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Synthesis of New Camphor-Based Carbene Ligands and Their Application in a Copper-Catalyzed Michael Addition with B_2Pin_2

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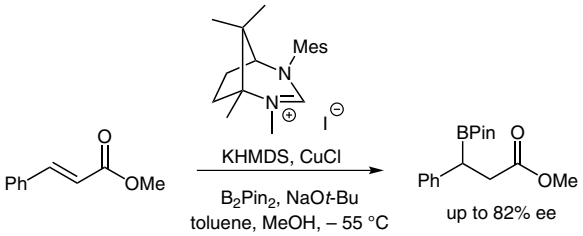

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Abstract In this work the synthesis of new asymmetric camphor-based carbene ligands from camphoric acid is described. The new carbenes can be prepared directly in high yields by the sequence: regioselective arylation of the less hindered primary amine group of (+)-*cis*-1,2,2-trimethylcyclopentane-1,3-diamine by Buchwald–Hartwig amination, treatment with trimethyl orthoformate, and finally treatment with a benzylic halide. The resulting carbenes, incorporating an aryl and a benzylic substituent, were successfully applied as ligands in a copper-catalyzed B_2Pin_2 [bis(pinacolato)diboron] addition to an unsaturated carbonyl compound. Depending on the substituents dual stereocontrol was observed and one enantiomer was obtained in up to 82% ee and the opposite enantiomer in up to 78% ee.

Key words N-heterocyclic carbenes, copper, catalysis, Michael addition, camphor

N-Heterocyclic carbenes (NHCs) have become an important type of ligand[2] since the isolation of a stable N-heterocyclic carbene by Arduengo et al. in 1991;[3] due to their nucleophilic character they can act as σ-donor ligands for various transition metals, e.g. platinum or palladium.[2] NHCs can replace phosphines and other classical ligands, such as amines or ethers, in metal coordination chemistry and show bonding properties similar or even superior to those of trialkylphosphines and alkylphosphinates.[4] Most reported carbene ligands are based on five-membered imidazolium and imidazolinium salts.[2]

Six- and seven-membered ring carbenes are even stronger σ-donors compared to five-membered carbenes from imidazolium and imidazolinium salts.[5] In addition to their increased nucleophilicity, the sterical environment is shifted closer to the coordinated metal atom due to the increased NCN angle of the six- and seven-membered N-heterocyclic carbenes.[5] Yet, in the literature examples of six- and seven-membered carbenes in catalysis are less represented.[6]

Beside achiral carbene complexes in catalysis the number of chiral carbenes applied in asymmetric catalysis has increased also and this topic has been reviewed in recent years.[7] The synthesis of these carbene ligands starts from various compounds derived from the chiral pool.[8] The increasing number of chiral N-heterocyclic carbenes is mainly based on five-membered systems and only a few examples have been reported for the synthesis and application of chiral six-membered carbenes, of which examples are depicted in Figure 1.[9]

Although camphor is a inexpensive desirable starting material from the chiral pool, only a few carbene precursors, such as **1**[10] and **2**,[11] have been prepared and successfully used in asymmetric catalysis. The imidazolinium salt **1** based carbene was applied by Hartwig in the asymmetric palladium-catalyzed intramolecular α-arylation of an amide.[10] The carbene derived from salt **2** after deprotonation was applied as an organocatalyst.[11] The Trapp group reported the synthesis of complex **5**[9e] and it was successfully applied in a palladium-catalyzed intramolecular α-arylation. The enantiopure six-membered ring carbene-based complex **6** was prepared by the McQuade group and applied in B_2Pin_2 addition to unsaturated carbonyl compounds.[9d] The same group applied **6** also in the asymmetric synthesis of chiral allylboronates from an *E*/*Z* mixture of allylic aryl ethers.[9f] Recently, the Oestreich group applied **6** in the enantioselective addition of silicon nucleophiles to aldimines in high enantiomeric excess.[9g]

Recently, we reported the syntheses of C_1 symmetric salts of type **3** based on camphor via (+)-*cis*-1,2,2-trimethylcyclopentane-1,3-diamine (**7**), which can be prepared in one step from (+)-camphoric acid via the Schmidt reac-

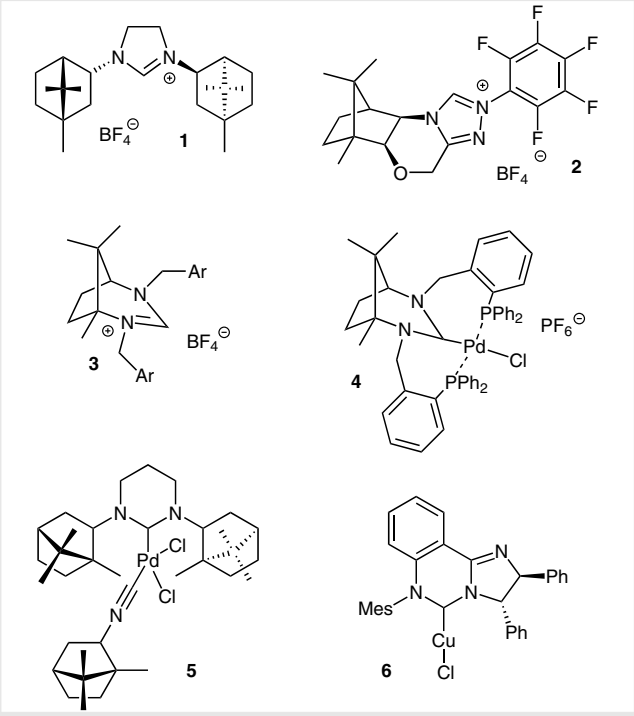
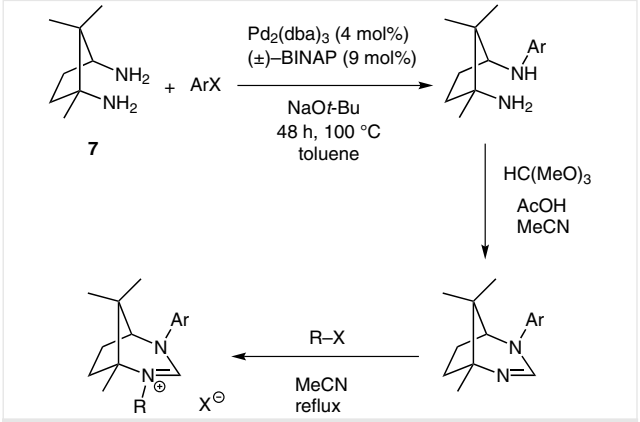


Figure 1 Chiral carbene precursors and complexes with a six- and seven-membered ring



Scheme 1 Synthesis of amidinium salts

tion.[12] We applied these salts as weak Lewis acid catalysts,[13] and after deprotonation as Lewis base carbene organocatalyst in a Wynberg reaction giving the product in up to 92% ee.[14] Thereafter, the groups of Newman and Cavell reported the synthesis of several new pincer complexes like **4**.[9i] However, although they investigated their complexes in several reactions, no significant enantiomeric excess has so far been reported with these types of carbene complexes.[9i–m]

Here we report a straightforward synthesis of new derivatives of these types of carbenes by incorporating at the less hindered nitrogen atom an arene substituent via a Buchwald–Hartwig amination[15] and on the other nitrogen atom an aliphatic or benzylic substituent. This gave a set of different enantiopure C_1-symmetric carbene ligands with different sterical and electronic substituents in the amidinium fragment and resulted in the successful application of these new ligands in an asymmetric copper-catalyzed B_2Pin_2 addition to an unsaturated ester.

The syntheses of the desired carbene precursors started by treating diamine **7** with different bromoarenes under Buchwald–Hartwig amination conditions resulting in the selective arylation of the less hindered amine function of diamine **7** (Scheme 1).[15] These diamines were transformed into cyclic amidines using trimethyl orthoformate in the presence of acetic acid in acetonitrile under reflux. The cyclic amidines were thereafter treated with various benzylic bromides and chlorides resulting in quaternization to give differently substituted amidinium chloride and bromide salts. The resulting products and intermediates are summarized in Table 1.

In general, the transformation of the monoarylated diamines **8**,[15] **15**,[15] **18**,[15] **21**,[15] and **29**[15] to their corresponding amidines **9**, **16**, **19**, **22**, and **30** was achieved in good to excellent yields (64–91%). From these amidines a series of different amidinium salts were prepared. A potential ligator atom, the pyridine substituent, was introduced in amidine **9**; precursors for potential tridentate ligands were prepared by treating **9** with 2-(chloromethyl)pyridine to give **14**. In order to investigate the influence of different sterical environments on the carbene ligands benzyl chloride and 9-(chloromethyl)anthracene were applied in the quaternization reaction of **9** to give salts **10** and **12**. Furthermore, benzhydryl chloride and di(naphthalen-1-yl)methyl bromide[16] were used in order to incorporate a large group in the resulting precursors **11** and **13**, and in case of **13** restricted rotation of the naphthalene units would occur adding a chiral relay effect to the carbene ligand.[17]

In addition to the amidine **9**, the other amidines **16**, **19**, **22**, and **30** were also transformed into the desired amidinium salts, resulting in a set of several carbene precursors incorporating different sterical environments around the two different nitrogen atoms of the amidinium unit. In salts such as **27**, **28**, and **31** substituents with additional ligator atoms were integrated in order to obtain potential precursors for bi- and tridentate carbene ligands.

