (100).

$C_{29}H_{35}NO_4$ (461.60): calcd C 75.46, H 7.64, N 3.03; found C 75.32, H 7.56, N 2.96.

5-Propyl-1-oxa-4-azacyclotridecan-13-one (39):

The *N*-Fmoc protected azamacrolide **12** (135 mg, 0.29 mmol) dissolved in EtOAc (10 mL) was stirred under H_2 (1 bar) in the presence of Pd on charcoal (31 mg, 5% w/w, 5 mol%) for 4 h. The mixture was filtered through a plug of alumina which was washed several times with EtOAc. After evaporation of the solvent, the residue was dissolved in THF (10 mL) and treated with Bu_4NF (0.6 mL, 1 M in THF) for 10 min at r.t. A standard extractive workup followed by flash chromatography (Alox, hexane/EtOAc 5:1) of the crude product afforded the azamacrolide **39** as a colorless syrup (58 mg, 83%).

^{1}H NMR (200 MHz, $CDCl_3$): δ = 4.28–4.15 (m, 2H), 3.07–2.97 (m, 1H), 2.85–2.69 (m, 1H), 2.52–2.26 (m, 3H), 1.74–1.61 (m, 1H), 1.50–1.17 (m, 16H), 0.94–0.88 (m, 3H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 173.7, 64.4, 56.5, 46.5, 37.5, 34.8, 32.1, 26.5, 26.0, 25.6, 23.8, 22.4, 19.3, 14.4.

IR (neat): ν = 3446, 3353, 2955, 2930, 2861, 1733, 1459, 1377, 1330, 1246, 1192, 1155, 1104, 1027 cm^{-1}.

MS (EI) *m/z* (rel intensity): 241 ([M^+], 5), 226 (4), 198 (100), 176 (11), 97 (12).

HRMS ($C_{14}H_{27}NO_2$): calcd 241.2042, found 241.2035.

Dec-9-en-4-ol (48):

A solution of 6-bromohex-1-ene (2.00 g, 12.27 mmol) in Et_2O (10 mL) was added dropwise to a suspension of Mg turnings (300 mg, 12.34 mmol) activated by two drops of 1.2-dibromoethane in Et_2O (5 mL) at such a rate as to maintain a gentle reflux. After stirring for 30 min at that temperature, a solution of butanal (864 mg, 1.08 mL, 12 mmol) in Et_2O (5 mL) was added dropwise to the Grignard reagent formed and the mixture was stirred for 1.5 h. Treatment with aq NH_4Cl followed by an extractive workup and flash chromatography (hexane/EtOAc 15:1) gave alcohol **48** as a colorless liquid (1.39 g, 74%).

^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.81 (ddt, 1H, J = 17.0, 10.2, 6.7 Hz), 5.05–4.91 (m, 2H), 3.62–3.57 (m, 1H), 2.11–2.01 (m, 2H), 1.70 (s, 1H), 1.61–1.23 (m, 10H), 0.98–0.86 (m, 3H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.9, 114.4, 71.6, 39.7, 37.3, 33.7, 29.0, 25.2, 18.9, 14.2.

IR (neat): ν = 3354, 3078, 2958, 2931, 2877, 2861, 1641, 1464, 1378, 1126, 992, 910 cm^{-1}.

MS (EI) *m/z* (rel intensity): 110 (18), 95 (90), 82 (13), 73 (51), 69 (33), 55 (100).

$C_{10}H_{20}O$ (156.15): calcd C 76.86, H 12.90; found C 76.76, H 12.83.

7-(4-Toluenesulfonyloxy)dec-1-ene (49):

Tosyl chloride (1.14 g, 6.0 mmol) was added in portions to a stirred solution of **48** (500 mg, 3.20 mmol) in CH_2Cl_2 (15 mL) and pyridine (5 mL) at 0 °C. After stirring for 24 h at ambient temperature, the reaction was quenched with H_2O (30 mL). A standard extractive workup followed by flash chromatography (hexane/EtOAc 25:1) afforded **49** as a colorless syrup (901 mg, 91%).

