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## A radical addition/cyclization of diverse ethers to 2-isocyanobiaryls under mildly basic aqueous conditions†

Cintia Anton-Torrecillas, Diego Felipe-Blanco and Jose C. Gonzalez-Gomez\*

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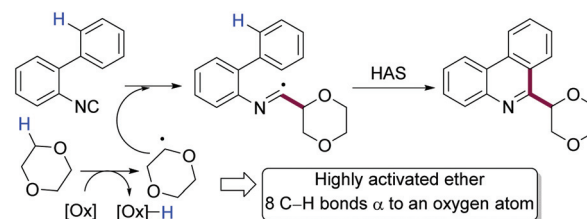
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Mildly basic aqueous conditions facilitated the *tert*-butyl peroxybenzoate (TBPB) mediated dehydrogenative addition of a range of ethers, including acetals, to diverse substituted 2-isocyanobiaryls. Mechanistic studies suggest that this radical cascade is an example of base promoted homolytic aromatic substitution (BHAS).

### Introduction

Phenanthridine is the scaffold of many naturally occurring products<sup>1</sup> that exhibit a wide range of bioactivities, such as antitumor,<sup>2</sup> antituberculosis,<sup>3</sup> antimicrobial,<sup>4</sup> antiviral,<sup>5</sup> acaricidal,<sup>6</sup> and fungicidal activities.<sup>7</sup> Some phenanthridine derivatives have also found application in biological chemistry as dyes for cytofluorometric assays<sup>8</sup> or even in materials science due to their optoelectronic properties.<sup>9</sup> Recently, the assembly of the phenanthridine framework has been elegantly achieved with a cascade that involves the addition of radicals to somophilic 2-isocyanobiphenyls, followed by intramolecular homolytic aromatic substitution.<sup>10,11</sup> In this context, and given the progress made in the C<sub>α</sub>-H oxidation of ethers with peroxides to form radicals,<sup>12</sup> the oxidative addition of ethers to 2-isocyanobiphenyls has been successfully achieved using different conditions.<sup>13</sup> This transformation requires a dual selective C-H bond functionalization, and constitutes a powerful tool to increase molecular complexity with high atom-economy, where only hydrogen is lost (Scheme 1). Moreover, ethers are very important raw materials and they are also common substructures of natural and synthetic bioactive products.<sup>14</sup> Consequently, the development of methods that make use of relatively unreactive ethers to build complex molecules, is highly demanded by organic and medicinal chemists.

It is worth noting that 1,4-dioxane is the model substrate for C-H bond functionalization of ethers in most of the reported studies.<sup>13</sup> This symmetric ether presents all eight C-H bonds adjacent to an oxygen atom, which stabilizes the



**Scheme 1** Oxidative addition of 1,4-dioxane to 2-isocyanobiphenyls: a radical cascade.

radical by hyperconjugation with the non-bonding electrons. Moreover, theoretical studies suggest that the release of ring strain upon radical formation is greater in 1,4-dioxane than in other cyclic ethers such as tetrahydrofuran.<sup>15</sup> As a matter of fact, when TBPB was used as the oxidant in the insertion of 2-isocyanobiaryls with ethers, only 1,4-dioxane was successful and THF failed.<sup>13a</sup> Notably, when benzoyl peroxide was used in the same transformation, another three ethers could be inserted with moderate results (40–45%).<sup>13b</sup> To the best of our knowledge, the greatest number of ethers tolerated in this reaction (seven examples) has been possible with the use of DTBP as the oxidant, FeCl<sub>3</sub> as the catalyst and DBU as the cocatalyst.<sup>13c</sup> With these precedents we decided to develop a new protocol for this reaction aimed at accommodating a range of ethers, free of transition-metal catalysts and using economical and environmentally friendly conditions (Scheme 2).

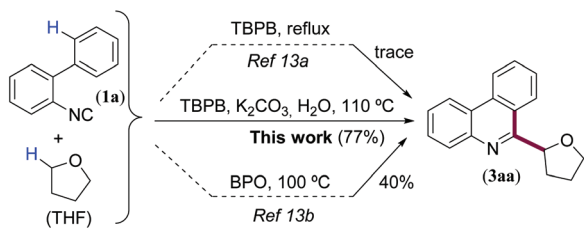
### Results and discussion

To explore new reaction conditions we selected 2-isocyanobiphenyl (**1a**) and THF (**2a**) as model substrates. In a control experiment we performed the reaction using BPO as the oxidant at 100 °C and we obtained 35% yield of the desired

Departamento de Química Orgánica, Facultad de Ciencias and Instituto de Síntesis Orgánica (ISO), Universidad de Alicante, Apdo. 99, 03080 Alicante, Spain.

E-mail: josecarlos.gonzalez@ua.es

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**Scheme 2** Previous results and our reaction conditions for THF.

product **3aa**, a similar result to the one obtained by the Cheng group,<sup>13b</sup> together with byproduct **4a** (Table 1, entry 1). Surprisingly, the addition of  $K_2CO_3$  and  $H_2O$  completely inhibited the formation of **3aa** (entry 2). Prompted by the excellent results in oxidative transformations achieved with  $Bu_4NI$  as the catalyst and TBHP,<sup>16</sup> we tried this combination, but **3aa** was obtained in low yield (entry 3). The use of DTBP or  $(NH_4)_2S_2O_8$  in combination with  $Bu_4NI$  was also unsuccessful in this transformation (entries 4–6). It is reported that TBPB fails to afford product **3aa** in this reaction and that only compound **4a** is obtained.<sup>13a</sup> To our surprise, the inclusion of  $H_2O$  in this reaction mixture afforded product **3aa**, although in low yield (entry 7). We were pleased to find that the same oxidant, but in the presence of  $K_2CO_3$  and  $H_2O$ , allowed full conversion of **1a** to obtain compound **3aa** in good yield (entry 10). While the addition of  $Bu_4NI$  had no important impact on the reaction, the amount of base and the control of the reaction temperature were crucial to obtain good and reliable results (entries

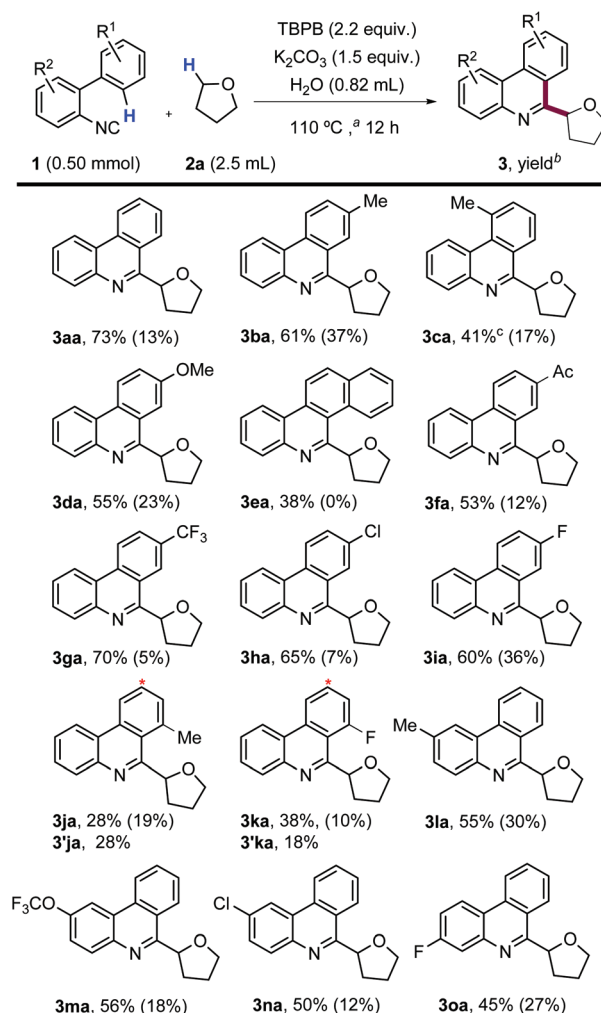
**Table 1** Screening of reaction conditions

Entry	Oxidant (mol%)/ additive (mol%)	Base (mol%)	Conv. <sup>a</sup> (%)	(3aa : 4a) <sup>b</sup>
1 <sup>c</sup>	BPO (120)	None	100	35 : 22
2	BPO (120)	$K_2CO_3$ (150)	37	—
3	TBHP (300)/ $Bu_4NI$ (20)	$K_2CO_3$ (150)	45	20 : 5
4	DTBP (300)/ $Bu_4NI$ (20)	None	0	—
5	DTBP (300)/ $Bu_4NI$ (20)	$K_2CO_3$ (150)	0	—
6	$(NH_4)_2S_2O_8$ (220)	$K_2CO_3$ (150)	0	—
7	TBPB (220)	None	100	12 : 4 <sup>c</sup>
8	TBPB (120)/ $Bu_4NI$ (20)	$K_2CO_3$ (150)	55	—
9	TBPB (220)	$K_2CO_3$ (100)	70	—
10 <sup>d</sup>	<b>TBPB (220)</b>	<b><math>K_2CO_3</math> (150)</b>	<b>100</b>	<b>77 : 23</b>
11	TBPB (220)/ $Bu_4NI$ (50)	$K_2CO_3$ (150)	100	75 : 25
12	TBPB (220)	$Na_2HPO_4$ (150)	90	75 : 25
13 <sup>c</sup>	TBPB (220)	DABCO (50)	100	18 : 0
14 <sup>c</sup>	TBPB (220)	DBU (50)	100	40 : 0

<sup>a</sup> By GC of the crude reaction mixture. <sup>b</sup> Yield calculated by <sup>1</sup>H-NMR of the crude reaction mixture using durene as the internal standard. <sup>c</sup> Formation of other products is observed by GC. <sup>d</sup> The conversion was 90% at 80 °C and 0% at 60 °C. BPO = benzoyl peroxide. DTBP = di-*tert*-butylperoxide. TBPB = *tert*-butylperoxybenzoate. DABCO = 1,4-diazabicyclo[2.2.2]octane. DBU = 1,8-diazabicyclo[5.4.0]undec-7-ene.

8–11). Similar results were obtained with  $Na_2HPO_4$ , and lower yields were obtained for the desired product when non-nucleophilic organic bases were used in substoichiometric amounts (entries 12–14).