Table 1 Synthesis of Amidinium Salts

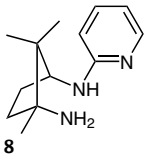
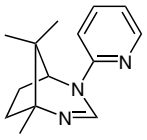
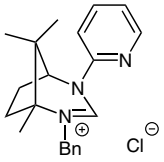
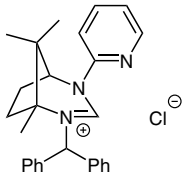
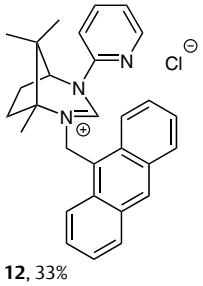
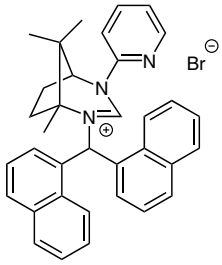
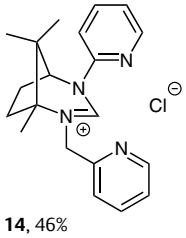
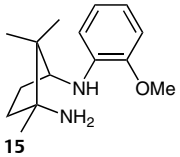
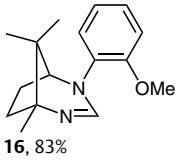
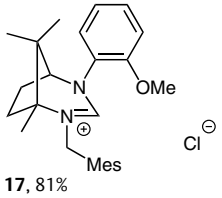
Entry	Diamine	Amidine	Amidinium Salt
1	 **8**	 **9**, 91%	 **10**, 75%
2			 **11**, 23%
3			 **12**, 33%
4			 **13**, 13%
5			 **14**, 46%
6	 **15**	 **16**, 83%	 **17**, 81%

Table 1 (continued)

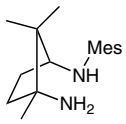
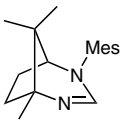
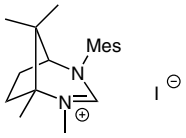
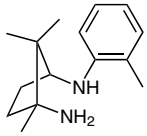
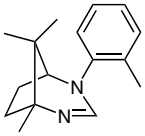
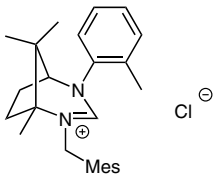
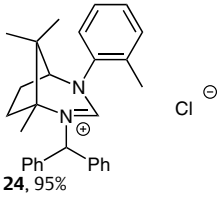
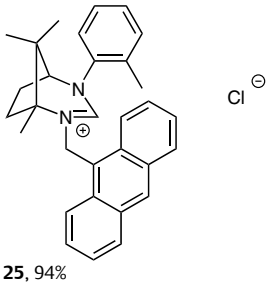
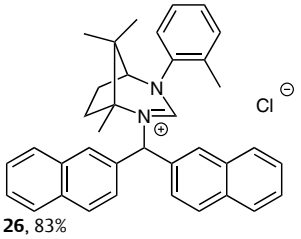
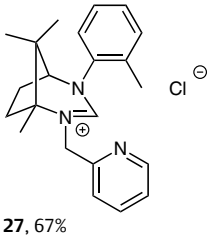
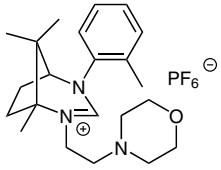
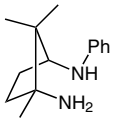
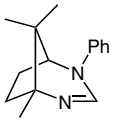
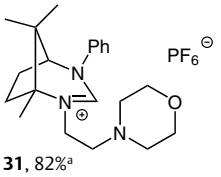
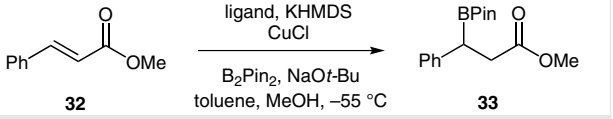
Entry	Diamine	Amidine	Amidinium Salt
7	 **18**	 **19**, 74%	 **20**, 74%
8	 **21**	 **22**, 80%	 **23**, 98%
9			 **24**, 95%
10			 **25**, 94%
11			 **26**, 83%
12			 **27**, 67%

Table 1 (continued)

Entry	Diamine	Amidine	Amidinium Salt
13			 **28**, 49%[a]
14	 **29**	 **30**, 64%	 **31**, 82%[a]

[a] Anion metathesis was performed with $NaPF_6$ directly after quaternization.

With these new carbene precursors now available, their potential as ligands in the copper-catalyzed addition of B_2Pin_2 to the α,β-unsaturated carbonyl compound **32** was investigated (Scheme 2).



Scheme 2 Copper-catalyzed addition of B_2Pin_2 to an α,β-unsaturated carbonyl compound

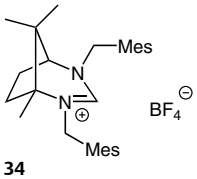
The different ligands were explored under the same conditions. The salt (11 mol%) was deprotonated with potassium hexamethyldisilazanide to generate the carbene in the presence of copper(I) chloride. The mixture was then transferred into a solution of B_2Pin_2 and the unsaturated ester **32**. The results are summarized in Table 2.

Carbenes with pyridine as additional ligating unit based in **10** and **12** gave a low enantiomeric excess, 3 and 6%, respectively (Table 2, entries 1 and 5). Introducing a large diphenylmethyl group in **11** or a larger di(naphthalen-1-yl)methyl unit in **13** increased the enantiomeric excess to 37 and 53%, respectively (entries 3 and 7). In case of **14**, which is a potential tridentate ligand, 69% ee was achieved (entry 8). When the pyridinyl unit was replaced by a non-coordinating aryl group like in salts **17**, **20**, **23**, **24**, and **25** the asymmetric induction changed and instead of the *S* product the *R* enantiomer was obtained in excess; ligand **20** gave the best 82% ee in 94% yield. When the catalyst loading with ligand **20** was reduced to 1 mol%, 77% ee and 68% yield were achieved (entries 24 and 25). The potential tridentate ligands **28** and **31** with a morpholine unit resulted in 22% and 51% ee. Interestingly, ligand **31** with a phenyl substituent induced the formation of the *S* enantiomer of the product, while **28** with an *o*-tolyl substituent gave the *R* enantiomer (entries 12 and 14). Since the Hoveyda group has shown that the reaction can also be catalyzed by chiral carbenes in the absence of copper,[18] the reaction of several carbenes were explored without copper. In general, it was found that the desired product were isolated in similar yields, however the obtained enantiomeric excesses were nearly racemic. Exceptions are carbenes derived from **14** and **27**. The salts incorporated a pyridin-2-ylmethyl substituent at one nitrogen atom of the amidinium salts; 78% and 31% ee were obtained in the absence of copper (entries 9 and 11) and in both cases the *S*-enantiomer of the product was formed in excess. Salt **34**[14] gave, in the copper-catalyzed reaction, the product in 42% yield with an ee of 6% (Table 2, entry 30). The *R*-enantiomer was formed in excess.

In conclusion new six-membered carbenes based on camphoric acid have been prepared via a highly regioselective arylation of diamine **7** via a Buchwald–Hartwig amination. The resulting new chiral carbene precursors incorporated an aryl group on one nitrogen and an aliphatic or benzylic group on the other nitrogen atom. The resulting ligands were explored in the copper-catalyzed B_2Pin_2 addition to an unsaturated ester resulting up to 82% ee. Depending on the substitution pattern also the other enantiomer of the desired product could be obtained in up to 78% ee. This dual stereocontrol allows both enantiomers of the desired product in excess to be obtained from one chiral precursor ligand.[19] So far attempts to isolate a Cu–NHC complex were not successful. Currently the new ligands are being explored in further catalytic transformations.