^{1}H NMR (200 MHz, $CDCl_3$): δ = 7.79 (dt, 2H, J = 8.4, 1.9 Hz), 7.37 (d, 2H, J = 8.1 Hz), 5.74 (ddt, 1H, J = 17.0, 10.3, 6.6 Hz), 5.00–4.89 (m, 2H), 4.57 (quint., 1H, J = 5.9 Hz), 2.44 (s, 3H), 2.04–1.90 (m, 2H), 1.69–1.50 (m, 4H), 1.37–1.09 (m, 6H), 0.83 (t, 3H, J = 7.1 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 144.4, 138.4, 134.8, 129.6, 127.7, 114.5, 84.2, 36.3, 34.0, 33.5, 28.6, 24.1, 21.6, 18.0, 13.8.

IR (neat): ν = 3074, 2960, 2934, 2873, 1641, 1599, 1458, 1361, 1188, 1176, 1097, 902, 815, 665, 577, 556 cm^{-1}.

MS (EI) *m/z* (rel intensity): 240 (5), 227 (9), 173 (13), 155 (98), 138 (50), 110 (80), 96 (98), 91 (100), 81 (68), 67 (83), 54 (97).

$C_{17}H_{26}O_3S$ (310.16): calcd C 65.77, H 8.45; found C 65.63, H 8.34.

2-(1-Propylhept-6-enylamino)ethanol (50):

A solution of **49** (1.70 g, 5.48 mmol) and 2-aminoethanol (1.003 g, 16.44 mmol) in THF (30 mL) was refluxed for 72 h. The solvent was removed in vacuo, sat. aq $NaHCO_3$ (50 mL) was added and the mixture was extracted with Et_2O (3 × 40 mL). Drying (Na_2SO_4), evaporation of the solvent and flash chromatography (hexane/EtOAc 10:1 → MeOH) provided **50** as a colorless syrup (929 mg, 85%).

^{1}H NMR (200 MHz, $CDCl_3$): δ = 5.81 (ddt, 1H, J = 17.0, 10.2, 6.7 Hz), 5.05–4.91 (m, 2H), 3.61 (t, 2H, J = 5.1 Hz), 2.73 (t, 2H, J = 5.1 Hz), 2.49 (s, 3H), 2.07–2.01 (m, 2H), 1.47–1.23 (m, 10H), 0.95–0.88 (m, 3H).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 138.9, 114.3, 61.1, 57.1, 48.2, 36.5, 33.9, 33.7, 29.2, 25.2, 19.9, 14.3.

IR (neat): ν = 3313, 3077, 2956, 2930, 2859, 1641, 1463, 1357, 1062, 992, 909 cm^{-1}.

MS (EI) *m/z* (rel intensity): 199 ([M^+], 4), 168 (12), 156 (57), 116 (100), 95 (5), 74 (9).

HRMS ($C_{12}H_{25}NO$): calcd 199.1936, found 199.1922.

$C_{12}H_{25}NO$ (199.19): calcd C 72.29, H 12.65, N 7.03; found C 72.22, H 12.56, N 7.13.

2-(1-Propylhept-6-enylamino)ethyl Hex-5-enoate (51a):

A mixture of hex-5-enoic acid (456 mg, 4 mmol), **50** (800 mg, 4.02 mmol) and 4-TsOH · H_2O (780 mg, 4.1 mmol) in toluene (70 mL) was refluxed in a Dean–Stark apparatus for 5 h. The solvent was removed in vacuo, the residue was dissolved in EtOAc (50 mL) and neutralized with sat. aq $NaHCO_3$. Drying of the organic phases (Na_2SO_4), evaporation of the organic layer followed by flash chromatography (Alox, hexane/EtOAc 5:1) afforded **51a** as a pale yellow syrup (947 mg, 80%).

^{1}H NMR (300 MHz, $CDCl_3$): δ = 5.85–5.79 (m, 2H), 5.05–4.96 (m, 4H), 4.18–4.14 (m, 2H), 2.83 (t, 2H, J = 5.5 Hz), 2.50–2.48 (m, 1H), 2.36–2.28 (m, 2H), 2.13–2.04 (m, 5H), 1.78–1.68 (m, 2H), 1.47–1.23 (m, 10H), 0.94–0.85 (m, 3H).

^{13}C NMR (75 MHz, $CDCl_3$): δ = 173.5, 138.9, 137.7, 115.4, 114.4, 64.3, 57.0, 45.3, 36.4, 33.9, 33.8, 33.5, 33.1, 29.2, 25.2, 24.1, 19.0, 14.3.

IR (neat): ν = 3454, 3358, 3078, 2956, 2931, 2858, 1739, 1641, 1460, 1374, 1238, 1171, 993, 912, 734 cm^{-1}.

