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Ring transformations of 2,3-dihydroisoxazoles via azomethine ylides—formation of annulated 5- and 7-membered N-heterocycles☆

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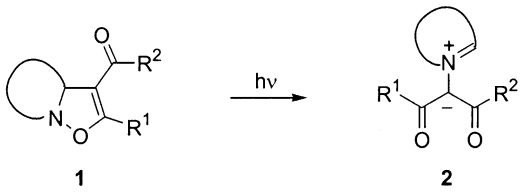
Abstract—On thermal activation the 2,3-dihydroisoxazoles **12**–**14** are transformed into annulated dihydroazepines **15**–**17** as main products, besides minor amounts of the corresponding pyrrole derivatives **18**–**20**. In the proposed mechanism the azomethine ylides of type **III** and **VI** are involved as intermediates which undergo 1,5- and 1,7-ring closure reactions, respectively. © 2001 Elsevier Science Ltd. All rights reserved.

1. Introduction

Among the various reduced isoxazole derivatives, the 2,3-dihydroisoxazoles belong to the less common isomers because of their notorious chemical instability under many conditions.[2] Besides decomposition material, the mainly isolated products are, if at all, pyrroles, 4-oxazolines, acyl aziridines and acyclic enamines, respectively, the kind and ratio of the products depending strongly on the substitution pattern.[3] However, as a common feature of many of these reactions the transformations are initiated by NO-cleavage and subsequent rebonding affording acyl aziridines which react further by ring opening to give azomethine ylides, the supposedly precursors of the observed variety of products (Scheme 1).[2,3]

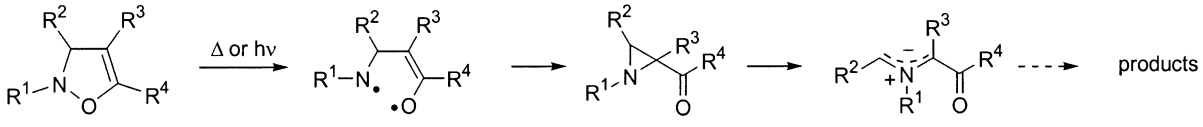
In earlier work we have shown that on photochemical activation of acyl-isoxazolines of type **1** the corresponding doubly stabilized azomethine ylides **2** can be isolated, and also evidence for the appearance of aziridines have been obtained (Scheme 2).[4]

The transient formation of azomethine ylides during reactions of those heterocycles prompted us to evaluate the potential of 2,3-dihydroisoxazoles as precursor of azomethine ylides. In particular, investigations were performed that should allow 1,5- and/or 1,7-dipolar cyclization reactions of the intermediate conjugated dipole species as deactivation pathways.[5]



1 **2**

Scheme 2.



Scheme 1.

☆ Part 5 in the series 'The pyrido[1,2-*a*]azepine system', for Part 4 see Ref. 1.

Keywords: 2,3-dihydroisoxazoles; azepines; azomethine ylides; dipolar cyclizations.

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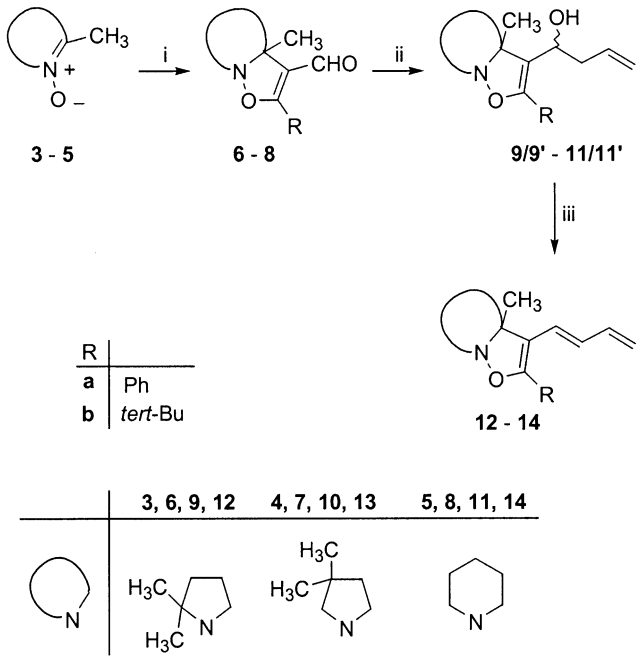
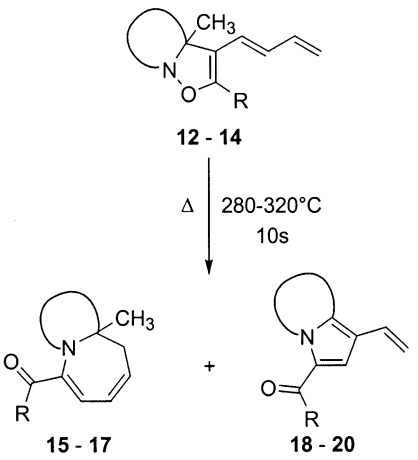


Scheme 3. i: R–C≡C–CHO, CH_2Cl_2 or Et_2O, r.t. ii: CH_2=CH–CH_2–MgBr, THF/Et_2O, 0°C. iii: CH_3SO_2Cl, NEt_3, DMAP, −78°C.



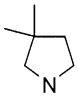
Scheme 4.

2. Results and discussion

Here we present results of our studies with 2,3-dihydroisoxazoles bearing a butadienyl group at C-3 (Scheme 3). The heterocyclic ring was constructed by 1,3-dipolar cycloaddition of the known cyclic nitrones **3**–**5** with phenyl and *tert*-butyl propiolic aldehyde, respectively. As predicted by FMO theory and found experimentally in other cases,[6,7] only the shown regioisomers **6**–**8** were formed. The further functionalization included Grignard reactions with allyl magnesium bromide affording the secondary alcohols **9**–**11** as diastereomeric mixtures[8] which were finally transformed into the isoxazolines **12a**,**b**–**14a**,**b** by water elimination.[9] The yields for most steps were between 70 and 90%, with the exception of **6b** (55%), **12b** (64%), **14a** (58%) and **14b** (40%).

The thermal reactions were performed with ca. 10^{-2} molar solutions of **12a**,**b**–**14a**,**b** in benzene under short-time thermolysis conditions[10] at 280–320°C with a contact time of ca. 10 s. This technique was superior to other methods such as flash-vacuum thermolysis or heating of solutions in an autoclave.[11] After purification of the reaction mixture by flash chromatography the product analysis revealed, besides higher molecular material, two monomeric products in each case. On the basis of the analytical and spectroscopic data the structure of the main products was identified as the isomeric bicyclic dihydroazepine systems **15**–**17**, whereas the minor components turned out to be the 1,2-annulated pyrroles **18**–**20**, which differ from the starting isoxazolines in the formal loss of a CH_4 unit; the yields are given in Table 1. For the structure elucidation of the reaction products special NMR techniques have been applied including HMBC spectra.[12]

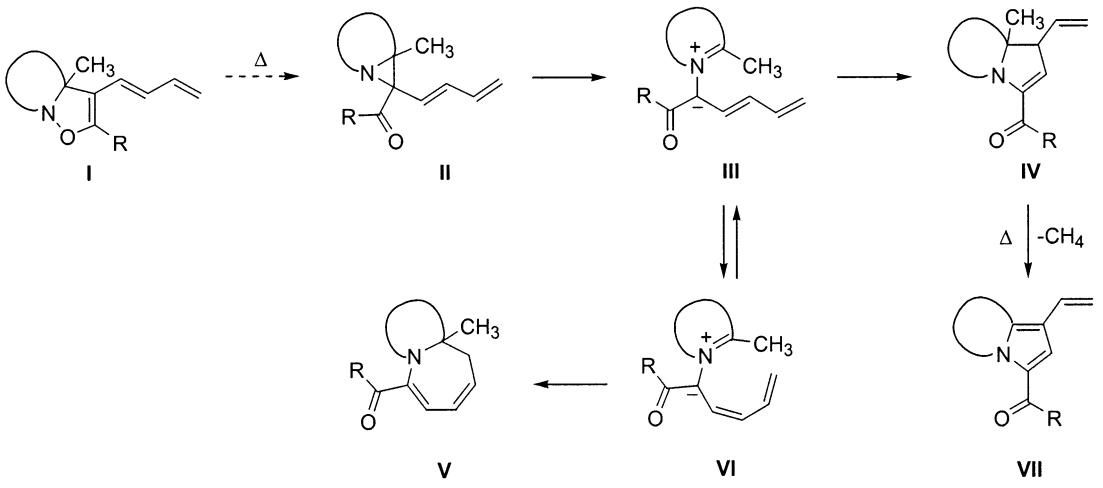
Table 1. Thermolysis products of **12a**,**b**, **13a**,**b** and **14a**,**b**

								
	15	**18**	**16**	**19**	**17**	**20**
a	59[a]	9[a]	48[a]	3[a]	42[b]	7[b]
b	13[b]	–	38[b]	tr[b]	41[b]	tr[b]

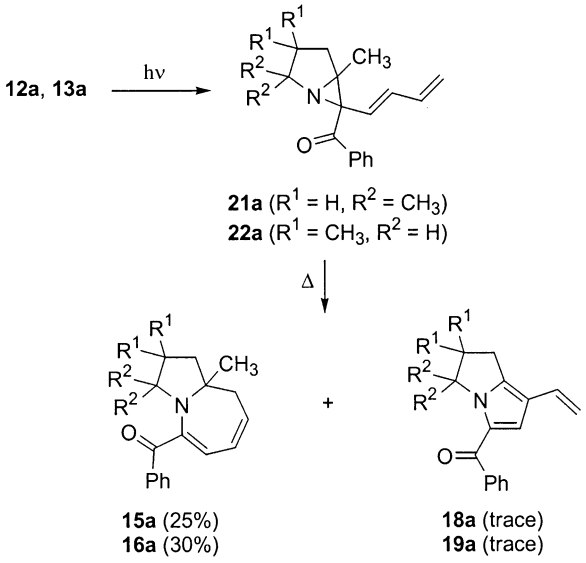
Yield in %, after chromatography.
[a] 320°C/10 s.
[b] 280°C/10 s.

For the transformation of **12**–**14** into the reaction products **15**–**17** and **18**–**20** a multi-step pathway has to be envisaged (Scheme 5). The first part of the mechanistic interpretation is based on the general reactivity of 2,3-dihydroisoxazoles[2] and includes the ring transformation of the compounds of general type **I** into the bicyclic aziridines **II** and subsequent C–C bond cleavage with formation of the azomethine ylide intermediates **III**. The conjugated dipole system then undergoes a 6π ring closure[13] affording the pyrrolines **IV** which under the harsh reaction conditions suffer CH_3-H elimination[14] to give the observed pyrroles **VII**. For rationalizing the formation of the main products **V** a preceding isomerization of the central double bond of the conjugated dipolar system must take place (**III**→**VI**). Analoguous (*E*)⇌(*Z*) isomerizations have been observed with diazo derivatives,[15] carbonyl ylides[16] and nitrones.[17] In case of a deprotonated 2-azadiaryl-heptatriene the geometrical change takes place even at −20°C.[18] Finally, the *syn*-arranged species **VI** undergoes a 1,7-dipolar electrocyclization process affording the azepine derivatives **V**.[1,19,20]

Further evidence for the occurrence of intermediates of type **II** was obtained by independent thermolysis experiments with the bicyclic aziridines **21a/22a** which can be selectively obtained on photoinduced transformation of the annulated isoxazolines **12a/13a** (Scheme 6): on short-time thermolysis of **21a** (320°C) and **22a** (280°C) the same ring expansion products **15/18** and **16/19**, respectively, are formed[21] as have been observed with the 2,3-dihydroisoxazoles **12a** and **13a** as starting materials in this work.