For all reactions standard Schlenk line techniques were applied. Diamine **7** was prepared according to the literature[12] from (+)-camphoric acid, which was purchased from commercial sources. The monoarylated diamines **8**,[15] **15**,[15] **18**,[15] **21**,[15] and **29**[15] and salt **34**[14]

Table 2 B_2Pin_2-Addition to **32** with Salt (11 mol%) and with and without Copper(I) Chloride in Toluene with Potassium Hexamethyldisilazanide[a]

Entry	Ligand	Salt	Yield (%)	ee (%)	Config
1	**10**	CuCl	52	3	*S*
2	**10**	–	48	6	*S*
3	**11**	CuCl	17	37	*S*
4	**11**	–	56	8	*S*
5	**12**	CuCl	14	6	*S*
6	**12**	–	24	0	–
7	**13**	CuCl	31	53	*S*
8	**14**	CuCl	69	69	*S*
9	**14**	–	48	78	*S*
10	**27**	CuCl	31	0	–
11	**27**	–	20	31	*S*
12	**31**	CuCl	44	51	*S*
13	**31**	–	44	3	*S*
14	**28**	CuCl	54	22	*R*
15	**28**	–	20	0	–
16	**17**	CuCl	22	53	*R*
17	**17**	–	17	0	–
18	**23**	CuCl	31	50	*R*
19	**24**	CuCl	23	57	*R*
20	**24**	–	50	0	–
21	**25**	CuCl	49	57	*R*
22	**26**	CuCl	24	0	–
23	**26**	–	25	0	–
24[b]	**20**	CuCl	94	82	*R*
25[c]	**20**	CuCl	68	77	*R*
26	SIMes	CuCl	45	–	–
27	SIMes	–	67	–	–
28	KHMDS	CuCl	10	–	–
29	KHMDS	–	0	–	–
30	 **34**	CuCl	42	6	*R*
31	**34**	–	53	4	*R*

[a] Reaction conditions: 1. carbene precursor (11 mol%), CuCl (10 mol%), KHMDS (9 mol%), toluene, –55 °C, 1 h; this was added to 2. B_2Pin_2 (1.1 equiv), NaO*t*-Bu (0.3 equiv), toluene, –55 °C, 10 min; then addition of 3. MeOH (2 equiv), –55 °C, 6 h.
[b] Two runs, which resulted the same yield and ee.
[c] 1 mol% carbene loading.

were prepared according to the literature from diamine **7**. The obtained chloride and bromide salts were slightly hygroscopic. Melting points were taken with an apparatus (Dr. Tottoli) and are uncorrected. IR spectra were recorded on a Bruker Vertex 70 FT-IR-spectrophotometer. ^{1}H NMR spectra were acquired at r.t. on a Bruker Avance 500 (500 MHz) in deuterated solvents as stated. ^{13}C NMR spectra were recorded at r.t. at 125 MHz and ^{15}N spectra at 51 Hz in deuterated solvents. NMR signals were assigned via COSY, HSQC, and HMBC. Mass spectra (EI) were recorded with a Hewlett Packard 5989B at 70 eV. HRMS (ESI) were recorded on Waters Quadrupole-ToF Synapt 2G. EI mass spectra were recorded on a Thermo Scientific Double-focusing sectorfield-MS DFS. Enantiomeric excess was determined on a Merck Hitachi HPLC system. Flash column chromatography was performed on Sorbisil C-60. Reactions were monitored by TLC with Merck Silica gel 60 F254 plates. Toluene was distilled from Na; MeCN was distilled from CaH_2.

Cyclic Amidines; General Procedure

Monoarylated diamine (1 equiv), trimethyl orthoformate (2.5 equiv), and AcOH (2.5 equiv) were dissolved in MeCN and refluxed for 2 h under N_2. The solvent was removed and to the residue 40% KOH (w/w) solution was added. The aqueous phase was extracted with CH_2Cl_2 (3 × 100 mL) and the combined organic phases were dried (Na_2SO_4). The solvent was removed and the crude product was purified by column chromatography.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(pyridin-2-yl)-2,4-diazabicyclo[3.2.1]oct-2-ene (9)

Diamine **8** (1.26 g, 5.74 mmol), trimethyl orthoformate (1.49 mL, 14.36 mmol), AcOH (0.91 mL, 14.36 mmol), and MeCN (30 mL) were used and after workup the product was purified by column chromatography (Et_2O–CH_2Cl_2, 3:2 + 4% Et_3N) to give **9** (1.20 g, 5.22 mmol, 91%) as a yellow oil. $[\alpha]_D^{20}$ –71.4 (*c* 1.2, CH_2Cl_2).

IR (ATR): 2961, 1622, 1584, 1471, 1435, 1315, 1248 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.21 (ddd, *J* = 4.9, 2.0, 0.9 Hz, 1 H, H6′), 7.94 (d, *J* = 1.2 Hz, 1 H, H3), 7.52 (ddd, *J* = 8.4, 7.3, 2.0 Hz, 1 H, H4′), 6.83–6.77 (m, 2 H, H5′, H3′), 4.06 (d, *J* = 5.1 Hz, 1 H, H5), 2.19–2.05 (m, 2 H, H7, H6), 1.91–1.79 (m, 2 H, H7, H6), 1.17 (s, 3 H, H11), 1.07 (s, 3 H, H10), 0.93 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.6 (C2′), 148.3 (C6′), 142.2 (C3), 138.1 (C4′), 117.1 (C5′), 108.1 (C3′), 64.4 (C1), 63.7 (C5), 40.4 (C8), 40.2 (C7), 31.8 (C6), 22.6 (C10), 19.8 (C11), 17.3 (C9).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 277.1 (br s, 1 N, N1′), 223.9 (br s, 1 N, N2), 143.0 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* (%) = 229 [M]$^+$, 214, 186, 160, 147, 133, 119, 110.

HRMS (ESI): *m*/*z* [M + H]$^+$ calcd for $C_{14}H_{20}N_3$: 230.1657; found: 230.1654.

(1*R*,5*S*)-4-(2-Methoxyphenyl)-1,8,8-trimethyl-2,4-diazabicyclo[3.2.1]oct-2-ene (16)

Diamine **15** (2.0 g, 3.02 mmol), trimethyl orthoformate (2.64 mL, 24.2 mmol), AcOH (0.91 mL, 14.36 mmol), and MeCN (30 mL) were used and after workup the product was purified by column chromatography (CH_2Cl_2–MeOH, 9:1 + 1% Et_3N) to give **19** (1.72 g, 6.22 mmol, 83%) as a yellow oil; mp 78 °C. $[\alpha]_D^{20}$ –43 (*c* 2.6, $CHCl_3$).

IR (KBr): 3435, 2959, 1617, 1503, 1460, 1385, 1370, 1343, 1285, 1257, 1212, 1180, 1163, 1119, 1052, 1025, 934, 860, 793, 756, 685, 615 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.20 (s, 1 H, H3), 7.17 (ddd, *J* = 8.2, 7.5, 1.7 Hz, 1 H, H5′), 7.02–6.98 (m, 1 H, H3), 6.95–6.90 (m, 2 H, H6′, H4′), 3.83 (s, 3 H, H2′-OCH_3), 3.38 (d, *J* = 5.0 Hz, 1 H, H5), 2.32–2.25 (m, 1 H, H7), 2.20 (ddd, *J* = 14.1, 9.6, 4.5 Hz, 1 H, H6), 2.09–2.01 (m, 1 H, H6), 1.93–1.85 (m, 1 H, H7), 1.24 (s, 3 H, H11), 1.14 (s, 3 H, H10), 1.07 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.4 (C2′), 147.8 (C3), 132.3 (C1′), 127.0 (C5′), 125.2 (C3′), 121.1 (C4′), 112.2 (C6′), 69.5 (C5), 63.7 (C1), 55.6 (2′-OCH_3), 41.0 (C7), 40.1 (C8), 32.4 (C6), 22.3 (C9), 19.3 (C11), 17.6 (C10).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 222.4 (br s, 1 N, N2), 123.0 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* (%) = 259 (19) $[M]^+$, 248 (16), 216 (10), 123 (100), 108 (15), 70 (10).

HRMS (ESI): *m*/*z* $[M + H]^+$ calcd for $C_{16}H_{23}N_2O$: 259.1810; found: 259.1814.

(1*R*,5*S*)-4-Mesityl-1,8,8-trimethyl-2,4-diazabicyclo[3.2.1]oct-2-ene (19)

Diamine **18** (5.31 g, 20.4 mmol), trimethyl orthoformate (6.7 mL, 61.0 mmol), AcOH (3.5 mL, 61.0 mmol), and MeCN (200 mL) were used and after workup the product was purified by column chromatography (CH_2Cl_2–MeOH, 9:1 + 1% Et_3N) to give **19** (4.1 g, 15.0 mmol, 74%) as a brown solid. $[\alpha]_D^{20}$ –342 (*c* 4.7, $CHCl_3$).

IR (ATR): 2960, 1616, 1481, 1447, 1371, 1339, 1302, 1282, 1261, 1243, 1218, 1206, 1160, 1118, 1100, 1016, 951, 894, 852, 737, 644, 614 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 6.89 (d, *J* = 10.5 Hz, 2 H, H5′, H3′), 6.81 (s, 1 H, H3), 3.16 (d, *J* = 3.7 Hz, 1 H, H5), 2.36 (s, 3 H, H4′-CH_3), 2.31–2.27 (m, 1 H, H7), 2.26 (s, 6 H, 6′-CH_3, 2′-CH_3), 2.12–2.03 (m, 1 H, H6), 1.96–1.86 (m, 2 H, H7, H6), 1.27 (s, 3 H, H10), 1.21 (s, 3 H, H11), 1.08 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 148.9 (C3), 137.9 (C1′), 136.5 (C4′), 135.7 (C2′), 135.2 (C6′), 130.2 (C3′), 130.1 (C5′), 68.3 (C5), 62.6 (C1), 40.8 (C8), 40.2 (C7), 32.2 (C6), 22.7 (C9), 20.7 (6′-CH_3), 20.4 (C11), 19.2 (2′-CH_3), 18.7 (4′-CH_3), 18.4 (C10).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 230.1 (br s, 1 N, N2), 119.5 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* (%) = 271 $[M + H]^+$, 270 $[M]^+$, 255, 227, 207, 188, 158, 146, 125, 110, 86, 58, 38.

