

Palladium-catalyzed chemoselective intramolecular cyclization of bromoanilinoalkenenitriles

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α -(*o*-Bromoanilino)alkenenitriles **1a–f** and **2a–e** and α -(*N*-alkenylamino)- β -(*o*-bromophenyl)propanenitriles **7a–c** and **8a–c** undergo palladium-catalyzed conversion into *o*-(methylamino)benzonitrile **12**, *o*-[(alkenylamino)ethenyl]benzonitriles **24a–c**, *N*-alkenylanilines **26b**, **26c**, 3-benzazepines **29a**, **29c**, **31a** and **32a**, γ -carbolines **36** and pyrrolo[3,2-*b*]indole **45**. The reactions involve intramolecular additions of arylpalladium to the cyano group and subsequent processes such as cyano group transposition, hydrolysis, electrocyclization, ethyl group transfer and oxidative aromatization. A general mechanism for the palladium-catalyzed arylation of a cyano group is proposed.

Introduction

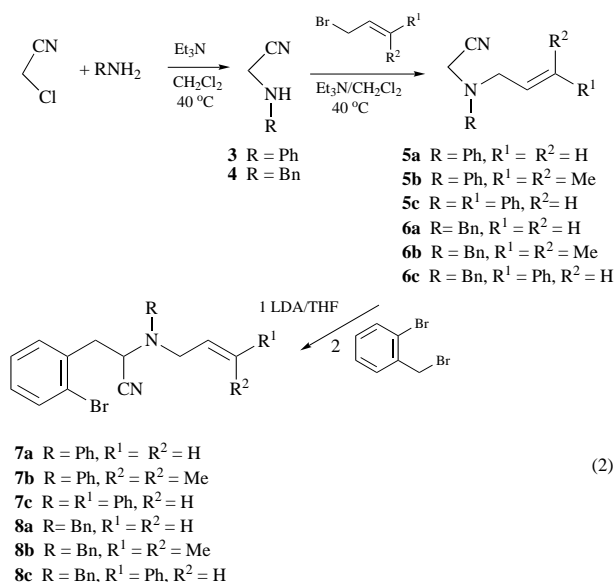
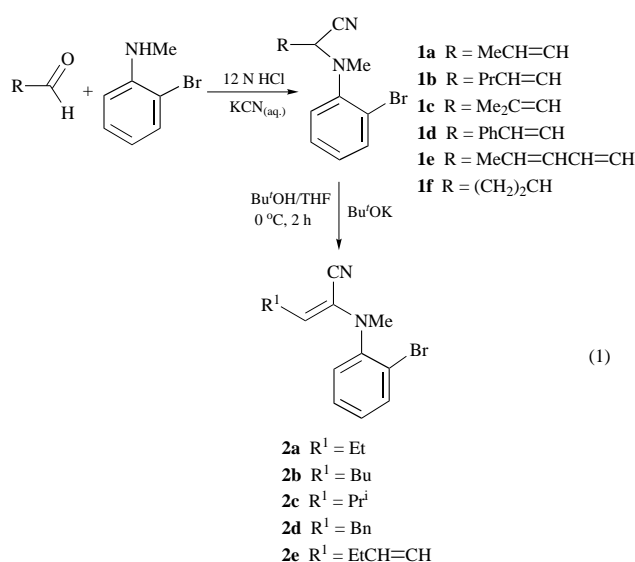
Heck reactions are important palladium-catalyzed reactions for carbon–carbon bond formation such as the well documented arylation of olefins;¹ the corresponding arylation of a cyano group is, however, unprecedented except for a previous report from our group.² A series of *N*-methyl-(*o*-bromoanilino)alk-3-enenitriles **1a–e**, 2-anilino-2-cyclopropylacetonitrile **1f**, *N*-methyl-(*o*-bromoanilino)alk-2-enenitriles **2a–e** and *N*-alkenylamino-3-(*o*-bromophenyl)propanenitriles **7a–c**, **8a–c** have been prepared, and their intramolecular palladium-catalyzed cyclizations studied.² Most of these compounds have olefin and cyano groups oriented in similar proximity to the arylpalladium complex. The palladium-catalyzed cyclization may occur by two competitive pathways: namely by attack on the olefinic function or on the cyano group. This study indicates that the palladium-catalyzed arylation occurs in most cases selectively at the cyano group to afford *o*-(methylamino)benzonitrile **12**, *o*-[(alkenylamino)ethenyl]benzonitriles **24**, *N*-alkenylanilines **26**, γ -carbolines **36** and pyrrolo[3,2-*b*]indole **45**.

Results and discussion

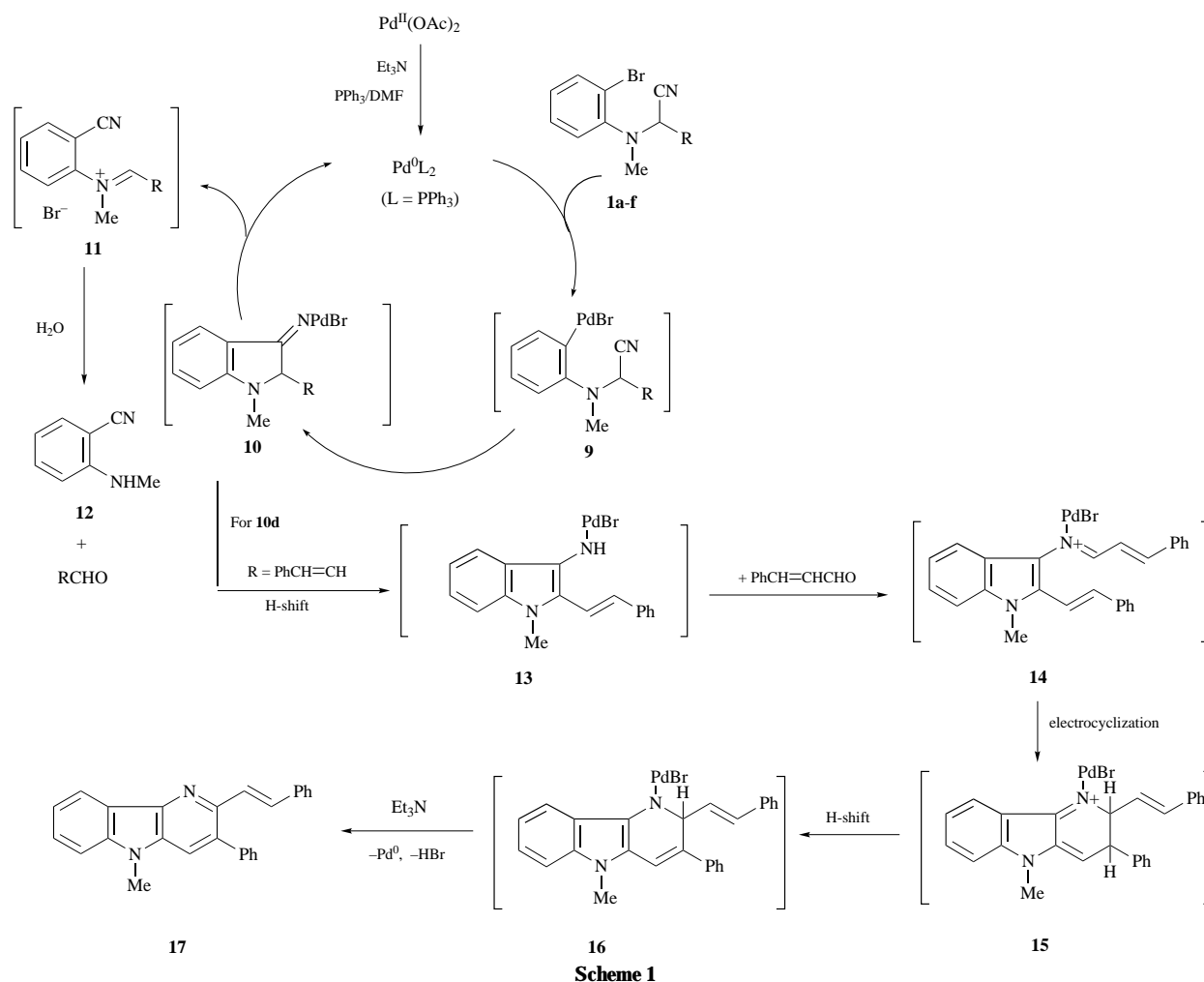
Non-conjugated α -(*o*-bromoanilino)alkenenitriles **1a–e** were prepared [eqn. (1)] by condensation of equimolar amounts of an appropriate unsaturated aldehyde, potassium cyanide and *N*-methyl-*o*-bromoaniline³ in the presence of hydrochloric acid (12 M).⁴ α -Amino(cyclopropyl)acetonitrile **1f** was similarly prepared from cyclopropanecarbaldehyde. Treatment of **1a–e** with a strong base Bu^t-OK in Bu^tOH–THF at 0 °C for 2 h gave the thermodynamically favoured conjugated α -aminoalkenenitriles **2a–e** predominantly as the 2*E*-isomer (*E*:*Z* > 10).⁵ 2-(Alkenylamino)acetonitriles **5a–c**, **6a–c**, prepared from *N*-alkylations of α -aminonitriles **3** and **4**,⁶ were treated with lithium diisopropylamide (LDA) and *o*-bromobenzyl bromide to give 2-(alkenylamino)-3-(*o*-bromophenyl)propanenitriles **7a–c** and **8a–c** [eqn. (2)].⁷

In a typical procedure⁸ (Table 1), α -(*o*-bromoanilino)alkenenitrile **1d** (1 mmol) in DMF (15 ml) was treated with Pd(OAc)₂ (0.1 mmol), PPh₃ (0.2 mmol) and Et₃N (1.2 mmol) for 6 h at 100 °C under an argon atmosphere to give 2-(methylamino)benzonitrile **12** and γ -carboline **17** in 38 and 36% yields, respectively. The reactions of **1a–c**, **e**, **f** gave the benzonitrile **12** (60–85%) and aldehydes RCHO.