Having found very simple optimized conditions for the model reaction, we evaluated its scope using different 2-isocyanobiaryls and THF (Scheme 3). We first examined substrates with substituents on the upper aromatic ring. Methyl-substituted products **3ba** and **3ca** were obtained in good to moderate yields, without observing any benzylic oxidation. During the formation of **3ca**, some compound **3aa** was also observed (GC-MS), likely by *ipso*-homolytic aromatic substitution, and its isolated yield was affected due to difficulties in the chromatographic purification. A more electron-donating group such as methoxy was compatible with this protocol, affording compound **3da** in reasonably good yield, as well as the corresponding byproduct **4d** (detected by GC-MS and <sup>1</sup>H-NMR).



**Scheme 3** Scope of 2-isocyanobiaryls with THF. <sup>a</sup> Measured temperature of the sand bath. <sup>b</sup> Yields after purification of isolated products and in parentheses are yields of 6-*H* phenanthridines **4** estimated by GC-MS of crude reaction mixtures. <sup>c</sup> Product **3aa** was also formed and purification of **3ca** was more difficult. \*The other regioisomer isolated (**3'**).

When 2-(2-isocyanophenyl)-naphthalene was used, compound **3ea** was the only regioisomer isolated in moderate yield, despite the steric hindrance between the ether moiety and the extra aromatic ring.<sup>17</sup> Electron-withdrawing groups, such as acetyl, trifluoromethyl, chloro and fluoro, were suitable substituents in the upper aromatic ring, furnishing products (**3fa**, **3ga**, **3ha** and **3ia**) in good isolated yields. Interestingly, when *meta*-substituted substrates **1j** and **1k** were used, both possible regioisomers were isolated after column chromatography. While the ratio of **3ja**/**3ja** was 1 : 1, for **1k** the major product was the most crowded regioisomer (**3ka**).<sup>18</sup> We also examined isocyanobiaryls substituted in the lower aromatic ring by electron-donating and electron-withdrawing groups, obtaining uniformly moderate yields in all cases (**3la–3oa**).

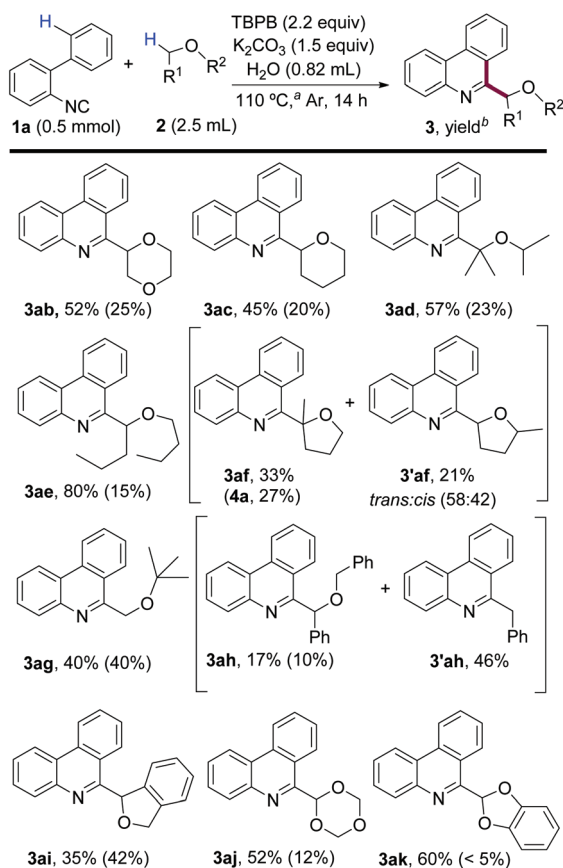
We further explore the performance of different ethers using the optimized procedure (Scheme 4). 1,4-Dioxane (**2b**) and THP (**2c**) were also suitable for this protocol, obtaining products **3ab** and **3ac** in moderate yields after purification, as well as compound **4a** as the byproduct. With THP, minor amounts of regioisomers were formed (see the ESI† for GC-MS of isomers), complicating the isolation of **3ac** in a pure form. Acyclic ethers such as *i*-Pr<sub>2</sub>O (**2d**), *n*-Bu<sub>2</sub>O (**2e**) and *t*-BuOMe (**2g**) afforded the corresponding products in good to excellent

yields, with linear *n*-Bu<sub>2</sub>O providing the best yield. 2-MeTHF (**2f**) was also examined, affording the more substituted compound **3af** as the major product and regioisomer **3'af** as an inseparable *trans/cis* mixture. Surprisingly, when Bn<sub>2</sub>O (**2h**) was examined, the expected product (**3ah**) was obtained in only 17% yield and the addition of a benzyl radical took place preferentially (**3'ah**). It seems reasonable that after H-abstraction from Bn<sub>2</sub>O, a  $\beta$ -fragmentation gives rise to the benzyl radical, which is finally added to **1a**. The addition of phthalan (**2i**) was also possible, but compound **3ai** was obtained in lower yield. Importantly, acetals **2j** and **2k** led, respectively, to products **3aj** and **3ak** in synthetically useful yields. These compounds could be easily hydrolyzed to obtain the corresponding 6-formylphenanthridine and the acetal moiety has the potential to be transformed into other functionalities.<sup>19</sup>

### Investigation of the reaction mechanism

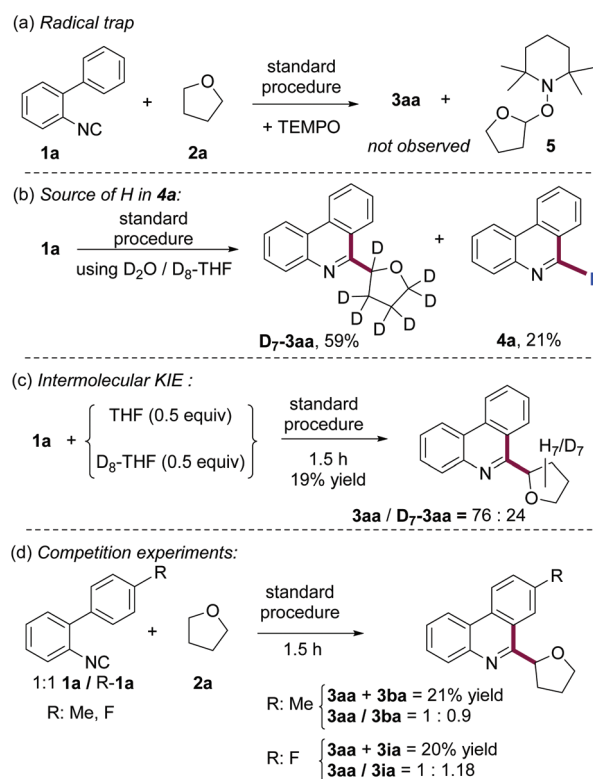
To gain insight into the reaction mechanism we performed some experiments. As shown in Scheme 5a, the use of TEMPO as a radical scavenger in our model reaction, under standard conditions, completely inhibited the formation of **3aa** and the coupling product **5** was detected by MS. Since compounds **4** are consistent byproducts of the radical cyclization studied here, we were intrigued about their formation and we have not found any experimental evidence of this in the literature.<sup>20</sup>

When the reaction was conducted using D<sub>2</sub>O and D<sub>8</sub>-THF (Scheme 5b), the expected product **D<sub>7</sub>-3aa** was obtained,



**Scheme 4** Scope of ethers. <sup>a</sup> Measured temperature of the sand bath.

<sup>b</sup> Yields after purification of isolated products and in parentheses are yields of **4a**.



**Scheme 5** Mechanistic investigations.

accompanied by phenanthridine **4a**. Importantly, the byproduct of this reaction is not deuterated, indicating that neither THF nor H<sub>2</sub>O is the source of hydrogen for the formation of this phenanthridine. We also studied the intermolecular kinetic isotopic effect (KIE) by competition experiments of equimolar amounts of THF and D<sub>8</sub>-THF with **1a** at the initial stage of the reaction (Scheme 5c). The large KIE obtained ( $k_{\text{H}}/k_{\text{D}} = 3.16$ ) suggests that the cleavage of the C(sp<sup>3</sup>)-H bond is involved in the rate determining step of this reaction. In addition, we also performed competition experiments at the initial state of the reaction, using equimolar quantities of **1a** and 2-isocyanobiphenyls substituted in position 4' by methyl or fluoro groups. The results shown in Scheme 4d suggested that electron-withdrawing substituents in the upper aromatic ring accelerate the reaction. Since this class of group stabilizes the LUMO of the upper aromatic ring, this result is also consistent with a radical cyclization pathway.<sup>21</sup>

An important feature of this protocol is the crucial role of K<sub>2</sub>CO<sub>3</sub> and H<sub>2</sub>O in a successful transformation (Table 1, entries 6 and 9). Since the seminal contribution of Studer and Curran,<sup>22</sup> several known reactions have been recognized as "base promoted homolytic substitutions" (BHAS) and many new transformations have been developed with this concept.<sup>11</sup> Based on literature precedents and our own results, we believe that this reaction is an example of BHAS. A possible reaction mechanism is depicted in Scheme 6. Firstly, homolysis of TBPB takes place upon heating. From the two generated radicals, it is reported that *t*-BuO<sup>•</sup> abstracts a hydrogen atom from THF faster than Bz<sup>•</sup> to generate the  $\alpha$ -furyl radical.<sup>23</sup> Addition of this intermediate to isonitrile **1a**, followed by intramolecular addition to the upper aromatic ring, is well documented in a number of examples.<sup>11</sup> DFT studies performed by the Studer group indicate that cyclohexadienyl radicals, such as **I**, are extremely strong acids ( $\text{p}K_{\text{a}} \sim -15$  in H<sub>2</sub>O).<sup>24</sup> Therefore, this radical intermediate can be deprotonated under mild basic aqueous conditions (e.g. K<sub>2</sub>CO<sub>3</sub> in H<sub>2</sub>O) to generate a radical anion **II**. This species is a potent reductant

that can easily transfer an electron to radical Bz<sup>•</sup> or to oxidant TBPB, while generating product **3aa**. In addition, intermediate **I** can transfer a hydrogen atom to **1a**, which after a similar BHAS process leads to the formation of byproduct **4a**. This explanation is consistent with our observation that neither THF nor H<sub>2</sub>O was the hydrogen source of **4a**.<sup>25</sup>

## Conclusions

In conclusion, we have demonstrated that TBPB can be used under mildly basic aqueous conditions to promote the radical addition of a range of ethers to 2-isocyanobiaryls followed by cyclization. Mechanistic investigations suggest that this transformation is an example of BHAS and a plausible explanation is provided for the formation of byproduct **4**. Some salient features of the developed methodology are: (a) neither transition metals nor any expensive additives are needed; (b) the wastes generated are harmless inorganic salts and can be easily removed by aqueous workup; (c) the reaction medium is constituted by the reactant ethers and water.