HRMS (ESI): *m*/*z* $[M]^+$ calcd for $C_{18}H_{26}N_2$: 270.2091; found: 270.2087.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-ene (22)

Diamine **21** (4.03 g, 17.2 mmol), trimethyl orthoformate (5.65 mL, 51.6 mmol), AcOH (2.95 mL, 51.6 mmol), and MeCN (180 mL) were used and after workup the product was purified by column chromatography (CH_2Cl_2–MeOH, 9:1 + 1% Et_3N) to give **22** (3.32 g, 13.7 mmol, 80%) as a brown oil. $[\alpha]_D^{20}$ –183 (*c* 6.6, $CHCl_3$).

IR (ATR): 2959, 2868, 1616, 1596, 1576, 1492, 1460, 1389, 1369, 1339, 1280, 1252, 1207, 1163, 1051 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.22 (d, *J* = 7.5 Hz, 1 H, H3′), 7.19 (dd, *J* = 7.6, 1.7 Hz, 1 H, H5′), 7.14 (td, *J* = 7.4, 1.4 Hz, 1 H, H4′), 7.06 (br s, 1 H, H3), 7.01 (dd, *J* = 7.7, 1.2 Hz, 1 H, H6′), 3.29 (d, *J* = 4.8 Hz, 1 H, H5), 2.33 (s, 3 H, 2′-CH_3), 2.31–2.25 (m, 1 H, H7), 2.16 (ddd, *J* = 13.9, 9.5, 4.4 Hz, 1 H, H6), 2.01 (ddt, *J* = 13.7, 11.9, 4.7 Hz, 1 H, H6), 1.95–1.86 (m, 1 H, H7), 1.24 (s, 3 H, H11), 1.22 (s, 3 H, H10), 1.09 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 147.6 (C3), 142.3 (C1′), 133.3 (C2′), 131.8 (C3′), 127.0 (C5′), 126.5 (C4′), 126.2 (C6′), 69.1 (C5), 63.5 (C1), 40.9 (C7), 40.4 (C8), 32.0 (C6), 22.4 (C9), 19.6 (C11), 18.6 (C10), 18.1 (2′-CH_3).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 229.8 (br s, 1 N, N2), 125.9 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* (%) = 242 $[M]^+$, 227, 199, 173, 136, 125, 118, 110, 107, 91, 65, 57.

HRMS (ESI): *m*/*z* $[M + H]^+$ calcd for $C_{16}H_{23}N_2$: 243.1861; found: 243.1866.

(1*R*,5*S*)-1,8,8-Trimethyl-4-phenyl-2,4-diazabicyclo[3.2.1]oct-2-ene (30)

Diamine **29** (2.56 g, 11.7 mmol), trimethyl orthoformate (3.2 mL, 29.3 mmol), AcOH (1.7 mL, 29.3 mmol), and MeCN (60 mL) were used; workup gave **30** (1.714 g, 7.5 mmol, 64%) as a brown oil. $[\alpha]_D^{20}$ +65.5 (*c* 0.83, CH_2Cl_2).

IR (ATR): 3304, 3048, 2964, 2873, 1618, 1592, 1493, 1343, 1294, 1249, 1211, 1166, 753, 692 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.33 (d, *J* = 1.2 Hz, 1 H, H3), 7.32–7.25 (m, 2 H, H2′, H6′), 7.06–7.01 (m, 1 H, H4′), 7.00–6.95 (m, 2 H, H3′, H5′), 3.52 (d, *J* = 5.0 Hz, 1 H, H5), 2.22–2.02 (m, 3 H, H6, H7), 1.92–1.83 (m, 1 H, H7), 1.18 (s, 3 H, H11), 1.07 (s, 3 H, H10), 1.02 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 144.7 (C3), 143.6 (C1′), 129.5 (C2′, C6′), 123.4 (C4′), 118.5 (C3′, C5′), 67.8 (C5), 63.8 (C1), 40.9 (C7), 40.3 (C8), 32.3 (C6), 22.5 (C10), 19.7 (C11), 17.5 (C9).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 241.7 (br s, 1 N, N2), 129.7 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* (%) = 218 (85) $[M]^+$, 201 (27), 186 (77), 132 (40), 126 (97), 119 (72), 109 (68), 93 (100), 77 (32), 70 (72), 57 (65), 41 (30).

HRMS (ESI): *m*/*z* $[M + H]^+$ calcd for $C_{15}H_{21}N_2$: 229.1700; found: 229.1151.

Amidinium Salts by Quaternization; General Procedure

Amidine (1 equiv) and benzylic halide (1–3.5 equiv) were dissolved in MeCN and refluxed for 2–16 h. The crude product was purified by column chromatography and/or by crystallization with a solvent mixture.

(1*R*,5*S*)-2-Benzyl-1,8,8-trimethyl-4-(pyridin-2-yl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (10)

Amidine **9** (780 mg, 3.4 mmol) and benzyl chloride (1.17 mL, 10.2 mmol) in MeCN (30 mL) were refluxed for 16 h. After column chromatography (CH_2Cl_2–MeOH, 9:1) the salt was treated with Et_2O (10 × 5 mL) to give **10** (0.91 g, 2.56 mmol, 75%) as a white solid; mp 181 °C. $[\alpha]_D^{20}$ +119 (*c* 2.4, $CHCl_3$).

IR (ATR): 3735, 1637, 1591, 1572, 1443, 1385, 1331, 1294, 1221, 1174, 1117, 1081, 990, 772, 737, 705, 669, 639 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 10.75 (s, 1 H, H3), 8.74 (d, *J* = 8.4 Hz, 1 H, H3′), 8.36 (ddd, *J* = 4.9, 1.9, 0.8 Hz, 1 H, H6′), 7.92 (ddd, *J* = 8.4, 7.4, 1.9 Hz, 1 H, H4′), 7.47–7.43 (m, 2 H, H5″, H3″), 7.38–7.28 (m, 3 H, H6″, H4″, H2″), 7.23 (ddd, *J* = 7.4, 4.9, 0.6 Hz, 1 H, H5′), 5.65 (d, *J* = 15.3 Hz, 1 H, H1‴), 5.17 (d, *J* = 15.3 Hz, 1 H, H1‴), 4.84 (d, *J* = 4.5 Hz, 1 H, H5), 2.35 (ddd, *J* = 14.2, 8.9, 5.2 Hz, 1 H, H7), 2.29–2.17 (m, 2 H, H6), 1.91–1.82 (m, 1 H, H7), 1.38 (s, 3 H, H11), 1.17 (s, 3 H, H10), 1.09 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.9 (C3), 150.8 (C2′), 147.9 (C6′), 140.1 (C4′), 135.3 (C1″), 129.1 (C6″, C2″), 128.6 (C4″), 128.3 (C5″, C3″), 122.5 (C5′), 115.1 (C3′), 73.0 (C1), 64.6 (C5), 54.6 (C1‴), 41.2 (C8), 40.2 (C7), 31.7 (C6), 21.9 (C10), 17.1 (C9), 14.9 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 284.0 (br s, 1 N, N1′), 153.5 (br s, 2 N, N4, N2).

MS (ESI+, 3 kV): *m*/*z* = 320 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{21}H_{26}N_3$: 320.2127; found: 320.2119.

(1*R*,5*S*)-2-Benzhydryl-1,8,8-trimethyl-4-(pyridin-2-yl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (11)

Amidine **9** (1 g, 4.4 mmol) and benzhydryl chloride (2.74 mL, 15.4 mmol) in MeCN (40 mL) were refluxed for 16 h. The solvent was removed and the salt was treated with Et_2O (5 × 5 mL) and recrystallized (CH_2Cl_2) to give **11** (0.44 g, 1.012 mmol, 23%) as a white solid; mp 281 °C. $[\alpha]_D^{20}$ +5.4 (*c* 1, CH_2Cl_2).

IR (ATR): 2987, 1631, 1591, 1566, 1448, 1337, 1278, 797, 752, 710, 693, 615, 552 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.71 (s, 1 H, H3), 8.20–8.14 (m, 2 H, H6′, H3′), 7.96 (t, *J* = 7.1 Hz, 1 H, H4′), 7.45 (m, 8 H, H6‴, H5‴, H5″, H4‴, H4″, H3‴, H3″, H2‴), 7.26 (d, *J* = 7.0 Hz, 2 H, H6″, H2″), 7.21 (dd, *J* = 7.4, 4.9 Hz, 1 H, H5′), 6.45 (s, 1 H, H1‴″), 5.09 (d, *J* = 4.0 Hz, 1 H, H5), 2.67–2.55 (m, 2 H, H7, H6), 2.35–2.26 (m, 1 H, H6), 2.17–2.07 (m, 1 H, H7), 1.57 (s, 3 H, H11), 1.38 (s, 3 H, H10), 1.20 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.8 (C3), 149.8 (C2′), 148.4 (C6′), 140.9 (C4′), 136.5 (C1‴), 136.2 (C1″), 130.0 (C5‴, C3‴), 129.8 (C5″, C3″), 129.6 (C4‴), 129.5 (C4″), 128.7 (C6″, C2″), 128.4 (C6‴, C2‴), 123.0 (C5′), 114.3 (C3′), 75.3 (C1), 67.4 (C1‴″), 66.4 (C5), 42.2 (C8), 40.6 (C7), 32.2 (C6), 21.9 (C10), 17.2 (C9), 15.3 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 278.9 (br s, 1 N, N1′), 163.7 (br s, 1 N, N2), 155.5 (br s, 1 N, N4).