A possible mechanism for the palladium-catalyzed reactions⁹ is illustrated by the formation of the benzonitrile **12** (Scheme 1). The reactions were presumably initiated by oxidative insertion



of Pd⁰ into the bromophenyl groups. The organopalladium **9** undergoing cyclisation by attack on the cyano group, giving **10**, but not the olefinic double bonds. The iminoindoline **10** might



Scheme 1

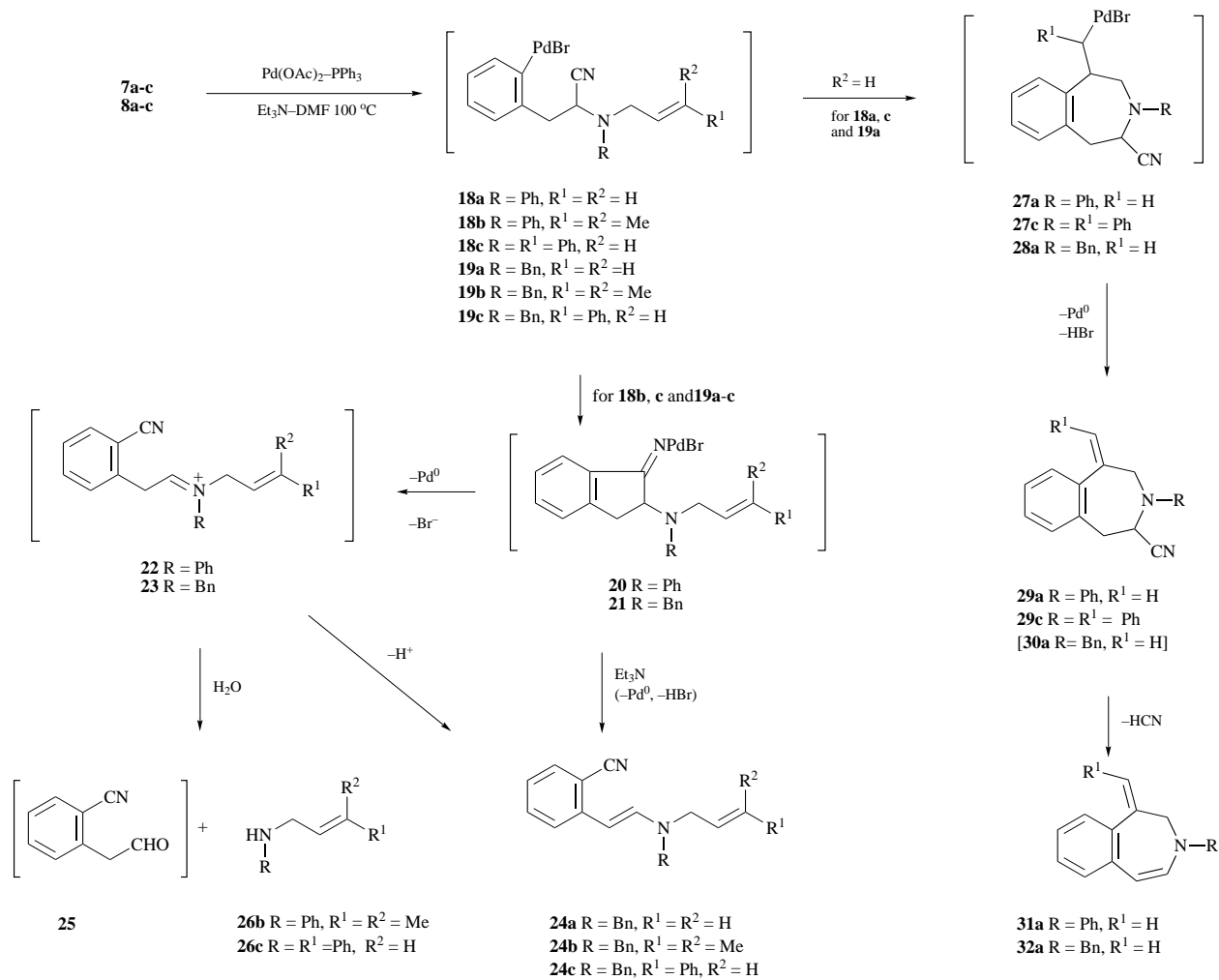
Table 1 Palladium-catalyzed chemoselective intramolecular cyclization of bromoanilinoalkenenitriles^a

Entry	Substrate	Base	Reaction time (h)	Products (yield, %) ^b	
				Addition to CN	Addition to C=C
1	1a	Et ₃ N	6	12 (81)	—
2	1b	Et ₃ N	6	12 (60)	—
3	1c	Et ₃ N	6	12 (85)	—
4	1d	Et ₃ N	6	12 (38) + 17 (36)	—
5	1e	Et ₃ N	6	12 (72)	—
6	1f	Et ₃ N	6	12 (80)	—
7	7a	Et ₃ N	8	—	29a (60) + 31a (18)
8	7b	Et ₃ N	8	26b (76)	—
9	7c	Et ₃ N	8	26c (66)	29c (16)
10	8a	Et ₃ N	8	24a (9)	32a (77)
11	8b	Et ₃ N	8	24b (78)	—
12	8c	Et ₃ N	8	24c (72)	—
13	2a	Et ₃ N	6	36a (88)	—
14	2b	Et ₃ N	6	36b (73)	—
15	2c	Et ₃ N	6	36c (85)	—
16	2d	Et ₃ N	6	36d (63)	—
17	2e	Et ₃ N	6	36e (75)	—
18	2a	Na ₂ CO ₃	12	45 (52)	—
19	2b	Na ₂ CO ₃	12	36e (51)	—
20	2c	Na ₂ CO ₃	12	48 (73)	—

^a The reactions were run under an argon atmosphere with 1 equiv. of bromoanilinoalkenenitrile, 1.2 equiv of base, 20 mol% of PPh₃, and 10 mol% of Pd(OAc)₂ in DMF at 100 °C. ^b Isolated yields after purification.

yield an iminium ion **11**, which is subsequently hydrolyzed to give 2-(methylamino)benzonitrile **12** and aldehydes RCHO. When R is a styryl group, the palladium amide **10d** reacted further with cinnamaldehyde to give γ -carboline **17**.¹⁰ This process might involve electrocyclization, H-shift and elimination of palladium and HBr.

Under similar reaction conditions, the palladium-catalyzed reactions of 2-(alkenylamino)-3-(*o*-bromophenyl)propane-nitrile **7b** afforded the alkenylamine **26b** (76%). This result was explained in terms of the organopalladium compound (**18** and **19**) attacking the cyano group selectively (Scheme 2). Thus, the benzonitrile iminium salts (**22** and **23**) generated from the



Scheme 2

iminoindoline intermediates (**20** and **21**) upon elimination of HBr would give the aminovinylbenzonitriles **24** or undergo hydrolysis to give the alkenylamines **26b, c**. On the other hand, analogous organopalladium compounds (**18a, c**) might attack the less hindered double bonds as shown in the transformation of **7a** and **7c** to 3-benzazepine derivatives **29a** (60%) and **29c** (16%). The reactions of **8a-c** followed similar pathways, the organopalladium intermediate attacking either the cyano group or the olefinic double bond depending on the nature of the substrates. At elevated reaction temperatures, elimination of HCN from **29a** and **30a** occurred to give the benzazepines **31a** and **32a**.

The palladium-catalyzed reactions of the conjugated bromo-anilinoalkenenitriles **2a-e** (as *E/Z*-mixtures) afforded γ -carbolines **36a-e** (63–88% entries 13–17). The organopalladium compound **34e** (R¹ = butenyl) had the potential to undergo 6 π electrocyclization and subsequent elimination of palladium and HBr to produce the γ -carboline **36e** (Scheme 3). Although the intermediates **34a, b, d** derived from **2a, b, d** (R = Et, Bu, Bn) could not undergo electrocyclization, capture of an ethyl group from Et₃NH⁺ would give **38a, b, d**. Subsequent elimination of palladium and HBr, followed by electrocyclization and oxidative aromatization would furnish the γ -carbolines **36a, b, d**. The intermediate **34c** derived from **2c** (R = Pr¹) underwent electrocyclization in a different way, *via* **40**, to furnish the 4-isopropyl- γ -carboline **36c**.

In order to determine whether the ethyl group was transferred from Et₃N in the conversion of **2a-c** into γ -carbolines **36a-c**, we replaced Et₃N with Na₂CO₃ (1.2 equiv.) as the base in the palladium-catalyzed reactions (entries 18–20).¹¹ Under such conditions, compounds **2a, 2b** and **2c** yielded to the pyrrolo-

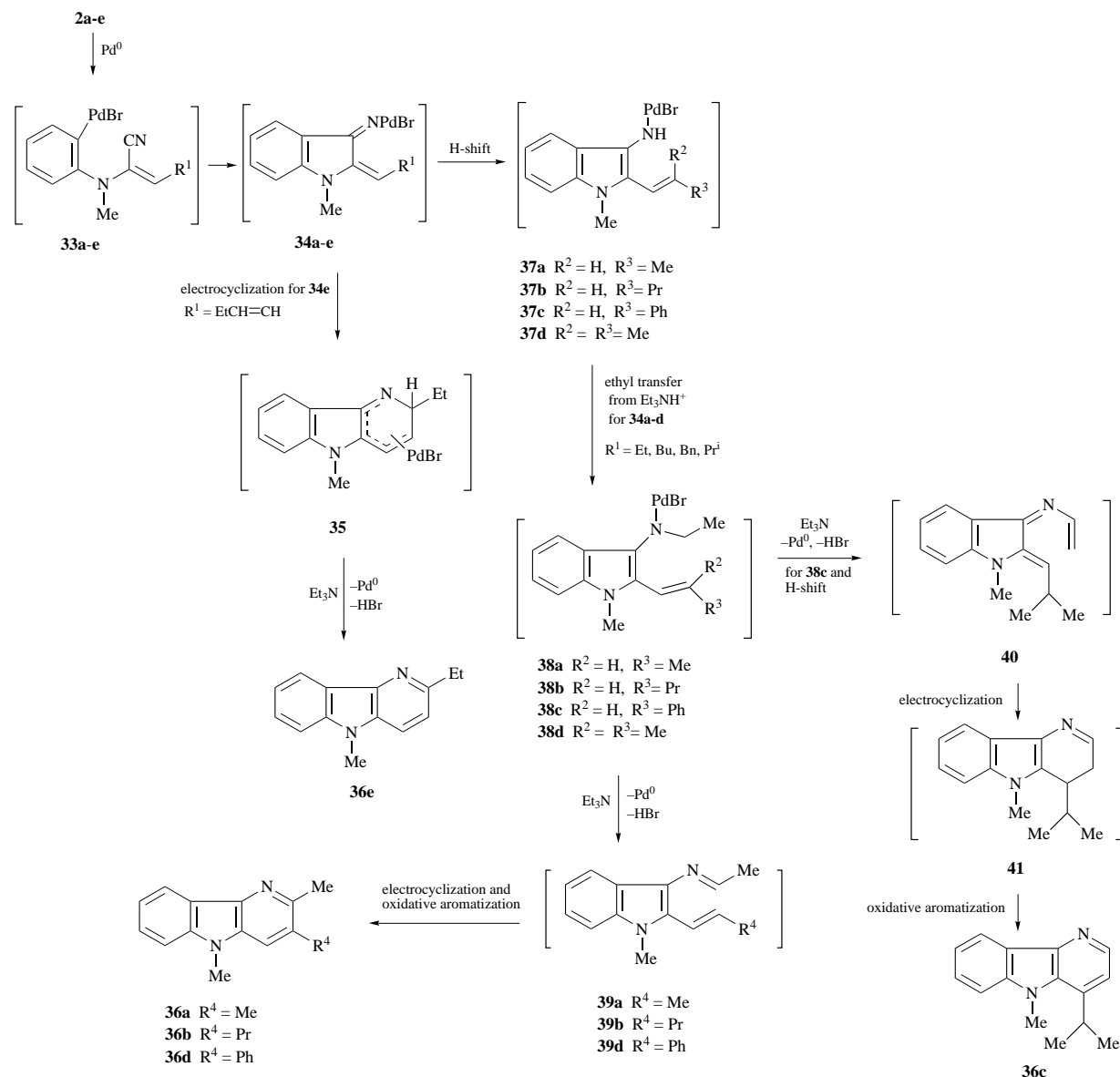
[3,2-*b*]indole **45** (52%), γ -carbolines **36e** (51%) and **48** (73%), respectively. The γ -H of the organopalladium compound **42a** was removed by Na₂CO₃ to give an anion **43a**, which yielded the pyrrolo[3,2-*b*]indole **45** as the result of a nucleophilic reaction and hydrogen shift (Scheme 4). For **2b** and **2c** (R = Pr¹ or Bu), the intermediates **43b** and **43c** might undergo the palladium transfer, giving the π -allylpalladium complex as **46d** and **46c**. Elimination of palladium and HBr followed by electrocyclization and oxidative aromatization would furnish the γ -carbolines **36e** and **48**.

