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Ring-Closing Metathesis Approach to Heteroaromatic Cations: Synthesis of Benzo[*a*]quinolizinium Salts

Ana Nuñez,[a] Beatriz Abarca,[a] Ana M. Cuadro,*[a] Julio Alvarez-Builla,[a] and Juan J. Vaquero*[a]

Dedicated to Professor José Barluenga on the occasion of his 70th birthday

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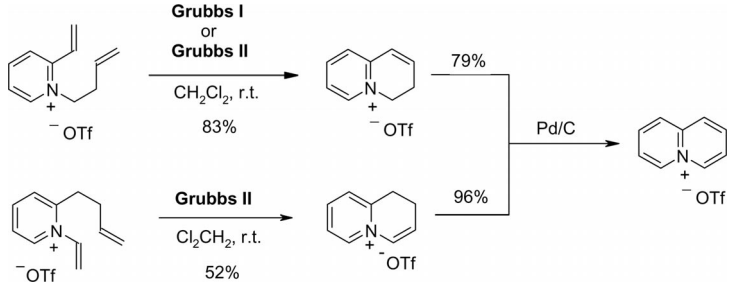
Benzo[*a*]quinolizinium salts have been synthesized through ring-closing metathesis reactions of 1-butenyl-2-vinylisoquinolinium, 2-butenyl-1-vinylisoquinolinium and 2-styryl-1-vinylpyridinium salts in the presence of Grubbs and Hoveyda–Grubbs catalysts. The results show that the last approach is the most efficient for the preparation of this heteroaromatic tricyclic system and several previously unknown derivatives have been prepared.

Introduction

The use of the ring-closing metathesis (RCM) reaction[1] in the construction of nitrogen heterocycles from azadiene substrates has become increasingly popular in the recent years.[2] Although the azadienes most commonly used in cyclization reactions have so far been protected dialkenylamines, a significant number of works have involved the use of different types of alkenyl enamides[3] and enamines[4] to build up a variety of aromatic heterocycles and macrocycles. Our group recently reported RCM reactions of a new type of azinium azadiene, which allowed a novel approach to dihydroquinolizinium and quinolizinium cations from pyridinium salts in good overall yields under mild reaction conditions (Scheme 1).[5]

The success of the RCM reactions involving charged dienes of this class, particularly those based on 2-alkenyl-1-vinylpyridinium substrates, led us to explore the synthesis of benzo-, dibenzo- and naphthoquinolizinium systems from the appropriate azinium salts.

Formally, all of these heteroaromatic cations can be envisaged as polycyclic aromatic hydrocarbons in which one of the bridgehead carbons is replaced by an azonia nitrogen. Replacements in anthracene and phenanthrene lead to benzo[*a*]-, benzo[*b*]- and benzo[*c*]quinolizinium salts (**1**–**3**, Figure 1) and a total of 18 heteroaromatic cations (six dibenzoquinolizinium, ten naphthoquinolizinium, a pyridophenanthridinium and a quinoquinolizinium cation) can be envisaged from the six possible tetracyclic aromatic hydrocarbons.



Scheme 1. Approaches to the quinolizinium system by ring-closing metathesis.

Derivatives of the three isomeric benzoquinolizinium salts have proven useful in some important applications such as cyanine dyes[6] and highly fluorescent compounds used as probes for the detection of biomolecules.[7] Furthermore, these compounds also showed relevant biological ac-

[a] Departamento de Química Orgánica, Universidad de Alcalá, 28871 Alcalá de Henares, Madrid, Spain
Fax: +34-91-8854686
E-mail: juanjose.vaquero@uah.es

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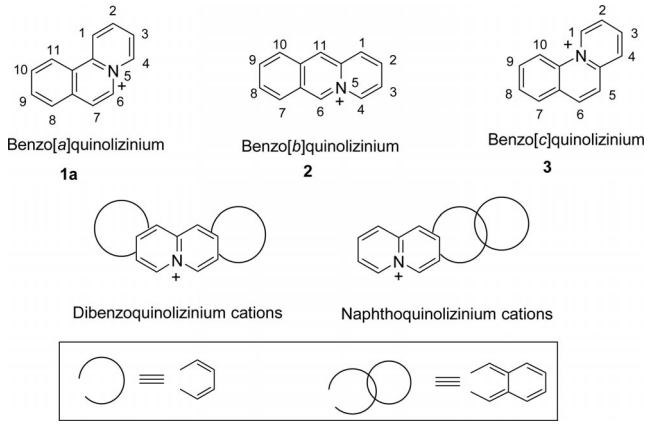


Figure 1. Tricyclic (top) and tetracyclic (bottom) azonia heteroaromatic cations.

tivity as NMDA antagonists,[8] activators of wild-type and mutant cystic fibrosis transmembrane conductance regulator (CFTR)[9] and inhibitors of protein kinase CKII.[10]

Most of the methods currently used to synthesize benzo- and naphthoquinolizinium cations still require rather harsh conditions. Classical cyclizations leading to the parent benzoquinolizinium salts **1**–**3**, for example, require high temperatures and strongly acidic media.[11] Here we report in full our results[12] from a comparative study of the use of ring-closing metathesis (RCM) reactions to access the benzo[*a*]quinolizinium system by different approaches, based on our previous studies on the synthesis of the quinolizinium system shown in Scheme 1.

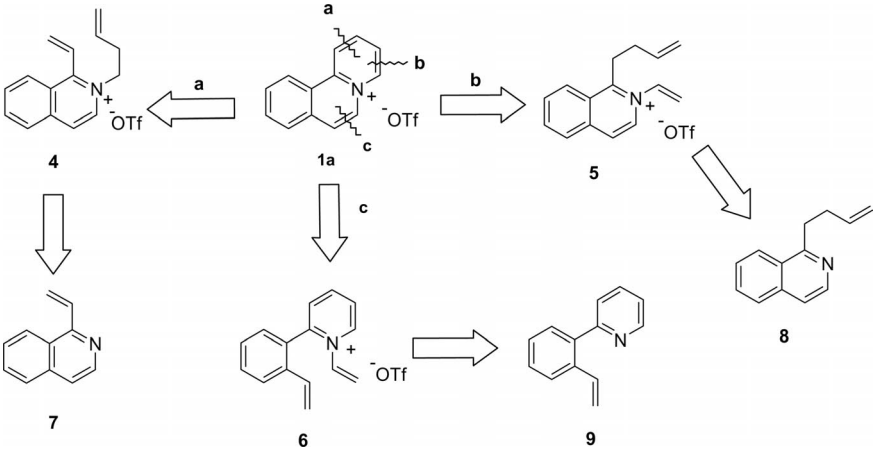
Results and Discussion

Studies involving RCM on charged substrates are restricted to a few examples. These include different pioneering works on ammonium salts,[13] the synthesis of the macrocycle moiety of the alkaloid (*R*)-(+)-muscopyridine by RCM on a pyridinium hydrochloride,[14] the total synthesis of manzamine, which involved as the key step a RCM reaction of an alkenyl pyridinium system to build up the 13-membered ring of this alkaloid,[15] and a previous study in our lab dealing with the use of azinium dienes and enines in RCM reactions leading to quinolizinium and related azonia systems.[5] Our goal was to investigate the processes described in Scheme 1 for quinolizinium synthesis in terms of their potential for production of benzoquinolizinium derivatives. Our first target, the benzo[*a*]quinolizinium salt **1a** (Scheme 2), had previously been prepared by four routes based on different cyclization reactions involving C11a–C11b[11e,11h] (two syntheses), C4–N5[11a] or C7–C8[11c] bond formation. Three of these approaches involved the use of a pyridine derivative as the starting material whereas that based on 4,5 bond formation started from 2-cyanoisoquinoline. In our alternative synthetic strategy it was envisaged that **1a** could be obtained through a RCM process by three different disconnections involving C1–C2 (strategy *a*), C3–C4 (strategy *b*) or C6–C7 (strategy *c*) bonds (Scheme 2).