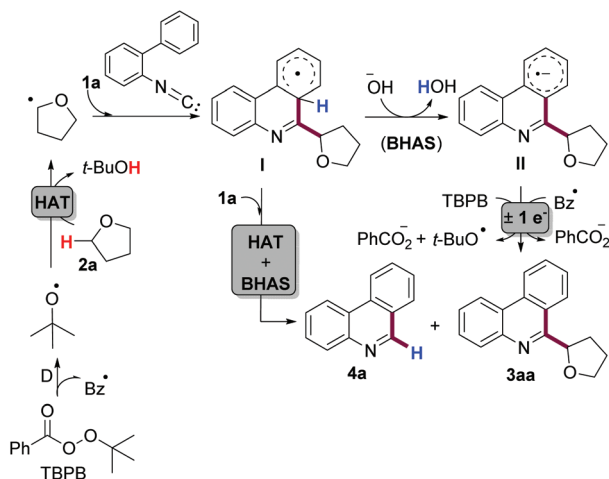
## Experimental section

### General remarks

All starting isonitriles were prepared according to a reported method.<sup>10b</sup> TLC was performed on silica gel 60 F<sub>254</sub>, using aluminium plates and visualized by exposure to ultraviolet light. Flash chromatography was carried out on hand-packed columns of silica gel 60 (230–400 mesh). Infrared (IR) spectra were recorded with a spectrophotometer equipped with an ATR component; wavenumbers are given in cm<sup>-1</sup>. LRMS were obtained using a mass spectrometer coupled with a gas chromatographer (GC); the mobile phase was helium (2 mL min<sup>-1</sup>); HP-1 column of 12 m was used; temperature program starts at 80 °C for 3 min, then up to 270 °C at a rate of 20 °C min<sup>-1</sup>, and 17.5 min at 270 °C. HRMS analyses were carried out using Electron Impact (EI) mode at 70 eV by Q-TOF. <sup>1</sup>H NMR spectra were recorded at 300 or 400 MHz for <sup>1</sup>H-NMR and 75 or 100 MHz for <sup>13</sup>C-NMR, using CDCl<sub>3</sub> as the solvent and TMS as an internal standard (0.00 ppm). The data are being reported as (s = singlet, d = doublet, t = triplet, m = multiplet or unresolved, br s = broad signal, coupling constant(s) in Hz, integration). <sup>13</sup>C-NMR spectra were recorded with <sup>1</sup>H-decoupling at 100 MHz and referenced to CDCl<sub>3</sub> at 77.16 ppm. DEPT-135 experiments were performed to assign CH, CH<sub>2</sub> and CH<sub>3</sub>.

### General procedure for the synthesis of compounds **3**

Into a pressure tube were added K<sub>2</sub>CO<sub>3</sub> (103 mg, 0.75 mmol) and H<sub>2</sub>O (0.82 mL). Then, to it were added sequentially the 2-isocyanobiaryl derivative **1** (0.50 mmol), ether **2** (2.5 mL) and *tert*-butyl peroxibenzoate (TBPB) (213  $\mu$ L, 1.10 mmol). The reaction mixture was stirred under an Ar atmosphere for 12–14 h at 110 °C (sand bath temperature). Upon full conver-



Scheme 6 Plausible mechanism.



sion of the isonitrile (TLC or GC), a saturated solution of NaHCO<sub>3</sub> (5 mL) and EtOAc (10 mL) was added to the reaction mixture. After phase separation, the aqueous phase was extracted with EtOAc (3 × 15 mL) and the combined organic layers were washed with brine (5 mL), dried over MgSO<sub>4</sub> and concentrated under reduced pressure. The residue was purified by flash column chromatography on silica gel to give the desired product.

**6-(Tetrahydrofuran-2-yl)phenanthridine (3aa).**<sup>13c</sup> Following the general procedure, compound **3aa** was obtained after column chromatography (hexane/EtOAc 9 : 1) as a yellow pale solid (91 mg, 0.36 mmol, 73%); *R*<sub>f</sub> 0.23 (95 : 5 hexane/EtOAc); <sup>1</sup>H-NMR (300 MHz, CDCl<sub>3</sub>) δ 8.63 (dd, *J* = 8.2, 1.3 Hz, 1H), 8.55 (dd, *J* = 8.0, 1.5 Hz, 1H), 8.45 (dd, *J* = 8.7, 1.0 Hz, 1H), 8.19 (dd, *J* = 7.9, 1.6 Hz, 1H), 7.83 (ddd, *J* = 8.3, 7.0, 1.3 Hz, 1H), 7.75–7.61 (m, 3H), 5.78 (t, *J* = 6.9 Hz, 1H), 4.26–4.15 (m, 1H), 4.13–4.01 (m, 1H), 2.82–2.65 (m, 1H), 2.50–2.35 (m, 1H), 2.30–2.03 (m, 2H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 159.4 (C), 143.4 (C), 133.4 (C), 130.6 (CH), 130.4 (CH), 128.6 (CH), 127.3 (CH), 127.0 (CH), 126.6 (CH), 124.9 (C), 124.2 (C), 122.5 (CH), 122.0 (CH), 79.7 (CH), 69.1 (CH<sub>2</sub>), 30.1 (CH<sub>2</sub>), 26.1 (CH<sub>2</sub>) ppm; IR ν 3073, 2981, 2881, 1583, 1444, 1300, 1057, 727 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 249 (M<sup>+</sup>, 5), 220 (15), 206 (100), 193 (48), 178 (15).

**8-Methyl-6-(tetrahydrofuran-2-yl)phenanthridine (3ba).** Following the general procedure, compound **3ba** was obtained after column chromatography (hexane/EtOAc 93 : 7) as a yellow pale solid (80 mg, 0.31 mmol, 61%); *R*<sub>f</sub> 0.20 (93 : 7 hexane/EtOAc); <sup>1</sup>H-NMR (400 MHz, CDCl<sub>3</sub>) δ 8.54–8.48 (m, 2H), 8.20 (br s, 1H), 8.16 (dd, *J* = 8.1, 1.1 Hz, 1H), 7.71–7.59 (m, 3H), 5.79–5.74 (m, 1H), 4.23–4.15 (m, 1H), 4.10–4.03 (m, 1H), 2.83–2.72 (m, 1H), 2.60 (s, 3H), 2.46–2.35 (m, 1H), 2.27–2.17 (m, 1H), 2.17–2.06 (m, 1H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 159.0 (C), 143.1 (C), 137.2 (C), 132.1 (CH), 131.2 (C), 130.5 (CH), 128.1 (CH), 126.9 (CH), 126.0 (CH), 125.1 (C), 124.3 (C), 122.3 (CH), 121.8 (CH), 79.5 (CH), 69.1 (CH<sub>2</sub>), 30.0 (CH<sub>2</sub>), 26.1 (CH<sub>2</sub>), 22.1 (CH<sub>3</sub>) ppm; IR ν 2955, 2867, 1577, 1460, 1052, 760 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 263 (M<sup>+</sup>, 6), 234 (10), 220 (100), 207 (57); HRMS (EI) *m/z* calcd for C<sub>18</sub>H<sub>17</sub>NO 263.1310, found 263.1307.

**10-Methyl-6-(tetrahydrofuran-2-yl)phenanthridine (3ca).** Following the general procedure, compound **3ca** was obtained after column chromatography (hexane/EtOAc 95 : 5–9 : 1) as a yellow pale solid (54 mg, 0.20 mmol, 41%); *R*<sub>f</sub> 0.20 (95 : 5 hexane/EtOAc); <sup>1</sup>H-NMR (300 MHz, CDCl<sub>3</sub>) δ 8.77 (br d, *J* = 8.2 Hz, 1H), 8.35 (dd, *J* = 8.1, 1.6 Hz, 1H), 8.23 (dd, *J* = 8.1, 1.5 Hz, 1H), 7.70 (ddd, *J* = 8.2, 7.0, 1.4 Hz, 1H), 7.67–7.55 (m, 3H), 5.81–5.75 (t, *J* = 6.8 Hz, 1H), 4.25–4.15 (m, 1H), 4.10–4.01 (m, 1H), 3.11 (s, 3H), 2.84–2.67 (m, 1H), 2.48–2.32 (m, 1H), 2.27–2.00 (m, 2H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 159.6 (C), 144.5 (C), 135.6 (C), 134.6 (CH), 132.9 (C), 130.9 (CH), 127.8 (CH), 126.7 (CH), 126.5 (CH), 126.4 (C), 126.1 (CH), 125.6 (C), 124.9 (CH), 79.7 (CH), 69.1 (CH<sub>2</sub>), 30.1 (CH<sub>2</sub>), 27.1 (CH<sub>2</sub>), 26.1 (CH<sub>3</sub>) ppm; IR ν 3069, 2968, 2871, 1587, 1437, 1054, 760 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 263 (M<sup>+</sup>, 8), 234 (18), 220 (100), 207 (59), 204 (21), 165 (18); HRMS (EI) *m/z* calcd for C<sub>18</sub>H<sub>17</sub>NO 263.1310, found 263.1306.