MS (EI, 70 eV): *m*/*z* = 396 [M – Cl]$^+$, 230, 229, 167, 214.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{27}H_{30}N_3$: 396.2440; found: 396.2426.

(1*R*,5*S*)-2-(Anthracen-9-ylmethyl)-1,8,8-trimethyl-4-(pyridin-2-yl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (12)

Amidine **9** (1.06 g, 4.62 mmol) and 9-(chloromethyl)anthracene (1.15 g, 5.09 mmol) in MeCN (15 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (basic alumina, CH_2Cl_2–MeOH, 99:1). Thereafter, the product was treated with pentane (5 × 5 mL), Et_2O (5 × 5 mL), and THF (5 × 5 mL) to give **12** (0.686 g, 1.51 mmol, 33%) as a yellow solid; mp 221 °C. $[\alpha]_D^{20}$ +107 (*c* 1.2, $CHCl_3$).

IR (ATR): 2983, 1631, 1590, 1571, 1442, 1385, 1294, 1228, 1169, 1112, 1073, 989, 786, 734, 602, 533, 405 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.95 (s, 1 H, H3), 8.52 (s, 1 H, H10″), 8.25 (d, *J* = 8.9 Hz, 2 H, H5″, H4″), 8.03 (d, *J* = 8.5 Hz, 2 H, H8″, H1″), 7.96 (ddd, *J* = 4.9, 1.8, 0.7 Hz, 1 H, H6′), 7.88 (d, *J* = 8.4 Hz, 1 H, H3′), 7.78 (ddd, *J* = 8.4, 7.4, 1.9 Hz, 1 H, H4′), 7.64 (ddd, *J* = 8.9, 6.6, 1.3 Hz, 2 H, H7″, H2″), 7.53–7.47 (m, 2 H, H6″, H3″), 7.06 (ddd, *J* = 7.4, 4.9, 0.6 Hz, 1 H, H5′), 6.07 (dd, *J* = 51.9, 15.2 Hz, 2 H, H1‴), 4.72 (d, *J* = 5.1 Hz, 1 H, H5), 2.68 (ddd, *J* = 14.5, 9.5, 4.7 Hz, 1 H, H7), 2.38 (ddt, *J* = 14.9, 12.1, 4.9 Hz, 1 H, H6), 2.22–2.09 (m, 1 H, H6), 2.09–1.99 (m, 1 H, H7), 1.64 (s, 3 H, H11), 1.28 (s, 3 H, H10), 1.15 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.6 (C3), 150.0 (C2′), 148.2 (C6′), 140.3 (C4′), 131.3 (C4″a, C4″b), 131.2 (C9″a, C8″a), 130.8 (C10″), 129.8 (C8″, C1″), 128.3 (C7″, C2″), 125.6 (C6″, C3″), 122.7 (C5′), 122.5 (C5″, C4″), 121.4 (C9″), 113.5 (C3′), 74.0 (C1), 65.7 (C5), 48.0 (C1‴), 41.8 (C8), 40.2 (C7), 32.0 (C6), 21.9 (C10), 17.1 (C9), 14.9 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 281.1 (br s, 1 N, N1′), 153.3 (br s, 2 N, N4, N2).

MS (ESI+, 3 kV): *m*/*z* = 420 [M – Cl]$^+$, 365, 191.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{29}H_{30}N_3$: 420.2440; found: 420.2440.

(1*R*,5*S*)-2-[Di(naphthalen-1-yl)methyl]-1,8,8-trimethyl-4-(pyridin-2-yl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Bromide (13)

Amidine **9** (617 mg, 2.69 mmol) and di(naphthalen-1-yl)methyl bromide[15] (1.03 g, 2.96 mmol) in MeCN (5 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 9:1). Thereafter, the product was treated with Et_2O (10 × 5 mL) to give **13** (0.196 g, 0.34 mmol, 13%) as a white solid; mp 236 °C. $[\alpha]_D^{20}$ +106 (*c* 2, $CHCl_3$).

IR (ATR): 3391, 2983, 1635, 1590, 1571, 1511, 1477, 1449, 1349, 1295, 1259, 1169, 1068, 786, 544 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.68 (s, 1 H, H3), 8.15–8.09 (m, 3 H, H6′, H3′, H8″), 8.05–7.95 (m, 4 H, H5‴, H4‴, H5″, H4″), 7.93 (p, *J* = 3.2 Hz, 1 H, H3″), 7.91–7.87 (m, 1 H, H4′), 7.85 (d, *J* = 7.0 Hz, 1 H, H8‴), 7.77 (m, 2 H, H3‴, H1‴″), 7.70 (t, *J* = 7.3 Hz, 1 H, H7″), 7.61 (t, *J* = 7.2 Hz, 1 H, H7‴), 7.53 (dt, *J* = 17.1, 7.2 Hz, 2 H, H6‴, H6″), 7.47 (d, *J* = 5.2 Hz, 2 H, H2‴, H2″), 7.15 (dd, *J* = 7.4, 4.9 Hz, 1 H, H5′), 5.06 (d, *J* = 4.6 Hz, 1 H, H5), 2.93 (m, 1 H, H7), 2.62–2.45 (m, 2 H, H6), 2.12–2.01 (m, 1 H, H7), 1.65 (s, 3 H, H11), 1.42 (s, 3 H, H10), 1.25 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.6 (C3), 150.0 (C2′), 148.2 (C6′), 140.7 (C4′), 134.6 (C8‴a), 134.5 (C8‴a), 131.1 (C4″a), 131.0 (C3″), 130.5 (C2″), 130.1 (C4‴a), 130.0 (C1‴), 129.9 (C5″), 129.8 (C1″), 129.8 (C5‴), 128.2 (C7″), 128.0 (C4″), 127.9 (C4‴), 126.9 (C6‴, C6″), 126.6 (C7‴), 125.6 (C2‴), 125.5 (C3‴), 123.0 (C5′), 121.7 (C8″), 121.0 (C8‴), 114.7 (C3′), 75.7 (C1), 66.6 (C5), 60.5 (C1‴″), 42.5 (C8), 41.0 (C7), 31.8 (C6), 22.0 (C10), 18.0 (C9), 15.3 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 280.4 (br s, 1 N, N1′), 156.0 (br s, 2 N, N4, N2).

MS (ESI+, 3 kV): *m*/*z* = 496 [M – Br]$^+$, 267.

HRMS (ESI+, 3 kV): *m*/*z* [M – Br]$^+$ calcd for $C_{35}H_{34}N_3$: 496.2753; found: 496.2726.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(pyridin-2-yl)-2-(pyridin-2-ylmethyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (14)

Amidine **9** (1 g, 4.4 mmol) and 2-(chloromethyl)pyridine (0.77 g, 6.02 mmol) in MeCN (10 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (basic alumina, CH_2Cl_2–MeOH, 97:3). Thereafter, the product was treated with pentane (5 × 5 mL) and Et_2O (5 × 5 mL) to give **14** (0.716 g, 2.01 mmol, 46%) as a yellow solid; mp 265 °C. $[\alpha]_D^{20}$ +38 (*c* 2.6, $CHCl_3$).

IR (ATR): 2962, 1632, 1591, 1571, 1447, 1384, 1317, 1292, 1256, 1213, 1176, 1121, 990, 775, 649 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 10.50 (s, 1 H, H3), 8.67 (d, *J* = 8.4 Hz, 1 H, H3′), 8.55–8.53 (m, 1 H, H6″), 8.37 (ddd, *J* = 4.9, 1.9, 0.8 Hz, 1 H, H6′), 7.92 (ddd, *J* = 8.4, 7.4, 1.9 Hz, 1 H, H4′), 7.79–7.73 (m, 2 H, H4″, H3″), 7.29–7.25 (m, 1 H, H5″), 7.23 (ddd, *J* = 7.4, 4.9, 0.8 Hz, 1 H, H5′), 5.84 (d, *J* = 15.8 Hz, 1 H, H1‴), 5.31 (d, *J* = 15.8 Hz, 1 H, H1‴), 4.83 (d,

J = 4.1 Hz, 1 H, H5), 2.50–2.41 (m, 1 H, H7), 2.31–2.18 (m, 2 H, H6), 1.94–1.84 (m, 1 H, H7), 1.45 (s, 3 H, H11), 1.20 (s, 3 H, H10), 1.14 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 154.8 (C3), 154.3 (C2″), 150.9 (C2′), 148.3 (C6″), 147.9 (C6′), 140.1 (C4′), 138.5 (C4″), 124.1 (C3″), 123.8 (C5″), 122.5 (C5′), 114.9 (C3′), 73.0 (C1), 64.8 (C5), 54.5 (C1‴), 41.3 (C8), 39.9 (C7), 31.8 (C6), 22.0 (C10), 17.2 (C9), 14.9 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 283.8 (br s, 1 N, N1′), 149.1 (br s, 1 N, N1″), 148.8 (br s, 1 N, N2), 148.4 (br s, 1 N, N4).