Conclusions

Our study of the palladium-catalyzed reactions shows three common features: (i) the organopalladium compounds **9** undergo cyclization by preferential attack on the cyano group rather than at the olefinic double bonds; (ii) the iminopalladium compounds **18** and **19** undergo either the transposition of cyano groups or cyclization at the olefinic double bonds; (iii) since Et₃NH⁺ may transfer an ethyl group to the iminopalladium compounds **34a-d**, the palladium-catalyzed reactions of **2a-d** proceeded differently on replacement of Et₃N by Na₂CO₃.

Experimental

Melting points are uncorrected. ¹H NMR spectra were recorded at 200 or 300 MHz; ¹³C NMR spectra were recorded at 50 or 75 MHz, TMS was used as an internal standard (*J* values in Hz). Mass spectra were recorded at an ionizing voltage of 70 eV. Merck silica gel 60F sheets were used for



Scheme 3

analytical thin-layer chromatography. Column chromatography was performed on SiO_2 (70–230 mesh); gradients of EtOAc and hexane were used as eluents. DMF, Et_3N and CH_2Cl_2 were distilled over CaH_2 , whilst THF was distilled from sodium benzophenone ketyl under N_2 .

Preparation of 2-(*N*-methyl-*o*-bromoanilino)alk-3-enitriles **1a–f**

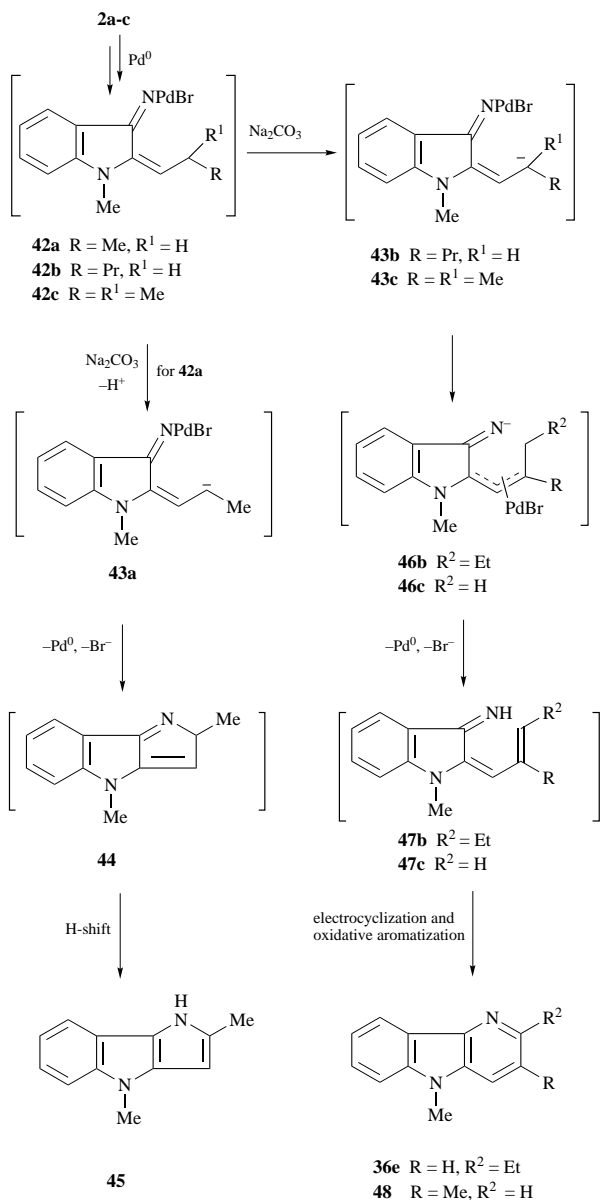
To a mixture of *N*-methyl-*o*-bromoaniline (15.0 mmol) and aq. HCl (12 M; 12.5 ml), the appropriate unsaturated aldehyde (18 mmol) was added dropwise at 0 °C, followed by aqueous KCN (1.05 g, 16.2 mol, 5 ml). After being stirred for 12 h at room temperature, the mixture was separated, the aqueous phase then being extracted with EtOAc. The combined organic phase and extracts were washed with aq. HCl (1 M) and brine, dried (Na_2SO_4) and concentrated under reduced pressure to give the title compound; compounds **1a–f** decomposed to give aniline and aldehydes if subjected to chromatography on a silica gel column.

2-(*N*-Methyl-*o*-bromoanilino)pent-3-enitrile **1a.** Yield 59%; oil; TLC [EtOAc–hexane (2:98)] R_f 0.28; $\nu_{max}(neat)/cm^{-1}$ 2960, 2801, 2240 (CN), 1590, 1476, 970 and 760; $\delta_H(CDCl_3)$ 1.73 (3 H, ddd, J 6, 1, 1, $CHCH_2$), 2.65 (3 H, s, NCH_3), 4.80 (1 H, br s, NCH), 6.56 (1 H, ddq, J 15, 3, 1, 3-H), 6.06 (1 H, dqd, J 15, 6, 1, 4-H), 6.88–6.96 (1 H, m, ArH), 7.20–7.23 (2 H, m, ArH) and 7.48 (1 H, dd, J 8,

1.5, ArH); $\delta_C(CDCl_3)$ 17.4 (q, C-5), 35.0 (q, NCH_3), 58.3 (d, C-2), 115.4 (s, CN), 120.3 (s), 123.2 (d), 123.6 (d), 126.1 (d), 128.4 (d), 131.8 (d), 133.7 (d) and 147.9 (s); m/z 266 ($[M + 2]^+$, 28%), 264 (M^+ , 32), 185 (68), 157 (100), 105 (52) and 77 (74) (Found: M , 266.0238. $C_{12}H_{13}N_2Br$ requires M , 266.0242).

2-(*N*-Methyl-*o*-bromoanilino)hept-3-enitrile **1b.** Yield 78%; oil; TLC [EtOAc–hexane (2:98)] R_f 0.25; $\nu_{max}(neat)/cm^{-1}$ 2960, 2800, 2240 (CN), 1590, 1490, 970 and 760; $\delta_H(CDCl_3)$ 0.90 (3 H, t, J 7, H-7), 1.35–1.50 (2 H, m, H-6), 2.08 (2 H, dt, J 7, 7, H-5), 2.72 (3 H, s, NCH_3), 4.89 (1 H, br dd, J 2, 1, NCH), 5.57 (1 H, dd, J 16, 2, 3-H), 6.10 (1 H, dtd, J 16, 7, 1, 4-H), 6.93–7.02 (1 H, m, ArH), 7.23–7.34 (2 H, m, ArH) and 7.55 (1 H, dd, J 8, 1, ArH); $\delta_C(CDCl_3)$ 13.5 (q, C-7), 21.8 (t, C-6), 33.9 (t, C-4), 35.0 (q, NCH_3), 58.3 (d, C-2), 115.4 (s, CN), 120.3 (s), 122.5 (d), 123.2 (d), 126.1 (d), 128.4 (d), 133.6 (d), 136.9 (d) and 147.9 (s); m/z 294 ($[M + 2]^+$, 9%), 292 (M^+ , 11), 185 (64), 157 (100), 105 (50) and 77 (76) (Found: M , 292.0574. $C_{14}H_{17}N_2Br$ requires M , 292.0575).

4-Methyl-2-(*N*-methyl-*o*-bromoanilino)pent-3-enitrile **1c.** Yield 83%; oil; TLC [EtOAc–hexane (2:98)] R_f 0.29; $\nu_{max}(neat)/cm^{-1}$ 2920, 2220 (CN), 1600, 1490, 770, 740 and 670; $\delta_H(CDCl_3)$ 1.68 [3 H, d, J 1, $1/2 \times C(CH_3)_2$], 1.81 [3 H, d, J 1, $1/2 \times C(CH_3)_2$], 2.84 (3 H, s, NCH_3), 4.91 (1 H, d, J 8, NCH), 5.34 (1 H, br d, J 8, 3-H), 6.95–7.06 (1 H, m, ArH), 7.26–7.35 (2 H, m, ArH) and 7.56 (1 H, d, J 8, ArH); $\delta_C(CDCl_3)$ 18.6 (q, C-5),



Scheme 4

25.8 (q, C-5'), 36.6 (q, NCH₃), 54.0 (d, C-2), 116.0 (s, CN), 117.1 (s), 120.7 (s), 123.7 (d), 126.3 (d), 128.3 (d), 133.7 (d), 140.7 (s) and 148.0 (s); *m/z* 280 ([M + 2]⁺, 7%), 278 (M⁺, 7), 265 (14), 263 (13), 185 (69), 157 (100) and 105 (51) (Found: M, 27.0421. C₁₃H₁₅N₂Br requires *M*, 27.0419).