Scheme 5.



Scheme 6.

3. Conclusion

In summary, the experiments with various 4-isoxazolines have shown that on thermal activation the main reaction pathway affords azomethine ylides as key intermediates which in the presence of appropriate π-substituents like a butadienyl group undergo electrocyclic ring closure reactions to annulated pyrrole and azepine derivatives, respectively. An extension of the work with 4-isoaxazolines bearing different side chains as well as more studies on the photochemical reactivity of such heterocycles are in progress.

4. Experimental

4.1. General

Melting points are uncorrected. ^{1}H NMR: 250, 400 and 500 MHz; ^{13}C NMR: 100 or 125 MHz, Brucker WM 250, WM 400, WM 500; $CDCl_3$ as solvent and TMS as internal standard; for assignments ATP, COSY, HMBC, NOESY techniques were used. IR: Perkin Elmer PE 297 Infracord FT–IR. UV: Perkin-Elmer Lambda 15. MS: Finnigan MAT 44 S spectrometer with Datasystem MAT SS 200 using electron impact ionization (EI, 70 eV) or chemical ionization (CI, 170 eV) with isobutane. Elemental analyses: Perkin-Elmer Elemental Analyzer 240. All reactions were carried out in flame-dried glassware under N_2 atmosphere unless otherwise stated. Analytical TLC: precoated silica gel Merck 60 F-254 (0.2 mm). Flash chromatography: ICN-Biomedicals silica gel (ICN Silica 32-36). Short-time thermolysis apparatus: a vertical, externally heated Pyrex tube (37×3 cm) packed with Raschig rings (Pyrex, 4×4 mm); packed height 18 cm, heating zone 30 cm; addition of the solutions through a dosing funnel (Normag N 8056) in a N_2-steam (flow rate 0.75 l/h), dropping rate 13 ml/h; temperature ±10°C, contact time ca. 10 s.[10,11]

4.2. Procedure for the preparation of the annulated dihydroisoxazoles 6–8

6a,b: To a solution of the nitrone **3**,[22] (ca. 4 mmol) in 5–10 ml dry CH_2Cl_2 of diethyl ether was added under argon 3-phenylpropynal[23] and 3-*tert*-butylpropynal,[17b] respectively, at r.t. The reaction mixture was further stirred under argon and light exclusion at room temperature for 24 h. After evaporation of the solvent the oily residue was purified by flash chromatography (SiO_2, cyclohexane/ethyl acetate 20:1). The compounds **7a,b** and **8a,b** were likewise prepared from the nitrones **4**[24] and **5**,[25] respectively, following the known protocol.[4b]

4.2.1. 3a,6,6-Trimethyl-2-phenyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazol-3-carbaldehyde (6a). The reaction of **3** (440 mg, 3.46 mmol) with 3-phenylpropynal (455 mg, 3.5 mmol) in 5 ml dry CH_2Cl_2 gave 717 mg (80%) of **6a** as pale yellow oil. ^{1}H NMR (250 MHz): δ=1.27 (s, 3 H, CH_3), 1.34 (s, 3 H, CH_3), 1.67 (s, 3 H, CH_3), 1.70–1.85 (m, 2 H, CH_2), 2.02 (ddd, 1 H, CH_2, ^2J=13.1 Hz, ^3J=9.1 Hz, ^3J=6.7 Hz), 2.43 (ddd, 1 H, CH_2, ^2J=13.1 Hz, ^3J=7.0 Hz, ^3J=4.9 Hz), 7.43–7.62 (m, 5 H, PhH), 9.64 (s, 1 H, CHO). ^{13}C NMR (100 MHz): δ=22.9 (CH_3), 27.2 (CH_3), 28.2 (CH_3), 36.2 (CH_2), 36.5 (CH_2), 69.8 (C_q), 77.2 (NC_q), 119.4 (=C_q),

126.3 ($C_{q,Ph}$), 128.6 (C_{Ph}), 128.8 (C_{Ph}), 131.4 (C_{Ph}), 169.4 (CO), 185.5 (CHO). IR: 2976 cm^{-1}, 2758, 1650 (CO),1598, 1493, 1447, 1351, 1136, 1071. UV (CH_3CN): λ=248 nm (ϵ 10,800), 308 nm (ϵ 9200). MS (CI): *m/z* (%)=258 (63) [M^++1], 184 (3), 147 (4), 123 (35), 112 (100). HRMS calcd. for $C_{16}H_{19}NO_2$: 257.1416; found 257.1420.

4.2.2. 2-*tert*-Butyl-3a,6,6-trimethyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazol-3-carbaldehyde (6b). The reaction of **3** (1.00 g, 7.9 mmol) with 3-*tert*-butylpropynal (0.87 g, 7.9 mmol) in 6 ml dry diethyl ether afforded 1.04 g (55%) of **6b** as pale yellow oil. ^{1}H NMR (250 MHz): δ=1.20 (s, 3 H, CH_3), 1.25 (s, 3 H, CH_3), 1.38 (s, 9H, *t*Bu), 1.55 (s, 3 H, CH_3), 1.59 (ddd, 1 H, CH_2, ^2J=12.5 Hz, ^3J=9.2 Hz, ^3J=7.3 Hz), 1.69 (ddd, 1 H, CH_2, ^2J=12.5 Hz, ^3J=4.7 Hz, ^3J=6.8 Hz), 1.94 (ddd, 1 H, CH_2, ^2J=13.1 Hz, ^3J=9.2 Hz, ^3J=6.8 Hz), 2.32 (ddd, 1 H, CH_2, ^2J=13.1 Hz, ^3J=7.3 Hz, ^3J=4.7 Hz), 10.01 (s, 1 H, CHO). ^{13}C NMR (100 MHz): δ=23.2 (CH_3), 27.5 (CH_3), 28.71 (CH_3), 30.1 (*t*Bu), 35.3 ($C_{q,tBu}$), 36.5 (CH_2), 36.7 (CH_2), 69.9 (NC_q), 77.3 (NC_q), 118.5 (=C_q), 178.4 (CO), 185.1 (CHO). IR: 2975 cm^{-1}, 2869, 1643, 1602, 1461, 1367, 1339, 1275, 1178. **UV** (CH_3CN): λ=295 nm (ϵ 9300), 225 nm (ϵ 5200). MS: *m/z* (%)=237 (12) [M^+], 222 (99), 168 (100), 152 (51), 124 (19), 84 (20), 69 (71). HRMS calcd. for $C_{14}H_{23}NO_2$: 237.1728; found 237.1729.

4.3. General procedure for the preparation of the alcohols 9a,b–11a,b

To stirred solutions of **6a,b**–**8a,b** (1–2 mmol) in 5 ml of dry THF at 0°C was added slowly the suspension of freshly prepared allylmagnesium bromide (1.2–2.5 equiv.) in diethyl ether (5 ml). After stirring for additional 15–120 min the reaction mixture was hydrolyzed at 0°C with saturated NH_4Cl solution and then extracted with diethyl ether (3×20 ml). The combined organic phase was washed (saturated $NaHCO_3$ and NaCl solution) and then dried ($MgSO_4$). Concentration in vacuo afforded a residue which was purified by flash chromatography (SiO_2, cyclohexane/ethyl acetate 10:1). In general, mixtures of the respective diastereomers **9**–**11**/**9′**–**11′** were isolated.[8] For characterization, small quantities of the single isomers were separated by repeated chromatography; however, no configurational attribution has been done.

4.3.1. 1-(3a,6,6-Trimethyl-2-phenyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazol-3-yl)-but-3-en-1-ol (9a/9′a). The reaction of **6a** (2.2 g, 8.55 mmol) yielded after flash chromatography (SiO_2, cyclohexane/ethyl acetate 20:1) 2.42 g (94%) of the mixture of **9a/9′a** as pale yellow crystals. **9a**: mp 95–96°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.23 (s, 3 H, CH_3), 1.28 (s, 3 H, CH_3), 1.54 (s, 3 H, CH_3), 1.71 (s_{br}, 1 H, OH), 1.74 (t, 2 H, CH_2, ^3J=6 Hz), 1.88 (dt, 1 H, CH_2), 2.30 (dt, 1 H, CH_2, ^2J=12,6 Hz, ^3J=7 Hz), 2.37–2.54 (m, 2 H, allyl-CH_2), 4.50 (dd, 1 H, CHOH, ^3J=5 Hz, ^3J=9 Hz), 5.06–5.13 (m, 2 H, =CH_2, ^3J=12 Hz, ^3J=18 Hz), 5.75–5.64 (m, 1 H, HC=, ^3J=12 Hz, ^3J=18 Hz), 7.36 (m_c, 3 H, PhH), 7.56 (m_c, 2 H, PhH). ^{13}C NMR (100 MHz): δ=21.9 (CH_3), 28.4 (CH_3), 30.7 (CH_3), 36.3 (CH_2), 36.5 (CH_2), 40.7 (allyl-CH_2), 67.2 (CHOH), 68.8 (C_q), 78.7 (NC_q), 113.8 (=C_q), 118.0 (=CH_2), 128.3 (C_{Ph}), 128.5 (C_{Ph}), 129.0 (C_{Ph}), 129.6 ($C_{q,Ph}$), 135.1 (HC=), 151.0 (CO). IR: 3618 cm^{-1} (OH), 3567 (OH), 3081, 2974, 1670, 1640, 1494, 1446, 1366, 1244, 1147. UV (CH_3CN): λ=222 nm (ϵ 11,500), 282 nm (ϵ 5000). MS (EI): *m/z* (%)=299 (5) [M^+], 284 (37), 230 (25), 188 (17), 105 (100), 77 (51). Anal. calcd. for $C_{19}H_{25}NO_2$: C 76.22, H 8.42, N 4.68; found C 76.32, H 8.52, N 4.68. **9′a**: ^{1}H NMR (250 MHz): δ=1.26 (s, 3 H, CH_3), 1.27 (s, 3 H, CH_3), 1.55 (s, 3 H, CH_3), 1.68–1.93 (m, 4 H, OH, CH_2), 2.27–2.56 (m, 3 H, CH_2, allyl-CH_2), 4.50 (m, 1 H, CHOH), 5.06–5.13 (m, 2 H, =CH_2), 5.64–5.89 (m, 1 H, HC=), 7.36 (m_c, 3 H, PhH), 7.56 (m_c, 2 H, PhH). ^{13}C NMR (100 MHz): δ=22.2 (CH_3), 28.6 (CH_3), 30.43 (CH_3), 35.8 (CH_2), 36.4 (CH_2), 41.2 (allyl-CH_2), 67.04 (CHOH), 68.9 (C_q), 78.7 (NC_q), 113.6 (=C_q), 118.3 (=CH_2), 128.3 (C_{Ph}), 128.5 (C_{Ph}), 129.1 (C_{Ph}), 129.6 ($C_{q,Ph}$), 135.1 (HC=), 151.2 (CO). MS (EI): *m/z* (%)=299 (4) [M^+], 284 (35), 230 (33), 188 (24), 105 (100), 77 (52). HRMS calcd. for $C_{19}H_{25}NO_2$: 299.1885; found 299.1881.