None of the key dienic substrates **4**–**6** had been described previously, so strategies *a* and *b* initially seemed, in principle, to be more suitable because the isoquinoline derivatives **7** and **8** were known compounds whereas the pyridine derivative **9** also had not been described previously.[16] 1-Vinylisoquinoline (**7**) was thus prepared by the literature procedure from 1-hydroxyisoquinoline through conversion into the triflate and a subsequent Stille reaction with tributylvinylstannane.[17] Alkylation of **7** with but-3-enyl triflate,[18] under conditions similar to those used with pyridine in the quinolizinium synthesis (Scheme 1), afforded the desired azadiene **4** in 70% yield.

It was found that **4** did not undergo the RCM reaction under different conditions in the presence either of the first- or of the second-generation Grubbs catalyst (**G-I**[19] and **G-II**[20]). However, the reaction was successful on using the Hoveyda–Grubbs catalyst,[21] with the best results (60% yield of isolated product) achieved in 1,2-dichloroethane at 80 °C for 6 h with 5 mol-% of the catalyst or, alternatively, in tetrachloroethane on heating at 130 °C for 1.5 h (Table 1, Entries 5 and 6).

It is noteworthy that the RCM of **4** afforded the fully oxidized compound rather than the corresponding 3,4-dihydro derivative, which was the expected product according to our previous results in quinolizinium synthesis. It is likely



Scheme 2. Retrosynthetic strategies for the benzo[*a*]quinolizinium system.

Table 1. Synthesis of **1a** through RCM of the diene **4**.

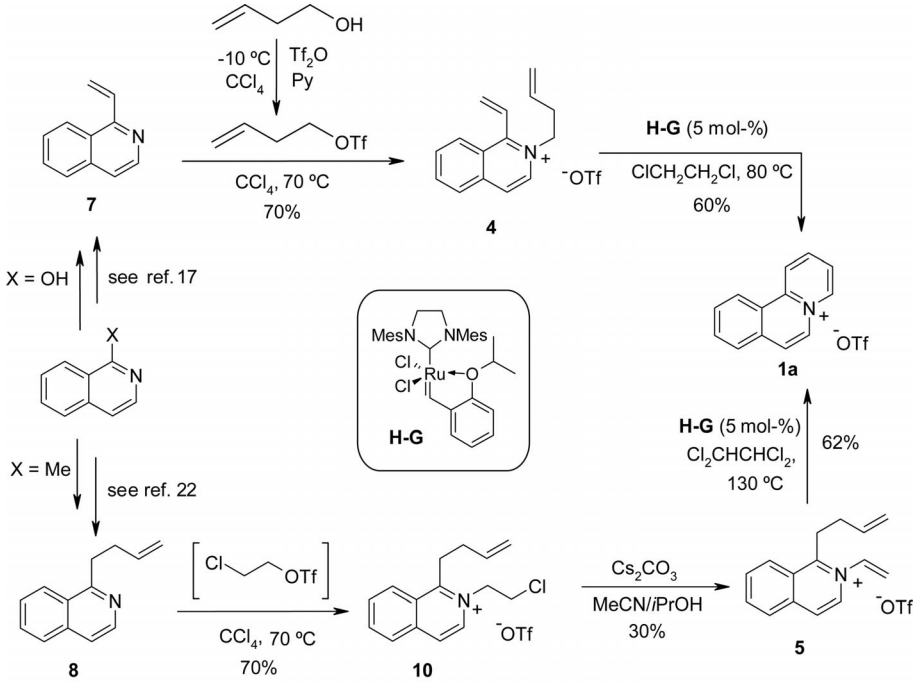
Entry	Catalyst	Conditions	Yield
1	G-II (5 mol-%)	CH_2Cl_2, 40 °C, 6 h	–
2	G-II (5 mol-%)	CH_2Cl_2, 40 °C, 6 h	–
3	H-G (5 mol-%)	CH_2Cl_2, 40 °C, 2.5 h	8
4	H-G (10 mol-%)	CH_2Cl_2, 40 °C, 5 h	8
5	H-G (5 mol-%)	$ClCH_2CH_2Cl$, 80 °C, 6 h	60
6	H-G (5 mol-%)	$Cl_2CHCHCl_2$, 130 °C, 1.5 h	60

that the higher temperature necessary for the RCM reaction of **4** to be successful also promotes dehydrogenation of the corresponding dihydro derivative, although this compound was not detected in the reaction mixture.

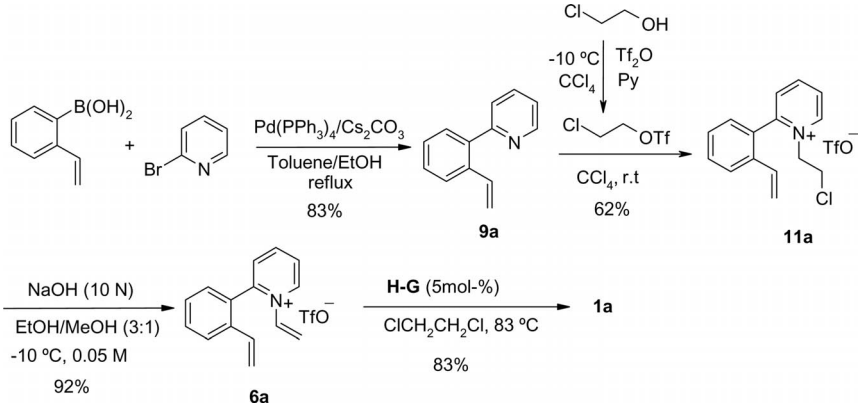
Strategy *b* (like strategy *a*) involves the use of an isoquinoline derivative as starting material and, as with strategy *c*, a highly electron-deficient *N*-vinylazinium species should be involved in the metathesis reaction. The appropriate isoquinoline derivative **8** for strategy *b* was easily obtained in good yield from 1-methylisoquinoline and allyl bromide by the literature procedure[22] (Scheme 3). The dienic substrate **5** was unknown and no methods dealing with the preparation of *N*-vinylisoquinolinium derivatives had been reported previously. However, there are a few reports relating to the synthesis of *N*-vinylpyridinium salts from *N*-haloalkylpyridinium salts in the presence of different bases.[23]

Attempts to apply the best conditions found for the synthesis of the *N*-vinylpyridinium derivative shown in Scheme 3 (NaOH/EtOH/MeOH) gave only very low isolated yields of **5**. After testing of different conditions, the highest yield (30%) was obtained with $CsCO_3$ as the base in MeCN/*i*PrOH at room temperature over 2 h. It is worth noting that under these conditions a significant amount of **10** was recovered, but all attempts to drive the reaction to completion to improve the yield, variously by use of a large excess of the base, by prolongation of the reaction time or by heating at different temperatures, failed. A more recently published alternative approach involved the synthesis of *N*-vinylpyridinium halides in good yields by treatment of pyridine with a 2,3-dihalopropionic acid in acetonitrile at reflux.[24] We found, however, that the vinylazinium halides were not formed under these reaction conditions and that the 1-(2′-carboxyvinyl)pyridinium bromide was the reaction product.[25] The RCM reaction of **5** was also successful under different reaction conditions, but in this case the optimal conditions were those shown in Scheme 3, which allowed the metathesis reaction of **5** to afford **1a** in a 62% yield, whereas in 1,2-dichloroethane at 80 °C **1a** was formed in only 30% yield.