2-(N-Methyl-*o*-bromoanilino)-4-phenylpent-3-enitrile 1d. Yield 86%; white solid, mp 86–88 °C; TLC [EtOAc–hexane (2:98)] *R*_f 0.20; *v*_{max}(KBr)/cm⁻¹ 3054, 2234 (CN), 1582, 1469, 968, 741 and 695; δ_{H} (CDCl₃) 2.78 (3 H, s, NCH₃), 5.11 (1 H, dd, *J* 4, 1, 2-H), 6.32 (1 H, dd, *J* 16, 4, 3-H), 6.97–7.08 (2 H, m, ArH), 7.26–7.30 (5 H, m, ArH), 7.45 (2 H, dd, *J* 8, 1, ArH) and 7.59 (1 H, d, *J* 8, ArH); δ_{C} (CDCl₃) 35.4 (q, NCH₃), 58.6 (d, C-2), 115.1 (s, CN), 120.4 (s), 121.6 (d), 123.3 (d), 126.3 (d), 126.8 (2 × d), 128.5 (d), 128.6 (d), 128.7 (2 × d), 133.7 (d), 134.9 (d), 135.1 (s) and 147.8 (s); *m/z* 328 ([M + 2]⁺, 7%), 326 (M⁺, 8), 247 (28), 157 (82), 142 (100), 115 (55) and 77 (14) (Found: M, 326.0420. C₁₇H₁₅N₂Br requires *M*, 326.0419).

2-(N-Methyl-*o*-bromoanilino)hepta-3,5-dienitrile 1e. Yield 83%; white solid, mp 65–67 °C; TLC [EtOAc–hexane (2:98)] *R*_f 0.19; *v*_{max}(KBr)/cm⁻¹ 2955, 2811, 2230 (CN), 1595, 1508, 990 and 743; δ_{H} (CDCl₃) 1.79 (3 H, d, *J* 7, CHCH₃), 2.73 (3 H, s, NCH₃), 4.98 (1 H, d, *J* 4, NCH), 5.66 (1 H, dd, *J* 15, 4, 3-H), 5.87 (1 H, dq, *J* 15, 7, 6-H), 6.12 (1 H, dd, *J* 15, 10, 5-H), 6.59 (1 H, dd, *J* 15, 10, 4-H), 6.97–7.04 (1 H, m, ArH), 7.29–7.31 (2 H,

m, ArH) and 7.57 (1 H, dd, *J* 8, ArH); δ_{C} (CDCl₃) 18.1 (q, C-7), 35.2 (q, NCH₃), 58.2 (d, C-2), 115.2 (s, CN), 120.3 (s), 121.8 (d), 123.2 (d), 126.1 (d), 128.4 (d), 129.4 (d), 132.9 (d), 133.7 (d), 135.2 (d) and 147.9 (s); *m/z* 292 ([M + 2]⁺, 26%), 290 (M⁺, 29), 277 (21), 275 (20), 211 (51), 185 (74), 157 (100), 106 (50) and 77 (60) (Found: M, 290.0417. C₁₄H₁₅N₂Br requires *M*, 290.0419).

2-Cyclopropyl-2-(N-methyl-*o*-bromoanilino)ethanenitrile 1f. Yield 78%; oil; TLC [EtOAc–hexane (5:95)] *R*_f 0.22; *v*_{max}(neat)/cm⁻¹ 2960, 2210 (CN), 1590, 1480, 1280 and 760; δ_{H} (CDCl₃) 0.61–0.83 [4 H, m, CH(CH₂)₂], 1.32–1.43 [1 H, m, CH(CH₂)₂], 2.91 (3 H, s, NCH₃), 4.15 (1 H, d, *J* 9, NCH), 6.96–7.04 (1 H, m, ArH), 7.30 (2 H, dd, *J* 8, ArH) and 7.56 (1 H, dd, *J* 8, ArH); δ_{C} (CDCl₃) 2.1 (t), 4.1 (t), 11.8 (d, C-3), 36.1 (q, NCH₃), 60.2 (d, C-2), 115.4 (s, CN), 120.5 (s), 123.6 (d), 126.2 (d), 128.4 (d), 133.6 (d) and 147.9 (s); *m/z* 266 ([M + 2]⁺, 68%), 264 (M⁺, 72), 240 (18), 238 (20), 225 (82), 223 (92), 186 (70), 184 (83), 105 (68), 84 (7), 77 (68) and 49 (100) (Found: M, 264.0268. C₁₂H₁₃N₂Br requires *M*, 264.0262).

Preparation of N-methyl-*o*-bromoanilinoalk-2-enitriles 2a–e

The appropriate N-methyl-*o*-bromoanilinoalk-3-enitrile was treated with Bu^tOK (1.1 equiv.) at 0 °C in a mixture of THF (10 ml) and Bu^tOH (2 ml). After 2 h the reaction was quenched by the addition of aqueous NH₄Cl (5 ml) to the mixture which was then extracted with ethyl acetate. The combined extracts were washed with brine, dried (Na₂SO₄), concentrated and purified by chromatography on a silica gel column with gradients of EtOAc and hexane to afford the title compounds.

2-(N-Methyl-*o*-bromoanilino)pent-2-enitrile 2a. Yield 64% (this compound was a mixture of two isomers, *E:Z* = 95:5). (*2E*)-Isomer: oil; TLC [EtOAc–hexane (2:98)] *R*_f 0.23; *v*_{max}(neat)/cm⁻¹ 2890, 2205 (CN), 1603, 1585, 1470, 750 and 720; δ_{H} (CDCl₃) 1.07 (3 H, t, *J* 6, CH₂CH₃), 2.36 (2 H, dq, *J* 6, 6, CHCH₂), 3.03 (3 H, s, NCH₃), 5.26 (1 H, t, *J* 6, 3-H), 7.09 (1 H, ddd, *J* 8, 8, 1, ArH), 7.18 (1 H, dd, *J* 8, 1, ArH), 7.33 (1 H, ddd, *J* 8, 8, 1, ArH) and 7.60 (1 H, dd, *J* 8, 1, ArH); δ_{C} (CDCl₃) 14.4 (q, C-5), 22.8 (t, C-4), 39.4 (q, NCH₃), 114.3 (s, CN), 121.9 (2 × s), 123.5 (d), 127.6 (d), 127.7 (d), 128.4 (d), 133.8 (d) and 144.8 (s); *m/z* 266 ([M + 2]⁺, 28%), 264 (M⁺, 32), 251 (75), 249 (74), 199 (51), 169 (100), 157 (23) and 77 (70) (Found: C, 54.02; H, 4.99; N, 10.58%; M, 266.0238. C₁₂H₁₃N₂Br requires C, 54.54; H, 4.96; N, 10.61%; M, 266.0242); (*2Z*)-isomer: δ_{H} (CDCl₃) 0.85 (3 H, t, *J* 6, CH₂CH₃), 3.12 (3 H, s, NCH₃) and 5.74 (1 H, t, *J* 6, 3-H).

2-(N-Methyl-*o*-bromoanilino)hept-2-enitrile 2b. Yield 62% (this compound was a mixture of two isomers, *E:Z* = 94:6). (*2E*)-Isomer: oil; TLC [EtOAc–hexane (2:98)] *R*_f 0.24; *v*_{max}(neat)/cm⁻¹ 2890, 2210 (CN), 1605, 1590, 1470, 745 and 720; δ_{H} (CDCl₃) 0.93 (3 H, t, *J* 7, CH₂CH₃), 1.30–1.46 (4 H, m, CH₂CH₂CH₂), 2.35 (2 H, dt, *J* 7, 7, CHCH₂), 3.04 (3 H, s, NCH₃), 5.25 (1 H, t, *J* 7, 3-H), 7.10 (1 H, ddd, *J* 8, 8, 1, ArH), 7.18 (1 H, dd, *J* 8, 1, ArH), 7.33 (1 H, ddd, *J* 8, 8, 1, ArH) and 7.60 (1 H, dd, *J* 8, 1, ArH); δ_{C} (CDCl₃) 13.8 (q, C-7), 22.0 (t, C-6), 29.1 (t, C-5), 31.9 (t, C-4), 39.5 (q, NCH₃), 114.4 (s, CN), 121.9 (s), 122.2 (d), 122.3 (s), 127.6 (d), 127.7 (d), 128.4 (d), 133.9 (d) and 144.9 (s); *m/z* 294 ([M + 2]⁺, 11%), 292 (M⁺, 11), 204 (100), 187 (59), 185 (61), 148 (18) and 77 (20) (Found: C, 57.13; H, 5.89; N, 9.57%; M, 292.0570. C₁₄H₁₇N₂Br requires C, 57.52; H, 5.87; N, 9.59%; M, 292.0575); (*2Z*)-isomer: δ_{H} (CDCl₃) 3.11 (3 H, s, NCH₃) and 5.79 (1 H, t, *J* 7, 3-H).

4-Methyl-2-(N-methyl-*o*-bromoanilino)pent-2-enitrile 2c. Yield 71% (this compound was a mixture of two isomers, *E:Z* = 91:9). (*2E*)-Isomer: oil; TLC [EtOAc–hexane (2:98)] *R*_f 0.24; *v*_{max}(neat)/cm⁻¹ 2960, 2220 (CN), 1600, 1500, 1470, 760, 750 and 730; δ_{H} (CDCl₃) 1.08 [6 H, d, *J* 7, CH(CH₃)₂], 2.72–2.91 [1 H, m, CH(CH₃)₂], 3.03 (3 H, s, NCH₃), 5.08 (1 H, d, *J* 10, 3-H), 7.05–7.20 (2 H, m, ArH), 7.26–7.37 (1 H, m, ArH) and 7.60 (1 H, dd, *J* 8, 1, ArH); δ_{C} (CDCl₃) 23.3 [2 × q, CH(CH₃)₂], 29.6 (d, C-4), 39.5 (q, NCH₃), 114.4 (s, CN), 120.6 (s), 121.8 (s), 127.5 (d), 127.6 (d), 128.4 (d), 129.5 (d), 133.9 (d) and 144.9 (s);

m/z 280 ($[M + 2]^+$, 20%), 278 (M^+ , 22), 265 (72), 263 (74), 199 (62), 169 (100) and 77 (24) (Found: C, 55.98; H, 5.42; N, 10.06%; M, 278.0421). $C_{13}H_{15}N_2Br$ requires C, 56.11; H, 5.44; N, 10.09%; M, 278.0419); (2*Z*)-isomer: $\delta_H(CDCl_3)$ 3.10 (3 H, s, NCH_3) and 5.52 (1 H, t, *J* 7, 3-H).