4.3.2. 1-(2-*tert*-Butyl-3a,6,6-trimethyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazol-3-yl)-but-3-en-1-ol (9b/9′b). The reaction of **6b** (400 mg, 1.68 mmol) gave 427 mg (91%) of **9b/9′b** as colorless crystals. **9b**: mp 129–130°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.18 (s, 3 H, CH_3), 1.20 (s, 3 H, CH_3), 1.23 (s, 9 H, *t*Bu), 1.51 (d, 1 H, OH, ^2J=2.3 Hz), 1.44 (s, 3 H, CH_3), 1.61–1.65 (m, 2 H, CH_2, ^2J=15 Hz, ^3J=8.8 Hz), 1.77 (dt, 1 H, CH_2, ^2J=14 Hz, ^3J=7 Hz), 2.38–2.55 (m, 3 H, allyl-CH_2, CH_2), 4.84 (ddd, 1 H, CHOH, ^2J=2.3 Hz, ^3J=4 Hz, ^3J=9 Hz), 5.13–5.20 (m, 2 H, =CH_2, ^3J=10 Hz, ^3J=16 Hz), 5.86 (m, 1 H, HC=, ^3J=10 Hz, ^3J=16 Hz). ^{13}C NMR (100 MHz): δ=22.6 (CH_3), 28.7 (CH_3), 29.7 (*t*Bu), 31.3 (CH_3), 33.3 ($C_{q,tBu}$), 36.6 (CH_2), 36.7 (CH_2), 42.8 (allyl-CH_2), 66.8 (*C*HOH), 68.5 (C_q), 78.4 (NC_q), 110.0 (=C_q), 118.1 (=CH_2), 135.7 (HC=), 157.8 (CO). IR: 3616 cm^{-1}, 3571, 3073, 2972, 1639, 1458, 1365, 1145. MS (EI): *m/z* (%)=279 (6) [M^+], 264 (65), 210 (78), 168 (28), 152 (27), 126 (13). HRMS calcd. for $C_{17}H_{29}NO_2$: 279.2198; found 279.2200. Anal. calcd. for $C_{17}H_{29}NO_2$: C 73.07, H 10.46, N 5.01; found C 73.14, H 10.43, N 4.96. **9′b**: mp 125–126°C (diethyl ether/pentane) ^{1}H NMR (250 MHz): δ=1.14 (s, 3 H, CH_3), 1.23 (s, 3 H, CH_3), 1.25 (s, 9 H, *t*Bu), 1.44 (d, 1 H, OH, ^2J=1.6 Hz), 1.46 (s, 3 H, CH_3), 1.58–1.70 (m, 2 H, CH_2), 1.80 (dt, 1 H, CH_2, ^2J=12,6 Hz, ^3J=7 Hz), 2.24 (dt, 1 H, CH_2, ^2J=12,6 Hz, ^3J=7 Hz), 2.42 (m, 1 H, allyl-CH_2), 2.52 (m, 1 H, allyl-CH_2), 4.85 (ddd, 1 H, CHOH, ^2J=1.6 Hz, ^3J=4 Hz, ^3J=9 Hz), 5.14–5.17 (m, 2 H, =CH_2, ^3J=10 Hz, ^3J=16 Hz), 5.87 (m, 1 H, HC=, ^3J=10 Hz, ^3J=16 Hz). ^{13}C NMR (100 MHz): δ=21.8 (CH_3), 28.7 (CH_3), 29.8 (*t*Bu), 32.0 (CH_3), 33.3 ($C_{q,tBu}$), 36.4 (CH_2), 36.8 (CH_2), 41.4 (allyl-CH_2), 67.0 (CHOH), 68.3 (C_q), 78.2 (NC_q), 110.2 (=C_q), 117.7 (=CH_2), 135.7 (HC=), 158.3 (CO). IR: 3616 cm^{-1}, 3571, 3073, 2973, 1639, 1458, 1364, 1138. MS (EI): *m/z* (%)=279 (6) [M^+], 264 (94), 210 (69), 168 (22), 152 (20), 126 (11). HRMS calcd. for $C_{17}H_{29}NO_2$: 279.2198; found 279.2197.

4.3.3. 1-(2-Phenyl-3a,5,5-trimethyl-3a,4,5,6,tetrahydropyrrolo[1,2-*b*]isoxazol-3-yl)-but-3-en-1-ol (10a/10′a). The reaction of **7a**[4b] (1.00 g, 3.89 mmol) afforded 1.02 g (87%) of **10a/10′a** as colorless crystals. **10a**: mp 95–100°C (diethyl ether/ pentane). ^{1}H NMR (250 MHz): δ=1.11 (s, 3 H, CH_3), 1.19 (s, 3 H, CH_3), 1.53 (s, 3 H, CH_3), 1.64 (dd, 1

H, 4-H, ^4J=1.2 Hz, ^2J=12.8 Hz), 1.86 (s, 1 H, OH), 2.40–2.50 (d, 1 H, 4-H, ^2J=12.8 Hz; m, 2 H, CH_2), 2.94 (d, 1 H, 6-H, ^2J=9.2 Hz), 3.26 (dd, 1 H, 6-H, ^4J=1.2 Hz, ^2J=9.2 Hz), 4.53 (m, 1 H, C*H*(OH)), 5.05–5.15 (m, 2 H, =CH_2), 5.78 (m, 1 H, HC=), 7.37 (m_c, 3 H, Ph-H), 7.55 (m_c, 2 H, Ph-H). ^{13}C NMR (100 MHz): δ=28.1 (CH_3), 29.0 (CH_3), 30.0 (CH_3), 36.2 (C_q), 40.9 (*C*H_2C=), 49.8 (CH_2), 67.0 (CHOH), 69.3 (NCH_2), 78.1 (NC_q), 115.2 (3-C), 118.4 (=CH_2), 128.3 (C_{Ph}), 128.6 (C_{Ph}), 129.2 (C_{Ph}), 129.9 ($C_{q,Ph}$), 135.1 (HC=), 149.2 (CO). IR: 3610 cm^{-1}, 3550, 3060, 2950, 2860, 1660, 1640, 1600, 1490, 1445, 1565, 1320, 1095. MS (EI): *m/z* (%)=299 (1) [M$^+$], 224 (6), 202 (8), 128 (5), 120 (61), 115 (5), 105 (100), 91 (18), 77 (75). HRMS calcd. for $C_{19}H_{25}NO_2$: 299.1885; found 299.1886. Anal. calcd. for $C_{19}H_{25}NO_2$: C 76.22, H 8.42, N 4.68; found C 76.32, H 8.38 N 4.63. **10′a**: ^{1}H NMR (250 MHz): δ=1.13 (s, 3 H, CH_3), 1.19 (s, 3 H, CH_3), 1.52 (s, 3 H, CH_3), 1.71 (dd, 1 H, 4-H, ^4J=1.2 Hz, ^2J=12.8 Hz), 1.90 (s, 1 H, OH), 2.24 (d, 1 H, 4-H, ^2J=12.8 Hz), 2.46 (m, 2 H, CH_2), 2.98 (d, 1 H, 6-H, ^2J=10.1 Hz), 3.26 (dd, 1 H, 6-H, ^4J=1.2 Hz, ^2J=10.1 Hz), 4.54 (m, 1 H, C*H*(OH)), 5.06–5.12 (m, 1 H, =CH_2), 5.14 (m, 1 H, =CH_2), 5.80 (m, 1 H, HC=), 7.36 (m_c, 3 H, Ph-H), 7.54 (m_c, 2 H, Ph-H). ^{13}C NMR (100 MHz): δ=28.2 (CH_3), 28.5 (CH_3), 30.1 (CH_3), 36.9 (C_q), 40.9 (CH_2C=), 51.3 (CH_2), 67.2 (CHOH), 69.7 (NCH_2), 78.7 (NC_q), 115.2 (3-C), 118.2 (=CH_2), 128.3 (C_{Ph}), 128.4 (C_{Ph}), 129.1 (C_{Ph}), 129.9 ($C_{q,Ph}$), 135.1 (HC=), 148.7 (CO). IR: 3610 cm^{-1}, 3550, 3060, 2950, 2860, 1660, 1640, 1600, 1490, 1445, 1565, 1320, 1095. MS (EI): *m/z* (%)=299 (1) [M$^+$], 224 (5), 202 (15), 196 (5), 120 (45), 115 (4), 105 (100), 91 (20), 77 (70). HRMS calcd. for $C_{19}H_{25}NO_2$: 299.1885; found 299.1890.