**8-Methoxy-6-(tetrahydrofuran-2-yl)phenanthridine (3da).** Following the general procedure, compound **3da** was obtained after column chromatography (hexane/EtOAc 95 : 5–75 : 25) as a white solid (78 mg, 0.28 mmol, 55%); *R*<sub>f</sub> 0.20 (9 : 1 hexane/EtOAc); <sup>1</sup>H-NMR (300 MHz, CDCl<sub>3</sub>) δ 8.53 (d, *J* = 9.1 Hz, 1H), 8.47–8.41 (m, 1H), 8.17–8.12 (m, 1H), 7.82 (d, *J* = 2.6 Hz, 1H), 7.68–7.56 (m, 2H), 7.44 (dd, *J* = 9.1, 2.6 Hz, 1H), 5.69 (t, *J* = 6.9 Hz, 1H), 4.24–4.12 (m, 1H), 4.12–4.01 (m, 1H), 3.98 (s, 3H), 2.87–2.71 (m, 1H), 2.47–2.32 (m, 1H), 2.28–2.05 (m, 2H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 158.6 (C), 158.4 (C), 142.5 (C), 130.5 (CH), 127.8 (C), 127.6 (CH), 127.0 (CH), 126.3 (C), 124.3 (C), 124.1 (CH), 121.5 (CH), 120.8 (CH), 107.1 (CH), 80.1 (CH), 69.1 (CH<sub>2</sub>), 55.6 (CH<sub>3</sub>), 29.8 (CH<sub>2</sub>), 26.2 (CH<sub>2</sub>) ppm; IR ν 3000, 2964, 2858, 1571, 1059, 754 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 279 (M<sup>+</sup>, 12), 250 (8), 236 (100), 223 (44), 207 (35); HRMS (EI) *m/z* calcd for C<sub>18</sub>H<sub>17</sub>NO<sub>2</sub> 279.1259, found 279.1261.

**5-(Tetrahydrofuran-2-yl)benzo[*z*]phenanthridine (3ea).** Following the general procedure, compound **3ea** was obtained after column chromatography (hexane/EtOAc 98 : 2–95 : 5) as a white solid (57 mg, 0.19 mmol, 38%); *R*<sub>f</sub> 0.35 (96 : 4 hexane/EtOAc); <sup>1</sup>H-NMR (400 MHz, CDCl<sub>3</sub>) δ 9.19 (H-1, d, *J* = 8.5 Hz, 1H), 8.57 (H-12 + H-4, dd, *J* = 8.7, 5.2 Hz, 2H), 8.23 (H-7, dd, *J* = 8.2, 1.1 Hz, 1H), 8.10 (H-11, d, *J* = 8.9 Hz, 1H), 7.98 (H-10, d, *J* = 7.9 Hz, 1H), 7.78–7.71 (H-2 + H-8, m, 2H), 7.68–7.63 (H-3 + H-9, m, 2H), 5.91 (H-2', t, *J* = 6.4 Hz, 1H), 4.47–4.38 (H-5', m, 1H), 4.20–4.13 (H-5', m, 1H), 2.99–2.86 (H-3', m, 1H), 2.59–2.37 (H-4', m, 1H), 2.27–2.07 (H-3' + H-4', m, 2H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 157.7 (C), 144.0 (C), 133.8 (C), 133.2 (C), 131.9 (C), 130.1 (CH), 129.9 (C), 128.8 (CH), 128.7 (CH), 128.4 (CH), 127.2 (CH), 126.9 (CH), 126.7 (CH), 123.7 (C), 123.0 (C), 122.5 (CH), 120.2 (CH), 80.5 (CH), 69.4 (CH<sub>2</sub>), 31.3 (CH<sub>2</sub>), 26.8 (CH<sub>2</sub>) ppm; IR ν 3019, 2961, 2937, 1561, 1465, 1350, 1051, 750 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 299 (M<sup>+</sup>, 14), 256 (100), 242 (28), 227 (19); HRMS (EI) *m/z* calcd for C<sub>21</sub>H<sub>17</sub>NO 299.1310, found 299.1304.

**1-(6-(Tetrahydrofuran-2-yl)phenanthridin-8-yl)ethan-1-one (3fa).** Following the general procedure, compound **3fa** was obtained after column chromatography (hexane/EtOAc 8 : 2) as a yellow pale solid (77 mg, 0.27 mmol, 53%); *R*<sub>f</sub> 0.20 (8 : 2 hexane/EtOAc); <sup>1</sup>H-NMR (300 MHz, CDCl<sub>3</sub>) δ 9.10 (br s, 1H), 8.65 (d, *J* = 8.7 Hz, 1H), 8.54 (d, *J* = 8.2 Hz, 1H), 8.35 (dd, 2H), 8.19 (dd, *J* = 8.1, 1.2 Hz, 1H), 7.77 (ddd, *J* = 8.3, 7.0, 1.4 Hz, 1H), 7.67 (ddd, *J* = 8.3, 7.1, 1.4 Hz, 1H), 5.77 (t, *J* = 7.0 Hz, 1H), 4.22–4.13 (m, 1H), 4.13–4.04 (m, 1H), 2.88–2.79 (m, 1H), 2.77 (s, 3H), 2.52–2.37 (m, 1H), 2.31–2.10 (m, 2H) ppm; <sup>13</sup>C-NMR (101 MHz, CDCl<sub>3</sub>) δ 197.5 (C), 159.8 (C), 144.2 (C), 136.5 (C), 135.3 (C), 130.7 (C), 129.8 (CH), 128.8 (CH), 128.2 (CH), 127.4 (CH), 124.5 (C), 123.5 (C), 122.9 (CH), 122.6 (CH), 79.9 (CH), 69.2 (CH<sub>2</sub>), 29.9 (CH<sub>2</sub>), 26.9 (CH<sub>2</sub>), 26.2 (CH<sub>3</sub>) ppm; IR ν 2977, 2921, 2856, 1683, 1615, 1251, 1052, 760 cm<sup>-1</sup>; LRMS (EI) *m/z* (%) = 291 (M<sup>+</sup>, 5), 263 (20), 248 (100), 235 (65), 207 (17); HRMS (EI) *m/z* calcd for C<sub>19</sub>H<sub>17</sub>NO<sub>2</sub> 291.1259, found 291.1265.

**6-(Tetrahydrofuran-2-yl)-8-(trifluoromethyl)phenanthridine (3ga).** Following the general procedure, compound **3ga** was obtained after column chromatography (hexane/EtOAc 95 : 5–9 : 1) as a yellow pale solid (111 mg, 0.35 mmol, 70%);

$R_f$  0.25 (95 : 5 hexane/EtOAc);  $^1\text{H-NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.81 (s, 1H), 8.72 (d,  $J = 8.6$  Hz, 1H), 8.54 (d,  $J = 8.1$  Hz, 1H), 8.20 (d,  $J = 8.1$  Hz, 1H), 8.00 (d,  $J = 8.6$  Hz, 1H), 7.78 (t,  $J = 7.4$  Hz, 1H), 7.69 (t,  $J = 7.5$  Hz, 1H), 5.72 (t,  $J = 6.9$  Hz, 1H), 4.19–4.12 (m, 1H), 4.12–4.03 (m, 1H), 2.88–2.75 (m, 1H), 2.48–2.35 (m, 1H), 2.30–2.08 (m, 2H);  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  159.2 (C), 144.0 (C), 135.6 (C), 130.7 (CH), 129.8 (CH), 129.1 (CH), 129.0 (C-8, d,  $^2J_{\text{C-F}} = 32.4$  Hz), 127.6 (CH), 126.3 (CH, q,  $^3J_{\text{C-F}} = 3.3$  Hz), 124.5 (CH, q,  $^3J_{\text{C-F}} = 4.3$  Hz), 124.4 (CH), 124.25 (d,  $^1J_{\text{C-F}} = 272.2$  Hz), 123.5 (CH), 123.3 (C), 122.4 (CH), 80.0 (CH), 69.2 ( $\text{CH}_2$ ), 29.8 ( $\text{CH}_2$ ), 26.2 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2966, 2874, 1722, 1625, 1173, 1122, 763  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 317 ( $\text{M}^+$ , 4), 288 (8), 274 (100), 261 (73), 247 ( $[(\text{M} + 1)^+ - \text{THF}]$ , 14), 226 (12); HRMS (EI)  $m/z$  calcd for  $\text{C}_{14}\text{H}_8\text{F}_3\text{N}$ , 247.0609, found 247.0612.

#### 8-Chloro-6-(tetrahydrofuran-2-yl)phenanthridine (3ha).

Following the general procedure, compound **3ha** was obtained after column chromatography (hexane/EtOAc 95 : 5) as an orange pale solid (92 mg, 0.32 mmol, 65%):  $R_f$  0.25 (95 : 5 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.53 (d,  $J = 8.9$  Hz, 1H), 8.46 (dd,  $J = 7.5$ , 1.8 Hz, 2H), 8.16 (dd,  $J = 8.1$ , 1.1 Hz, 1H), 7.78–7.68 (m, 2H), 7.64 (ddd,  $J = 8.4$ , 7.1, 1.5 Hz, 1H), 5.65 (t,  $J = 6.9$  Hz, 1H), 4.20–4.11 (m, 1H), 4.11–4.01 (m, 1H), 2.87–2.71 (m, 1H), 2.47–2.30 (m, 1H), 2.29–2.00 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  158.3 (C), 143.3 (C), 133.3 (C), 131.8 (C), 130.9 (CH), 130.7 (CH), 128.9 (CH), 127.4 (CH), 126.2 (CH), 126.0 (C), 124.2 (CH), 123.6 (C), 121.9 (CH), 79.8 (CH), 69.1 ( $\text{CH}_2$ ), 29.7 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  3063, 2939, 2839, 1617, 1460, 1220, 1038, 759  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 283 ( $\text{M}^+$ , 8), 254 (15), 240 ( $[\text{M}^+ - \text{C}_2\text{H}_3\text{O}]$ , 100), 217 (12), 207 (65), 177 (39); HRMS (EI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{11}\text{ClN}$  240.0580, found 240.0586.