2-(*N*-Methyl-*o*-bromoanilino)-4-phenylpent-2-enitrile 2d. Yield 67% (this compound was a mixture of two isomers, *E*:*Z* = 93:7). (2*E*)-Isomer: oil; TLC [EtOAc-hexane (2:98)] R_f 0.17; $\nu_{max}(neat)/cm^{-1}$ 3020, 2220 (CN), 1610, 1496, 1020 and 690; $\delta_H(CDCl_3)$ 3.04 (3 H, s, NCH_3), 3.68 (2 H, d, *J* 8, $PhCH_2$), 5.34 (1 H, t, *J* 8, 3-H), 7.10 (1 H, ddd, *J* 8, 8, 1, ArH), 7.18–7.34 (7 H, m, ArH) and 7.59 (1 H, dd, *J* 8, 1, ArH); $\delta_C(CDCl_3)$ 32.4 (t, $PhCH_2$), 39.4 (q, NCH_3), 114.2 (s, CN), 119.2 (d), 119.7 (s), 122.0 (s), 126.5 (d), 127.7 (d), 127.9 (3 C, d), 128.4 (2 C, d), 133.8 (2 C, d), 137.6 (s) and 144.7 (s); m/z 328 ($[M + 2]^+$, 38%), 326 (M^+ , 35), 247 (100), 169 (60), 155 (42), 91 (68) and 77 (30) (Found: M, 326.0410). $C_{17}H_{15}N_2Br$ requires M, 326.0419); (2*Z*)-isomer: $\delta_H(CDCl_3)$ 3.16 (3 H, s, NCH_3) and 5.92 (1 H, t, *J* 7, 3-H).

2-(*N*-Methyl-*o*-bromoanilino)hepta-2,4-dienitrile 2e. Yield 65% (this compound was a mixture of two isomers, 2*E*:2*Z* = 90:10). (2*E*)-Isomer: oil; TLC [EtOAc-hexane (2:98)] R_f 0.26; $\nu_{max}(neat)/cm^{-1}$ 2960, 2221 (CN), 1575, 1476, 962, 764 and 725; $\delta_H(CDCl_3)$ 1.02 (3 H, t, *J* 7.5, CH_2CH_3), 2.16 (2 H, qdd, *J* 7.5, 7.5, 1, CH_2CH_3), 3.11 (3 H, s, NCH_3), 5.80 (1 H, dq, *J* 16, 7.5, 5-H), 5.82 (1 H, d, *J* 10, 3-H), 6.38 (1 H, ddq, *J* 16, 10, 1, 4-H), 7.12 (1 H, ddd, *J* 8, 8, 1, ArH), 7.20 (1 H, dd, *J* 8, 1), 7.34 (1 H, ddd, *J* 8, 8, 1, ArH) and 7.62 (1 H, dd, *J* 8, 1, ArH); $\delta_C(CDCl_3)$ 13.5 (q, CH_2CH_3), 26.0 (t, CH_2CH_3), 39.6 (q, NCH_3), 114.4 (s, CN), 119.8 (d), 120.1 (s), 122.5 (s), 125.1 (d), 128.3 (d), 128.6 (2 × d), 134.0 (d), 137.7 (d) and 144.5 (s); m/z 292 ($[M + 2]^+$, 31%), 290 (M^+ , 29), 211 (100), 182 (59) and 169 (21) (Found: C, 57.82; H, 5.23; N, 9.64%; M, 290.0439). $C_{14}H_{15}N_2Br$ requires C, 57.92; H, 5.21; N, 9.66%; M, 290.0419); (2*Z*,4*E*)-isomer: $\delta_H(CDCl_3)$ 3.15 (3 H, s, NCH_3) and 6.18 (1 H, dd, *J* 9, 1, 3-H).

Preparation of 2-alkenylamino-3-(*o*-bromophenyl)propanenitriles 7a–c and 8a–c

Under an atmosphere of argon, a solution of diisopropylamine (0.9 ml, 5.5 mmol) in THF (10 ml) was cooled to $-15^\circ C$ and a solution of BuLi (1.6 M in hexane; 3.5 ml, 5.5 mmol) was added dropwise to it. After 15 min, the LDA solution was cooled to $-78^\circ C$, and a solution of the appropriate 2-(alkenylamino)acetonitrile (5 mmol) in THF (5 ml) was added dropwise to it. The resulting orange-coloured solution was stirred for 45 min after which a solution of *o*-bromobenzyl bromide (1.5 g, 6 mmol) in THF (5 ml) was added dropwise to it. The reaction solution was warmed to room temperature and kept for an additional 6 h before being quenched with saturated aqueous NH_4Cl . The mixture was concentrated under reduced pressure, and the residue was taken up with EtOAc. The resulting solution was washed with brine, dried (Na_2SO_4) and concentrated under reduced pressure. The crude product was purified by chromatography on a silica gel column with gradients of EtOAc and hexane to give the title compound.

2-(*N*-Allylanilino)-3-(*o*-bromophenyl)propanenitrile 7a. Yield 81%; oil; TLC [EtOAc-hexane (2:98)] R_f 0.27; $\nu_{max}(neat)/cm^{-1}$ 3050, 2230 (CN), 1640, 1600, 1590, 750 and 690; $\delta_H(CDCl_3)$ 3.25 (1 H, dd, *J* 13, 9, $1/2 \times NCHCH_2$), 3.41 (1 H, dd, *J* 13, 6.6, $1/2 \times NCHCH_2$), 4.00 (2 H, d, *J* 6, $NCH_2CH=CH_2$), 4.84 (1 H, dd, *J* 9, 6.6, NCHCN), 5.23 (1 H, dd, *J* 9, 1, $1/2 \times NCH_2CH=CH_2$), 5.33 (1 H, dd, *J* 17, 1, $1/2 \times NCH_2CH=CH_2$), 5.89 (1 H, ddt, *J* 17, 9, 6, $NCH_2CH=CH_2$), 6.96–7.05 (3 H, m, ArH), 7.12–7.36 (5 H, m, ArH) and 7.60 (1 H, d, *J* 8, ArH); $\delta_C(CDCl_3)$ 38.4 (t), 52.9 (t), 53.0 (d, C-2), 117.4 (s, CN), 117.5 (t, C= CH_2), 118.2 (2 C, d), 121.4 (d), 124.4 (s), 127.6 (d), 129.1 (2 × d), 129.2 (d), 131.9 (d), 132.9 (d), 134.0 (d), 134.4 (s) and 147.0 (s); m/z 342 ($[M + 2]^+$, 4%), 340 (M^+ , 4), 171 (98), 104 (100) and 77 (65) (Found: C, 63.41; H, 5.06; N, 8.19%; M, 340.0569). $C_{18}H_{17}N_2Br$ requires C, 63.52; H, 5.04; N, 8.24%; M, 340.0575).

3-(*o*-Bromophenyl)-2-[*N*-(3-methylbutenyl)anilino]propanenitrile 7b. Yield 75%; oil; TLC [EtOAc-hexane (5:95)] R_f 0.28; $\nu_{max}(neat)/cm^{-1}$ 2930, 2210 (CN), 1600, 1500, 1030, 760 and 690; $\delta_H(CDCl_3)$ 1.73 [3 H, d, *J* 1, $1/2 \times C(CH_3)_2$], 1.76 [3 H, s, $1/2 \times C(CH_3)_2$], 3.22 (1 H, dd, *J* 13, 9, $1/2 \times NCHCH_2$), 3.38 (1 H, dd, *J* 13, 7, $1/2 \times NCHCH_2$), 3.85 (1 H, dd, *J* 14, 6, $1/2 \times NCH_2CH=C$), 4.00 (1 H, dd, *J* 14, 7, $1/2 \times NCH_2CH=C$), 4.79 (1 H, dd, *J* 9, 7, NCHCN), 5.16 (1 H, dd, *J* 7, 6, ArH), 6.99–7.06 (3 H, m, ArH), 7.10–7.35 (5 H, m, ArH) and 7.58 (1 H, d, *J* 8, ArH); $\delta_C(CDCl_3)$ 18.1 (q), 25.8 (q), 38.6 (t), 48.6 (t), 52.9 (d, C-2), 117.9 (s, CN), 119.1 (2 × d), 120.9 (d), 121.7 (d), 124.5 (s), 127.7 (d), 129.2 (3 × d), 132.1 (d), 133.0 (d), 134.8 (s), 135.8 (s) and 147.3 (s); m/z 370 ($[M + 2]^+$, 14%), 368 (M^+ , 13), 344 (40), 342 (42), 199 (100), 131 (35) and 69 (81) (Found: M, 368.0893). $C_{20}H_{21}N_2Br$ requires M, 368.0888).

3-(*o*-Bromophenyl)-2-(*N*-cinnamylanilino)propanenitrile 7c. Yield 83%; oil; TLC [EtOAc-hexane (2:98)] R_f 0.18; $\nu_{max}(neat)/cm^{-1}$ 3050, 2250 (CN), 1600, 1500, 980, 760 and 690; $\delta_H(CDCl_3)$ 3.29 (1 H, dd, *J* 14, 9, $1/2 \times NCHCH_2$), 3.48 (1 H, dd, *J* 14, 7, $1/2 \times NCHCH_2$), 4.16 (2 H, d, *J* 5.6, $NCH_2CH=CH$), 4.90 (1 H, dd, *J* 9, 7, NCHCN), 6.23 (1 H, dt, *J* 16, 5.6, $CH=CHPh$), 6.66 (1 H, d, *J* 16, $CH=CHPh$), 7.10 (1 H, dd, *J* 8, 8, ArH), 7.14–7.40 (12 H, m, ArH) and 7.57 (1 H, d, *J* 8, ArH); $\delta_C(CDCl_3)$ 38.8 (t), 53.1 (d, C-2), 53.2 (t), 117.9 (s, CN), 118.8 (2 × d), 121.9 (d), 124.7 (s), 125.8 (d), 126.5 (2 × d), 127.8 (2 × d), 128.6 (2 × d), 129.5 (3 × d), 132.2 (d), 132.8 (d), 133.2 (d), 134.8 (s), 136.6 (s) and 147.4 (s); m/z 418 (4, $[M + 2]^+$, 4%), 416 (M^+ , 4), 247 (12), 171 (13), 169 (13), 117 (100), 91 (22) and 77 (18) (Found: C, 68.99; H, 5.11; N, 6.70%; M, 416.0881). $C_{24}H_{21}N_2Br$ requires C, 69.22; H, 5.09; N, 6.73%; M, 416.0888).