4.3.4. 1-(2-*tert*-Butyl-3a,5,5-trimethyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazol-3-yl)-but-3-en-1-ol (10b/10′b). The reaction of **7b**[4b] (500 mg, 2.11 mmol) gave 517 mg (88%) of **10b/10′b** as colorless crystals. **10b**: ^{1}H NMR (250 MHz): δ=1.08 (s, 3 H, CH_3), 1.15 (s, 3 H, CH_3), 1.22 (s, 9 H, *t*Bu), 1.40 (s, 3 H, CH_3), 1.48 (d, 1 H, OH, ^2J=2 Hz), 1.55 (dd, 1 H, 4-H, ^2J=12.9 Hz, ^4J=1.3 Hz), 2.44 (m, 2 H, CH_2), 2.54 (d, 1 H, 4′-H, ^2J=12,9 Hz), 2.74 (d, 1 H, 6-H, ^2J=9 Hz), 3.09 (dd, 1 H, 6′-H, ^2J=9 Hz, ^4J=1.3 Hz), 4.89 (ddd, 1 H, C*H*OH, ^2J=2 Hz, ^3J=4.7 Hz, ^3J=9.1 Hz), 5.14–5.20 (m, 2 H, =CH_2, ^3J=10 Hz, ^3J=15 Hz), 5.82–5.89 (m, 1 H, HC=, ^3J=10 Hz, ^3J=15 Hz). ^{13}C NMR (100 MHz): δ=28.2 (CH_3), 29.0 (CH_3), 29.3 (*t*Bu), 30.7 (CH_3), 32.9 ($C_{q,tBu}$), 36.1 (C_q), 41.9 (CH_2), 50.2 (CH_2), 66.5 (CHOH), 68.5 (NCH_2), 77.3 (NC_q), 112.0 (3-C), 118.1 (=CH_2), 135.6 (HC=), 156.2 (CO). IR: 3616 cm^{-1}, 3565, 3073, 2958, 1639, 1467, 1367, 1113. MS (EI): *m/z* (%)=279 (7) [M$^+$], 264 (40), 238 (11), 222 (43), 194 (20), 182 (55), 166 (64), 152 (33), 148 (30), 138 (25), 124 (32), 107 (28), 98 (30). HRMS calcd. for $C_{17}H_{29}NO_2$: 279.2198; found 279.2200. **10′b**: mp 97–98°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.09 (s, 3 H, CH_3), 1.16 (s, 3 H, CH_3), 1.21 (s, 9 H, *t*Bu), 1.45 (s, 3 H, CH_3), 1.57 (d, 1 H, OH, ^2J=2.6 Hz), 1.93 (dd, 1 H, 4-H, ^2J=12.9 Hz, ^4J=1.3 Hz), 2.17 (d, 1 H, 4′-H, ^2J=12,9 Hz), 2.41 (m, 1 H, CH_2), 2.52 (m, 1 H, CH_2), 2.74 (d, 1 H, 6-H, ^2J=9 Hz), 3.11 (dd, 1 H, 6′-H, ^2J=9 Hz, ^4J=1.3 Hz), 4.87 (ddd, 1 H, C*H*OH, ^2J=2 Hz, ^3J=4 Hz, ^3J=9.7 Hz), 5.16–5.19 (m, 2 H, =CH_2, ^3J=10 Hz, ^3J=15 Hz), 5.82–5.89 (m, 1 H, HC=, ^3J=10 Hz, ^3J=15 Hz). ^{13}C NMR (100 MHz): δ=28.3 (CH_3), 28.6 (CH_3), 29.2 (*t*Bu), 31.1 (CH_3), 32.8 ($C_{q,tBu}$), 36.4 (C_q), 42.3 (CH_2), 51.2 (CH_2), 66.7 (CHOH), 68.7 (NCH_2), 77.9 (NC_q), 111.7 (3-C), 117.9 (=CH_2), 135.4 (HC=), 155.1 (CO). IR: 3623 cm^{-1}, 3584, 3073, 2958, 1638, 1466, 1366. MS (EI): *m/z* (%)=279 (5) [M$^+$], 264 (33), 222 (28), 194 (16), 182 (30), 166 (42), 152 (28), 148 (26), 138 (22), 124 (27), 107 (28), 98 (29). HRMS calcd. for $C_{17}H_{29}NO_2$: 279.2198; found 279.2200. Anal. calcd. for $C_{17}H_{29}NO_2$: C 73.07, H 10.46, N 5.01; found C 73.11, H 10.46, N 5.02.

4.3.5. 1-(3a-Methyl-2-phenyl-4,5,6,7-tetrahydro-3aH-isoxazolo[2,3-*a*]pyridin-3-yl)-but-3-en-1-ol (11a/11′a). The reaction of **8a**[4b] (0.946 g, 3.89 mmol) yielded 738 mg (66%) of **11a/11′a** as colorless crystals. **11a**: mp 104–105°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.43 (s, 3 H, CH_3), 1.46–1.73 (m, 5 H, CH_2), 1.90 (d, 1 H, ^3J=1.8 Hz, OH), 2.29–2.64 (m, 3 H, CH_2), 2.86 (m, 1 H, CH_2), 3.31 (m, 1 H, CH_2), 4.64 (m, 1 H, CHOH), 5.12, (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=17 Hz), 5.18 (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=11 Hz), 5.85 (m, 1 H, HC=), 7.34–7.48 (m, 5 H, PhH). ^{13}C NMR (100 MHz): δ=21.4 (CH_2), 23.4 (CH_2), 30.5 (CH_3), 32.9 (CH_2), 41.0 (CH_2), 51.7 (CH_2), 66.9 (CHOH), 70.34 (NC_q), 115.6 (=C_q), 118.2 (=CH_2), 128.3, 128.8, 129.3, 130.0 ($C_{q,Ph}$), 135.2 (HC=), 151.0 (CO). IR: 3620 cm^{-1} (OH), 3570 (OH), 3080, 2940, 2860, 1660, 1640, 1600, 1495, 1445, 1325, 1195, 920. MS (EI): *m/z* (%)=285 (15) [M$^+$], 270 (100), 256 (10), 244 (42), 228 (11), 200 (12), 188 (47), 180 (16), 105 (98), 77 (45). HRMS calcd. for $C_{18}H_{23}NO_2$: 285.1729; found 285.1727. Anal. calcd. for $C_{18}H_{23}NO_2$: C 75.76, H 8.12, N 4.91; found C 75.75, H 8.06, N 4.84. **11′a**: ^{1}H NMR (250 MHz): δ=1.47 (s, 3 H, CH_3), 1.47–1.78 (m, 10 H, CH_2,OH), 2.23–2.65 (m, 3 H, CH_2), 2.92 (m, 1 H, CH_2), 3.28 (m, 1 H, CH_2), 4.64 (m, 1 H, CHOH), 5.12, (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=17 Hz), 5.18 (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=11 Hz), 5.85 (m, 1 H, HC=), 7.34–7.50 (m, 5 H, PhH). IR: 3620 cm^{-1} (OH), 3570 (OH), 3080, 2940, 2860, 1660, 1640, 1600, 1495, 1445, 1325, 1195. MS (EI): *m/z* (%)=285 (14) [M$^+$], 270 (100), 256 (8), 244 (35), 228 (10), 200 (10), 188 (36), 180 (12), 105 (87), 77 (38).

4.3.6. 1-[2-(*tert*-Butyl)-3a-methyl-4,5,6,7-tetrahydro-3aH-isoxazolo[2,3-*a*]pyridin-3-yl] but-3-en-1-ol (11b/11′b). The reaction of **8b**[4b] (400 mg, 1.82 mmol) afforded after flash chromatography (SiO_2, cyclohexane/ethyl acetate 20:1) 402 mg (83%) of **11b/11′b** as colorless crystals. **11b**: mp 99–100°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.21 (s, 9 H, *t*Bu), 1.31 (s, 3 H, CH_3), 1.42–1.65 (m, 6 H, CH_2), 2.30 (d_{br}, 1 H, ^2J=13 Hz), 2.38 (dt, 1 H, CH_2, ^2J=14 Hz, ^3J=5 Hz), 2.50 (dt, 1 H, CH_2, ^2J=14 Hz, ^3J=8 Hz), 2.69 (dt, 1 H, CH_2, ^2J=11 Hz, ^3J=3 Hz) 3.10 (m, 1 H, CH_2, ^2J=11 Hz), 4.98 (ddd, 1 H, C*H*OH, ^2J=2.2 Hz, ^3J=4 Hz, ^3J=9 Hz), 5.16–25.20 (m, 2 H, =CH_2, ^3J=11 Hz, ^3J=18 Hz), 5.86 (m, 1 H, HC=). ^{13}C NMR (100 MHz): δ=21.5 (CH_2), 23.3 (CH_2), 29.4 (*t*Bu), 31.0 (CH_3), 33.0 ($C_{q,tBu}$), 33.1 (CH_2), 41.4 (CH_2), 50.9 (CH_2), 66.8 (CHOH), 69.6 (NC_q), 111.7 (=C_q), 117.9 (=CH_2), 135.6 (HC=), 158.1 (CO). IR: 3616 cm^{-1}, 3565, 3073, 2953, 1639, 1450, 1364, 1275, 1106, 1000. MS (EI): *m/z* (%)=265 (7) [M$^+$], 250 (100), 232 (40), 224 (27), 208 (37), 190 (20), 180 (21), 168 (41), 148 (24), 93 (20). HRMS calcd. for $C_{16}H_{27}NO_2$: 265.2042; found 265.2046. Anal.

calcd. for $C_{16}H_{27}NO_2$: C 72.48, H 10.24, N 5.15; found C 72.41, H 10.26, N 5.20. **11′b**: mp 84–84°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.21 (s, 9 H, *t*Bu), 1.36 (s, 3 H, CH_3), 1.43–1.66 (m, 6H, CH_2), 2.31–2.38 (m, 2 H, CH_2), 2.54 (dt, 1 H, CH_2, ^2J=14 Hz, ^3J=8 Hz), 2.63 (m, 1 H, CH_2, ^2J=11 Hz, ^3J=3 Hz), 3.11 (m, 1 H, CH_2, ^2J=11 Hz), 5.02 (ddd, 1 H, CHOH, ^2J=2.2 Hz, ^3J=4 Hz, ^3J=9 Hz), 5.15 (d_{br}, 1 H, =CH_2, ^3J=10 Hz), 5.18 (d_{br}, 1 H, =CH_2, ^3J=17 Hz), 5.89 (m, 1 H, HC=). ^{13}C NMR (100 MHz): δ=21.6 (CH_2), 23.2 (CH_2), 29.3 (*t*Bu), 31.4 (CH_3), 32.2 (CH_2), 33.0 ($C_{q,tBu}$), 42.5 (CH_2), 51.0 (CH_2), 67.0 (CHOH), 69.8 (NC_q), 111.6 (=C_q), 117.8 (=CH_2), 135.6 (HC=), 156.6 (CO). IR: 3616 cm^{-1}, 3578, 3073, 2953, 1639, 1456, 1363, 1275, 1105, 1017. MS (EI): *m/z* (%)=265 (5) [M$^+$], 250 (100), 232 (21), 224 (19), 208 (28), 190 (12), 180 (16), 168 (32), 148 (14), 93 (14). HRMS calcd. for $C_{16}H_{27}NO_2$: 265.2042; found 265.2044. Anal. calcd. for $C_{16}H_{27}NO_2$: C 72.48, H 10.24, N 5.15; found C 72.4, H 10.26, N 5.20.

4.4. General procedure for the preparation of 12–14

According to a method described by Overman et al.[9] the stirred solution of the alcohols **9**–**11** (ca. 1.5 mmol), dry triethylamine (20 ml), 9 mol% of 4-*N*,*N*′-dimethylaminopyridine (DMAP) in 15–25 ml of dry CH_2Cl_2 at −78°C was treated dropwise with the solution of methanesulfonic acid chloride (1.3 equiv.) in 1–2 ml of dry CH_2Cl_2. The mixture was stirred for additional 40–60 min at −78°C and then warmed up to room temperature. After recooling to −30°C, hydrolysis with 20 ml of water and separation of the the two layers, the aqueous phase was extracted with CH_2Cl_2 (3×50 ml). The combined organic phase was then dried ($MgSO_4$) and concentrated in vacuo. Flash chromatography of the oily residue (SiO_2, cyclohexane/ethyl acetate 20:1 or 10:1) afforded **12**–**14** as pure *E*-isomers.