MS (EI) *m/z* (rel intensity): 295 ([M$^+$], 6), 252 (73), 212 (100), 168 (10), 156 (32), 141 (43), 116 (45).

HRMS ($C_{18}H_{33}NO_2$): calcd 295.2514, found 295.2513.

$C_{18}H_{33}NO_2$ (295.25): calcd C 73.16, H 11.26, N 4.74; found C 72.97, H 11.20, N 4.64.

N-(9-Fluorenylmethoxycarbonyl)-2-(1-propylhept-6-enylamino)ethyl Hex-5-enoate (51c):

9-Fluorenylmethyl chloroformate (155 mg, 0.60 mmol) in THF (5 mL) was added slowly at 0 °C to a stirred solution of **51a** (150 mg, 0.51 mmol) in THF (5 mL) and 10% aq $NaHCO_3$ (10 mL). After stirring for 4 h at that temperature, the mixture was extracted with Et_2O (3 × 20 mL), the organic phases were dried (Na_2SO_4) and the solvent was removed in vacuo. Flash chromatography provided **51c** as a colorless syrup (244 mg, 92%).

^{1}H NMR (200 MHz, $CDCl_3$, rotamers): δ = 7.75 (d, 2H, J = 6.8 Hz), 7.57 (d, 2H, J = 7.2 Hz), 7.43–7.25 (m, 4H), 5.86–5.66 (m, 2H), 5.07–4.89 (m, 4H), 4.59 (s, 1H), 4.57 (s, 1H), 4.22 (t, 1H, J = 5.8 Hz), 4.12 (t, 1H, J = 6.5 Hz), 3.95 (q, 1H, J = 7.1 Hz), 3.79 (t, 1H, J = 6.7 Hz), 3.25 (t, 1H, J = 6.5 Hz), 3.02 (t, 1H, J = 6.8 Hz), 2.27 (t, 2H, J = 7.7 Hz), 2.13–1.91 (m, 4H), 1.70 (q, 2H, J = 7.3 Hz), 1.40–0.98 (m, 10H), 0.89–0.82 (m, 1.5H), 0.73 (t, 1.5H, J = 6.5 Hz).

^{13}C NMR (50 MHz, $CDCl_3$, rotamers): δ = 173.4, 173.1, 156.8, 156.5, 144.1, 141.3, 138.7, 137.5, 127.5, 127.0, 124.6, 124.5, 119.9, 115.4, 115.3, 114.4, 66.5, 62.4, 62.0, 56.4, 47.5, 47.3, 41.1, 35.5, 35.4, 33.6, 33.3, 33.1, 33.0, 28.7, 28.6, 25.8, 23.9, 19.5, 13.9, 13.8.

IR (neat): ν = 3071, 2931, 2861, 1738, 1698, 1641, 1451, 1416, 1344, 1293, 1232, 1166, 994, 912, 740 cm^{-1}.

MS (EI) *m/z* (rel intensity): 517 ([M$^+$], <0.1), 252 (2), 212 (3), 178 (100).

$C_{33}H_{43}NO_4$ (517.32): calcd C 76.55, H 8.38, N 2.71; found C 76.68, H 8.39, N 2.74.

N-(9-Fluorenylmethoxycarbonyl)-5-propyl-1-oxa-4-azacyclopentadec-10-en-15-one (52c):

A solution of diene **51c** (100 mg, 0.19 mmol) and the carbene complex **1** (10 mg, 0.001 mmol, 5 mol%) in CH_2Cl_2 each (30 mL) were simultaneously added at r.t. to CH_2Cl_2 (30 mL) with vigorous stirring over a period of 36 h. The solvent was evaporated and the residue purified by flash chromatography to afford **52c** as a pale yellow syrup (83 mg, 89%).

^{1}H NMR (300 MHz, $CDCl_3$, rotamers): δ = 7.77–7.73 (m, 2H), 7.57 (m, 2H), 7.40–7.27 (m, 4H), 5.36–5.19 (m, 2H), 4.65–4.48 (m, 2H), 4.22–2.90 (m, 6H), 2.31–2.19 (m, 2H), 2.06–0.67 (m, 19H).