2-(*N*-Allyl-*N*-benzylamino)-3-(*o*-bromophenyl)propanenitrile 8a. Yield 80%; oil; TLC [EtOAc-hexane (10:90)] R_f 0.39; $\nu_{max}(neat)/cm^{-1}$ 3050, 2800, 2220 (CN), 1640, 1500, 740 and 690; $\delta_H(CDCl_3)$ 2.98–3.22 (3 H, m, $NCHCH_2$, $1/2 \times NCH_2CH=CH_2$), 3.36–3.52 (2 H, m, $1/2 \times NCH_2CH=CH_2$, $1/2 \times PhCH_2$), 4.04–4.16 (2 H, m, NCHCN, $1/2 \times PhCH_2$), 5.22 (1 H, br d, *J* 10, $1/2 \times NCH_2CH=CH_2$), 5.30 (1 H, br d, *J* 19.5, $1/2 \times NCH_2CH=CH_2$), 5.73–5.84 (1 H, m, $NCH_2CH=CH_2$), 7.10–7.26 (8 H, m, ArH) and 7.50 (1 H, dd, *J* 8, 1, ArH); $\delta_C(CDCl_3)$ 38.1 (t), 52.9 (d), 54.2 (t), 116.8 (s, CN), 118.6 (t, $NCH_2CH=CH_2$), 124.5 (s), 127.3 (2 × d), 128.3 (2 × d), 128.5 (2 × d), 128.9 (d), 131.9 (d), 132.8 (d), 134.5 (d), 135.1 (s) and 137.5 (s); m/z 356 ($[M + 2]^+$, 0.3%), 354 (M^+ , 0.3), 185 (79), 171 (18), 169 (19), 91 (100) and 65 (23) (Found: C, 64.12; H, 5.41; N, 7.87). $C_{19}H_{19}BrN_2$ requires C, 64.23; H, 5.39; N, 7.89%).

3-(*o*-Bromophenyl)-2-[*N*-(3-methylbutenyl)-*N*-benzylamino]propanenitrile 8b. Yield 74%; oil; TLC [EtOAc-hexane (5:95)] R_f 0.27; $\nu_{max}(neat)/cm^{-1}$ 2905, 2220 (CN), 1590, 1450, 750 and 690; $\delta_H(CDCl_3)$ 1.67 [3 H, s, $1/2 \times C(CH_3)_2$], 1.75 [3 H, s, $1/2 \times C(CH_3)_2$], 3.04–3.27 (4 H, m, $NCHCH_2$, $NCH_2CH=C$), 3.39 (1 H, d, *J* 14, $1/2 \times CH_2Ph$), 4.05 (1 H, d, *J* 14, $1/2 \times CH_2Ph$), 4.14 (1 H, t, *J* 8, NCHCN), 5.08–5.18 (1 H, m, $NCH_2CH=C$), 7.14–7.36 (8 H, m, ArH) and 7.52 (1 H, d, *J* 8, ArH); $\delta_C(CDCl_3)$ 18.1 (q), 25.9 (q), 38.3 (t), 49.1 (t), 52.7 (d, C-2), 55.4 (t), 117.1 (s, CN), 120.5 (d), 124.5 (s), 127.3 (d), 127.4 (d), 128.3 (2 × d), 128.6 (2 × d), 128.9 (d), 132.0 (d), 132.9 (d), 135.3 (s), 137.2 (s) and 137.9 (s); m/z 384 ($[M + 2]^+$, 0.3%), 382 (M^+ , 0.2), 345 (21), 343 (20), 277 (50), 275 (45), 254 (65), 171 (52), 91 (100) and 69 (85) (Found: M, 382.1038). $C_{21}H_{23}N_2Br$ requires M, 382.1044).

3-(*o*-Bromophenyl)-2-(*N*-cinnamyl-*N*-benzylamino)propanenitrile 8c. Yield 79%; oil; TLC [EtOAc-hexane (2:98)] R_f 0.17; $\nu_{max}(neat)/cm^{-1}$ 3050, 2250, 1620, 1500, 970, 750 and 690; $\delta_H(CDCl_3)$ 3.15–3.40 (3 H, m, $NCHCH_2$, $1/2 \times NCH_2CH=CH$), 3.52 (1 H, d, *J* 14, $1/2 \times CH_2Ph$), 3.66 (1 H, dd, *J* 14, 4, $1/2 \times NCH_2CH=CH$), 4.05–4.28 (2 H, m, $1/2 \times NCH_2CH=CH$, NCHCN), 6.19 (1 H, ddd, *J* 16, 8, 6.6, $NCH_2CH=CH$), 6.65 (1 H, d, *J* 16, $NCH_2CH=CH$), 7.14–7.43 (13 H, m, ArH) and 7.54 (1 H, d, *J* 8, ArH); $\delta_C(CDCl_3)$ 38.1 (t), 52.9 (d, C-2), 53.6 (t), 55.5 (t), 116.8 (s, CN), 124.5 (s), 125.8 (d), 126.2 (2 × d), 127.4

(2 × d), 127.44 (d), 127.6 (d), 128.35 (d), 128.4 (2 × d), 128.5 (2 × d), 128.9 (d), 131.9 (d), 132.8 (d), 133.5 (d), 135.0 (s), 136.5 (s) and 137.4 (s); m/z 432 [M + 2]⁺, 2%, 430 (M⁺, 2), 261 (42), 117 (100) and 91 (52) (Found: M, 430.1052. C₂₅H₂₃N₂Br requires M, 430.1044).

General procedure for the palladium-catalyzed reactions

To a stirred solution of **1** (1 mmol) in DMF (10 ml) were sequentially added Et₃N (0.167 ml), PPh₃ (52 mg, 0.2 mmol), and Pd(OAc)₂ (22.5 mg, 0.1 mmol) at room temperature under an argon atmosphere. The reaction mixture was stirred and heated at 100 °C for 6–8 h and then cooled to room temperature, diluted with EtOAc (50 ml), washed with water (3 × 15 ml), dried (Na₂SO₄), filtered and concentrated under reduced pressure. The residue was separated by chromatography on a silica gel column with gradients of EtOAc and hexane to give the products shown in Table 1.

2-(Methylamino)benzonitrile 12. Solid, mp 62–64 °C; TLC [EtOAc–hexane (5:95)] R_f 0.13; ν_{\max} (KBr)/cm⁻¹ 3280 (NH), 3020, 2250 (CN), 1576, 1480, 1210 and 743; δ_{H} (CDCl₃) 2.77 (3 H, d, *J* 7, NCH₃), 4.65 (1 H, br s, NH), 6.52 (1 H, d, *J* 8, Ph), 6.56 (1 H, d, *J* 8, Ph) and 7.28 (2 H, ddd, *J* 8, 8, 1, Ph); δ_{C} (CDCl₃) 29.7 (q, NCH₃), 95.2 (s), 109.9 (d), 116.0 (d), 117.8 (s, CN), 132.4 (d), 134.1 (d) and 151.0 (s); m/z 132 [M + 2]⁺, 84%, 131 (100), 104 (48) and 77 (24).

9-Methyl-2-phenyl-3-(2E-phenylethenyl)- γ -carboline 17. White solid, mp 197–199 °C; TLC [EtOAc–hexane (5:95)] R_f 0.23; ν_{\max} (KBr)/cm⁻¹ 2960, 1630, 1496, 965, 815 and 750; δ_{H} (CDCl₃) 3.83 (3 H, s, NCH₃), 7.21–7.61 (15 H, m, ArH), 7.97 (1 H, d, *J* 16, ArCH=CHPh) and 8.51 (1 H, d, *J* 8, ArH); δ_{C} (CDCl₃) 29.1 (q, NCH₃), 108.7 (d), 116.7 (d), 119.8 (d), 121.4 (d), 122.3 (s), 126.6 (d), 127.0 (2 C, d), 127.4 (2 × d), 127.8 (d), 128.3 (2 × d), 128.5 (2 × d), 130.2 (2 × d), 131.0 (d), 134.2 (s), 137.8 (s), 140.5 (s), 141.2 (s), 142.7 (s), 145.2 (s) and 151.0 (s); m/z 360 (M⁺, 100%), 359 (89), 283 (74), 268 (22), 91 (31) and 77 (75) (Found: C, 86.47; H, 5.57; N, 7.74%; M, 360.1634. C₂₆H₂₀N₂ requires C, 86.63; H, 5.60; N, 7.78%; M, 360.1626).

N-Allyl-N-benzyl-2-(*o*-cyanophenyl)ethenylamine 24a. Oil; TLC [EtOAc–hexane (2:98)] R_f 0.09; ν_{\max} (neat)/cm⁻¹ 3026, 2214 (s, CN), 1622, 1588, 940, 753 and 698; δ_{H} (CDCl₃) 3.78 (2 H, dd, *J* 6, 1, NCH₂CH=CH₂), 4.37 (2 H, s, CH₂Ph), 5.19 (1 H, dt, *J* 9, 1, 1/2 × NCH₂CH=CH₂), 5.26 (1 H, d, *J* 14, 1/2 NCH₂CH=CH), 5.61 (1 H, d, *J* 14, NCH=CH), 5.81 (1 H, ddt, *J* 14, 9, 6, NCH₂CH=CH), 6.93 (1 H, ddd, *J* 8, 8, 1, ArH), 7.14 (1 H, d, *J* 14, NCH=CH), 7.25–7.38 (7 H, m, ArH) and 7.44 (1 H, d, *J* 8, ArH); δ_{C} (CDCl₃) 53.4 (t), 55.5 (t), 93.9 (d), 107.0 (s), 118.0 (t), 119.2 (s, CN), 121.7 (d), 122.6 (2 × d), 127.5 (2 × d), 128.9 (2 × d), 132.2 (d), 132.6 (d), 133.0 (d), 135.0 (s), 141.7 (d) and 143.8 (s); m/z 274 (M⁺, 10%), 273 (7), 158 (7), 128 (9), 91 (100) and 65 (21) (Found: C, 83.01; H, 6.64; N, 10.18. C₁₉H₁₈N₂ requires C, 83.17; H, 6.62; N, 10.22%).