4.4.1. 3-[Buta-1(*E*),3-dienyl]-3a,6,6-trimethyl-2-phenyl-3a,4,5,6-tetrahydropyrrolo [1,2-*b*]isoxazole (12a). The reaction of the mixture of **9a** (2.31 g, 7.71 mmol), dry triethylamine (2.42 g, 23.9 mmol), DMAP (85 mg, 0.5 mmol) in 45 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (832 mg, 7.27 mmol) afforded 1.50 g (69%) of **12a** as yellow oil. ^{1}H NMR (250 MHz): δ=1.19 (s, 3 H, CH_3), 1.32 (s, 3 H, CH_3), 1.59 (s, 3 H, CH_3), 1.68–1.83 (m, 2 H, CH_2), 1.95 (ddd, 1 H, CH_2, ^2J=12.5 Hz, ^3J=7.0 Hz, ^3J=4.9 Hz), 2.47 (ddd, 1 H, CH_2, ^2J=12.5 Hz, ^3J=9.1 Hz, ^3J=7.5 Hz), 5.00 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=10 Hz), 5.15 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=16.6 Hz), 6.19 (dd, 1 H, HC=, ^3J=15.8 Hz, ^4J=10.4 Hz), 6.32–6.40 (ddd, 1 H, =CH, ^3J=16.6 Hz, ^3J=10 Hz, ^4J=10.4 Hz), 6.38 (d, 1 H, HC=, ^3J=15.8 Hz), 7.34–7.41 (m, 3 H, PhH), 7.52 (m_c, 2 H, PhH). ^{13}C NMR (100 MHz): δ=21.0 (CH_3), 28.3 (CH_3), 29.0 (CH_3), 35.0 (CH_2), 36.5 (CH_2), 68.6 (C_q), 76.8 (NC_q), 114.8 (=CH_2), 115.5 (=C_q), 124.1 (=CH), 126.8 (=CH), 128.3 (C_{Ph}), 128.4 (C_{Ph}), 129.1 (C_{Ph}), 129.2 ($C_{q,Ph}$), 138.1 (HC=), 152.2 (CO). IR: 3086 cm^{-1}, 2972, 1615, 1491, 1446, 1345, 1238, 1168, 1068, 1001. UV (CH_3CN): λ= 250 nm (ϵ 12,500), 333 nm (ϵ 14,300). MS (EI): *m/z* (%)=281 (15) [M$^+$], 266 (19), 212 (9), 148 (10), 120 (11), 105 (100), 77 (36). HRMS calcd. for $C_{19}H_{23}NO$: 281.17796; found 281.17801.

4.4.2. 3-[Buta-(1*E*),3-dienyl]-2-(*tert*-butyl)-3a,6,6-trimethyl-3a,4,5,6-tetrahydropyrrolo [1,2-*b*]isoxazole (12b). The reaction of the mixture of **9b** (380 mg, 1.36 mmol), dry NEt_3 (0.43 g, 4.20 mmol), DMAP (15 mg, 0.12 mmol) in 15 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (200 mg, 1.77 mmol) afforded 242 mg (64%) of **12b** as colorless crystals; mp 41–44°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.12 (s, 3 H, CH_3), 1.25 (s, 3 H, CH_3), 1.27 (s, 9 H, *t*Bu), 1.47 (s, 3 H, CH_3), 1.60–1.75 (m, 2 H, CH_2), 1.87 (ddd, 1 H, CH_2, ^2J=12 Hz, ^3J=7 Hz, ^3J=5 Hz), 2.34 (ddd, 1 H, CH_2, ^2J=12 Hz, ^3J=9 Hz, ^3J=7.5 Hz), 4.95 (dd, 1 H, =CH_2, ^2J=0.8 Hz, ^3J=10 Hz), 5.09 (dd, 1 H, =CH_2, ^2J=0.8 Hz, ^3J=16.9 Hz), 5.99 (dd, 1 H, HC=, ^3J= 15.8 Hz, ^4J=10.4 Hz), 6.35 (ddd, 1 H, =CH, ^3J=16.9 Hz, ^3J=10 Hz, ^4J=10.4 Hz), 6.54 (d, 1 H, HC=, ^3J=15.8 Hz). ^{13}C NMR (100 MHz): δ=21.3 (CH_3), 28.3 (CH_3), 29.3 (CH_3), 29.5 (*t*Bu), 33.8 (C_q), 35.4 (CH_2), 36.5 (CH_2), 68.3 (C_q), 76.7 (NC_q), 111.8 (=CH_2), 113.8 (=C_q), 124.4 (=CH), 124.8 (=CH), 138.5 (HC=), 160.2 (CO). IR: 2972 cm^{-1}, 1615, 1572, 1460, 1365, 1166, 1000. UV (CH_3CN): λ= 312 nm (ϵ 27,000), 240 nm (ϵ 8900). MS (EI): *m/z* (%)=261 (12) [M$^+$], 246 (12), 234 (7), 176 (20), 149 (10), 134 (10), 120 (12), 107 (11), 91 (14), 57 (100). HRMS calcd. for $C_{17}H_{27}NO$: 261.2093; found 261.2093. Anal. calcd for $C_{17}H_{27}NO$: C 78.11, H 10.41, N 5.36; found C 78.08, H 10.49, N 5.12.

4.4.3. 3-[Buta-(1*E*),3-dienyl]-2-phenyl-3a,5,5-trimethyl-3a,4,5,6-tetrahydropyrrolo[1,2-*b*]isoxazole (13a). The reaction of the mixture of **10a** (620 mg, 2.09 mmol), dry NEt_3 (660 mg, 6.48 mmol), DMAP (23 mg, 0.19 mmol) in 25 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (310 mg, 2.71 mmol) afforded unchanged **10a** (135 mg, 22%) and 0.430 g (73%) of **13a** as pale yellow oil. ^{1}H NMR (250 MHz): δ=1.09 (s, 3 H, CH_3), 1.24 (s, 3 H, CH_3), 1.59 (s, 3 H, CH_3), 1.82 (dd, 1 H, 4-H, ^2J=12.5 Hz, ^4J=1.5 Hz), 2.30 (d, 1 H, 4-H, ^2J=12.5 Hz), 2.89 (d, 1 H, 6-H, ^2J=8.9 Hz), 3.33 (dd, 1 H, 6-H, ^2J=8.9 Hz, ^4J= 1.5 Hz), 5.03 (ddd, 1 H, =CH_2, ^2J=0.9 Hz, ^3J=10.1 Hz, ^4J=0.6 Hz), 5.17 (ddd, 1 H, =CH_2, ^2J=0.9 Hz, ^3J= 16.8 Hz, ^4J=0.6 Hz), 6.13 (m, 1 H, =CH, ^3J=15.9, 10.4 Hz), 6.37 (m, 2 H, =CH, ^3J=10.4, 10.1, 15.6, 16.8 Hz), 7.40 (m, 3 H, Ph-H), 7.51 (m, 2 H, Ph-H). ^{13}C NMR (100 MHz): δ=27.8 (CH_3), 28.2 (CH_3), 28.2 (CH_3), 37.2 (C_q), 50.1 CH_2), 69.4 (NCH_2), 76.8 (NC_q), 115.1 (=CH_2), 116.1 (3-C), 124.2 (=CH), 127.3 (C_{Ph}), 128.3 (C_{Ph}), 128.4 (=CH), 129.2 (C_{Ph}), 129.7 ($C_{q,Ph}$), 138.0 (=CH), 150.0 (CO). IR: 3080 cm^{-1}, 2970, 2870, 1615, 1490, 1445, 1340, 1170, 1120, 1060, 1000, 990. UV (CH_3CN): λ=327 nm (ϵ 19,400), 246 nm (ϵ 11,000), 235 nm (ϵ 11,900). MS (EI): *m/z* (%)=281 (33) [M$^+$], 266 (18), 224 (20), 196 (14), 120 (95), 105 (100), 91 813). HRMS calcd. for $C_{19}H_{23}NO$: 281.1779; found 281.1780.

4.4.4. 3-[Buta-1(*E*),3-dienyl]-2-(*tert*-butyl)-3a,5,5-trimethyl-3a,4,5,6-tetrahydropyrrolo [1,2-*b*]isoxazole (13b). The reaction of the mixture of **10b** (410 mg, 1.47 mmol), dry NEt_3 (460 mg, 4.55 mmol), DMAP (16 mg, 0.13 mmol) in 15 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (220 mg, 1.9 mmol) afforded 263 mg (74%) of **13b** as pale yellow oil. ^{1}H NMR (250 MHz): δ=1.06 (s, 3 H, CH_3), 1.19 (s, 3 H, CH_3), 1.25 (s, 9 H, *t*Bu), 1.46 (s, 3 H,

CH_3), 1.73 (dd, 1 H, 4-H, ^2J=12.6 Hz, ^4J=1.4 Hz), 2.20 (d, 1 H, 4-H, ^2J=12.6 Hz), 2.67 (d, 1 H, 6-H, ^2J=8.8 Hz), 3.17 (dd, 1 H, 6-H, ^2J=8.6 Hz, ^4J=1.4 Hz), 4.98 (dd_{br}, 1 H, =CH_2, ^2J=0.6 Hz, ^3J=10.7 Hz), 5.11 (dt_{br}, 1 H, =CH_2, ^2J=0.6 Hz, ^3J=16.8 Hz), 5.91 (dd, 1 H, =CH, ^3J=15.9, 10.5 Hz), 6.35 (ddd, 1 H, =CH, ^3J=10.5, 10.7, 16.8 Hz), 6.58 (d, 1 H, HC=, ^3J=15.9 Hz). ^{13}C NMR (100 MHz): δ=27.8 (CH_3), 28.1 (CH_3), 28.4 (CH_3), 29.3 (*t*Bu), 33.5 ($C_{q,tBu}$), 37.1 (C_q), 50.4 (CH_2), 68.9 (NCH_2), 76.4 (NC_q), 112.8 (=CH_2), 114.2 (3-C), 124.6 (=CH), 125.5 (=CH), 138.4 (=CH), 158.0 (CO). IR: 2959 cm^{-1}, 1616, 1572, 1466, 1370, 1254, 1165, 1124, 1000. UV (CH_3CN): λ= 304 nm (ϵ 26,600), 236 nm (ϵ 6600). MS (EI): *m/z* (%)=263 (94) [M^++2], 235 (75), 207 (99), 178 (100), 128 (20), 102 (16), 89 (30). MS (CI): *m/z* (%)=262 (100) [M^++1], 204 (9), 177 (6), 148 (6). HRMS calcd. for $C_{17}H_{27}NO$: 261.2093; found 261.2095.

4.4.5. 3-[Buta-1(*E*),3-dienyl]-3a-methyl-2-phenyl-4,5,6,7-tetrahydro-3aH-isoxazolo[2,3-*a*] pyridine (14a). The reaction of the mixture of **11a** (700 mg, 2.48 mmol), dry NEt_3 (780 mg, 7.7 mmol), DMAP (27 mg, 0.22 mmol) in 25 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (370 mg, 3.23 mmol) afforded unreacted **11a** (220 mg, 31%) and 388 mg (58%) of **14a** as orange oil. ^{1}H NMR (250 MHz): δ=1.23–1.36 (m, 2 H, CH_2), 1.45 (s, 3 H, CH_3), 1.47–1.78 (m, 3 H, CH_2), 2.38 (m, 1 H, CH_2), 2.90 (dt, 1 H, CH_2, ^3J=4 Hz, 11 Hz), 3.36 (m, 1 H, CH_2), 5.03 (dd, 1 H, =CH_2, ^2J=1.8 Hz, ^3J=9 Hz), 5.17 (dd, 1 H, =CH_2, ^2J=1.8 Hz, ^3J=16 Hz), 6.24–6.52 (m, 3 H, =CH), 7.38–7.53 (m, 5 H, Ph-H). ^{13}C NMR (100 MHz): δ=20.0 (CH_2), 23.0 (CH_2), 27.6 (CH_3), 31.8 (CH_2), 51.4 (NCH_2), 70.2 (NC_q), 114.9 (=C_q), 115.1 (=C), 125.0 (=C), 126.7 (=C), 128.4 (=C), 128.5 (=C), 129.3 (=C), 130.0 (=$C_{q,Ph}$), 138.3 (=C), 152.7 (=CO). IR: 3090 cm^{-1}, 3030, 2940, 2860, 1615, 1490, 1445, 1340, 1170, 1060. UV (CH_3CN): λ=233 nm (ϵ 13,000), 329 nm (ϵ 15,400). MS (EI): *m/z* (%)=267 (45) [M^+], 252 (87), 238 (10), 210 (11), 162 (14), 120 (13), 105 (100), 77 (44). HRMS calcd. for $C_{18}H_{21}NO$: 267.1623; found 267.1623.