^{13}C NMR (75 MHz, $CDCl_3$, rotamers): δ = 173.6, 144.4, 144.3, 144.1, 141.6, 141.5, 133.1, 132.8, 131.8, 129.4, 129.2, 129.1, 127.6, 127.0, 124.8, 124.4, 119.9, 66.3, 64.6, 64.2, 63.9, 63.6, 47.7, 47.4, 35.6, 35.5, 35.3, 35.3, 33.8, 33.1, 31.9, 31.7, 31.6, 31.2, 30.0, 29.5, 29.2, 26.8, 25.7, 25.2, 23.4, 22.6, 22.1, 19.8, 14.1, 13.9.

IR (neat): ν = 3066, 3040, 3017, 2955, 2929, 2858, 1736, 1695, 1451, 1413, 1387, 1378, 1344, 1293, 1269, 1227, 1193, 1158, 1131, 1110, 1055, 1022, 972, 758, 740 cm^{-1}.

MS (EI) *m/z* (rel intensity): 489 ([M$^+$], <1), 224 (3), 178 (100).

HPLC analysis of this material shows that it consists of two isomers in a ratio of 1.97:1. Separation of 333.7 mg of the mixture of isomers was achieved using a Zorbax PSM 60 column at 308 K with hexane/propan-2-ol (99.3:0.7) as eluent at a flow rate of 20 mL/min to afford 124 mg of (*E*)-**52c** and 74 mg of (*Z*)-**52c**.

Epilachnene (40) and its (*E*)-Isomer:

A solution of (*Z*)-**52c** (52 mg, 0.11 mmol) and Bu_4NF (1 M, 0.5 mL) in THF (10 mL) was stirred for 5 min. Dilution of the mixture with H_2O (5 mL) followed by a standard extractive workup and a final flash chromatography (Alox, hexane/EtOAc 10:1) provided epilachnene as a colorless syrup (27 mg, 89%).

^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.42–5.36 (m, 1H), 5.30–5.24 (m, 1H), 4.36–4.31 (m, 1H), 3.99–3.94 (m, 1H), 2.98 (ddd, 1H, J = 11.0, 8.0, 3.0 Hz), 2.77 (ddd, 1H, J = 12.0, 6.8, 2.1 Hz), 2.46–2.31 (m, 3H), 2.20–2.02 (m, 4H), 1.85–1.79 (m, 1H), 1.72–1.68 (m, 1H), 1.43–1.12 (m, 11H), 0.90 (t, 3H, J = 6.9 Hz).

^{13}C NMR (100 MHz, $CDCl_3$): δ = 173.6, 131.4, 129.4, 63.4, 56.3, 45.6, 38.2, 34.2, 32.2, 28.8, 27.5, 25.8, 25.6, 24.1, 19.2, 14.4.

IR (neat): ν = 3001, 2955, 2933, 2853, 1737, 1653, 1459, 1447, 1383, 1310, 1159, 863, 696 cm^{-1}.

MS (EI) *m/z* (rel intensity): 267 ([M$^+$], 21), 252 (6), 224 (100), 170 (18), 116 (8), 97 (22), 84 (18), 67 (12).

The experimental data are in accordance with those reported in the literature.[23,24]

The *trans*-isomer of epilachnene has been obtained analogously from (*E*)-**52c** and exhibits the following spectroscopic properties:

^{1}H NMR (400 MHz, $CDCl_3$): δ = 5.35–5.25 (m, 2H), 4.30 (ddd, 1H, J = 11.2, 6.8, 2.6 Hz), 3.98 (ddd, 1H, J = 11.3, 6.9, 2.7 Hz), 2.87 (ddd, 1H, J = 13.2, 6.8, 2.7 Hz), 2.71 (ddd, 1H, J = 13.2, 7.0, 2.7 Hz), 2.42–2.33 (m, 3H), 2.21–2.11 (m, 1H), 2.08–1.99 (m, 3H), 1.88–1.77 (m, 1H), 1.73–1.61 (m, 1H), 1.44–1.17 (m, 11H), 0.89 (t, 3H, J = 7.1 Hz).

^{13}C NMR (50 MHz, $CDCl_3$): δ = 173.6, 132.6, 129.7, 63.3, 56.3, 45.6, 38.3, 33.8, 32.0, 31.6, 31.3, 28.7, 24.0, 22.5, 19.5, 14.4.

IR (neat): ν = 3449, 3359, 3026, 2954, 2927, 2854, 1740, 1458, 1439, 1413, 1385, 1346, 1233, 1209, 1175, 1159, 1014, 969, 732, 718 cm^{-1}.

The MS spectrum is identical to that of epilachnene.

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