#### 8-Fluoro-6-(tetrahydrofuran-2-yl)phenanthridine (3ia).

Following the general procedure, compound **3ia** was obtained after column chromatography (hexane/EtOAc 95 : 5–8 : 2) as a yellow pale solid (80 mg, 0.30 mmol, 60%):  $R_f$  0.21 (95 : 5 hexane/EtOAc);  $^1\text{H-NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.60 (H-10, dd,  $J_{\text{H-F}} = 9.1$ , 5.4 Hz, 1H), 8.46 (dd,  $J = 8.1$ , 1.1 Hz, 1H), 8.17 (dd,  $J = 8.1$ , 1.2 Hz, 1H), 8.12 (H-7, dd,  $J_{\text{H-F}} = 10.2$ , 2.6 Hz, 1H), 7.70 (ddd,  $J = 8.2$ , 7.0, 1.5 Hz, 1H), 7.64 (ddd,  $J = 8.3$ , 7.0, 1.5 Hz, 1H), 7.56 (H-9, ddd,  $J_{\text{H-F}} = 9.1$ , 8.0, 2.7 Hz, 1H), 5.63 (H-2', t,  $J = 6.9$  Hz, 1H), 4.20–4.13 (H-5', m, 1H), 4.09–4.02 (H-5', m, 1H), 2.84–2.71 (m, 1H), 2.44–2.34 (m, 1H), 2.27–2.06 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  161.33 (C-8, d,  $^1J_{\text{C-F}} = 248.0$  Hz), 158.53 (C, d,  $^4J_{\text{C-F}} = 4.3$  Hz), 142.94 (C), 130.62 (CH), 130.11 (C), 128.51 (CH), 127.43 (CH), 126.24 (C-6a, d,  $^3J_{\text{C-F}} = 7.8$  Hz), 124.93 (C-10, d,  $^3J_{\text{C-F}} = 8.5$  Hz), 123.82 (C), 121.76 (CH), 119.64 (CH, d,  $^2J_{\text{C-F}} = 23.9$  Hz), 111.59 (CH, d,  $^2J_{\text{C-F}} = 21.8$  Hz), 80.08 (CH), 69.14 ( $\text{CH}_2$ ), 29.79 ( $\text{CH}_2$ ), 26.08 ( $\text{CH}_2$ ); IR  $\nu$  2958, 2873, 1773, 1697, 1480, 1196, 1054, 759  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 267.1 ( $\text{M}^+$ , 5), 238 (12), 224 (100), 211 (59), 197 (19), 169 (11); HRMS (EI)  $m/z$  calcd for  $\text{C}_{17}\text{H}_{14}\text{FNO}$  267.1059, found 267.1042.

#### 7-Methyl-6-(tetrahydrofuran-2-yl)phenanthridine (3ja).

Following the general procedure, compound **3ja** was obtained after column chromatography (hexane/EtOAc 98 : 2–95 : 5) as a yellow pale solid (38 mg, 0.14 mmol, 28%):  $R_f$  0.16

(98 : 2 hexane/EtOAc);  $^1\text{H-NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.53 (d,  $J = 8.3$  Hz, 1H), 8.51 (d,  $J = 8.3$  Hz, 1H), 8.12 (dd,  $J = 8.1$ , 1.4 Hz, 1H), 7.71–7.57 (m, 3H), 7.49 (d,  $J = 7.2$  Hz, 1H), 5.97 (dd,  $J = 6.9$ , 5.2 Hz, 1H), 4.20–4.12 (m, 1H), 4.04–3.95 (m, 1H), 3.09 (s, 3H), 2.89–2.80 (m, 1H), 2.32–2.12 (m, 2H), 2.11–1.96 (m, 1H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  159.4 (C), 142.5 (C), 136.5 (C), 134.9 (C), 132.0 (CH), 130.2 (CH), 129.6 (CH), 128.4 (CH), 126.9 (CH), 125.4 (C), 124.4 (C), 122.2 (CH), 120.9 (CH), 80.3 (CH), 68.9 ( $\text{CH}_2$ ), 30.3 ( $\text{CH}_2$ ), 25.8 ( $\text{CH}_2$ ), 25.2 ( $\text{CH}_3$ ) ppm; IR  $\nu$  2959, 2874, 1573, 1449, 1286, 1048, 749  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 263 ( $\text{M}^+$ , 8), 248 (6), 234 (13), 220 (100), 207 (13), 193 (19); HRMS (EI)  $m/z$  calcd for  $\text{C}_{18}\text{H}_{17}\text{NO}$  263.1310, found 263.1312.

**9-Methyl-6-(tetrahydrofuran-2-yl)phenanthridine (3'ja).** From the same reaction where compound **3ja** was obtained, and after column chromatography (hexane/EtOAc 95 : 5–100% EtOH), isomer **3'ja** was isolated as a yellow pale solid (37 mg, 0.14 mmol, 28%):  $R_f$  0.19 (95 : 5 hexane/EtOAc);  $^1\text{H-NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.52 (dd,  $J = 8.1$ , 1.5 Hz, 1H), 8.40 (H-10, s, 1H), 8.31 (d,  $J = 8.4$  Hz, 1H), 8.16 (dd,  $J = 8.1$ , 1.0 Hz, 1H), 7.68 (ddd,  $J = 8.2$ , 7.1, 1.4 Hz, 1H), 7.60 (ddd,  $J = 8.3$ , 7.1, 1.4 Hz, 1H), 7.50 (dd,  $J = 8.4$ , 1.4 Hz, 1H), 5.73 (t,  $J = 6.9$  Hz, 1H), 4.23–4.16 (m, 1H), 4.11–4.00 (m, 1H), 2.76–2.65 (m, 1H), 2.62 (s, 3H), 2.46–2.32 (m, 1H), 2.27–2.04 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  159.3 (C), 143.6 (C), 140.7 (C), 133.5 (C), 130.5 (CH), 129.0 (CH), 128.4 (CH), 126.7 (CH), 126.4 (CH), 124.1 (C), 123.0 (C), 122.1 (CH), 121.9 (CH), 79.8 (CH), 69.1 ( $\text{CH}_2$ ), 30.2 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ), 22.3 ( $\text{CH}_3$ ) ppm; IR  $\nu$  2875, 2868, 1618, 1460, 1053, 760; LRMS (EI)  $m/z$  (%) = 263 ( $\text{M}^+$ , 5), 234 (13), 220 (100), 207 (51), 192 (23); HRMS (EI)  $m/z$  calcd for  $\text{C}_{18}\text{H}_{17}\text{NO}$  263.1310, found 263.1312.

#### 7-Fluoro-6-(tetrahydrofuran-2-yl)phenanthridine (3ka).

Following the general procedure, compound **3ka** was obtained after column chromatography (hexane/EtOAc 93 : 7) as a white solid (51 mg, 0.19 mmol, 38%):  $R_f$  0.19 (9 : 1 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.49 (d,  $J = 8.2$  Hz, 1H), 8.45 (d,  $J = 8.4$  Hz, 1H), 8.22 (dd,  $J = 8.2$ , 1.2 Hz, 1H), 7.82–7.70 (m, 2H), 7.64 (ddd,  $J = 8.3$ , 7.1, 1.4 Hz, 1H), 7.36 (ddd,  $J = 12.5$ , 7.9, 1.0 Hz, 1H), 6.02 (dt,  $J = 8.2$ , 4.3 Hz, 1H), 4.43–4.32 (m, 1H), 4.17–4.05 (m, 1H), 2.60–2.45 (m, 1H), 2.40–2.23 (m, 1H), 2.13–1.96 (m, 1H) ppm;  $^{13}\text{C-NMR}$  (75 MHz,  $\text{CDCl}_3$ )  $\delta$  160.2 (C-7, d,  $^1J_{\text{C-F}} = 255.2$  Hz), 158.8 (C, d,  $^3J_{\text{C-F}} = 7.9$  Hz), 143.3 (CH), 136.0 (C, d,  $^4J_{\text{C-F}} = 4.4$  Hz), 131.0 (C-9, d,  $^3J_{\text{C-F}} = 9.8$  Hz), 130.8 (CH), 129.3 (CH), 127.3 (CH), 122.7 (C, d,  $^5J_{\text{C-F}} = 2.7$  Hz), 122.3 (CH), 118.7 (C-10, d,  $^4J_{\text{C-F}} = 4.0$  Hz), 114.2 (CH), 114.1 (CH), 114.0 (C-6a, d,  $^2J_{\text{C-F}} = 24.6$  Hz), 81.9 (C-2', d,  $^4J_{\text{C-F}} = 14$  Hz), 69.3 ( $\text{CH}_2$ ), 31.7 ( $\text{CH}_2$ ), 25.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2970, 2870, 1581, 1451, 1240, 757  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 267 ( $\text{M}^+$ , 2), 224 (100), 211 (64), 197 (19), 169 (9); HRMS (EI)  $m/z$  calcd for  $\text{C}_{17}\text{H}_{14}\text{FNO}$  267.1059, found 267.1050.

#### 9-Fluoro-6-(tetrahydrofuran-2-yl)phenanthridine (3'ka).

From the same reaction where compound **3ka** was obtained, and after column chromatography (hexane/EtOAc 95 : 5), isomer **3'ka** was isolated as a white solid (24 mg, 0.09 mmol, 18%):  $R_f$  0.27 (9 : 1 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.52 (H-7, dd,  $J = 9.1$ , 5.8 Hz, 1H), 8.41 (H-1, dd,  $J = 8.2$ ,

1.1 Hz, 1H), 8.22 (H-10, dd,  $J = 10.5, 2.6$  Hz, 1H), 8.17 (H-4, dd,  $J = 8.3, 1.2$  Hz, 1H), 7.74 (ddd,  $J = 8.3, 7.0, 1.5$  Hz, 1H), 7.64 (ddd,  $J = 8.3, 7.0, 1.4$  Hz, 1H), 7.42 (H-8, ddd,  $J = 9.1, 8.2, 2.6$  Hz, 1H), 5.70 (H-2', t,  $J = 6.9$  Hz, 1H), 4.21–4.11 (H-5', m, 1H), 4.10–4.01 (H-5', m, 1H), 2.88–2.71 (m, 1H), 2.47–2.31 (m, 1H), 2.29–2.05 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  163.70 (C-9, d,  $^1J_{\text{C-F}} = 251.5$  Hz); 158.7 (C), 143.6 (C), 135.9 (C-10a, d,  $^3J_{\text{C-F}} = 9.4$  Hz), 130.6 (CH), 129.8 (C-7, d,  $^3J_{\text{C-F}} = 9.3$  Hz), 129.3 (CH), 127.1 (CH), 123.8 (C-6a, d,  $^4J_{\text{C-F}} = 4.1$  Hz), 122.2 (CH), 122.0 (C-6, d,  $^5J_{\text{C-F}} = 2$  Hz), 116.3 (C-10/C-8, d,  $^2J_{\text{C-F}} = 23.7$  Hz), 107.5 (C-8/C-10, d,  $^2J_{\text{C-F}} = 22.1$  Hz), 80.0 (CH), 69.1 ( $\text{CH}_2$ ), 29.8 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2962, 2877, 1619, 1496, 1195, 1052, 760  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 267 ( $\text{M}^+$ , 3), 238 (13), 224 (100), 211 (55), 197 (17), 169 (9); HRMS (EI)  $m/z$  calcd for  $\text{C}_{17}\text{H}_{14}\text{FNO}$  267.1059, found 267.1054.