4.4.6. 3-[Buta-1(*E*),3-dienyl]-2-(*tert*-butyl)-3a-methyl-4,5,6,7-tetrahydro-3aH-isoxazolo [2,3-*a*]pyridine (14b). The reaction of the mixture of **11b** (390 mg, 1.49 mmol), dry NEt_3 (470 mg, 4.63 mmol), DMAP (16 mg, 0.13 mmol) in 17 ml of dry CH_2Cl_2 with methanesulfonic acid chloride (220 mg, 1.90 mmol) afforded unreacted **11b** (60 mg, 15%) and 147 mg (40%) of **14b** as pale yellow oil. ^{1}H NMR (250 MHz): δ=1.20–1.27 (m, 1 H, CH_2), 1.24 (s, 9 H, *t*Bu), 1.30 (s, 3 H, CH_3), 1.49–1.65 (m, 4 H, CH_2), 2.23 (ddt, 1 H, CH_2, ^2J=14 Hz, ^3J=4 Hz, 2 Hz), 2.71 (dt, 1 H, CH_2, ^3J=4 Hz, 11 Hz), 3.14 (ddt, 1 H, CH_2, ^2J=11 Hz, ^3J=4 Hz, 1 Hz), 4.98 (dd, 1 H, =CH_2, ^2J=0.6 Hz, ^3J= 10.2 Hz), 5.11 (dd, 1 H, =CH_2, ^2J=0.6 Hz, ^3J=17 Hz), 6.06 (dd, 1 H, =CH, ^3J=10 Hz, 15.9 Hz), 6.34 (ddd, 1 H, =CH, ^3J=10 Hz, 10.2 Hz, 17 Hz), 6.57 (d, 1 H, HC=, ^3J=15.9 Hz). ^{13}C NMR (100 MHz): δ=20.0 (CH_2), 23.0 (CH_2), 28.2 (CH_3), 29.1 (*t*Bu), 31.6 (CH_2), 33.6 ($C_{q,tBu}$), 50.9 (NCH_2), 69.9 (NC_q), 110.8 (=C_q), 114.4 (CH), 125.5 (CH), 125.7 (CH), 138.6 (CH), 160.6 (=CO). IR: 2968 cm^{-1}, 1619, 1571, 1452, 1370, 1276, 1164, 1116, 1000. UV (CH_3CN): λ=300 nm (ϵ 24,000), 239 nm (ϵ 7500). MS (EI): *m/z* (%)=247 (5) [M^+], 232 (13), 190 (8), 162 (8), 148 (19), 134 (8), 93 (13), 91 (13), 57 (100). HRMS calcd. for $C_{16}H_{25}NO$: 247.1936; found 247.1937.

4.5. General procedure of the short-time thermolysis[10]

10^{-2}–10^{-3} Molar solutions of **12**–**14** in dry benzene were slowly dropped through the heated thermolysis column in a nitrogen stream at the given temperature (the details of the apparatus are described in Section 4.1). The reaction mixture was collected at 0°C and then concentrated in vacuo. After ^{1}H NMR analysis of the raw material, purification was accomplished by flash chromatography (SiO_2, cyclohexane/ethyl acetate 50:1 or 100:1). In some cases additional purification by MPLC (SiO_2, *n*-hexane/ethyl acetate 50:1) was performed.

4.5.1. Thermolysis of 12a. The solution of **12a** (200 mg, 0.71 mmol) in 75 ml of dry benzene at 320°C afforded 118 mg (59%) of phenyl-(3,3,9a-trimethyl-2,3,9,9a-tetrahydro-1H-pyrrolo[1,2-*a*]azepin-5-yl)-methanone (**15a**) as yellow crystals and 17 mg (9%) of phenyl-(5,5-dimethyl-1-vinyl-6,7-dihydro-5H-pyrrolizin-3-yl)-methanone (**18a**) as yellow oil. **15a**: mp 66–67°C (diethyl ether/pentane). ^{1}H NMR (250 MHz): δ=1.02 (d, 3 H, 10-CH_3, ^4J= 1.2 Hz), 1.20 (s, 3 H, CH_3), 1.21 (s, 3 H, CH_3), 1.65 (ddd, 1 H, 1′-H, $^2J_{1',1}$=12.3 Hz, $^3J_{1',2}$=6.7 Hz, $^3J_{1',2'}$=2.7 Hz), 1.8 (dt_{br}, 1 H, 1-H, ^2J=12.3 Hz, $^3J_{1,2'}$=6.7 Hz), 1.9 (dd, 1 H, 2′-H, $^2J_{2',2}$=12.3 Hz, $^3J_{2',1}$=6.7 Hz, $^3J_{2',1'}$=2.7 Hz), 2.25 (dt_{br}, 1 H, 2-H, ^2J=12.3 Hz, $^3J_{2,1'}$=6.7 Hz), 2.33 (m_{br}, 1 H, 9′-H, $^2J_{9',9}$=15.7 Hz, $^3J_{9',8}$=3 Hz, $^4J_{9',7}$=3 Hz, $^4J_{9',CH3}$= 1.2 Hz, $^5J_{9',6}$=0.5 Hz), 2.5 (dd, 1 H, 9-H, $^2J_{9,9'}$=15.7 Hz, $^3J_{9,8}$=8.3 Hz), 5.18 (m_c, 1 H, 6-H, $^3J_{6,7}$=8.3 Hz, $^4J_{6,8}$= 1 Hz, $^5J_{6,9'}$=0.5 Hz), 5.78 (dddd, 1 H, 8-H, $^3J_{8,7}$=10.8 Hz, $^3J_{8,9}$=8.3 Hz, $^3J_{8,9'}$=3 Hz, $^4J_{8,6}$=1.2 Hz), 5.99 (ddd, 1 H, 7-H, $^3J_{7,8}$=10.8 Hz, $^3J_{7,6}$=8.3 Hz, $^3J_{7,9'}$=3 Hz), 7.43 (m_c, 2 H, *m*-PhH), 7.52 (m_c, 1 H, *p*-PhH), 8.00 (m_c, 2 H, *o*-PhH). ^{13}C NMR (100 MHz): δ=25.2 (CH_3), 29.9 (CH_3), 30.2 (CH_3), 38.5 (CH_2), 39.9 (CH_2), 46.0 (9-CH_2), 61.1 (NC_q), 65.6 ($C(CH_3)_2$), 109.5 (=CH), 125.0 (=CH), 127.7 (=CH), 128.0 (C_{Ph}), 130.4 (C_{Ph}), 132.5 (C_{Ph}), 138.3 ($C_{q,Ph}$), 142.8 (=CN), 197.1 (CO). IR: 3060 cm^{-1}, 2970, 1665, 1600, 1550, 1450, 1370, 1320, 1260, 1235, 1175, 1020. UV (CH_3CN): λ=248 nm (ϵ 16,400), 303 nm (ϵ 7700), 393 nm (ϵ 2900). MS (EI): *m/z* (%)=281 (2) [M^+], 265 (48), 210 (68), 132 (14), 105 (100), 77 (78). HRMS calcd. for $C_{19}H_{23}NO$: 281.1780; found 281.1783. Anal. calcd. for $C_{19}H_{23}NO$: C 81.10, H 8.24, N 4.98; found C 80.96, H 8.26, N 4.89. **18a**: ^{1}H NMR (250 MHz): δ=1.71 (s, 6 H, CH_3), 2.44 (t, 2 H, CH_2, ^3J=7.5 Hz), 2.96 (t, 2 H, CH_2, ^3J= 7.5 Hz), 5.00 (dd, 1 H, =CH_2, ^2J=1.3 Hz, ^3J=11 Hz), 5.27 (dd, 1 H, =CH_2, ^2J=1.3 Hz, ^3J=17.7 Hz), 6.47 (dd, 1 H, =CH, ^3J=11 Hz, ^3J=17.7 Hz), 6.76 (s, 1 H, pyrrole-H), 7.43 (m_c, 2 H, *m*-PhH), 7.51 (m_c, 1 H, *p*-PhH), 7.77 (m_c, 2 H, *o*-PhH). ^{13}C NMR (100 MHz): δ=23.3 (CH_2), 27.1 (2×CH_3), 44.1 (Ar-CH_2), 65.0 ($C(CH_3)_2$), 110.5 (=CH_2), 114.8 (C_q), 124.7 (HC=), 126.7 (C_q), 128.0 (C_{Ph}), 129.0 ($CH_{pyrrole}$), 129.2 (C_{Ph}), 131.0 (C_{Ph}), 140.5 (C_q), 144.4 (C_q), 184.2 (CO). IR: 3080 cm^{-1}, 2967, 1627 (CO), 1578, 1453, 1381, 1315, 1240, 1172. MS (EI): *m/z* (%)=265 (48) [M^+], 237 (10), 210 (68), 132 (14), 105 (100), 77 (79). HRMS calcd. for $C_{18}H_{19}NO$: 265.1467; found 265.1468.

4.5.2. Thermolysis of 12b. The solution of **12b** (110 mg,

0.42 mmol) in 55 ml of dry benzene at 280°C afforded after flash chromatography and MPLC 14 mg (13%) of phenyl-(3,3,9a-trimethyl-2,3,9,9a-tetrahydro-1H-pyrrolo[1,2-*a*]-azepin-5-yl)-methanone (**15b**) as colorless solid. ^{1}H NMR (500 MHz): δ=0.97 (s, 3 H, 10-CH_3), 1.16 (s, 3 H, CH_3), 1.22 (s, 3 H, CH_3), 1.29 (s, 9 H, *t*Bu), 1.70 (ddd, 1 H, 1′-H, $^2J_{1',1}$=12.4 Hz, $^3J_{1',2}$=6.3 Hz, $^3J_{1',2'}$=1.9 Hz), 1.84 (ddd, 1 H, 1-H, ^2J=12 Hz, $^3J_{1,2'}$=6.9 Hz, ^3J=2 Hz), 1.88 (ddd, 1 H, 2′-H, $^2J_{2',2}$=12 Hz, $^3J_{2',1}$=6.9 Hz, $^3J_{2',1'}$=1.9 Hz), 2.15 (ddd, 1 H, 2-H, ^2J=12 Hz, $^3J_{2,1'}$=6.9 Hz), 2.32 (m, 2 H, 9,9′-H), 4.96 (d, 1 H, 6-H, $^3J_{6,7}$=8 Hz), 5.67 (ddd, 1 H, 8-H, $^3J_{8,7}$=11 Hz, $^3J_{8,9}$=6 Hz, $^3J_{8,9'}$=4 Hz), 5.91 (ddd, 1 H, 7-H, $^3J_{7,8}$=11 Hz, $^3J_{7,6}$=8 Hz, $^3J_{7,9'}$=2 Hz). ^{13}C NMR (125 MHz): δ=24.8 (CH_3), 29.9 (*t*Bu), 29.8 (CH_3), 29.8 (CH_3), 38.3 (CH_2), 39.6 (CH_2), 44.7 (9-CH_2), 45.2 ($C_{q,tBu}$), 61.6 (NC_q), 64.5 ($C(CH_3)_2$), 105.8 (=CH), 124.5 (=CH), 126.3 (=CH), 143.0 (=CN), 214.6 (CO). IR: 2966 cm^{-1}, 1684, 1570, 1460, 1431, 1391, 1366, 1246, 1153, 1097. MS (EI): *m/z* (%)=261 (100) [M$^+$], 246 (99), 192 (82), 176 (52), 161 (38), 120 (99), 80 (65). HRMS calcd. for $C_{17}H_{27}NO$: 261.2093; found 261.2091.