MS (ESI+, 3 kV): *m*/*z* = 321 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{20}H_{25}N_4$: 321.2079; found: 321.2100.

(1*R*,5*S*)-4-(2-Methoxyphenyl)-1,8,8-trimethyl-2-(2,4,6-trimethylbenzyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (17)

Amidine **16** (750 mg, 2.9 mmol) and 2,4,6-trimethylbenzyl chloride (1.47 g, 8.71 mmol) in MeCN (30 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 9:1 + 1% Et_3N). Thereafter, the product was treated with Et_2O (10 × 5 mL) to give **17** (1.01 g, 2.35 mmol, 81%) as a white solid; mp 203 °C. $[\alpha]_D^{20}$ +24 (*c* 3.8, $CHCl_3$).

IR (ATR): 3435, 2973, 1652, 1503, 1465, 1398, 1368, 1278, 1217, 1172, 1126, 1018, 855, 767 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.32 (ddd, *J* = 8.4, 7.6, 1.6 Hz, 1 H, H5′), 7.24 (dd, *J* = 7.9, 1.6 Hz, 1 H, H3′), 7.08 (s, 1 H, H3), 7.02 (ddd, *J* = 7.9, 6.5, 2.6 Hz, 1 H, H 4′), 6.96 (dd, *J* = 8.4, 1.1 Hz, 1 H, H6′), 6.90 (br s, 2 H, H5″, H3″), 5.01 (d, *J* = 14.2 Hz, 1 H, H1‴), 4.74 (d, *J* = 14.2 Hz, 1 H, H1‴), 3.77 (s, 3 H, 2′-OC*H*$_3$), 3.74 (d, *J* = 4.2 Hz, 1 H, H5), 2.97–2.89 (m, 1 H, H7), 2.48 (ddd, *J* = 12.1, 9.1, 3.4 Hz, 1 H, H6), 2.36 (s, 6 H, 6″-C*H*$_3$, 2″-C*H*$_3$), 2.31 (ddd, *J* = 17.6, 12.8, 4.3 Hz, 2 H, H7, H6), 2.24 (s, 3 H, 4″-C*H*$_3$), 1.73 (s, 3 H, H11), 1.31 (s, 3 H, H10), 1.30 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 152.5 (C2′), 151.3 (C3), 140.2 (C1′), 138.4 (C6″, C2″), 130.5 (C5′), 130.2 (C5″, C3″), 128.9 (C4″), 126.0 (C3′), 124.2 (C1″), 122.0 (C4′), 112.7 (C6′), 72.9 (C1), 71.8 (C5), 55.9 (2′-OC*H*$_3$), 48.2 (C1‴), 41.7 (C8), 40.1 (C7), 32.1 (C6), 21.9 (C9), 20.9 (4″-CH$_3$), 19.7 (6″-CH$_3$, 2″-CH$_3$), 17.4 (C10), 14.4 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 146.9 (br s, 1 N, N2), 135.3 (br s, 1 N, N4).

MS (ESI+, 3 kV): *m*/*z* = 391 [M – Cl]$^+$, 259.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{26}H_{35}N_2O$: 391.2749; found: 391.2744.

(1*R*,5*S*)-4-Mesityl-1,2,8,8-tetramethyl-2,4-diazabiclyclo[3.2.1]oct-2-en-2-ium Iodide (20)

Amidine **19** (800 mg, 2.96 mmol) and MeI (1.84 mL, 29.6 mmol) in MeCN (30 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 95:5). Thereafter, the product was treated with Et_2O (10 × 5 mL) and EtOAc (2 × 5 mL) to give **20** (0.91 g, 2.2 mmol, 74%) as a white solid; mp 194 °C. $[\alpha]_D^{20}$ –40 (*c* 4, $CHCl_3$).

IR (ATR): 3417, 2925, 1648, 1454, 1400, 1365, 1314, 1273, 1211, 1184, 1170, 1141, 1114, 1098, 1023, 995, 952, 885, 846, 727, 650, 615 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.98 (s, 1 H, H3), 6.97 (s, 1 H, H3′), 6.90 (s, 1 H, H5′), 3.58 (s, 3 H, H1″), 3.47 (d, *J* = 3.8 Hz, 1 H, H5), 2.65–2.53 (m, 1 H, H7), 2.45 (s, 3 H, 4′-C*H*$_3$), 2.35–2.31 (m, 1 H, H6), 2.30 (s, 3 H, 6′-C*H*$_3$), 2.26 (s, 3 H, 2′-C*H*$_3$), 2.17–2.03 (m, 2 H, H7, H6), 1.44 (s, 3 H, H11), 1.41 (s, 3 H, H10), 1.20 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 155.5 (C3), 139.7 (C1′), 134.7 (C2′), 134.6 (C6′), 133.8 (C4′), 131.1 (C5′), 130.8 (C3′), 70.2 (C5), 69.9 (C1), 42.2 (C8), 39.6 (C7), 37.9 (C1″), 31.1 (C6), 22.1 (C9), 20.8 (6′-C*H*$_3$), 19.4 (2′-C*H*$_3$), 19.3 (4′-C*H*$_3$), 18.1 (C10), 14.6 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 135.8 (br s, 2 N, N4, N2).

MS (ESI+, 3 kV): *m*/*z* = 285 [M – I]$^+$, 172.

HRMS (ESI+, 3 kV): *m*/*z* [M – I]$^+$ calcd for $C_{19}H_{29}N_2$: 285.2331; found: 285.2345.

Anal. Calcd for $C_{19}H_{29}N_2I$: C, 55.34; H, 7.09; N, 6.79. Found: C, 55.71; H, 7.02; N, 6.87.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(*o*-tolyl)-2-(2,4,6-trimethylbenzyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (23)

Amidine **22** (520 mg, 2.15 mmol) and 2,4,6-trimethylbenzyl chloride (534 mg, 3.22 mmol) in DMF (2 mL) were heated for 16 h at 80 °C. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 90:10) to give **23** (865 mg, 2.1 mmol, 98%) as a white solid; mp 250 °C. $[\alpha]_D^{20}$ –13 (*c* 2, CH_2Cl_2).

IR (KBr): 3429, 3225, 2977, 1657, 1605, 1497, 1469, 1399, 1314, 1194, 1037, 944, 862, 779, 725, 614, 458 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.37–7.28 (m, 2 H, H5′, H3′), 7.29–7.22 (m, 1 H, H 4′), 7.13 (dd, *J* = 5.9, 3.3 Hz, 1 H, H6′), 6.93 (s, 1 H, H3), 6.92 (s, 2 H, H5″, H3″), 5.06 (d, *J* = 14.2 Hz, 1 H, H1‴), 4.74 (d, *J* = 14.2 Hz, 1 H, H1‴), 3.80 (s, 1 H, H5), 2.96 (d, *J* = 3.7 Hz, 1 H, H7), 2.43–2.34 (m, 3 H, H6, H7, H6), 2.36 (s, 6 H, 6″-C*H*$_3$, 2″-C*H*$_3$), 2.25 (s, 3 H, 4″-C*H*$_3$), 2.17 (s, 3 H, 2′-C*H*$_3$), 1.78 (s, 3 H, H11), 1.38 (s, 3 H, H10), 1.35 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.1 (C3), 140.4 (C1′), 139.1, (C2′), 138.2 (C6″, C2″), 132.6 (C5′), 132.2 (C4″), 130.4 (C5″, C3″), 129.7 (C3′), 128.4 (C1″), 126.3 (C4′), 123.9 (C6′), 72.8 (C1), 71.5 (C5), 48.2, (C1‴), 41.7 (C8), 40.1 (C7), 32.1 (C6), 21.8 (C9), 21.1 (4″-CH$_3$), 19.9 (6″-CH$_3$, 2″-CH$_3$), 18.2 (2′-CH$_3$), 17.8 (C10), 14.5 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 146.8 (br s, 1 N), 139.1 (br s, 1 N).

MS (ESI+, 3 kV): *m*/*z* = 375.2 [M – Cl]$^+$, 301.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{26}H_{35}N_2$: 375.2800; found: 375.2799.

(1*R*,5*S*)-2-Benzhydryl-1,8,8-trimethyl-4-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (24)

Amidine **22** (765 mg, 3.15 mmol) and benzhydryl chloride (2.24 g, 11.05 mmol) in MeCN (30 mL) were refluxed for 16 h. The solvent was removed and the product was treated with pentane (5 × 5 mL) and Et_2O (5 × 5 mL) to give **24** (1.34 g, 3.01 mmol, 95%) as a white solid; mp 281 °C. $[\alpha]_D^{20}$ –21 (*c* 1, CH_2Cl_2).