Strategy *c* resembles that used in the synthesis of phenanthrenes[26] and other polycyclic aromatic hydrocarbons by RCM reactions,[27] although this approach is based on the preparation of the diene **6a** (Scheme 4) – rather than 2,2′-divinylbiphenyls – as the key step. In this case the metathesis reaction would also involve two vinyl groups, although one of them is highly electron-deficient because it is attached to a quaternary nitrogen (*N*-vinylpyridinium salt). This strategy for **1a** was also of interest because of the fact that the synthesis of a small number of dibenzo- and naphthoquinoliziniums by strategies such as *a* and *b* is not feasible because the presence of two benzo-fused rings precludes the appropriate bond disconnections. In this strategy our goal was the synthesis of the key intermediate 1-vinyl-2-(2-vinylphenyl)pyridinium salt **6a**. It was envisaged that **6a** might be obtainable from 2-(2-vinylphenyl)pyridine (**9a**, Scheme 4), which in turn might be obtainable by dehy-

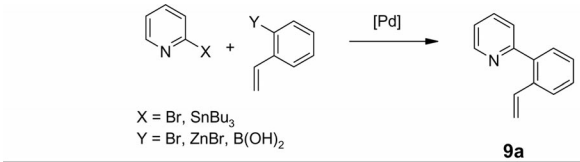


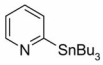
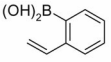
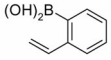
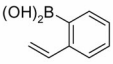
Scheme 3. Synthesis of the benzo[*a*]quinolizinium system through strategies *a* and *b*.



Scheme 4. Synthesis of the benzo[*a*]quinolizinium system through strategy *c*.

Table 2. Synthesis of **9** by palladium-catalysed coupling reactions.



Entry	Pyridine derivative	Styryl derivative	Catalyst	Conditions	Yield (%)[a] of **9a**
1			$Pd(PPh_3)_4/CuI$	DMF/r.t.	n.r.
2			$Pd(PPh_3)_4/CuI$	DMF/90 °C	traces + decomposition
3			$Pd(PPh_3)_4$	THF/r.t	homocoupling + decomposition
4			$Pd(PPh_3)_4/K_2CO_3$	toluene/ EtOH/reflux	32
5			$Pd_2(dba)_3/P(o\text{-}tol)_3$, K_2CO_3	toluene/ EtOH/reflux	n.r.
6			$Pd(PPh_3)_4/Cs_2CO_3$	toluene/ EtOH/reflux	83

[a] Yield refers to **9a** as isolated product. NR: no reaction.

drohalogenation of the corresponding pyridinium salt **11a**. The synthesis of **9a** through different palladium-catalysed reactions with pyridine and styryl derivatives employed as electrophilic or organometallic partners was attempted. The results are summarized in Table 2 and it can be seen that only the Suzuki reaction between 2-vinylphenylboronic acid and 2-bromopyridine was successful in producing the coupled compound **9a**, which was obtained in 83% yield after optimization.

The alkylation of **9a** to produce the pyridinium derivative **11a** gave a 62% yield under the same conditions as described above for **10**, but the transformation to give **6a** required a broad study of the reaction conditions. This investigation enabled the optimal conditions for the dehydrohalogenation reaction to be established and, as shown in Scheme 3, these afforded the desired diene **6a** in 92% yield. The diene **6a** having been obtained, the RCM reaction was attempted with the **G-I**, **G-II** and **H-G** catalysts, with the best yield (83%) again being obtained with the last of these under the conditions shown in Scheme 4.

At this stage we had been able to access the benzo[*a*]-quinolizinium cation by three different approaches, each based on a RCM reaction as the key step for the construction of the tricyclic system either from a bicyclic (strategies *a* and *b*) or a monocyclic (strategy *c*) cationic dienic system. Our next goal was to select the most suitable of these strategies for application to the preparation of derivatives of **1a** in order to evaluate the scope and limitations of the approach.

Although the three strategies all have the same number of steps (four) from a commercially available starting material, strategy *b* can clearly be ruled out when compared to *a* and *c* because of the low yield (30%) obtained in the dehydrohalogenation step leading to intermediate **5**, which

resulted in an overall yield of **1a** of only 11%. Strategy *a* affords **1a** in lower overall yield than strategy *c* (25% vs. 39%) and has the further disadvantage that the number of commercially available 1-hydroxyquinoline derivatives is very limited in relation to the number of 2-bromopyridine derivatives available from commercial sources. Furthermore, substituted 2-vinylboronic acids also seem to be easily accessible, thus opening a route to disubstituted benzo[*a*]quinolizinium derivatives. We consequently decided to explore strategy *c* as the most convenient method based on a RCM approach to synthesize benzo[*a*]quinolizinium derivatives. It is worth noting that this strategy also affords the best overall yield of **1a** relative to previously reported syntheses of this system (see Table 3).

In order to study the scope of the selected RCM approach for the synthesis of benzo[*a*]quinolizinium derivatives, our initial targets were the series of styrylpyridine de-

Table 3. Syntheses of benzo[*a*]quinolizinium triflate (**1a**).

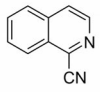
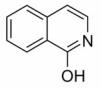
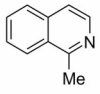
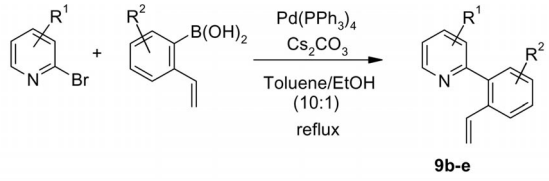
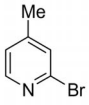
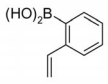
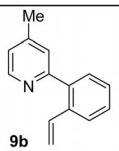
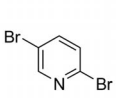
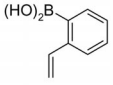
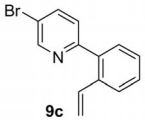
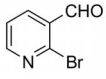
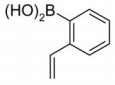
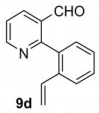
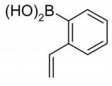
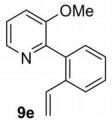
Entry	Starting material	Steps	Overall yield (%)	References/ strategy
1		4	22	[11h]
2		4	17	[11e]
3		2	35	[11c]
4		3	32	[11a]
5		4	25	RCM (*a*)
6		4	11	RCM (*b*)
7		4	38	RCM (*c*)

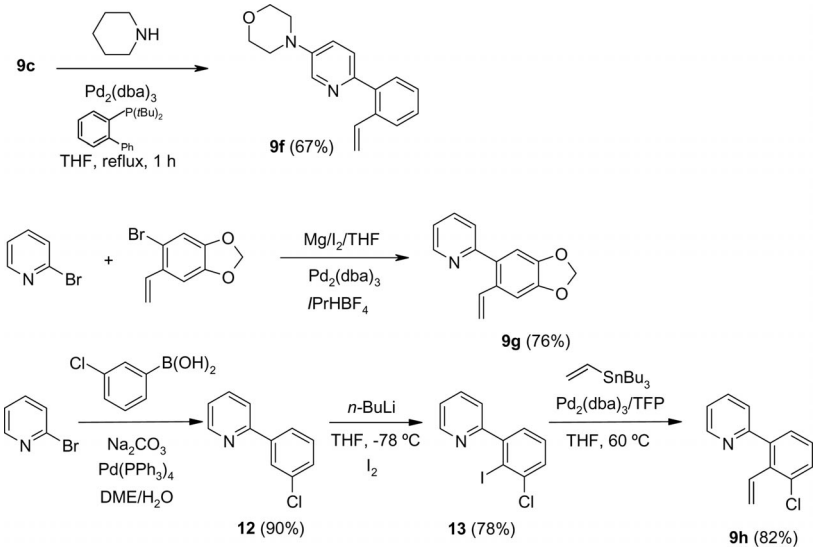
Table 4. Synthesis of the styrylpyridine derivatives **9**.