### 2-Methyl-6-(tetrahydrofuran-2-yl)phenanthridine (3la).

Following the general procedure, but from 0.30 mmol of **1l**, compound **3la** was obtained after column chromatography (hexane/EtOAc 94:6–93:7) as a yellow pale solid (43 mg, 0.16 mmol, 55%):  $R_f$  0.17 (93:7 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.61 (d,  $J = 8.3$  Hz, 1H), 8.42 (dd,  $J = 8.3, 0.7$  Hz, 1H), 8.31 (s, 1H), 8.07 (d,  $J = 8.3$  Hz, 1H), 7.79 (ddd,  $J = 8.3, 7.0, 1.3$  Hz, 1H), 7.66 (ddd,  $J = 8.3, 7.0, 1.3$  Hz, 1H), 7.53 (dd,  $J = 8.3, 1.6$  Hz, 1H), 5.74 (t,  $J = 6.9$  Hz, 1H), 4.25–4.14 (m, 1H), 4.11–4.00 (m, 1H), 2.83–2.66 (m, 1H), 2.61 (s, 3H), 2.48–2.33 (m, 1H), 2.28–2.02 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  158.3 (C), 141.7 (C), 136.8 (C), 133.1 (C), 130.3 (CH), 130.3 (CH), 130.1 (CH), 127.1 (CH), 126.5 (CH), 125.0 (C), 124.0 (C), 122.4 (CH), 121.6 (CH), 79.8 (CH), 69.1 ( $\text{CH}_2$ ), 30.1 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ), 22.1 ( $\text{CH}_3$ ) ppm; IR  $\nu$  2971, 2923, 2867, 1582, 1496, 1295, 1051, 822, 729  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 263 ( $\text{M}^+$ , 6), 234 (12), 220 (100), 207 (47), 192 (15), 165 (12); HRMS (EI)  $m/z$  calcd for  $\text{C}_{18}\text{H}_{17}\text{NO}$  263.1310, found 263.1312.

**6-(Tetrahydrofuran-2-yl)-2-(trifluoromethoxy)phenanthridine (3ma).** Following the general procedure, but from 0.45 mmol of **1m**, compound **3ma** was obtained after column chromatography (hexane/EtOAc 94:6) as a red solid (84 mg, 0.25 mmol, 55%):  $R_f$  0.20 (93:7 hexane/EtOAc);  $^1\text{H-NMR}$  (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.55 (d,  $J = 8.3$  Hz, 1H), 8.48 (d,  $J = 7.9$  Hz, 1H), 8.34 (d,  $J = 1.7$  Hz, 1H), 8.21 (d,  $J = 8.9$  Hz, 1H), 7.87 (ddd,  $J = 8.4, 7.1, 1.3$  Hz, 1H), 7.75 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.57 (ddd,  $J = 8.9, 2.6, 1.1$  Hz, 1H), 5.77 (t,  $J = 6.9$  Hz, 1H), 4.23–4.15 (m, 1H), 4.12–4.04 (m, 1H), 2.81–2.65 (m, 1H), 2.50–2.35 (m, 1H), 2.31–2.06 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  160.1 (C), 147.7 (C), 141.7 (C), 132.8 (C), 132.5 (CH), 130.7 (CH), 128.2 (CH), 126.8 (CH), 125.1 (C-2, d,  $^3J_{\text{C-F}} = 10.5$  Hz), 122.6 (CH), 121.9 (CH), 120.8 (q,  $^1J_{\text{C-F}} = 257.5$  Hz), 113.7 (CH), 79.6 (CH), 69.2 ( $\text{CH}_2$ ), 30.1 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2964, 2860, 1619, 1587, 1492, 1254, 1214  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 333 ( $\text{M}^+$ , 5), 304 (24), 290 (100), 277 (51), 263 (8); HRMS (EI)  $m/z$  calcd for  $\text{C}_{18}\text{H}_{14}\text{F}_3\text{NO}_2$  333.0977, found 333.0950.

### 2-Chloro-6-(tetrahydrofuran-2-yl)phenanthridine (3na).

Following the general procedure, but from 0.30 mmol of **1n**, compound **3na** was obtained after column chromatography (hexane/EtOAc 94:6–93:7) as a white solid (42 mg,

0.15 mmol, 50%):  $R_f$  0.20 (93:7 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.53 (d,  $J = 8.2$  Hz, 1H), 8.48 (d,  $J = 2.1$  Hz, 1H), 8.44 (d,  $J = 8.1$  Hz, 1H), 8.10 (d,  $J = 8.7$  Hz, 1H), 7.87–7.79 (m, 1H), 7.71 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.64 (dd,  $J = 8.7, 2.3$  Hz, 1H), 5.74 (t,  $J = 6.9$  Hz, 1H), 4.24–4.14 (m, 1H), 4.11–4.01 (m, 1H), 2.79–2.65 (m, 1H), 2.49–2.34 (m, 1H), 2.28–2.03 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  159.7 (C), 141.8 (C), 132.9 (C), 132.4 (C), 132.0 (CH), 130.7 (CH), 129.1 (CH), 128.0 (CH), 126.7 (CH), 125.3 (C), 125.1 (C), 122.5 (CH), 121.7 (CH), 79.6 (CH), 69.2 ( $\text{CH}_2$ ), 30.0 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2967, 2869, 1584, 1495, 1255, 1054, 822, 767  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 283 ( $\text{M}^+$ , 4), 254 (16), 240 ( $[\text{M}^+ - \text{C}_2\text{H}_3\text{O}]$ , 100), 227 (51), 213 (13), 177 (29); HRMS (EI)  $m/z$  calcd for  $\text{C}_{15}\text{H}_{11}\text{ClN}$  240.0580, found 240.0576.

### 3-Fluoro-6-(tetrahydrofuran-2-yl)phenanthridine (3oa).

Following the general procedure, but from 0.30 mmol of **1o**, compound **3oa** was obtained after column chromatography (hexane/EtOAc 96:4) as a brown oil (36 mg, 0.13 mmol, 45%):  $R_f$  0.20 (93:7 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.54 (d,  $J = 8.3$  Hz, 1H), 8.49 (H-1, dd,  $J = 9.1, 5.9$  Hz, 1H), 8.43 (d,  $J = 8.2$  Hz, 1H), 7.87–7.78 (m, 2H), 7.67 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.38 (H-2, ddd,  $J = 8.9, 8.1, 2.7$  Hz, 1H), 5.76 (t,  $J = 6.9$  Hz, 1H), 4.24–4.14 (m, 1H), 4.11–4.01 (m, 1H), 2.78–2.64 (m, 1H), 2.48–2.34 (m, 1H), 2.29–2.03 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (101 MHz,  $\text{CDCl}_3$ )  $\delta$  162.7 (C-3, d,  $^1J_{\text{C-F}} = 247.6$  Hz), 160.9 (C), 144.7 (C-4a, d,  $^3J_{\text{C-F}} = 11.9$  Hz), 133.2 (C), 130.8 (CH), 127.2 (CH), 126.7 (CH), 124.5 (C, d,  $^4J_{\text{C-F}} = 1.0$  Hz), 123.9 (C-1, d,  $^3J_{\text{C-F}} = 9.5$  Hz), 122.3 (CH), 120.9 (d,  $J_{\text{C-F}} = 2.1$  Hz), 116.0 (CH, d,  $^2J_{\text{C-F}} = 23.7$  Hz), 115.0 (CH, d,  $^2J_{\text{C-F}} = 20.5$  Hz), 79.5 (CH), 69.2 ( $\text{CH}_2$ ), 30.1 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2972, 2871, 1618, 1580, 1484, 1459, 1053, 764  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 267 ( $\text{M}^+$ , 5), 238 (15), 224 (100), 211 (55), 196 (17); HRMS (EI)  $m/z$  calcd for  $\text{C}_{17}\text{H}_{14}\text{FNO}$  267.1059, found 267.1048.

**6-(1,4-Dioxan-2-yl)phenanthridine (3ab).**<sup>13a</sup> Following the general procedure, compound **3ab** was obtained after column chromatography (hexane/EtOAc 85:15–75:25) as a white solid (69 mg, 0.26 mmol, 52%):  $R_f$  0.25 (8:2 hexane/EtOAc).  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.66 (d,  $J = 8.3$  Hz, 1H), 8.60–8.52 (m, 1H), 8.48–8.39 (m, 1H), 8.26–8.15 (m, 1H), 7.90–7.80 (m, 1H), 7.78–7.63 (m, 3H), 5.49 (p,  $J = 6.3$  Hz, 1H), 4.34–4.29 (m, 2H), 4.21–4.06 (m, 2H), 3.99–3.88 (m, 2H) ppm;  $^{13}\text{C-NMR}$  (75 MHz,  $\text{CDCl}_3$ )  $\delta$  156.2 (C), 143.3 (C), 133.3 (C), 130.6 (CH), 130.6 (CH), 128.7 (CH), 127.5 (CH), 127.4 (CH), 126.2 (CH), 124.6 (C), 124.1 (C), 122.6 (CH), 122.0 (CH), 76.3 (CH), 70.2 ( $\text{CH}_2$ ), 67.9 ( $\text{CH}_2$ ), 66.7 ( $\text{CH}_2$ ) ppm; IR  $\nu$  2965, 2856, 1114, 10856, 912, 759  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 265 ( $\text{M}^+$ , 4), 206 (100), 179 (24), 151 (12), 102 (5).