IR (KBr): 3418, 3047, 2982, 1634, 1579, 1496, 1449, 1383, 1161, 1051, 781, 749, 706, 913, 573 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.47–7.32 (m, 6 H, H6‴, H4‴, H2‴, H6″, H4″, H2″), 7.31 (s, 1 H, H3), 7.30–7.25 (m, 4 H, H5‴, H3‴, H5″, H3″), 7.22–7.18 (m, 3 H, H5′, H4′, H3′), 7.12 (dd, *J* = 1.5, 7.5 Hz, 1 H, H6′), 6.85 (s, 1 H, H1‴), 3.78 (d, *J* = 4.9 Hz, 1 H, H5), 3.04–2.98 (m, 1 H, H7), 2.43–2.37 (m, 1 H, H6), 2.34–2.21 (m, 2 H, H7, H6), 1.93 (s, 3 H, 2′-CH$_3$), 1.57 (s, 3 H, H11), 1.35 (s, 3 H, H10), 1.24 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.4 (C3), 139.2 (C1′), 137.0 (C1″), 136.4 (C1‴), 132.5 (C3′), 132.1 (C2′), 130.0 (C5″, C3″), 129.9 (C5‴, C3‴), 129.6 (C4″), 129.5 (C4‴), 129.14 (C4′), 129.12 (C6″, C2″), 128.4 (C5′), 128.3 (C6‴, C2‴), 126.2 (C6′), 74.8 (C1), 71.9 (C5), 66.4 (C1‴), 42.1 (C8), 40.8 (C7), 32.3 (C6), 22.1 (C9), 18.1 (C10), 17.9 (2′-CH$_3$), 15.2 (C11).

MS (ESI+, 3 kV): *m*/*z* = 409 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{29}H_{33}N_2$: 409.2644; found: 409.2635.

(1*R*,5*S*)-2-(Anthracen-9-ylmethyl)-1,8,8-trimethyl-4-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (25)

Amidine **22** (750 mg, 3.09 mmol) and 9-(chloromethyl)anthracene (1.72 g, 7.59 mmol) in MeCN (25 mL) and DMF (5 mL) with Et_3N (0.5 mL, 3.4 mmol) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 95:5 + 1% Et_3N). Thereafter, the product was treated with Et_2O (10 × 5 mL) and EtOAc (10 × 5 mL) to give **25** (1.37 g, 2.92 mmol, 94%) as a yellow solid; mp 261 °C. $[\alpha]_D^{20}$ +69 (*c* 4.1, $CHCl_3$).

IR (ATR): 2972, 1656, 1495, 1447, 1398, 1364, 1327, 1312, 1294, 1269, 1221, 1161, 1104, 1070, 1040, 1022, 945, 917, 888, 870, 850, 798, 769, 737, 659, 622 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.42 (s, 1 H, H10″), 8.24 (d, *J* = 8.8 Hz, 2 H, H8″, H1″), 7.97 (d, *J* = 8.5 Hz, 2 H, H5″, H4″), 7.74 (ddd, *J* = 8.8, 6.6, 1.2 Hz, 2 H, H7″, H2″), 7.51 (dd, *J* = 7.8, 6.8 Hz, 2 H, H6″, H3″), 7.11–7.04 (m, 2 H, H5′, H4′), 6.96–6.93 (m, 1 H, H3′), 6.88–6.85 (m, 1 H, H6′), 6.44 (s, 1 H, H3), 6.02 (d, *J* = 14.7 Hz, 1 H, H1‴), 5.40 (d, *J* = 14.7 Hz, 1 H, H1‴), 3.66 (d, *J* = 4.7 Hz, 1 H, H5), 3.53–3.46 (m, 1 H, H7), 2.48–2.37 (m, 2 H, H7, H6), 2.32–2.24 (m, 1 H, H6), 2.01 (s, 3 H, H11), 1.62 (s, 3 H, 2′-C*H*$_3$), 1.40 (s, 3 H, H10), 1.35 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 150.8 (C3), 138.8 (C1′), 132.2 (C3′), 132.1 (C2′), 131.2 (C4″a, C4‴b), 131.1 (C10″), 131.0 (C9″a, C8″a), 129.8 (C5″, C4″), 129.5 (C4′), 128.9 (C7″, C2″), 128.0 (C5′), 126.1 (C6′), 125.8 (C6″, C3″), 122.7 (C8″, C1″), 119.7 (C9″), 73.3 (C1), 71.8 (C5), 46.5 (C1‴), 42.1 (C8), 41.1 (C7), 32.2 (C6), 22.0 (C9), 18.0 (C10), 17.7 (2′-C*H*$_3$), 15.4 (H11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 149.4 (br s, 1 N, N2), 142.6 (br s, 1 N, N4).

MS (ESI+, 3 kV): *m*/*z* = 433 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{31}H_{33}N_2$: 433.2644; found: 433.2652.

(1*R*,5*S*)-2-[Di(naphthalene-2-yl)methyl]-1,8,8-trimethyl-4-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (26)

Amidine **22** (750 mg, 3.1 mmol) and di(naphthalene-2-yl)methyl chloride[20] (1.31 g, 4.33 mmol) in MeCN (30 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 95:5 and CH_2Cl_2–MeOH, 9:1 + 1% Et_3N). Thereafter, the product was treated with Et_2O (10 × 5 mL) and EtOAc (10 × 5 mL) to give **26** (1.39 g, 2.55 mmol, 83%) as a yellow solid; mp 195 °C. $[\alpha]_D^{20}$ +16 (*c* 3.7, $CHCl_3$).

IR (ATR): 2978, 1634, 1601, 1578, 1494, 1450, 1400, 1359, 1318, 1291, 1266, 1197, 1163, 1116, 1045, 943, 864, 818, 785, 757, 717, 659, 623 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 8.04 (d, *J* = 8.3 Hz, 1 H, H4‴), 7.93 (d, *J* = 8.5 Hz, 1 H, H4″), 7.86 (dd, *J* = 7.6, 5.5 Hz, 2 H, H8‴, H8″), 7.82–7.74 (m, 5 H, H7‴, H6‴, H5‴, H3‴, H1‴), 7.56–7.45 (m, 6 H, H7″, H6″, H5″, H3″, H1″, H3), 7.31–7.19 (m, 4 H, H6′, H5′, H4′, H1⁗), 7.13 (d, *J* = 7.0 Hz, 1 H, H3′), 3.80 (d, *J* = 4.2 Hz, 1 H, H5), 3.27–3.15 (m, 1 H, H7), 2.59–2.46 (m, 1 H, H6), 2.38–2.23 (m, 2 H, H7, H6), 1.95 (s, 3 H, 2′-C*H*$_3$), 1.66 (s, 3 H, H11), 1.44 (s, 3 H, H10), 1.25 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.4 (C3), 139.2 (C1′), 134.2 (C2‴), 133.9 (C2″), 133.3 (C4‴a), 133.2 (C4″a), 133.2 (C8‴a), 133.1 (C8″a), 132.5 (C3′), 132.3 (C2′), 130.3 (C4‴), 129.9 (C4″), 129.8 (C4′), 129.4 (C1‴), 128.5 (C5‴), 128.4 (C6‴), 128.3 (C7‴), 128.2 (C5′), 127.8 (C8‴), 127.8 (C8″), 127.5 (C1″), 127.3 (C5″), 127.2 (C6″), 127.1 (C7″), 126.6 (C6′), 125.7 (C3‴), 125.5 (C3″), 75.0 (C1), 72.1 (C5), 67.0 (C1⁗), 42.3 (C8), 41.0 (C7), 32.4 (C6), 22.2 (C9), 18.3 (C10), 18.1 (2′-C*H*$_3$), 15.4 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 160.4 (br s, 1 N, N2), 144.6 (br s, 1 N, N4).

MS (ESI+, 3 kV): *m*/*z* = 509 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{37}H_{37}N_2$: 509.2957; found: 509.2960.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(pyridin-2-ylmethyl)-4-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Chloride (27)

Amidine **22** (750 mg, 3.1 mmol) and 2-(chloromethyl)pyridine (1.18 g, 9.28 mmol) in MeCN (30 mL) were refluxed for 16 h. The solvent was removed and the salt was purified by column chromatography (CH_2Cl_2–MeOH, 85:15). Thereafter, the product was treated with Et_2O (10 × 5 mL) and EtOAc (2 × 5 mL) to give **27** (0.762 g, 2.06 mmol, 67%) as a white solid; mp 156 °C. $[\alpha]_D^{20}$ –127 (*c* 4.2, $CHCl_3$).

IR (ATR): 3435, 2956, 1642, 1591, 1496, 1435, 1380, 1323, 1199, 1170, 1114, 1086, 1028, 997, 769, 717, 567 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 9.17 (s, 1 H, H3), 8.58 (d, *J* = 4.7 Hz, 1 H, H6″), 7.98–7.83 (m, 2 H, H4″, H3″), 7.63–7.55 (m, 1 H, H5′), 7.42–7.35 (m, 1 H, H5″), 7.34–7.27 (m, 3 H, H6′, H4′, H3′), 5.69 (d, *J* = 16.3 Hz, 1 H, H1‴), 5.37 (d, *J* = 16.1 Hz, 1 H, H1‴), 3.54 (d, *J* = 4.9 Hz, 1 H, H5), 2.89–2.76 (m, 1 H, H7), 2.57–2.51 (m, 1 H, H6), 2.51 (s, 3 H, 2′-C*H*$_3$), 2.11 (ddt, *J* = 14.6, 12.1, 4.9 Hz, 1 H, H6), 1.93 (ddd, *J* = 14.5, 12.2, 4.4 Hz, 1 H, H7), 1.41 (s, 3 H, H11), 1.37 (s, 3 H, H10), 1.16 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 157.0 (C3), 154.0 (C2″), 147.3 (C6″), 139.7 (C4″), 139.3 (C1′), 133.4 (C2′), 132.3 (C3′), 129.7 (C4′), 127.9 (C6′), 127.7 (C5′), 124.8 (C3″), 124.1 (C5″), 72.0 (C1), 71.1 (C5), 53.6 (C1‴), 42.1 (C8), 39.8 (C7), 31.7 (C6), 22.1 (C9), 18.8 (2′-C*H*$_3$), 18.1 (C10), 15.0 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 142.2 (br s, 3 N, N1″, N4, N2).