9b-e

Entry	Pyridine derivative	Boronic acid	Time (h)	Styryl pyridine	Yield (%)[a]
1			20	 **9b**	54
2			4	 **9c**	83
3			17	 **9d**	95
4			19	 **9e**	80

[a] Yields refer to compounds **9** as isolated products.

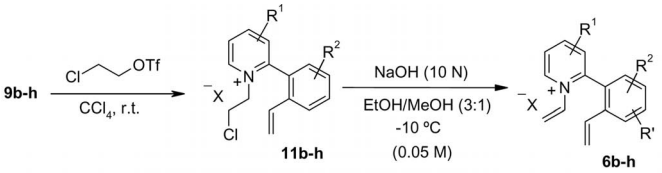


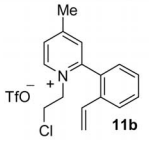
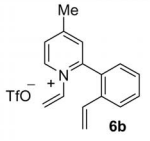
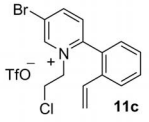
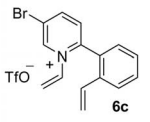
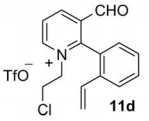
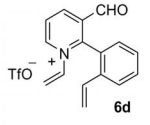
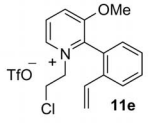
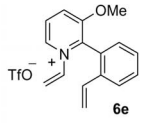
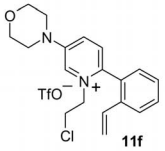
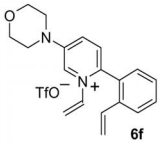
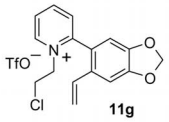
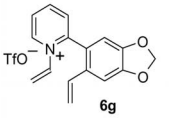
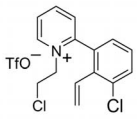
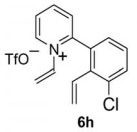
Scheme 5. Syntheses of the styrylpyridine derivatives **9f**–**h**.

rivatives **9b**–**h**. Compounds **9b**–**e** were obtainable in acceptable or good yields by the same general procedure as employed in the preparation of **9a** (Table 4).

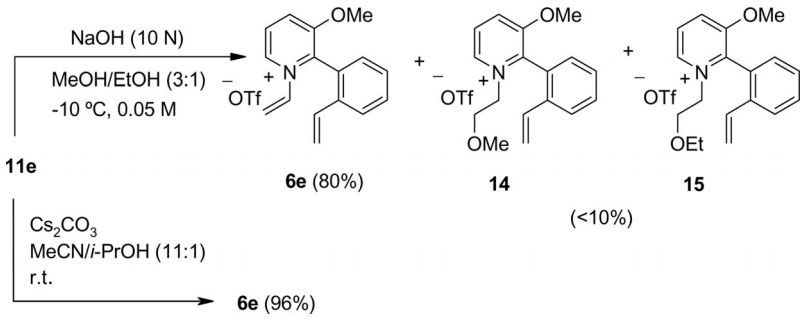
One further derivative (**9f**) with substitution on the pyridine ring was obtained in acceptable yield from the coupling reaction between **9c** and morpholine under the conditions shown in Scheme 5. Two other derivatives with substituents on the styryl moiety were obtained in good yields by the procedures shown in Scheme 4. The derivative **9g** was obtained from the coupling reaction[28] between 2-bromopyridine and 5-bromo-6-vinylbenzo[1,3]dioxolane.[29] Compound **9h** was obtained through a Suzuki coupling between 2-bromopyridine and 3-chlorophenylboronic acid, followed by iodination[30] of the resulting chlorophenylpyr-

Table 5. Synthesis of the pyridiniumazadienes **6**.



Entry	Styryl-pyridine	*N*-Alkylation		Dehydrohalogenation	
		N-Alkylated compound **11**	Yield (%)[a]	Azadiene **6**	Yield (%)[a]
1	**9b**	 **11b**	47	 **6b**	77
2	**9c**	 **11c**	39	 **6c**	75
3	**9d**	 **11d**	54[b]	 **6d**	_[c]
4	**9e**	 **11e**	86	 **6e**	96[c]
5	**9f**	 **11f**	71	 **6f**	91
6	**9g**	 **11g**	73	 **6g**	99
7	**9h**	 **11h**	88	 **6h**	73

[a] Yields refer to **11** and **6** as isolated products. [b] Yield by NMR. [c] Cs_2CO_3/CH_3CN/*i*PrOH (11:1), r.t.



Scheme 6. Dehydrohalogenation of **11e**.

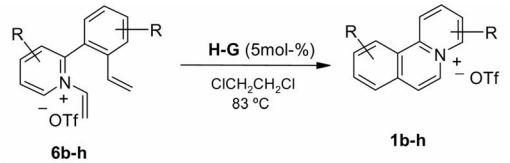
idine derivative **12** and a subsequent Stille reaction with tributylvinylstannane.

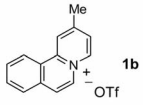
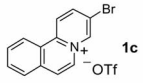
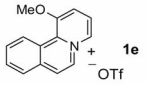
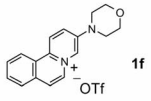
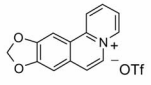
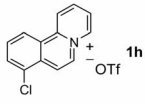
The syntheses of the azadienes **6** from compounds **9** were achieved by sequential *N*-alkylation of the pyridine ring followed by dehydrohalogenation under basic conditions. The yields of the alkylated compounds **11b**–**h** and the corresponding azadienes **6b**–**h** are shown in Table 5. In only one case was the desired diene not available by use of the *N*-alkylation/dehydrohalogenation procedure (Table 5, Entry 3, compound **6d**). In this case the formyl-substituted pyridinium salt **11d** was formed in only moderate yield and was impure due to the presence of other salts, which precluded its purification. Extensive decomposition of the crude reaction product occurred under the dehydrohalogenation conditions. For the rest of the substrates the *N*-alkylation reaction afforded moderate (Table 5, Entries 1 and 2) or good yields (Table 5, Entries 4–7), whereas good to excellent yields were obtained in the dehydrohalogenations of the styrylpyridinium derivatives **6** (Scheme 6). Compound **6e** was formed along with some impurities, identified as salts **14** and **15**, formed by replacement of the chloro substituent by methoxy and ethoxy groups. Although these salts were formed in low yields (<10%), their presence precluded the purification of **6e** either by chromatography or by crystallization.

The formation of the salts **14** and **15** was minimized by carrying out the reaction with only 1 equiv. of NaOH but the yield of **6e** was lower (80%). A brief study of other reaction conditions with use of a less nucleophilic base and without the use of MeOH or EtOH allowed the formation of **6e** in excellent yield (96%) in Cs_2CO_3/CH_3CN/*i*PrOH (11:1) at room temperature. These conditions were also applied to **11d** in a final attempt to prepare **6d**, but this reaction again failed to produce this azadiene.

The dienes **6b**, **6c** and **6e**–**h** were subjected to RCM under the same optimized conditions as used in the synthesis of **1a** from **6a**. Although these conditions afforded good yields in the cases of the 2-methylbenzo[*a*]quinolizinium salt **1b** and the methylenedioxy derivative **1g** (Table 6, Entries 1 and 5), in the remaining cases the RCM reactions gave only moderate or low yields of the corresponding tricyclic cations. Consequently, we studied a new set of conditions in order to improve the yields of the reactions that gave poor results. We found that the reaction temperature and/or the amount of catalyst seemed to be significant factors in increasing the yield of **1h**. The best yield was thus obtained on heating the reaction mixture in a sealed tube at 100 °C in the presence of 15% of the catalyst (Table 6, Entry 6). Under these conditions the yield of **1h** was improved from 23% to 81%. It is worth noting that neither these conditions nor other tested conditions (5 mol-%, $Cl_2CHCHCl_2$, 130 °C or 10 mol-%), $ClCH_2CH_2Cl$, 83 °C) led to any im-

Table 6. Synthesis of the benzo[*a*]quinolizinium salts **1**.