### 6-(Tetrahydro-2H-pyran-2-yl)phenanthridine (3ac).

<sup>13c</sup> Following the general procedure, compound **3ac** was obtained after column chromatography (hexane/EtOAc 98:2–9:1) as a white solid (57 mg, 0.22 mmol, 43%):  $R_f$  0.20 (95:5 hexane/EtOAc);  $^1\text{H-NMR}$  (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.62 (ddd,  $J = 8.2, 1.3, 0.6$  Hz, 1H), 8.56–8.50 (m, 2H), 8.25–8.19 (m, 1H), 7.80 (ddd,  $J = 8.3, 7.0, 1.3$  Hz, 1H), 7.74–7.66 (m, 2H), 7.65–7.57 (m, 1H), 5.20 (dd,  $J = 11.1, 2.2$  Hz, 1H), 4.34–4.24 (m, 1H), 3.81 (td,  $J = 11.6, 2.4$  Hz, 1H), 2.37–2.19 (m, 1H), 2.15–2.00 (m, 2H), 1.96–1.77



(m, 2H), 1.74–1.63 (m, 1H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  159.6 (C), 143.4 (C), 133.5 (C), 130.5 (CH), 130.3 (CH), 128.6 (CH), 127.1 (CH), 127.0 (CH), 126.8 (CH), 124.5 (C), 124.1 (C), 122.4 (CH), 121.9 (CH), 80.7 (CH), 69.6 ( $\text{CH}_2$ ), 30.6 ( $\text{CH}_2$ ), 26.1 ( $\text{CH}_2$ ), 24.0 ( $\text{CH}_2$ ) ppm; IR  $\nu$  3075, 2930, 2839, 1083, 1039, 754, 723  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 262 ( $\text{M}^+ - 1$ , 1), 235 (20), 206 (100), 193 (12).

#### 6-(2-Isopropoxypropan-2-yl)phenanthridine (3ad).<sup>13c</sup>

Following the general procedure, compound **3ad** was obtained after column chromatography (100% hexane to hexane/EtOAc 98:2) as a brown pale oil (79 mg, 0.28 mmol, 57%):  $R_f$  0.29 (100% hexane);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  9.25 (ddd,  $J = 8.5$ , 1.4, 0.6 Hz, 1H), 8.70–8.64 (m, 1H), 8.57 (dd,  $J = 8.0$ , 1.6 Hz, 1H), 8.17–8.12 (m, 1H), 7.81 (ddd,  $J = 8.3$ , 7.0, 1.3 Hz, 1H), 7.77–7.61 (m, 3H), 3.75 (p,  $J = 6.1$  Hz, 1H), 1.92 (s, 6H), 1.02 (d,  $J = 6.1$  Hz, 6H) ppm;  $^{13}\text{C}$ -NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  163.7 (C), 142.9 (C), 133.9 (C), 130.6 (CH), 130.3 (CH), 129.9 (CH), 128.5 (CH), 127.0 (CH), 126.1 (CH), 124.5 (C), 124.1 (C), 122.3 (CH), 121.9 (CH), 81.8 (C), 67.0 (CH), 29.1 ( $\text{CH}_3$ ), 24.8 ( $\text{CH}_3$ ); IR  $\nu$  2983, 2933, 1578, 1379, 1162, 1110, 996, 760, 730  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 264 ( $\text{M}^+$ , 0.2), 236 (18), 221 ( $[\text{M}^+ - \text{C}_5\text{H}_7\text{O}]$ , 100), 204 (34), 179 (54), 150 (18); HRMS (EI)  $m/z$  calcd for  $\text{C}_{16}\text{H}_{14}\text{N}$  220.1126, found 220.1128.

**6-(1-Butoxybutyl)phenanthridine (3ae).**<sup>13b</sup> Following the general procedure, compound **3ae** was obtained after column chromatography (hexane/EtOAc 99:1–98:2) as a yellow oil (123 mg, 0.40 mmol, 80%):  $R_f$  0.65 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.94–8.89 (m, 1H), 8.69–8.64 (m, 1H), 8.57 (dd,  $J = 8.0$ , 1.6 Hz, 1H), 8.20–8.15 (m, 1H), 7.84 (ddd,  $J = 8.3$ , 7.0, 1.3 Hz, 1H), 7.77–7.62 (m, 3H), 4.98 (dd,  $J = 8.8$ , 5.4 Hz, 1H), 3.52–3.33 (m, 2H), 2.28–2.13 (m, 1H), 2.01–1.87 (m, 1H), 1.76–1.46 (m, 4H), 1.40–1.23 (m, 4H), 0.95 (t,  $J = 7.4$  Hz, 3H), 0.83 (t,  $J = 7.3$  Hz, 3H) ppm;  $^{13}\text{C}$ -NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  161.9 (C), 143.4 (C), 133.5 (C), 130.5 (CH), 130.2 (CH), 128.7 (CH), 127.0 (CH), 124.5 (C), 124.1 (C), 122.4 (CH), 122.0 (CH), 86.5 (CH), 69.5 ( $\text{CH}_2$ ), 38.3 ( $\text{CH}_2$ ), 32.2 ( $\text{CH}_2$ ), 20.0 ( $\text{CH}_2$ ), 19.5 ( $\text{CH}_2$ ), 14.1 ( $\text{CH}_3$ ), 14.0 ( $\text{CH}_3$ ) ppm; IR  $\nu$  2957, 2932, 2870, 1759, 1459, 1092, 727  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 265 ( $\text{M}^+ - \text{C}_3\text{H}_6$ , 12), 250 (9), 235 (37), 206 (100), 151 (9).

#### 6-(2-Methyltetrahydrofuran-2-yl)phenanthridine (3af).

Following the general procedure, compound **3af** was obtained after column chromatography (hexane/EtOAc 99:1–9:1) as a colorless oil (43 mg, 0.16 mmol, 33%):  $R_f$  0.75 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  9.14 (d,  $J = 8.4$  Hz, 1H), 8.63 (d,  $J = 8.3$  Hz, 1H), 8.53 (dd,  $J = 8.1$ , 1.5 Hz, 1H), 8.12 (d,  $J = 8.0$  Hz, 1H), 7.78 (ddd,  $J = 8.1$ , 6.6, 1.2 Hz, 1H), 7.72–7.58 (m, 3H), 4.14–4.03 (m, 1H), 3.80–3.69 (m, 1H), 3.66–3.56 (m, 1H), 2.10–1.88 (m, 3H), 1.83 (s, 3H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  163.1, 142.9, 134.0, 130.4, 130.0, 129.3, 128.4, 126.9, 126.6, 124.4, 124.1, 122.4, 121.9, 88.7, 68.1, 37.4, 28.2, 25.2 ppm; IR  $\nu$  3065, 2970, 2930, 2872, 1570, 1097, 758  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 263 ( $\text{M}^+$ , 18), 235 (48), 207 (86), 179 (55), 85 (100); HRMS (EI) calcd for  $\text{C}_{18}\text{H}_{17}\text{NO}$  263.1310, found 263.1308.

**6-(5-Methyltetrahydrofuran-2-yl)phenanthridine (3'af).** From the same reaction where compound **3af** was obtained, and

after column chromatography (hexane/EtOAc 99:1–9:1), isomer **3'af** was isolated as a white solid (26 mg, 0.10 mmol, 21%) [*trans/cis* mixture in a 58:42 ratio ( $^1\text{H}$ -NMR)]:  $R_f$  0.75 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.62 (d,  $J = 8.3$  Hz, 1.10H), 8.53 (d,  $J = 8.2$  Hz, 1.51H), 8.46 (d,  $J = 7.9$  Hz, 0.6H), 8.21–8.15 (m, 1H), 7.81 (ddt,  $J = 8.3$ , 7.0, 1.3 Hz, 1.09H), 7.75–7.59 (m, 3.58H), 5.91 (t,  $J = 6.9$  Hz, 0.58H), 5.69 (t,  $J = 7.1$  Hz, 0.42H), 4.53–4.43 (m, 0.64H), 4.37–4.27 (m, 0.47H), 2.91–2.73 (m, 1.06H), 2.52–2.42 (m, 0.62H), 2.42–2.27 (m, 1.02H), 2.27–2.14 (m, 0.44H), 1.87–1.67 (m, 1.5H), 1.39 (dd,  $J = 6.1$ , 3.3 Hz, 3H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  159.9 (C), 159.2 (C), 143.34 (C), 143.28 (C), 133.43 (C), 133.42 (C), 130.5 (CH), 130.4 (CH), 128.6 (CH), 128.6 (CH), 127.3 (CH), 127.3 (CH), 127.0 (CH), 126.9 (CH), 126.7 (CH), 125.1 (C), 124.9 (C), 124.3 (C), 124.2 (C), 122.5 (CH), 122.4 (CH), 122.0 (CH), 80.6 (CH), 79.2 (CH), 76.1 ( $\text{CH}_2$ ), 33.9 ( $\text{CH}_2$ ), 33.2 ( $\text{CH}_2$ ), 30.6 ( $\text{CH}_2$ ), 30.0 ( $\text{CH}_2$ ), 21.6 ( $\text{CH}_3$ ), 21.4 ( $\text{CH}_3$ ) ppm; IR  $\nu$  3074, 2971, 2929, 2877, 2861, 1583, 1444, 1073, 725  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 263 ( $\text{M}^+$ , 11), 220 (72), 208 (100), 179 (58); HRMS (EI) calcd for  $\text{C}_{18}\text{H}_{17}\text{NO}$  263.1310, found 263.1301.

**6-(tert-Butoxymethyl)phenanthridine (3ag).**<sup>13c</sup> Following the general procedure, compound **3ag** was obtained after column chromatography (hexane/EtOAc 95:5–93:2) as a yellow solid (53 mg, 0.20 mmol, 40%):  $R_f$  0.24 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.61 (d,  $J = 8.3$  Hz, 1H), 8.53 (td,  $J = 8.1$ , 1.3 Hz, 2H), 8.17 (dd,  $J = 7.8$ , 1.4 Hz, 1H), 7.87–7.79 (m, 1H), 7.75–7.61 (m, 3H), 5.09 (s, 2H), 1.40 (s, 9H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  158.7 (C), 143.6 (C), 133.4 (C), 130.6 (CH), 130.2 (CH), 128.6 (CH), 127.6 (CH), 127.3 (CH), 127.1 (CH), 125.7 (C), 124.5 (C), 122.2 (CH), 122.0, 74.7 (CH), 66.9 ( $\text{CH}_2$ ), 27.9 (3 $\text{CH}_3$ ) ppm; IR  $\nu$  2974, 2932, 1719, 1364, 1145, 760  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 265 ( $[(\text{M} + 1)^+ - \text{CH}_3]$ , 1), 235 (37), 208 (100), 192 (48), 180 (51), 165 (25).