4.5.3. Thermolysis of 13a. The solution of **13a** (115 mg, 0.41 mmol) in 48 ml of dry benzene at 320°C afforded 56 mg (48%) of phenyl-(2,2,9a-trimethyl-2,3,9,9a-tetrahydro-1H-pyrrolo[1,2-*a*]azepine-5-yl)-methanone (**16a**) and 4 mg (3%) of phenyl-(6,6-dimethyl-1-vinyl-6,7-dihydro-5H-pyrrolizin-3-yl)-methanone (**19a**), both as orange oils. **16a**: ^{1}H NMR (250 MHz): δ=0.95 (s, 3 H, CH_3), 0.97 (d, 3 H, 10-CH_3, ^4J=1.1 Hz), 0.99 (s, 3 H, CH_3), 1.72 (d, 1 H, 1-H, ^2J=12.8 Hz), 1.97 (dd, 1 H, 1′-H, ^2J=12.8 Hz, $^4J_{1',3'}$= 0.8 Hz), 2.14 (m_{br}, 1 H, 9′-H, $^2J_{9',9}$=15.8 Hz, $^3J_{9',8}$=3.5 Hz, $^4J_{9',7}$=3.5 Hz, $^4J_{CH3}$=1.1 Hz), 2.51 (dd, 1 H, 9-H, $^2J_{9,9'}$= 15.8 Hz, $^3J_{9,8}$=8.3 Hz), 2.63 (d, 1 H, 3-H, ^2J=10.2 Hz), 3.23 (d_{br}, 1 H, 3′-H, ^2J=10.2 Hz), 5.26 (d, 1 H, 6-H, $^3J_{6,7}$=8.0 Hz), 5.80 (ddd, 1 H, 8-H, $^3J_{8,7}$=11.5 Hz, $^3J_{8,9}$= 8.3 Hz, $^3J_{8,9'}$=3.5 Hz), 6.10 (ddd, 1 H, 7-H, $^3J_{7,8}$=11.5 Hz, $^3J_{7,6}$=8.0 Hz, $^3J_{7,9'}$ =3.5 Hz), 7.41 (m_c, 2 H, *m*-PhH), 7.52 (m_c, 1 H, *p*-PhH), 7.90 (m_c, 2 H, *o*-PhH). ^{13}C NMR (100 MHz): δ=25.0 (CH_3), 27.4 (CH_3), 27.4 (CH_3), 35.8 (C_q), 46.0 (CH_2), 56.5 (CH_2), 60.3 (NC_q), 65.3 (CH_2), 105.7 (=CH), 126.0 (=CH), 126.9 (=CH), 128.1 (C_{Ph}), 129.9 (C_{Ph}), 132.7 (C_{Ph}), 137.9 ($C_{q,Ph}$), 143.6 (=CN), 196.4 (C=O). IR: 3060 cm^{-1}, 3010, 2960, 2870, 2830, 1660 (C=O), 1600, 1560, 1450, 1280, 1150. UV (CH_3CN): λ=388 nm (ϵ 3000), 288 nm (ϵ 6500), 248 nm (ϵ 13,800). MS (EI): *m/z* (%)=281 (53) [M$^+$], 266 (28), 252 (14), 184 (95), 176 (35), 161 (17), 120 (17), 105 (100), 91 (12), 80 (68), 77 (51). HMRS calcd. for $C_{19}H_{23}NO$: 281.1780; found 281.1780. **19a**: ^{1}H NMR (250 MHz): δ=1.31 (s, 6 H, CH_3), 2.76 (s, 2 H, CH_2), 4.18 (s, 2 H, NCH_2), 5.02 (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=11 Hz), 5.28 (dd, 1 H, =CH_2, ^2J=1.5 Hz, ^3J=17.7 Hz), 6.48 (dd, 1 H, =CH, ^3J=11 Hz, ^3J=17.7 Hz), 6.82 (s, 1 H, pyrrole-H), 7.41–7.57 (m, 3 H, PhH), 7.81 (m_c, 2 H, *o*-PhH). IR: 3060 cm^{-1}, 2980, 2870, 1620 (C=O), 1600, 1460, 1390, 1275, 1260, 1160. MS (EI): *m/z* (%)=265 (67) [M$^+$], 250 (42), 239 (15), 224 (13), 210 (17), 149 (61), 105 (79), 77 (29).

4.5.4. Thermolysis of 13b. The solution of **13b** (127 mg, 0.48 mmol) in 60 ml of dry benzene at 280°C afforded after flash chromatography and MPLC 48 mg (38%) of 1-(2,2,9a-trimethyl-2,3,9,9a-tetrahydro-1H-pyrrolo[1,2-*a*]azepin-5-yl)-2,2-dimethylpropan-1-one (**16b**) and traces (1-2 mg, ca. 1%) of 1-(2,2-dimethyl-7-vinyl-2,3-dihydro-1H-pyrrolizin-5-yl)-2,2-dimethylpropan-1-one (**19b**), both as yellow oils. **16b**: ^{1}H NMR (500 MHz): δ=1.01 (s, 3 H, CH_3), 1.20 (s, 3 H, 10-CH_3), 1.25 (s, 3 H, CH_3), 1.27 (s, 9 H, *t*Bu), 1.71 (d, 1 H, 1-H, ^2J=12.8 Hz), 1.95 (dd, 1 H, 1′-H, ^2J=12.8 Hz, $^4J_{1',3'}$=0.9 Hz), 2.00 (m_{br}, 1 H, 9′-H, $^2J_{9',9}$=15.2 Hz, $^3J_{9',8}$=3.6 Hz, $^4J_{9',7}$=3.7 Hz), 2.41 (dd, 1 H, 9-H, $^2J_{9,9'}$= 15.2 Hz, $^3J_{9,8}$=8.3 Hz), 2.76 (d, 1 H, 3-H, ^2J=10.1 Hz), 3.00 (d, 1 H, 3′-H, ^2J=10.1 Hz), 4.66 (d, 1 H, 6-H, $^3J_{6,7}$=7.6 Hz), 5.56 (ddd, 1 H, 8-H, $^3J_{8,7}$=11.5 Hz, $^3J_{8,9}$= 8.5 Hz, $^3J_{8,9'}$=3.6 Hz), 6.10 (ddd, 1 H, 7-H, $^3J_{7,8}$=11.5 Hz, $^3J_{7,6}$=7.6 Hz, $^3J_{7,9'}$=3.7 Hz). ^{13}C NMR (125 MHz): δ=25.0 (CH_3), 27.8 (CH_3), 27.9 (*t*Bu), 28.1 (CH_3), 35.9 (2-C_q), 44.4 ($C_{q,tBu}$), 45.5 (CH_2), 56.4 (CH_2), 62.5 (NC_q), 66.0 (CH_2), 95.9 (=CH), 122.9 (=CH), 126.0 (=CH), 144.0 (=CN), 212.8 (C=O). IR: 2959 cm^{-1}, 1690, 1575, 1437, 1291, 1157, 1091. MS (EI): *m/z* (%)=261 (100) [M$^+$], 246 (80), 204 (55), 190 (25), 176 (54), 164 (88), 162 (29), 120 (22), 112 (39), 91 (22), 80 (32), 57 (62). HRMS calcd. for $C_{17}H_{27}NO$: 261.2093; found 261.2093. **19b**: ^{1}H NMR (400 MHz): δ=1.25 (s, 6H, CH_3), 1.35 (s, 9 H, *t*Bu), 2.68 (s, 2 H, CH_2), 4.08 (s, 2 H, NCH_2), 5.00 (dd, 1 H, =CH_2, ^2J=1 Hz, ^3J=11 Hz), 5.28 (dd, 1 H, =CH_2, ^2J=1 Hz, ^3J=18 Hz), 6.51 (dd, 1 H, =CH, ^3J=11 Hz, ^3J=18 Hz), 7.00 (s, 1 H, pyrrole-H).

4.5.5. Thermolysis of 14a. The solution of **14a** (150 mg, 0.56 mmol) in 70 ml of dry benzene at 280°C afforded after flash chromatography 72 mg (42%) of phenyl-(10a-methyl-1,2,3,4,10,10a-hexahydro-pyrido[1,2-*a*]azepin-6-yl)-methanone (**17a**) and 10 mg (7%) of phenyl-(1-vinyl-4,5,6,7-tetrahydro-indolizin-3-yl)-methanone (**20a**), both as deep yellow oils. **17a**: ^{1}H NMR (250 MHz): δ=1.03 (s_{br}, 3 H, CH_3), 1.14–1.36 (m, 4 H, CH_2), 1.40–1.60 (m, 3 H, CH_2), 1.70–1.75 (m, 2 H, CH_2), 2.22 (dd, 1 H, 10-H, $^2J_{10,10'}$= 17 Hz, $^3J_{10,9}$=7.9 Hz), 2.37 (ddd, 1 H, 4′-H, $^2J_{4',4}$= 13.7 Hz, $^3J_{4',3}$=10.7 Hz, $^3J_{4',3'}$=3.7 Hz), 2.65 (m_c, 1 H, 10′-H, $^2J_{10',10}$=17 Hz, $^3J_{10',9}$=3 Hz), 2.88 (dt, 1 H, 4-H, $^2J_{4,4'}$=13.7 Hz, $^3J_{4,3,3'}$=4 Hz), 5.94–6.15 (m, 3 H, 7-H, 8-H, 9-H), 7.37–7.54 (m, 3 H, PhH), 7.92 (m_c, 2 H, *o*-PhH). ^{13}C NMR (100 MHz): δ=20.1 (CH_2), 24.0 (CH_3), 25.5 (CH_2), 39.2 (CH_2), 39.5 (CH_2), 50.2 (NCH_2), 55.0 (NC_q), 116.1 (HC=), 125.2 (HC=), 127.8 (C_{Ph}), 129.8 (C_{Ph}), 131.9 (C_{Ph}), 132.0 (HC=), 138.8 ($C_{q,Ph}$), 146.9 (=CN), 196.8 (CO). IR: 3030 cm^{-1}, 2940, 2870, 1655 (CO), 1600, 1560, 1450, 1380, 1275, 1240, 1130. MS (EI): *m/z* (%)=267 (83) [M$^+$], 252 (100), 238 (21), 224 (24), 210 (25), 184 (68), 162 (32), 149 (39), 132 (21), 105 (78). HRMS calcd. for $C_{18}H_{21}NO$: 267.1623; found 267.1623. **20a**: ^{1}H NMR (250 MHz): δ=1.83–2,04 (m, 4 H, CH_2), 2.87 (t, 2 H, CH_2, ^3J=6 Hz), 4.46 (t, 2 H, CH_2, ^3J=6 Hz), 5.00 (dd, 1 H, =CH_2, ^2J=1.2 Hz, ^3J=11 Hz), 5.33 (dd, 1 H, =CH_2, ^2J=1.2 Hz, ^3J=17 Hz), 6.52 (dd, 1 H, HC=, ^3J=17 Hz, ^3J=11 Hz), 6.81 (s, 1 H, $C_{pyrrole}$H), 7.41–7.54 (m, 3 H, PhH), 7.77 (m_c, 2 H, *o*-PhH). IR: 3080 cm^{-1}, 2950, 2870, 1625 (CO), 1600, 1490, 1470, 1385, 1320, 1240, 1175. MS (EI): *m/z* (%)=251 (99) [M$^+$], 250 (100), 225 (31), 224 (36), 149 (60), 105 (54), 77 (47). HRMS calcd. for $C_{17}H_{17}NO$: 251.1310; found 251.1310.