Entry	Azadiene **6**	Benzo[*a*]quinolizinium derivative **1**	Yield (%)[a]
1	**6b**	 **1b**	83
2	**6c**	 **1c**	42
3	**6e**	 **1e**	35
4	**6f**	 **1f**	39
5	**6g**	 **1g**	88
6	**6h**	 **1h**	81[b]

[a] Isolated yields. [b] 15 mol-%, $ClCH_2CH_2Cl$, 83 °C, 100 °C, sealed tube.

provement in the yields of **1c**, **1d** or **1f** (Table 6, Entries 2–4). It is noteworthy that only the 2-methylbenzo[*a*]quinolizinium system **1b** has previously been described and that this was obtained in only 20% overall yield.[31]

Conclusions

We have synthesized benzo[*a*]quinolizinium systems by three different approaches, each based on a ring-closing metathesis reaction of a pyridinium diene. In a comparative study the strategy involving disconnection of the C5–C6 bond of the tricyclic system afforded better overall yields than strategies based on the formation of C1–C2 and C3–C4 bonds. Moreover, a variety of unknown benzo[*a*]quinolizinium salts are also available through ring-closing metathesis reactions of 2-styryl-1-vinylpyridinium derivatives in the presence of the Hoveyda–Grubbs catalyst. We are currently extending the scope of the RCM reactions of cationic heteroaromatic dienes to the synthesis of other relevant benzo-, dibenzo- and naphthoquinolizinium systems.

Experimental Section

2-(But-3-enyl)-1-vinylisoquinolinium Triflate (4): A solution of but-3-enol (0.403 g, 2.6 mmol) and dry pyridine (0.205 g, 2.6 mmol) in dry CCl_4 (2 mL) was stirred under argon at room temperature for 5–10 min. The mixture was added dropwise (5–10 min) to a cooled (–10 °C) solution of triflic anhydride (0.733 g, 6 mmol) in dry CCl_4 (3 mL). The resulting white solid was filtered off through sodium sulfate. The filtrate was added by cannula to a solution of the vinyl derivative **7** (2 mmol) in dry CCl_4 (2 mL) and the reaction mixture was stirred for 24 h at 70 °C. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography on silica gel (eluent: CH_2Cl_2/MeOH 9.5:0.5) to afford **4** (0.323 g, 70%) as a yellow oil. ^{1}H NMR (200 MHz, [D$_6$]acetone): δ = 8.83 (d, J = 6.8 Hz, 1 H, Ar-H), 8.64–8.53 (m, 2 H, Ar-H), 8.39 (d, J = 8.1 Hz, 1 H, Ar-H), 8.28 (td, J = 1.3, 7.2 Hz, 1 H, Ar-H), 8.08 (td, J = 1.3, 8.1 Hz, 1 H, Ar-H), 7.53 (dd, J = 5.5, 12.3 Hz, 1 H, C-CH=), 6.57 (d, J = 12.3 Hz,1 H, CH_2=CH-), 6.21 (d, J = 17.8 Hz, 1 H, CH_2=CH-), 6.07–5.86 (m, 1 H, -CH=CH_2), 5.15–4.96 (m, 4 H, N-CH_2-, -CH_2-), 2.94–2.82 (m, 2 H, CH_2=CH-) ppm. ^{13}C NMR (75 MHz, [D$_6$]acetone): δ = 138.9, 137.4, 136.2, 133.6, 132.8, 132.2, 131.0, 128.7, 126.9, 126.0, 121.9 (q, J = 319.4 Hz), 119.5, 58.8, 34.9 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3085, 1634, 1565, 1435, 1263, 1154, 1030, 638 cm^{-1}. HRMS (ESI$^+$): calcd. for $C_{15}H_{16}N$: 210.1281; found 210.1283.

1-(But-3-enyl)-2-(2-chloroethyl)isoquinolinium Triflate (10): Dry pyridine (0.103 g, 0.106 mL, 1.3 mmol) was added under argon to a solution of 2-chloroethanol (0.105 g, 87 μL, 1.3 mmol) in dry CCl_4 (1 mL), and the reaction mixture was stirred at room temperature for 5–10 min. The resulting solution was added dropwise during 5–10 min to a cooled solution (–10 °C) of triflic anhydride (0.327 g, 0.219 mL, 1.3 mmol) in dry CCl_4 (1.5 mL). The resulting white solid was filtered off through sodium sulfate and the filtrate was added by cannula to a solution of **8** (0.183 g, 1 mmol) in dry CCl_4 (1.5 mL). The reaction mixture was stirred at 70 °C for 24 h. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography on silica gel [eluent: CH_2Cl_2/MeOH (9.5:0.5)] to afford **10** (0.128 g, 70%) as a grey solid. ^{1}H NMR (200 MHz, [D$_6$]acetone): δ = 8.87–8.82 (m, 2 H, Ar-H), 8.52 (d, J = 6.8 Hz, 1 H, Ar-H), 8.38 (d, J = 8.1 Hz, 1 H, Ar-H), 8.29 (t, J = 6.8 Hz, 1 H, Ar-H), 8.14 (td, J = 1.3, 8.5 Hz, 1 H, Ar-H), 6.16–6.03 (m, 1 H, -CH=CH_2), 5.44 (t, J = 5.9 Hz, 2 H, N-CH_2-), 5.21–5.05 (m, 2 H, CH_2=CH-), 4.42 (t, J = 5.9 Hz, 2 H, -CH_2-Cl), 4.04 (t, J = 7.9 Hz, 2 H, C-CH_2-), 2.87–2.69 (m, 2 H, -CH_2-) ppm. ^{13}C NMR (75 MHz, [D$_6$]acetone): δ = 163.9, 138.7, 137.6, 137.1, 136.3, 132.5, 129.6, 129.3, 128.3, 125.5, 121.5 (q, J = 319.3 Hz), 117.6, 59.5, 43.7, 34.2, 30.6 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3094, 1634, 1569, 1443, 1268, 1155, 1030, 638 cm^{-1}. HRMS (ESI$^+$): calcd. for $C_{15}H_{16}N$: 246.1050; found 246.1054.

1-(But-3-enyl)-2-vinylisoquinolinium Triflate (5): Cs_2CO_3 (0.163 g, 0.5 mmol, 2 equiv.) was added to a solution of **10** (0.099 g, 0.25 mmol, 0.05 M) in CH_3CN/*i*PrOH (11:1, 5 mL), and the mixture was stirred at room temperature for 1 h. The solid was then removed by filtration and the solution was neutralized with acetic acid and concentrated under reduced pressure at 20 °C. The residue was purified by flash chromatography on silica gel (eluent: CH_2Cl_2/MeOH 9.5:0.5) to afford **5** (29.7 mg, 30%) as a yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.42 (t, J = 6.8 Hz, 2 H, Ar-H), 8.23 (d, J = 6.8 Hz, 1 H, Ar-H), 8.09 (d, J = 5.8 Hz, 2 H, Ar-H), 8.03–7.91 (m, 1 H, Ar-H), 7.84–7.73 (m, 1 H, N-CH=), 6.01–5.95 (m, 2 H, CH_2=CH-), 5.89–5.73 (m, 1 H, -CH=CH_2), 5.04–4.97 (m, 2 H, CH2=CH-), 3.71 (t, J = 7.6 Hz, 2 H, C-CH_2-), 2.50 (m, 2 H, -CH_2-) ppm. ^{13}C NMR (50 MHz, [D$_6$]acetone): δ = 156.1, 137.8, 137.0, 135.9, 133.8, 132.6, 131.1, 129.1, 128.2, 125.6, 124.0, 121.6, 121.1 (q, J = 316.2 Hz), 116.9, 34.2, 32.5 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3090, 1645, 1456, 1279, 1160, 1030, 638 cm^{-1}. HRMS (ESI$^+$): calcd. for $C_{15}H_{16}N$: 210.1283; found 210.1289.