MS (ESI+, 3 kV): *m*/*z* = 334 [M – Cl]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – Cl]$^+$ calcd for $C_{22}H_{28}N_3$: 334.2283; found: 334.2285.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(2-morpholinoethyl)-2-(*o*-tolyl)-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Hexafluorophosphate (28)

Amidine **22** (650 mg, 2.68 mmol) and 2-chloromorpholine (0.44 mL, 3.22 mmol) in MeCN (2.5 mL) were refluxed for 60 h. The solvent was removed and the salt was purified by treating it with pentane (3 × 5 mL) and Et_2O (3 × 5 mL). $NaPF_6$ (675 mg, 4 mmol) was added to the crude chloride salt. A mixture of CH_2Cl_2 and H_2O (1:1; 100 mL) was added and the mixture was stirred for 60 h at r.t. The organic phase was separated and washed with H_2O (3 × 20 mL) and dried (Na_2SO_4). The solvent was removed and the crude product was purified by column chromatography (CH_2Cl_2–MeOH, 95:5). Thereafter, the product was dissolved in a small amount of MeOH and added dropwise to Et_2O (100 mL). The solvent was removed by filtration to give **28** (0.658 g, 1.31 mmol, 49%) as a white solid; mp 172.9 °C. $[\alpha]_D^{20}$ –58 (*c* 0.53, CH_2Cl_2).

IR (ATR): 2970, 1653, 1342, 1111, 848, 555 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.61 (s, 1 H, H3), 7.36–7.22 (m, 4 H, H3′, H4′, H5′, H6′), 3.72–3.60 (m, 2 H, H1″), 3.60 (t, *J* = 4.2 Hz, 4 H, H2″, H6″), 3.53 (d, *J* = 4.4 Hz, 1 H, H5), 2.72–2.60 (m, 2 H, H6, H2‴), 2.59–2.42 (m, 6 H, H7, H3″, H5″, H2‴), 2.37 (s, 3 H, 2′-C*H*$_3$), 2.21–2.05 (m, 2 H, H6, H7), 1.43 (s, 3 H, H11), 1.31 (s, 3 H, H10), 1.20 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 154.7 (C3), 139.0 (C1′), 133.4 (C2′), 132.4 (ArC), 130.0 (ArC), 127.9 (ArC), 127.6 (ArC), 71.1 (C1), 70.9 (C5), 66.8 (C2″, C6″), 57.2 (C2‴), 53.3 (C3″, C5″), 45.9 (C1‴), 41.7 (C8), 40.4 (C7), 31.9 (C6), 21.9 (C9), 18.3 (2′-CH_3), 17.5 (C10), 14.4 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 142.7 (br s, 2 N, N2, N4), 38.2 (br s, 1 N, N4″).

MS (ESI+, 3 kV): *m*/*z* = 356.2 [M – PF_6]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – PF_6]$^+$ calcd for $C_{22}H_{34}N_3O$: 356.2697; found: 356.2700.

Anal. Calcd for $C_{22}H_{34}N_3OPF_6$: C, 52.69; H, 6.83; N, 8.38. Found: C, 52.41; H, 6.64; N, 8.42.

(1*R*,5*S*)-1,8,8-Trimethyl-4-(2-morpholinoethyl)-2-phenyl-2,4-diazabicyclo[3.2.1]oct-2-en-2-ium Hexafluorophosphate (31)

Amidine **30** (683 mg, 2.99 mmol) and 2-chloromorpholine (0.49 mL, 3.59 mmol) in MeCN (2.5 mL) were refluxed for 60 h. The solvent was removed and the salt was purified by treating it with pentane (3 × 5 mL) and Et_2O (3 × 5 mL). $NaPF_6$ (753 mg, 4.49 mmol) was added to the crude chloride salt. A mixture of CH_2Cl_2 and H_2O (1:1; 100 mL) was added and the mixture was stirred for 60 h at r.t. The organic phase was separated and washed with H_2O (3 × 20 mL) and dried (Na_2SO_4). The solvent was removed and the crude product was purified by column chromatography (CH_2Cl_2–MeOH, 95:5). Thereafter, the product was dissolved in a small amount of MeOH and added dropwise to Et_2O (100 mL). The solvent was removed by filtration to give **31** (1.195 g, 2.45 mmol, 82%) as a white solid; mp 170.9 °C. $[\alpha]_D^{20}$ +36 (*c* 0.99, CH_2Cl_2).

IR (ATR): 2984, 2947, 2863, 2806, 1639, 1114, 829, 762, 693, 555 cm^{-1}.

^{1}H NMR (500 MHz, $CDCl_3$): δ = 7.90 (s, 1 H, H3), 7.50–7.44 (m, 2 H, H3′, H5′), 7.41–7.36 (m, 1 H, H4′), 7.34–7.30 (m, 2 H, H2′, H6′), 3.79 (d, *J* = 5.0 Hz, 1 H, H5), 3.73 (dd, *J* = 10.5 Hz, 2 H, H1‴), 3.58 (*t*, *J* = 4.4 Hz, 4 H, H2″, H6″), 2.74–2.62 (m, 2 H, H7, H2‴), 2.62–2.47 (m, 5 H, H3″, H5″, H2‴), 2.47–2.39 (m, 1 H, H6), 2.34–2.25 (m, 1 H, H6), 2.13–2.04 (m, 1 H, H7), 1.42 (s, 3 H, H11), 1.22 (s, 3 H, H10), 1.19 (s, 3 H, H9).

^{13}C NMR (126 MHz, $CDCl_3$): δ = 153.3 (C3), 140.6 (C1′), 130.5 (C2′, C6′), 128.9 (C4′), 122.3 (C3′, C5′), 71.5 (C1), 70.8 (C5), 66.8 (C2″, C6″), 57.1 (C2‴), 53.1 (C3″, C5″), 45.7 (C1‴), 41.2 (C8), 40.7 (C7), 32.3 (C6), 21.7 (C10), 16.9 (C9), 14.3 (C11).

^{15}N NMR (51 MHz, $CDCl_3$): δ = 143.0 (br s, 2 N, N2, N4), 38.7 (br s, 1 N, N4″).

MS (ESI+, 3 kV): *m*/*z* = 342.2 [M – PF_6]$^+$.

HRMS (ESI+, 3 kV): *m*/*z* [M – PF_6]$^+$ calcd for $C_{21}H_{32}N_3O$: 342.2540; found: 342.2539.

Anal. Calcd for $C_{21}H_{32}N_3OPF_6$: C, 51.74; H, 6.62; N, 8.62. Found: C, 51.57; H, 6.29; N, 8.62.

B_2Pin_2 Addition to 32; General Procedure

In a Schlenk tube **32** (0.62 mmol, 1 equiv), B_2Pin_2 (172 mg, 0.678 mmol, 1.1 equiv), NaO*t*-Bu (17.8 mg, 0.185 mmol, 0.3 equiv), and toluene (1.5 mL) were added and the mixture was cooled to –55 °C. The carbene precursor (0.068 mmol, 11 mol%), CuCl (6.1 mg, 0.06 mmol, 10 mol%), and toluene were added to a second Schlenk tube; to the suspension 0.5 M KHMDS in toluene (0.11 mL, 0.055 mmol, 9 mol%) was added and the solution was stirred for 1 h and transferred by a cannula to the first Schlenk tube. The mixture was stirred at –55 °C and after 10 min MeOH (0.05 mL, 1.2 mmol, 2 equiv) was added and the mixture was stirred at this temperature for 6 h. Thereafter, the reaction was allowed to warm up to r.t. and the solvent was removed under reduced pressure. The crude product was purified by column chromatography (*n*-hexane–EtOAc, 20:1) and isolated as a colorless oil. The spectral data were consistent with literature values.[9d] For yields and conditions see Table 2. For enantiomeric excess measurements the product was oxidized. The product was dissolved in EtOAc (20 mL), and H_2O_2 (35%, 25 equiv) and 1 M aq NaOH (25 equiv) were added and the mixture was stirred for 1 h at r.t. Thereafter, H_2O (30 mL) was added and the mixture was extracted with EtOAc (3 × 70 mL). The combined organic phases were dried (Na_2CO_3) and the solvent was removed under reduced pressure. The crude product was purified by column chromatography (isohexane–EtOAc, 9:1) and obtained as a colorless oil. The spectral data were consistent with literature values.[9d] The enantiomeric excess was determined by chiral HPLC: Chiralpak IB OD-H, *n*-hexane–*i*-PrOH, 95:05, 0.5 mL/min, λ = 259 nm, t_R = 26.7 min (*S*-enantiomer), t_R = 34.0 (*R*-enantiomer). For enantiomeric excess values see Table 2.

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Supporting Information

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