4.5.6. Thermolysis of 14b. The solution of **14b** (76 mg,

0.31 mmol) in 40 ml of dry benzene at 280°C afforded after flash chromatography and MPLC 31 mg (41%) of 1-(10a-methyl-1,2,3,4,10,10a-hexahydropyrido[1,2-*a*]azepin-6-yl)-2,2-dimethylpropan-1-one (**17b**) as pale yellow oil and traces (<1%) of 2,2-dimethyl-1-(1-vinyl-5,6,7,8-tetrahydroindolizin-3-yl)-propan-1-one (**20b**). **17b**: ^{1}H NMR (250 MHz): δ=0.99 (s_{br}, 3 H, CH_3), 1.28 (s, 9 H, *t*Bu), 1.53–1.66 (m, 4 H, CH_2), 1.70–1.75 (m, 2 H, CH_2), 2.08 (dd, 1 H, 10-H, $^2J_{7,7'}$=17 Hz, $^3J_{7,9}$=8 Hz), 2.39 (ddd, 1 H, 9′-H, $^2J_{9',9}$=14 Hz, $^3J_{9',7}$=9 Hz, $^3J_{9',7'}$=5 Hz), 2.66 (m_c, 1 H, 7′-H, $^2J_{7',7}$=17 Hz, $^3J_{7',9}$=3 Hz), 2.93 (dt, 1 H, 9-H, $^2J_{9,9'}$=14 Hz, $^3J_{9,7'}$=3 Hz), 5.23 (d, 1 H, 7-H, ^3J=8 Hz), 5.77 (ddd, 1 H, 9-H, $^3J_{9,9}$=11 Hz, ^3J=8 Hz, ^4J=3 Hz), 5.95 (ddd, 1 H, 9-H, $^3J_{9,9'}$=11 Hz, $^3J_{9,10}$=8 Hz, $^3J_{9,10'}$= 3 Hz). ^{13}C NMR (125 MHz): δ=20.3 (CH_2), 24.4 (CH_3), 25.7 (CH_2), 28.1 (*t*Bu), 38.3 (CH_2), 40.0 (CH_2), 44.5 ($C_{q,tBu}$), 50.7 (NCH_2), 54.9 (NC_q), 109.9 (3-CH), 125.4 (5-CH), 129.1 (4-CH), 149.2 (=CN), 213.5 (CO). IR: 2936 cm^{-1}, 1675, 1576, 1478, 1378, 1257, 1147, 1119, 1097. MS (EI): *m/z* (%)=247 (30) [M$^+$], 232 (100), 190 (16), 176 (11), 164 (18), 147 (10). HRMS calcd. for $C_{16}H_{25}NO$: 247.1936; found 247.1937. **20b**: ^{1}H NMR (250 MHz): δ=1.37 (s, 9 H, *t*Bu), 1.78–1.94 (m, 4 H, CH_2), 2.82 (t, 2 H, CH_2, ^3J=6 Hz), 4.30 (t, 2 H, CH_2, ^3J=6 Hz), 5.02 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=11 Hz), 5.37 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=17.7 Hz), 6.55 (dd, 1 H, HC=, ^3J=17.7 Hz, ^3J=11 Hz), 7.12 (s, 1 H, $C_{pyrrole}$H).

4.5.7. Thermolysis of 21a. The thermolysis of a solution of 20 mg (0.07 mmol) of **21a** (see Section 4.6.1) in 14 ml of dry benzene at 280°C gave a crude material which according to the ^{1}H NMR analysis contained **15a** and **18a**, respectively. Flash chromatography (SiO_2, cyclohexane/ethyl acetate 20:1) of the residue afforded 5 mg (25%) of **15a** and traces of **18a**.[21]

4.5.8. Thermolysis of 22a. The thermolysis of a solution of 33 mg (0.12 mmol) of **22a** (see Section 4.6.2) in 20 ml of dry benzene at 320°C gave a crude material which according to the ^{1}H NMR analysis contained **16a** and **19a**, respectively. Flash chromatography (SiO_2, cyclohexane/ethyl acetate 20:1) of the residue afforded 10 mg (30%) of **16a** and traces of **19a**.[21]

4.6. Photolysis of 12a and 13a

4.6.1. Photolysis of 12a. A solution of **12a** (200 mg, 0.71 mmol) in 100 ml of dry benzene at 20°C was irradiated for 15 min with a high pressure mercury lamp (Hanau TQ 150, 150 W) using a Jena filter (λ > 290 nm). After concentration flash chromatography of the residue (SiO_2, cyclohexane/ethyl acetate 40:1) afforded 95 mg (47%) of phenyl-(6-buta-1,3-dienyl-2,2,5-trimethyl-1-aza-bicyclo[3.1.0]-hex-6-yl)-methanone (**21a**) as pale red solid. ^{1}H NMR (250 MHz): δ=1.18 (s, 3 H, CH_3), 1.25 (s, 3 H, CH_3), 1.37 (s, 3 H, CH_3), 1.35–1.43 (m, 1 H, 3-CH_2), 1.72 (dd, 1 H, 3-CH_2, ^2J=13.7 Hz, ^3J=9.1 Hz), 2.10 (ddd, 1 H, 4-CH_2, ^2J=14.4 Hz, ^3J=10.4 Hz, ^3J=9.4 Hz), 2.37 (ddd, 1 H, 4-CH_2, ^2J=14.4 Hz, ^3J=10.7 Hz, ^3J=9.4 Hz), 5.03 (dd, 1 H, =CH_2), ^2J=1.6 Hz, ^3J=10.7 Hz), 5.15 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=16.3 Hz), 5.87 (d, 1 H, 8-HC=, ^3J= 14.7 Hz), 6.23–6.35 (m, 2 H, 7-/9-HC=), 7.41 (m_c, 2 H, *m*-PhH), 7.49 (m_c, 1 H, *p*-PhH), 7.95 (m_c, 2 H, *o*-PhH). ^{13}C NMR (100 MHz): δ=21.9 (CH_3), 24.4 (CH_3), 31.9 (CH_3), 32.8 (3-CH_2), 39.6 (4-CH_2), 54.7 ($C_{aziridine}$), 55.58 ($C_{aziridine}$), 66.3 ($C(CH_3)_2$), 118.5 (=CH_2), 126.9 (=CH), 128.3 (C_{Ph}), 129.6 (C_{Ph}), 132.7 (C_{ph}), 136.0 ($C_{q,Ph}$), 136.2 (=CH), 139.1 (HC=), 196.1 (CO). IR: 3060 cm^{-1}, 2963, 1675 (CO), 1597, 1449, 1381, 1365, 1258, 1170, 1003. MS (EI): *m/z* (%)=281 (31) [M$^+$], 266 (16), 212 (30), 176 (9), 120 (71), 105 (48), 800 (100), 77 (49). HRMS calcd. for $C_{19}H_{23}NO$: 281.1780; found 281.1777.

4.6.2. Photolysis of 13a. A degassed solution of **13a** (200 mg, 0.71 mmol) in 230 ml of dry benzene at 20°C was irradiated for 20 min with a high pressure mercury lamp (Hanau TQ 150, 150 W) using a Jena filter (λ>290 nm). After concentration flash chromatography of the residue (SiO_2, cyclohexane/ethyl acetate 100:1) afforded 61 mg (30%) of phenyl-(6-buta-1,3-dienyl-3,3,5-trimethyl-1-aza-bicyclo[3.1.0]hex-6-yl)-methanone (**22a**) as orange oil. ^{1}H NMR (250 MHz): δ=1.05 (s, 3 H, CH_3), 1.26 (s, 3 H, CH_3), 1.28 (s, 3 H, CH_3), 1.70 (dd, 1 H, 4-CH_2, ^2J=13.6 Hz, ^3J=0.8 Hz), 2.05 (d, 1 H, 4-CH_2, ^2J= 13.6 Hz), 2.64 (d, 1 H, 2-CH_2, ^2J=12 Hz), 3.10 (dd, 1 H, 2-CH_2, ^2J=12 Hz, ^3J=0.8 Hz), 5.10 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=10.7 Hz), 5.14 (dd, 1 H, =CH_2, ^2J=1.6 Hz, ^3J=16.6 Hz), 5.69 (d_{br}, 1 H, 8-HC=, ^3J=15.5 Hz), 6.23–6.41 (m, 2 H, 7-/9-HC=), 7.41 (m_c, 2 H, *m*-PhH), 7.50 (m_c, 1 H, *p*-PhH), 7.90 (m_c, 2 H, *o*-PhH). ^{13}C-NMR (100 MHz): δ=23.1 (CH_3), 25.2 (CH_3), 32.2 (CH_3), 45.8 (C_q), 48.8, 58.8 ($C_{aziridine}$), 59.8 ($C_{aziridine}$), 63.1 (NCH_2), 119.3 (=CH_2), 125.5 (CH), 128.1 (CH), 128.4 (CH), 129.6 (CH), 130.0 (CH), 133.0 (CH), 136.0 ($C_{q,Ph}$), 136.1 (CH), 139.8 (CH), 196.7 (CO). IR: 3060 cm^{-1}, 2960, 2880, 1680 (CO), 1600, 1450, 1370, 1260, 1175, 1025. MS (EI): *m/z* (%)=281 (7) [M$^+$], 266 (7), 176 (48), 122 (11), 120 (10), 105 (100), 91 (12), 80 (16), 77 (71). HRMS calcd. for $C_{19}H_{23}NO$: 281.1780; found 281.1778.

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