N-Benzyl-N-(3-methylbut-2-enyl)-2-(*o*-cyanophenyl)ethenylamine 24b. Oil; TLC [EtOAc–hexane (2:98)] R_f 0.15; ν_{\max} (neat)/cm⁻¹ 2910, 2205 (s, CN), 1620, 1590, 940, 760 and 697; δ_{H} (CDCl₃) 1.61 [3 H, d, *J* 1, 1/2 × C(CH₃)₂], 1.74 [3 H, d, *J* 1, 1/2 × C(CH₃)₂], 3.75 (2 H, d, *J* 7, NCH₂CH=C), 4.33 (2 H, s, CH₂Ph), 5.21 (1 H, br d, *J* 7, NCH₂CH=C), 5.58 (1 H, d, *J* 14, NCH=CH), 6.90 (1 H, ddd, *J* 8, 8, 1, ArH), 7.15 (1 H, d, *J* 14, NCH=CH), 7.24–7.36 (7 H, m, ArH) and 7.42 (1 H, dd, *J* 8, 1, ArH); δ_{C} (CDCl₃) 17.8 (q), 25.6 (q), 48.3 (t), 55.3 (t), 93.2 (d), 106.7 (s), 119.2 (d), 121.4 (d), 122.2 (d), 127.3 (d), 127.32 (s), 127.4 (2 × d), 128.5 (2 × d), 132.1 (d), 132.9 (d), 136.5 (s), 137.5 (s), 141.9 (d) and 143.9 (s); m/z 302 (M⁺, 16%), 233 (24), 106 (30), 91 (100) and 69 (57) (Found: M, 302.1786. C₂₁H₂₂N₂ requires M, 302.1783).

N-Benzyl-N-cinnamyl-2-(*o*-cyanophenyl)ethenylamine 24c. Oil; TLC [EtOAc–hexane (5:95)] R_f 0.09; ν_{\max} (neat)/cm⁻¹ 3030, 2210 (s, CN), 1620, 1590, 750 and 697; δ_{H} (CDCl₃) 3.96 (2 H, d, *J* 6, NCH₂CH=CH), 4.44 (2 H, s, CH₂Ph), 5.73 (1 H, d, *J* 14, NCH=CH), 6.18 (1 H, dt, *J* 16, 6, NCH₂CH=CH), 6.55 (1 H, d,

J 16, NCH₂CH=CH), 6.94 (1 H, ddd, *J* 8, 8, 1, ArH) and 7.20–7.53 (14 H, m, ArH); δ_{C} (CDCl₃) 52.8 (t), 55.2 (t), 93.8 (d), 106.8 (s), 119.1 (s, CN), 121.5 (d), 122.4 (d), 123.9 (d), 126.3 (2 × d), 127.4 (3 × d), 127.6 (d), 128.4 (2 × d), 128.5 (2 × d), 132.1 (d), 132.7 (d), 133.1 (d), 136.2 (s), 137.1 (s), 141.6 (d) and 143.5 (s); m/z 350 (M⁺, 6%), 128 (9), 117 (84) and 91 (100) (Found: C, 85.41; H, 6.35; N, 8.02%; M, 350.1772. C₂₅H₂₂N₂ requires C, 85.67; H, 6.33; N, 8.00%; M, 350.1783).

N-(3-Methylbut-2-enyl)aniline 26b. Oil; TLC [EtOAc–hexane (1:99)] R_f 0.10; ν_{\max} (neat)/cm⁻¹ 3400 (NH), 2905, 1600, 1490, 760 and 695; δ_{H} (CDCl₃) 1.87 [3 H, s, 1/2 × C(CH₃)₂], 1.91 [3 H, s, 1/2 × C(CH₃)₂], 3.66 (1 H, br s, NH), 3.82 (2 H, d, *J* 6.6, NCH₂CH=C), 5.48 (1 H, t, *J* 6, NCH₂CH=C), 6.76 (2 H, d, *J* 8, Ph), 6.86 (1 H, dd, *J* 8, 8, Ph) and 7.36 (2 H, dd, *J* 8, 8, Ph); δ_{C} (CDCl₃) 18.5 (q), 26.2 (q), 42.5 (t), 113.4 (2 × d), 117.8 (d), 122.3 (d), 129.7 (2 × d), 135.9 (s) and 149.0 (s); m/z 161 (M⁺, 36%), 146 (23), 106 (37), 93 (100), 77 (52) and 69 (64) (Found: M, 161.1213. C₁₁H₁₅N requires M, 161.1204).

N-Cinnamylaniline 26c. Oil; TLC [EtOAc–hexane (1:99)] R_f 0.07; ν_{\max} (neat)/cm⁻¹ 3400 (NH), 3020, 1625, 1590, 1500, 963, 760 and 695; δ_{H} (CDCl₃) 3.57 (1 H, br s, NH), 3.96 (2 H, dd, *J* 6, 1.4, NCH₂CH=CH), 6.36 (1 H, dt, *J* 16, 6, NCH₂CH=CH), 6.66 (1 H, d, *J* 16, NCH₂CH=CH), 6.70–6.74 (2 H, m, Ph), 6.77 (1 H, ddd, *J* 8, 8, 1, Ph) and 7.22–7.42 (7 H, m, Ph); δ_{C} (CDCl₃) 46.1 (t), 113.0 (2 × d), 117.5 (d), 126.3 (2 × d), 127.0 (d), 127.4 (d), 128.5 (2 × d), 129.2 (2 × d), 131.4 (d), 136.8 (s) and 148.0 (s); m/z 209 (M⁺, 78%), 117 (100), 91 (30), 65 (20) and 51 (14) (Found: M, 209.1219. C₁₅H₁₅N requires M, 209.1204).

4-Cyano-1-methylene-3-phenyl-2,3,4,5-tetrahydro-1H-3-benzazepine 29a. Solid, mp 115–117 °C; TLC [EtOAc–hexane (5:95)] R_f 0.28; ν_{\max} (KBr)/cm⁻¹ 3030, 2220 (CN), 1590, 1500, 760 and 695; δ_{H} (CDCl₃) 3.18 (1 H, dd, *J* 14, 5, 1/2 × NCHCH₂), 3.51 (1 H, dd, *J* 14, 12, 1/2 × NCHCH₂), 4.35 (1 H, d, *J* 20, 1/2 × NCH₂), 4.49 (1 H, dd, *J* 12, 5, NCHCH₂), 4.61 (1 H, ddd, *J* 20, 2, 2, 1/2 × NCH₂), 5.34 (1 H, dd, *J* 2, 2, 1/2 × C=CH₂), 5.51 (1 H, dd, *J* 2, 2, 1/2 × C=CH₂), 6.72–6.82 (3 H, m, ArH), 7.11–7.24 (5 H, m, ArH) and 7.45 (1 H, dd, *J* 8, 1, ArH); δ_{C} (CDCl₃) 38.6 (t), 51.05 (d), 51.10 (t), 113.1 (t), 113.8 (2 × d), 118.6 (s), 119.4 (d), 127.8 (d), 128.4 (2 × d), 129.3 (3 × d), 132.6 (s), 139.6 (s), 148.6 (s) and 148.8 (s); m/z 260 (M⁺, 54%), 259 (35), 245 (34), 129 (71), 115 (85) and 77 (100) (Found: C, 82.95; H, 6.23; N, 10.75. C₁₈H₁₆N₂ requires C, 83.03; H, 6.20; N, 10.77%).

4-Cyano-1-phenylmethylene-3-phenyl-2,3,4,5-tetrahydro-1H-3-benzazepine 29c. Oil; TLC [EtOAc–hexane (1:99)] R_f 0.04; ν_{\max} (neat)/cm⁻¹ 3010, 2905, 2210 (CN), 1590, 1500, 760 and 690; δ_{H} (CDCl₃) 3.23 (1 H, dd, *J* 14, 5.5, 1/2 × NCHCH₂), 3.53 (1 H, dd, *J* 14, 12, 1/2 × NCHCH₂), 4.53 (1 H, dd, *J* 12, 5.5, NCHCH₂), 4.73 (2 H, d, *J* 2, NCH₂), 6.67 (1 H, dd, *J* 8, 1, ArH), 6.78 (1 H, ddd, *J* 8, 8, 1, ArH), 6.92 (1 H, d, *J* 2, C=CHPh), 7.14–7.31 (11 H, m, ArH) and 7.47 (1 H, dd, *J* 8, 1); δ_{C} (CDCl₃) 38.4 (t), 49.5 (t), 51.4 (d), 114.2 (2 × d), 118.7 (s), 119.6 (d), 127.3 (d), 127.6 (d), 128.0 (d), 128.4 (d), 128.6 (2 × d), 128.7 (d), 129.2 (4 × d), 129.8 (d), 132.9 (s), 136.5 (s), 141.5 (s), 142.0 (s), 148.6 (s); m/z 336 (M⁺, 35%), 245 (52), 128 (30), 115 (32), 104 (50), 91 (100) and 77 (84) (Found: C, 85.50; H, 6.03; N, 8.37. C₂₄H₂₀N₂ requires C, 85.67; H, 6.00; N, 8.33%).

2,3-Dihydro-1-methylene-3-phenyl-1H-3-benzazepine 31a. Oil, TLC [EtOAc–hexane (10:90)] R_f 0.53; ν_{\max} (neat)/cm⁻¹ 2930, 1630, 1600, 1350, 760 and 690; δ_{H} (CDCl₃) 4.34 (2 H, s, NCH₂), 4.96 (1 H, d, *J* 1, 1/2 × C=CH₂), 5.42 (1 H, d, *J* 1, 1/2 × C=CH₂), 5.62 (1 H, d, *J* 9.5, NCH=CH), 6.54 (1 H, d, *J* 9.5, NCH=CH) and 6.99–7.42 (9 H, m, ArH); δ_{C} (CDCl₃) 54.8 (t), 106.3 (d), 114.3 (t), 119.5 (2 × d), 122.1 (d), 124.1 (d), 127.5 (d), 127.6 (d), 129.3 (2 × d), 129.7 (d), 134.6 (d), 134.62 (s), 138.2 (s), 143.4 (s) and 146.0 (s); m/z 233 (M⁺, 43%), 232 (32), 141 (17), 130 (23), 115 (31), 104 (62) and 77 (100) (Found: M, 233.1198. C₁₇H₁₅N requires M, 233.1204) (Found: C, 87.45; H, 6.50; N, 6.04. C₁₇H₁₅N requires C, 87.51; H, 6.48; N, 6.01%).

3-Benzyl-2,3-dihydro-1-methylene-1H-3-benzazepine 32a. Oil;

TLC [EtOAc–hexane (2:98)] R_f 0.32; ν_{\max} (neat)/ cm^{-1} 3026, 1619, 1591, 1487, 765 and 697; δ_{H} (CDCl_3) 3.58 (2 H, s, NCH_2), 4.19 (2 H, s, NCH_2Ph), 4.75 (1 H, s, $1/2 \times \text{C}=\text{CH}_2$), 5.23 (1 H, d, J 9, $\text{NCH}=\text{CH}$), 5.40 (1 H, s, $1/2 \times \text{C}=\text{CH}_2$), 6.25 (1 H, d, J 9, $\text{NCH}=\text{CH}$), 6.95 (1 H, dd, J 8, 8, ArH), 7.07–7.15 (2 H, m, ArH) and 7.24–7.34 (6 H, m, ArH); δ_{C} (CDCl_3) 55.2 (t), 59.6 (t), 100.5 (d), 114.1 (t), 123.0 (d), 127.4 (d), 127.5 (2 \times d), 128.0 (2 \times d), 128.5 (2 \times d), 128.9 (d), 135.7 (s), 137.6 (s), 138.0 (s), 138.1 (d) and 143.8 (s); m/z 247 (M^+ , 36%), 156 (22), 91 (100), 77 (14) and 65 (25) (Found: C, 87.32; H, 6.97; N, 5.70%; M , 247.3385. $\text{C}_{18}\text{H}_{17}\text{N}$ requires C, 87.41; H, 6.93; N, 5.66%; M , 247.3397).