General Procedure for the Preparation of the 2-(2′-Vinylphenyl)pyridines 9: $Pd(PPh_3)_4$ (5 mol-%, 0.116 g, 0.1 mmol) was added under argon to a solution of the corresponding 2-bromopyridine as triflate or bromide (2 mmol), Cs_2CO_3 (0.717 g, 2.2 mmol) and 2-vinylphenylboronic acid (0.458 g, 3 mmol) in toluene/EtOH (10:1, 14 mL) and the reaction mixture was heated at 100 °C for 4–20 h. Water (12 mL) was then added, the mixture was extracted with EtOAc (3 × 5 mL), the organic phase was dried with anhydrous Na_2SO_4, the solvent was evaporated under reduced pressure, and the product was isolated by flash chromatography on silica gel.

2-(2′-Vinylphenyl)pyridine (9a): This compound was obtained from 2-bromopyridine (0.316 g, 0.191 mL) by the general procedure after heating of the reaction mixture for 7 h; purification of the crude product by flash chromatography with hexane/EtOAc (9:1) as eluent afforded **9a** (0.300 g, 83%) as a pale green oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 8.70 (ddd, J = 0.7, 1.6, 4.8 Hz, 1 H, Ar-H), 7.71 (td, J = 1.8, 7.9 Hz, 1 H, Ar-H), 7.63 (dd, J = 2.0, 8.9 Hz, 1 H, Ar-H), 7.48 (dd, J = 1.8, 6.8 Hz, 1 H, Ar-H), 7.41 (dd, J = 0.9, 7.9 Hz, 1 H, Ar-H), 7.38–7.32 (m, 2 H, Ar-H), 7.23 (td, J = 1.4, 5.1 Hz, 1 H, Ar-H), 6.77 (dd, J = 11.0, 17.4 Hz, 1 H, C-CH=), 5.71 (dd, J = 1.3, 17.4 Hz, 1 H, CH_2=CH-), 5.22 (dd, J = 1.3, 11.0 Hz, 1 H, CH_2=CH-) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 149.4, 139.3, 136.0, 135.9, 135.6, 129.9, 128.5, 127.7, 126.1, 124.9, 121.7, 118.7, 115.2 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3061, 1585, 1425, 912, 749 cm^{-1}. MS (DIP-EI): m/z (%) = 180 (100) [M – 1], 181 (23) [M]$^+$. $C_{13}H_{11}N$ (181.24): calcd. C 86.15, H 6.12, N 7.73; found C 85.90, H 6.42, N 8.04.

General Procedure for the Preparation of the *N*-(2-Chloroethyl)pyridinium Salts 11: Dry pyridine (0.103 g, 0.106 mL, 1.3 mmol) was added under argon to a solution of 2-chloroethanol (0.105 g, 87 μL, 1.3 mmol) in dry CCl_4 (1 mL), and the reaction mixture was stirred at room temperature for 5–10 min. This solution was then added dropwise (5–10 min) to a cooled solution (–10 °C) of triflic

anhydride (0.327 g, 0.219 mL, 1.3 mmol) in dry CCl_4 (1.5 mL). The resulting white solid was filtered off through sodium sulfate and the solution was added by cannula to a solution of a 2-(2′-vinylphenyl)pyridine **9** (0.182 g, 1 mmol) in dry CCl_4 (1.5 mL). The reaction mixture was stirred at room temperature or heated at 60 °C (**9g**) for 24 h. Removal of the solvent under reduced pressure and purification by flash chromatography on silica gel (CH_2Cl_2/MeOH 9.5:0.5) afforded compounds **11** (washing with ether and recrystallisation from CH_2Cl_2/Et_2O for **11g**.).

1-(2-Chloroethyl)-2-(2-vinylphenyl)pyridinium Triflate (11a): This compound was obtained from **9a** (0.182 g, 1 mmol) by the above general procedure, giving **11a** (0.244 g, 62%) as a pale yellow oil. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 9.28 (d, J = 6.3 Hz, 1 H, Ar-H), 8.57 (td, J = 1.2, 7.8 Hz, 1 H, Ar-H), 8.19 (td, J = 1.5, 6.4 Hz, 1 H, Ar-H), 7.82 (dd, J = 1.3, 7.9 Hz, 1 H, Ar-H), 7.74 (d, J = 7.9 Hz, 1 H, Ar-H), 7.62 (td, J = 2.0, 7.0 Hz, 1 H, Ar-H), 7.49 (td, J = 1.0, 6.8 Hz, 1 H, Ar-H), 7.46 (dd, J = 2.0, 8.0 Hz, 1 H, Ar-H), 6.20 (dd, J = 10.8, 17.1 Hz, 1 H, C-CH=), 5.76 (d, J = 17.1 Hz, 1 H, CH_2=CH-), 5.40 (d, J = 10.9 Hz, 1 H, CH_2=CH-), 5.00 (dt, J = 5.1, 14.2 Hz, 1 H, N-CH_2-), 4.75 (dt, J = 6.1, 14.1 Hz, 1 H, N-CH_2-), 3.82 (t, J = 6.0 Hz, 2 H, -CH_2-Cl) ppm. ^{13}C NMR (50 MHz, [D_6]acetone): δ = 155.9, 147.7, 147.6, 137.2, 133.2, 132.6, 132.2, 130.8, 130.1, 129.4, 128.5, 127.0, 122.1 (q, J = 318.5 Hz), 119.6, 59.8, 42.8 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3086, 1625, 1512, 1487, 1259, 1159, 1030, 779 cm^{-1}. MS (ES$^+$): m/z (%) = 244 (100) [M]$^+$, 246 (33) [M + 2]. $C_{16}H_{15}ClF_3NO_3S$ (393.82): calcd. C 48.80, H 3.84, N 3.56, S 8.14; found C 48.45, H 4.23, N 3.88, S 8.04.

Synthesis of the *N*-Vinylazinium Salts 6

General Procedure A: A solution of NaOH (10 N, 0.275 mmol, 1.1 equiv.) was added dropwise at –10 °C to a solution of the corresponding *N*-(chloroethyl)azinium salt **11** (0.05 M, 0.25 mmol) in EtOH/MeOH (3:1, 5 mL). The reaction mixture was stirred for 15 min. and then neutralized with acetic acid, and the solvent was removed under reduced pressure at 20 °C. The residue was treated with acetone, the solid was filtered off, and the solution was concentrated under reduced pressure at 20 °C. The *N*-vinylazinium salts **6** were purified by flash chromatography on silica gel (CH_2Cl_2/MeOH 9.5:0.5 as eluent). Compound **6h** was purified by recrystallization.

General Procedure B: Cs_2CO_3 (0.163 g, 0.5 mmol, 2 equiv.) was added to a solution of the *N*-(2-chloroethyl)azinium salt (0.05 M, 0.25 mmol) in CH_3CN/*i*PrOH (11:1, 5 mL), and the mixture was stirred at room temperature for 1–1.5 h. The solid was then removed by filtration and the solution was neutralized with acetic acid and concentrated under reduced pressure at 20 °C. The residue was subjected to silica gel flash chromatography (CH_2Cl_2/MeOH 9.5:0.5 as eluent).