#### 6-((Benzyloxy)(phenyl)methyl)phenanthridine (3ah).

Following the general procedure, compound **3ah** was obtained after column chromatography (hexane/EtOAc 99:1–98:2) as a yellow solid (32 mg, 0.08 mmol, 17%):  $R_f$  0.5 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.65–8.55 (m, 3H), 8.30–8.25 (m, 1H), 7.81–7.66 (m, 3H), 7.57–7.43 (m, 3H), 7.39–7.25 (m, 7H), 7.24–7.19 (m, 1H), 6.27 (s, 1H), 4.73 (d,  $J = 11.7$  Hz, 1H), 4.64 (d,  $J = 11.7$  Hz, 1H) ppm;  $^{13}\text{C}$ -NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  159.9 (C), 143.4 (C), 140.8 (C), 138.3 (C), 133.9 (C), 130.5 (CH), 130.5 (CH), 128.8 (CH), 128.4 (CH), 128.3 (CH), 128.0 (CH), 127.7 (CH), 127.4 (CH), 127.1 (CH), 126.3 (CH), 124.5 (C), 124.3 (C), 122.3 (CH), 122.1 (CH), 86.5 (CH), 71.7 ( $\text{CH}_2$ ) ppm; IR  $\nu$  3060, 3029, 2915, 2850, 1572, 1449, 1067, 722  $\text{cm}^{-1}$ . LRMS (EI-DIP)  $m/z$  (%) = 284 ( $\text{M}^+ - \text{C}_7\text{H}_7$ , 52), 269 (100), 268 (52), 178 (16), 91 (32); HRMS (EI) calcd for  $\text{C}_{27}\text{H}_{21}\text{NO}$  375.1623, found 375.1605.

**6-Benzylphenanthridine (3'ah).**<sup>26</sup> From the same reaction where compound **3ah** was obtained, and after column chromatography (hexane/EtOAc 99:1–98:2), compound **3'ah** was isolated as a yellow solid (62 mg, 0.23 mmol, 46%):  $R_f$  0.5 (9:1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.56 (br d,  $J = 8.3$  Hz, 1H), 8.51 (dd,  $J = 8.2$ , 1.4 Hz, 1H), 8.18 (ddd,  $J = 9.7$ , 8.1, 1.3 Hz, 2H), 7.72 (ddd,  $J = 8.2$ , 7.0, 1.4 Hz, 2H), 7.61 (ddd,



$J = 8.3, 7.0, 1.4$  Hz, 1H), 7.53 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.33–7.28 (m, 2H), 7.26–7.10 (m, 4H), 4.74 (s, 2H) ppm;  $^{13}\text{C}$ -NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  160.2 (C), 143.8 (C), 139.2 (C), 133.3 (C), 130.4 (CH), 129.9 (CH), 128.7 (CH), 128.6 (2CH), 127.4 (CH), 127.1 (CH), 126.7 (CH), 126.4 (CH), 125.4 (C), 124.0 (C), 122.5 (CH), 122.0 (CH), 43.2 ( $\text{CH}_2$ ) ppm; IR  $\nu$  3062, 3025, 1684, 1581, 1362, 723  $\text{cm}^{-1}$ . LRMS (EI-DIP)  $m/z$  (%) = 269 ( $\text{M}^+$ , 41), 268 ( $\text{M}^+ - 1$ , 100), 254(6), 134 (11), 57 (6).

#### 6-(1,3-Dihydroisobenzofuran-1-yl)phenanthridine (3ai).

Following the general procedure, compound 3ai was obtained after column chromatography (hexane/EtOAc 99 : 1–98 : 2) as a yellow crystalline solid (52 mg, 0.17 mmol, 35%);  $R_f$  0.4 (9 : 1 hexane/EtOAc); mp 120–121 °C (3 : 1 EtOAc/MeOH);  $^1\text{H}$ -NMR (400 MHz,  $\text{CDCl}_3$ )  $\delta$  8.65 (br d,  $J = 8.3$  Hz, 1H), 8.56 (dd,  $J = 8.1, 1.4$  Hz, 1H), 8.25 (br d,  $J = 8.3$  Hz, 1H), 8.17 (dd,  $J = 8.0, 1.2$  Hz, 1H), 7.80 (s, 1H), 7.72 (ddd,  $J = 8.2, 7.0, 1.6$  Hz, 1H), 7.66 (ddd,  $J = 8.4, 7.0, 1.5$  Hz, 1H), 7.59 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.41–7.37 (m, 1H), 7.35–7.30 (m, 1H), 7.23–7.13 (m, 2H), 6.97 (t,  $J = 2.5$  Hz, 1H), 5.59 (dd,  $J = 12.3, 2.7$  Hz, 1H), 5.42 (dd,  $J = 12.3, 2.0$  Hz, 1H) ppm;  $^{13}\text{C}$ -NMR (101 MHz,  $\text{CDCl}_3$ )  $\delta$  158.8 (C), 143.4 (C), 140.9 (C), 139.2 (C), 133.9 (C), 130.7 (CH), 130.4 (CH), 128.7 (CH), 128.0 (CH), 127.5 (CH), 127.3 (CH), 127.3 (CH), 126.6 (CH), 124.6 (C), 124.4 (C), 122.8 (CH), 122.6 (CH), 122.0 (CH), 121.3 (CH), 87.8 (CH), 73.8 ( $\text{CH}_2$ ) ppm; IR  $\nu$  3074, 2851, 1572, 1027, 720  $\text{cm}^{-1}$ . LRMS (EI)  $m/z$  (%) = 297 ( $\text{M}^+$ , 2), 268 (100), 251 (3), 119 (12); HRMS (EI) calcd for  $\text{C}_{21}\text{H}_{15}\text{NO}$  297.1154, found 297.1141.

**6-(1,3,5-Trioxan-2-yl)phenanthridine (3aj).** Following the general procedure, compound 3aj was obtained after column chromatography (100% hexane to hexane/EtOAc 8 : 2) as a white solid (96 mg, 0.26 mmol, 52%);  $R_f$  0.2 (9 : 1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  9.10–9.04 (m, 1H), 8.64 (d,  $J = 8.3$  Hz, 1H), 8.60–8.55 (m, 1H), 8.23–8.18 (m, 1H), 7.90–7.83 (m, 1H), 7.79–7.67 (m, 1H), 6.48 (s, 1H), 5.50 (q,  $J = 6.5$  Hz, 4H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  153.6 (C), 142.8 (C), 134.0 (C), 131.0 (CH), 130.6 (CH), 128.9 (CH), 128.3 (CH), 128.1 (CH), 127.4 (CH), 125.0 (C), 123.7 (C), 122.2 ( $2\text{CH}$ ), 106.1 (CH), 94.2 ( $2\text{CH}_2$ ) ppm; IR  $\nu$  3037, 2884, 1418, 1199, 1100, 1047, 944, 750, 723  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 267 ( $\text{M}^+$ , 1), 208 (67), 179 (100), 151 (31); HRMS (EI) calcd for  $\text{C}_{16}\text{H}_{13}\text{NO}_3$  267.0895, found 267.0879.

**6-(Benzo[d][1,3]dioxol-2-yl)phenanthridine (3ak).** Following the general procedure, compound 3ak was obtained after column chromatography (hexane/EtOAc 99 : 1–98 : 2) as a white crystalline solid (90 mg, 0.3 mmol, 60%);  $R_f$  0.49 (9 : 1 hexane/EtOAc); mp 105–107 °C (MeOH);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  8.64 (br d,  $J = 8.3$  Hz, 1H), 8.56 (dd,  $J = 8.0, 1.4$  Hz, 1H), 8.30–8.21 (m, 2H), 7.82 (ddd,  $J = 8.4, 7.0, 1.3$  Hz, 1H), 7.79–7.66 (m, 2H), 7.60 (ddd,  $J = 8.3, 7.0, 1.2$  Hz, 1H), 7.43 (s, 1H), 7.04–6.91 (m, 4H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  152.5 (C), 147.5 (2C), 142.9 (C), 133.9 (C), 130.9 (2CH), 129.0 (CH), 128.4 (CH), 127.7 (CH), 125.9 (CH), 125.0 (C), 123.8 (C), 122.6 (CH), 122.3 (2CH), 122.1 (CH), 112.2 (CH), 109.4 (2CH) ppm; IR  $\nu$  3078, 2909, 1479, 1338, 1229, 724  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 299 ( $\text{M}^+$ , 2), 270 (100), 241 (9), 178 (7); HRMS (EI) calcd for  $\text{C}_{20}\text{H}_{13}\text{NO}_2$  299.0946, found 299.0949.

**Phenanthridine (4a).**<sup>13a</sup> This compound was obtained as the by-product of 3aa and of all compounds represented in Scheme 3. After purification by column chromatography (hexane/EtOAc 9 : 1), it was isolated as a white solid.  $R_f$  0.25 (9 : 1 hexane/EtOAc);  $^1\text{H}$ -NMR (300 MHz,  $\text{CDCl}_3$ )  $\delta$  9.28 (s, 1H), 8.63–8.54 (m, 1H), 8.20 (dd,  $J = 8.1, 1.3$  Hz, 1H), 8.03 (br d,  $J = 7.9$  Hz, 1H), 7.84 (ddd,  $J = 8.4, 7.1, 1.4$  Hz, 1H), 7.78–7.63 (m, 2H) ppm;  $^{13}\text{C}$ -NMR (75 MHz,  $\text{CDCl}_3$ )  $\delta$  153.7 (CH), 144.6 (C), 132.7 (C), 131.1 (CH), 130.3 (CH), 128.9 (CH), 128.8 (CH), 127.6 (CH), 127.2 (CH), 126.5 (C), 124.2 (C), 122.3 (CH), 122.0 (CH) ppm; IR  $\nu$  2924, 2851, 1457, 1245, 890, 745  $\text{cm}^{-1}$ ; LRMS (EI)  $m/z$  (%) = 179 ( $\text{M}^+$ , 100), 151 (13), 76(100), 179 (8).

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