2,8,9-Trimethyl- γ -carboline 36a. Solid, mp 97–98 °C; TLC [EtOAc–hexane (5:95)] R_f 0.11; ν_{\max} (KBr)/ cm^{-1} 3050, 1615, 1598 and 1490; δ_{H} (CDCl_3) 2.41 (3 H, s, ArCH_3), 2.66 (3 H, s, ArCH_3), 3.66 (3 H, s, NCH_3), 7.23–7.32 (3 H, m, ArH), 7.48 (1 H, dd, J 8, 8, ArH) and 8.37 (1 H, d, J 8, ArH); δ_{C} (CDCl_3) 20.3 (q, ArCH_3), 22.5 (q, ArCH_3), 28.7 (q, NCH_3), 108.4 (d), 116.5 (d), 119.2 (d), 120.3 (d), 121.7 (2 \times s), 125.6 (d), 128.3 (s), 133.4 (s), 141.2 (s) and 148.8 (s); m/z 211 ($[\text{M} + 1]^+$, 24%), 210 (100, M^+), 209 (56) and 195 (75) (Found: C, 80.03; H, 6.69; N, 13.29%; M , 210.1156. $\text{C}_{13}\text{H}_{12}\text{N}_2$ requires C, 79.96; H, 6.72; N, 13.33%; M , 210.1157).

3,9-Dimethyl-2-propyl- γ -carboline 36b. Solid, mp 71–73 °C; TLC [EtOAc–hexane (5:95)] R_f 0.07; ν_{\max} (KBr)/ cm^{-1} 3050, 1610, 1600 and 1490; δ_{H} (CDCl_3) 1.08 (3 H, t, J 7, CH_2CH_3), 1.66–1.84 (2 H, m, ArCH_2CH_2), 2.76 (3 H, s, NCH_3), 2.79 (2 H, d, J 7.6, ArCH_2), 3.81 (3 H, s, NCH_3), 7.33 (1 H, ddd, J 8, 8, 1, ArH), 7.40–7.42 (2 H, m, ArH), 7.52 (1 H, ddd, J 8, 8, 1, ArH) and 8.41 (1 H, dd, J 8, 1, ArH); δ_{C} (CDCl_3) 14.0 (q, CH_2CH_3), 22.2 (q, ArCH_3), 23.4 (t), 28.9 (q, NCH_3), 35.8 (t, ArCH_2), 108.5 (d), 115.9 (d), 119.3 (d), 120.5 (d), 121.8 (s), 126.7 (d), 132.8 (s), 133.5 (s), 138.8 (s), 141.5 (s) and 148.5 (s); m/z 238 (M^+ , 46%), 209 (100), 193 (18) and 57 (42) (Found: C, 80.55; H, 7.64; N, 11.73%; M , 238.1478. $\text{C}_{16}\text{H}_{18}\text{N}_2$ requires C, 80.62; H, 7.62; N, 11.76%; M , 238.1470).

9-Methyl-1-isopropyl- γ -carboline 36c. Oil; TLC [EtOAc–hexane (15:85)] R_f 0.23; ν_{\max} (neat)/ cm^{-1} 2967, 1612, 1572, 1479, 750 and 740; δ_{H} (CDCl_3) 1.43 [6 H, d, J 7, $\text{CH}(\text{CH}_3)_2$], 3.73–3.90 [1 H, m, $\text{ArCH}(\text{CH}_3)_2$], 4.03 (3 H, s, NCH_3), 7.20–7.31 (2 H, m, ArH), 7.37 (1 H, d, J 8, ArH), 7.50 (1 H, ddd, J 8, 8, 1, ArH), 8.36 (1 H, dd, J 8, 1, ArH) and 8.45 (1 H, d, J 8, ArH); δ_{C} (CDCl_3) 23.5 [2 \times q, 2 \times $\text{CH}(\text{CH}_3)_2$], 27.7 (d, ArCH), 32.4 (q, NCH_3), 108.6 (d), 116.9 (d), 119.6 (d), 120.5 (d), 122.0 (s), 127.4 (d), 129.5 (s), 132.0 (s), 140.0 (s), 141.9 (d) and 142.3 (s); m/z 224 (M^+ , 100%), 209 (97), 194 (73), 181 (13) and 104 (14) (Found: C, 80.25; H, 7.22; N, 12.46%; M , 224.1324. $\text{C}_{15}\text{H}_{16}\text{N}_2$ requires C, 80.31; H, 7.19; N, 12.50%; M , 224.1313).

3,9-Dimethyl-2-phenyl- γ -carboline 36d. Solid, mp 132–134 °C; TLC [EtOAc–hexane (2:98)] R_f 0.10; ν_{\max} (KBr)/ cm^{-1} 3048, 1620, 1593, 1487, 747 and 702; δ_{H} (CDCl_3) 2.65 (3 H, s, ArCH_3), 3.55 (3 H, s, NCH_3), 7.20 (1 H, dd, J 8, 1, ArH), 7.25 (1 H, dd, J 8, 1, ArH), 7.33–7.46 (7 H, m, ArH) and 8.40 (1 H, d, J 8, ArH); δ_{C} (CDCl_3) 23.3 (q, ArCH_3), 28.6 (q, NCH_3), 108.4 (d), 116.5 (d), 119.3 (d), 120.5 (d), 121.4 (s), 127.0 (2 \times d), 128.1 (2 \times d), 129.2 (2 \times d), 132.7 (s), 133.7 (s), 139.9 (s), 141.2 (s), 141.7 (s) and 147.3 (s); m/z 272 (M^+ , 100%), 271 (52), 256 (14) and 128 (12) (Found: C, 83.66; H, 5.97; N, 10.34%; M , 272.1298. $\text{C}_{19}\text{H}_{16}\text{N}_2$ requires C, 83.78; H, 5.93; N, 10.29%; M , 272.1313).

3-Ethyl-9-methyl- γ -carboline 36e. Oil; TLC [EtOAc–hexane (10:90)] R_f 0.25; ν_{\max} (neat)/ cm^{-1} 2961, 1620, 1475, 1410, 845, 817 and 749; δ_{H} (CDCl_3) 1.40 (3 H, t, J 7.5, CH_2CH_3), 3.02 (2 H, q, J 7.5, ArCH_2), 3.75 (3 H, s, NCH_3), 7.21 (1 H, d, J 8, ArH), 7.27 (1 H, dd, J 8, 8, ArH), 7.35 (1 H, d, J 8, ArH), 7.50 (1 H, dd, J 8, 1, ArH), 7.54 (1 H, dd, J 8, 1, ArH) and 8.41 (1 H, dd, J 8, 1, ArH); δ_{C} (CDCl_3) 15.0 (q, CH_2CH_3), 28.8 (t, ArCH_2), 31.4

(q, NCH_3), 108.5 (d), 115.8 (d), 118.6 (d), 119.3 (d), 120.8 (d), 121.8 (s), 127.2 (d), 132.7 (s), 141.0 (s), 141.6 (s) and 155.4 (s); m/z 211 ($[\text{M} + 1]^+$, 23%), 210 (M^+ , 100), 209 (54) and 195 (25) (Found: C, 79.80; H, 6.75; N, 13.37%; M , 210.1155. $\text{C}_{14}\text{H}_{14}\text{N}_2$ requires C, 79.96; H, 6.72; N, 13.33%; M , 210.1157).

3,8-Dihydro-2,8-dimethylpyrrolo[3,2-*b*]indole 45. Solid, mp 162–164 °C; TLC [EtOAc–hexane (5:95)] R_f 0.13; ν_{\max} (KBr)/ cm^{-1} 3040 (NH), 3010, 1600, 1495 and 740; δ_{H} (CDCl_3) 2.45 (3 H, d, J 0.6, ArCH_3), 3.76 (3 H, s, NCH_3), 5.91 (1 H, q, J 0.6, ArH), 7.07–7.20 (2 H, m, ArH), 7.30 (1 H, dd, J 8, 1, ArH), 7.53 (1 H, dd, J 8, 1, ArH) and 7.85 (1 H, br s, NH); δ_{C} (CDCl_3) 14.3 (q), 30.8 (q, NCH_3), 89.1 (d), 108.8 (d), 115.3 (s), 115.6 (d), 117.6 (d), 118.0 (s), 119.3 (d), 132.2 (s), 136.1 (s) and 140.1 (s); m/z 184 (M^+ , 100%), 183 (93), 169 (20), 168 (24), 102 (9) and 91 (13) (Found: C, 78.28; H, 6.54; N, 15.18. $\text{C}_{12}\text{H}_{12}\text{N}_2$ requires C, 78.22; H, 6.57; N, 15.21%).

2,9-Dimethyl- γ -carboline 48. Solid, mp 84–86 °C; TLC [EtOAc–hexane (5:95)] R_f 0.11; ν_{\max} (KBr)/ cm^{-1} 2960, 1610, 1580, 750 and 740; δ_{H} (CDCl_3) 2.37 (3 H, s, ArCH_3), 3.50 (3 H, s, NCH_3), 7.13–7.22 (3 H, m, ArH), 7.38 (1 H, ddd, J 8, 8, 1, ArH), 8.22 (1 H, s, ArH) and 8.24 (1 H, dd, J 8, 1, ArH); δ_{C} (CDCl_3) 19.0 (q, ArCH_3), 28.4 (q, NCH_3), 108.5 (d), 115.3 (d), 119.4 (d), 120.2 (d), 121.7 (s), 126.8 (d), 129.5 (s), 134.2 (s), 139.3 (s), 141.4 (s) and 142.2 (d); m/z 197 ($[\text{M} + 1]^+$, 35%), 196 (M^+ , 99), 195 (100), 181 (31), 167 (15), 153 (12) and 98 (21) (Found: C, 79.47; H, 6.20; N, 14.24%; M , 196.0989. $\text{C}_{13}\text{H}_{12}\text{N}_2$ requires C, 79.55; H, 6.17; N, 14.28%; M , 196.1000).

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