1-Vinyl-2-(2-vinylphenyl)pyridinium Triflate (6a): Compound **6a** was obtained from **11a** (98.6 mg) as a pale-brown oil (82.1 mg, 92%) by General Procedure A. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 9.29 (d, J = 6.3 Hz, 1 H, Ar-H), 8.61 (t, J = 7.9 Hz, 1 H, Ar-H), 8.31 (t, J = 7.3 Hz, 1 H, Ar-H), 7.86 (d, J = 7.9 Hz, 1 H, Ar-H), 7.70 (dd, J = 0.9, 7.9 Hz, 1 H, Ar-H), 7.61 (t, J = 7.2 Hz, 1 H, Ar-H), 7.48 (t, J = 7.6 Hz, 1 H, Ar-H), 7.42 (d, J = 7.6 Hz, 1 H, Ar-H), 6.87 (dd, J = 8.2, 15.1 Hz, 1 H, N-CH=), 6.22 (dd, J = 3.4, 15.2 Hz, 1 H, C-CH=), 6.15 (dd, J = 10.9, 17.1 Hz, 1 H, CH_2=CH-), 5.66 (d, J = 17.3 Hz, 1 H, CH_2=CH-), 5.62 (dd, J = 3.2, 8.1 Hz, 1 H, CH_2=CH-), 5.34 (d, J = 10.9 Hz, 1 H, CH_2=CH-) ppm. ^{13}C NMR (75 MHz, [D_6]acetone): δ = 148.0, 145.3, 137.6, 137.4, 133.7, 132.7, 131.5, 130.9, 130.2, 129.3, 128.6, 127.1, 119.1, 119.0 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3152, 1620, 1503, 1478, 1261, 1157, 1031, 779 cm^{-1}. MS (ES$^+$): m/z (%) = 208 (100) [M]$^+$. $C_{16}H_{14}F_3NO_3S$ (357.36): calcd. C 53.78, H 3.95, N 3.92, S 8.97; found C 53.35, H 4.23, N 3.88, S 8.74.

Ring-Closing Metathesis of Salts 6

General Procedure A: The **H-G** catalyst (5–10 mol-%) was added under argon to a solution of the corresponding *N*-vinylazinium salt **6** or **4** (0.15 mmol) in dry $ClCH_2CH_2Cl$ (3 mL). The reaction mixture was heated under reflux (83 °C) for 1.5–20 h. The solvent was evaporated under reduced pressure and the residue was purified either by washing with CH_2Cl_2/Et_2O and recrystallization or by flash chromatography on silica gel (CH_2Cl_2/MeOH 9:1 as eluent).

General Procedure B: The **H-G** catalyst (15 mol-%) was added under argon to a solution of the corresponding *N*-vinylazinium salt (0.15 mmol) in dry $ClCH_2CH_2Cl$ (3 mL). The reaction was allowed to proceed at 100 °C for 15 h in a sealed tube reactor. The solvent was evaporated under reduced pressure and the residue was washed with CH_2Cl_2/Et_2O and recrystallized.

General Procedure C: The **H-G** catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) was added under argon to a solution of the corresponding *N*-vinylazinium salt (0.15 mmol) in dry $Cl_2CHCHCl_2$ (3 mL), and the mixture was heated at 130 °C for 4 h. The solvent was evaporated under reduced pressure and the residue was purified by flash chromatography on silica gel (CH_2Cl_2/MeOH 9:1 as eluent).

Benzo[*a*]quinolizinium Triflate (1a): This compound was obtained from **6a** (53.5 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) by General Procedure A; after heating of the reaction mixture for 2.5 h, compound **1a** (41.0 mg, 83%) was isolated as a pale grey solid, m.p. 164–165 °C (CH_2Cl_2).[32]

This compound was also obtained from **4** (53.8 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) by General Procedure A; after heating of the reaction mixture for 1.5 h, compound **1a** (29.6 mg, 60%) was isolated as a pale grey solid, m.p. 164–165 °C (CH_2Cl_2). ^{1}H NMR (300 MHz, CD_3OD): δ = 9.48 (d, J = 8.8 Hz, 1 H, Ar-H), 9.40 (d, J = 6.6 Hz, 1 H, Ar-H), 9.13 (d, J = 8.0 Hz, 1 H, Ar-H), 8.91 (d, J = 7.3 Hz, 1 H, Ar-H), 8.67 (td, J = 1.3, 8.8 Hz, 1 H, Ar-H), 8.31 (t, J = 6.9 Hz, 2 H, Ar-H), 8.24–8.11 (m, 3 H, Ar-H) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 141.3, 140.5, 135.5, 133.2, 132.4, 132.0, 129.6, 126.7, 126.2, 125.4, 124.9, 124.3, 122.0 (q, J = 315.0 Hz) ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 2922, 1634, 1482, 1258, 1145, 1033, 822, 755 cm^{-1}. MS (ES$^+$): m/z (%) = 180 (100) [M]$^+$. $C_{14}H_{10}F_3NO_3S$ (329.30): calcd. C 51.06, H 3.06, N 4.25, S 9.74; found C 51.48, H 3.00, N 3.91, S 9.83.

2-Methylbenzo[*a*]quinolizinium Triflate (1b): This compound was obtained from **6b** (55.6 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) by General Procedure A; after heating of the reaction mixture for 4 h, compound **1b** (42.7 mg, 83%) was obtained as a brown greyish solid, m.p. 156–158 °C (CH_2Cl_2).[31] ^{1}H NMR (300 MHz, CD_3OD): δ = 9.24 (s, 1 H, Ar-H), 9.13 (d, J = 6.9 Hz, 1 H, Ar-H), 8.99 (d, J = 8.2 Hz, 1 H, Ar-H), 8.69 (d, J = 7.3 Hz, 1 H, Ar-H), 8.15–7.95 (m, 5 H, Ar-H), 2.80 (s, 3 H, C-CH_3) ppm. ^{13}C NMR (75 MHz, DC_3OD): δ = 155.5, 139.7, 135.2, 133.1, 132.2, 131.5, 129.5, 127.0, 126.7, 125.9, 123.9, 123.6, 121.7 (q, J = 317.9 Hz), 119.6, 22.3 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3077, 1641, 1480, 1262, 1160, 1031, 832, 757 cm^{-1}. MS (ES$^+$): m/z (%) = 194 (100) [M]$^+$, 195 (80) [M + 1]. $C_{15}H_{12}F_3NO_3S$ (343.33): calcd. C 52.48, H 3.52, N 4.08, S 9.34; found C 52.39, H 3.57, N 3.65, S 9.26.

3-Bromobenzo[*a*]quinolizinium Triflate (1c): This compound was obtained from **6c** (65.4 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) by General Procedure A; after heating of

the mixture reaction for 20 h, compound **1c** (25.7 mg, 42%) was obtained as a pale brown solid, m.p. 210–211 °C. ^{1}H NMR (300 MHz, CD_3OD): δ = 9.77 (d, J = 1.8 Hz, 1 H, Ar-H), 9.39 (d, J = 9.3 Hz, 1 H, Ar-H), 9.12 (d, J = 8.2 Hz, 1 H, Ar-H), 8.85 (d, J = 7.1 Hz, 1 H, Ar-H), 8.80 (dd, J = 1.8, 9.3 Hz, 1 H, Ar-H), 8.37 (d, J = 7.3 Hz, 1 H, Ar-H), 8.30 (dd, J = 1.3, 7.7 Hz, 1 H, Ar-H), 8.21 (td, J = 1.1, 7.1 Hz, 1 H, Ar-H), 8.15 (td, J = 1.6, 7.1 Hz, 1 H, Ar-H) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 42.6, 139.7, 134.6, 132.2, 131.6, 130.2, 128.5, 125.6, 125.1, 124.6, 123.9, 120.6 (q, J = 316.3 Hz), 119.2 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 2921, 1475, 1265, 1225, 1131, 754 cm^{-1}. MS (ES$^+$): *m*/*z* (%) = 258 (100) [M]$^+$, 260 (99) [M + 2]. $C_{14}H_9BrF_3NO_3S{\cdot}2H_2O$ (444.20): calcd. C 37.85, H 2.95, N 3.15, S 7.22; found C 37.31, H 2.48, N 2.78, S 8.01.

1-Methoxybenzo[*a*]quinolizinium Triflate (1e): This compound was obtained from **6e** (58.0 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol) by General Procedure A; after heating of the reaction mixture for 24 h, compound **1e** (18.8 mg, 35%) was obtained as a green pale solid, m.p. 170–171 °C. ^{1}H NMR (300 MHz, CD_3OD): δ = 9.83 (d, J = 8.6 Hz, 1 H, Ar-H), 9.08 (d, J = 6.2 Hz, 1 H, Ar-H), 8.90 (d, J = 7.1 Hz, 1 H, Ar-H), 8.34 (d, J = 8.6 Hz, 1 H, Ar-H), 8.24 (t, J = 7.3 Hz, 2 H, Ar-H), 8.18–8.04 (m, 3 H, Ar-H), 4.43 (s, 3 H, O-CH_3) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 158.9, 134.5, 133.7, 133.4, 132.2, 132.0, 131.1, 129.3, 126.3, 125.6, 125.2, 121.8 (q, J = 316.9 Hz), 121.7, 58.4 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 2922, 1574, 1436, 1337, 1261, 1159, 1031, 754 cm^{-1}. MS (ES$^+$): *m*/*z* (%) = 210 (100) [M]$^+$, 211 (54) [M + 1]. $C_{15}H_{12}F_3NO_4S$ (359.33): calcd. C 50.14, H 3.37, N 3.90, S 8.92; found C 50.35, H 2.87, N 4.11, S 8.90.

3-(4-Morpholinyl)benzo[*a*]quinolizinium Triflate (1f): This compound was obtained by General Procedure A from **6f** (66.4 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol); after heating for 15 h and purification by chromatography, compound **1f** (24.2 mg, 39%) was obtained as a green solid, m.p. 160–161 °C (Cl_2CH_2/acetone). ^{1}H NMR (300 MHz, [D$_6$]acetone): δ = 9.23 (d, J = 9.9 Hz, 1 H, Ar-H), 8.95 (dd, J = 3.5, 4.4 Hz, 1 H, Ar-H), 8.90 (d, J = 2.6 Hz, 1 H, Ar-H), 8.78 (d, J = 7.3 Hz, 1 H, Ar-H), 8.45 (dd, J = 2.6, 9.9 Hz, 1 H, Ar-H), 8.24–8.20 (m, 2 H, Ar-H), 8.11–8.08 (m, 2 H, Ar-H), 4.04 (t, J = 4.9 Hz, 4 H, N-CH_2-CH_2-O), 3.65 (t, J = 4.9 Hz, 4 H, N-CH_2-CH_2-O) ppm. ^{13}C NMR (75 MHz, [D$_6$]acetone): δ = 147.6, 135.5, 132.9, 131.7, 131.2, 130.7, 129.0, 128.9, 125.9, 124.9, 124.4, 123.7, 122.9, 122.1 (q, J = 320.0 Hz), 66.4, 47.6 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 2922, 1624, 1254, 1223, 1128, 777 cm^{-1}. MS (ES$^+$): *m*/*z* (%) = 265 (100) [M]$^+$. $C_{18}H_{17}F_3N_2O_4S$ (414.41): calcd. C 52.17, H 4.13, N 6.76, S 7.74; found C 51.87, H 4.48, N 6.85, S 8.07.

[1,3]Benzodioxolo[5,6-*a*]quinolizinium Triflate (1g): This compound was obtained by General Procedure A from **6g** (60.2 mg) in the presence of the catalyst (5 mol-%, 4.7 mg, 0.0075 mmol); after heating for 2 h, compound **1g** (49.3 mg, 88%) was obtained as a pale-brown solid, m.p. 181–182 °C (Cl_2CH_2/acetone). ^{1}H NMR (300 MHz, CD_3OD/[D$_6$]acetone): δ = 9.24 (d, J = 6.8 Hz, 1 H, Ar-H), 9.20 (d, J = 9.1 Hz, 1 H, Ar-H), 8.82 (d, J = 7.1 Hz, 1 H, Ar-H), 8.48 (t, J = 8.0 Hz, 1 H, Ar-H), 8.44 (s, 1 H, Ar-H), 8.18 (d, J = 7.1 Hz, 1 H, Ar-H), 8.05 (t, J = 6.8 Hz, 1 H, Ar-H), 7.62 (s, 1 H, Ar-H), 6.40 (s, 2 H, O-CH_2-O) ppm. ^{13}C NMR (75 MHz, CD_3OD/[D$_6$]acetone): δ = 155.6, 153.4, 143.5, 139.4, 132.4, 130.8, 124.1, 123.9, 123.2, 121.8 (q, J = 319.9 Hz), 119.7, 106.2, 105.3, 103.6 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 2921, 1621, 1478, 1260, 1159, 1030, 638 cm^{-1}. MS (ES$^+$): *m*/*z* (%) = 224 (100) [M]$^+$. $C_{15}H_{10}F_3NO_5S$ (373.31): calcd. C 48.26, H 2.70, N 3.75, S 8.59; found C 48.66, H 3.08, N 3.42, S 8.70.

8-Chlorobenzo[*a*]quinolizinium Triflate (1h): This compound was obtained from **6h** (58.7 mg) in the presence of the **H-G** catalyst (15 mol-% , 14.1 mg, 0.022 mmol) by General Procedure B; compound **1h** (42.0 mg, 81%) was obtained as a pale green solid, m.p. 180–182 °C (CH_2Cl_2). ^{1}H NMR (300 MHz, CD_3OD): δ = 9.53 (d, J = 8.9 Hz, 1 H, Ar-H), 9.47 (d, J = 6.7 Hz, 1 H, Ar-H), 9.12 (d, J = 8.4 Hz, 1 H, Ar-H), 9.02 (d, J = 7.5 Hz, 1 H, Ar-H), 8.74 (ddd, J = 1.3, 7.3, 8.7 Hz, 1 H, Ar-H), 8.61 (d, J = 7.5 Hz, 1 H, Ar-H), 8.30 (dd, J = 0.9, 7.7 Hz, 1 H, Ar-H), 8.28 (t, J = 6.4 Hz, 1 H, Ar-H), 8.09 (t, J = 8.0 Hz, 1 H, Ar-H) ppm. ^{13}C NMR (75 MHz, CD_3OD): δ = 144.7, 142.1, 141.0, 135.5, 133.8, 133.3, 132.7, 130.7, 128.0, 126.1, 126.0, 124.8, 121.8 (q, J = 316.3 Hz), 120.5 ppm. IR (NaCl): $\tilde{\nu}_{max}$ = 3071, 1633, 1263, 1173, 1149, 1033, 806 cm^{-1}. MS (ES$^+$): *m*/*z* (%) = 214 (100) [M]$^+$, 216 (54) [M + 2]. $C_{14}H_9ClF_3NO_3S$ (363.75): calcd. C 46.23, H 2.49, N 3.85, S 8.81; found C 46.35, H 2.83, N 4.01, S 8.98.

Supporting Information (see footnote on the first page of this article): experimental procedures and full spectroscopic data and NMR spectra for compounds **6b**–**h**, **9b**–**h**, and **11b**–**h**.

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