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Synthesis of α-Aminonaphthalenes via Copper-Catalyzed Aminobenzannulation of (*o*-Alkynyl)arylketones with Amines

Mingliang Zhang,[†] Wenqing Ruan,[†] Hui-Jun Zhang,* Weiwei Li, and Ting-Bin Wen*

Department of Chemistry, College of Chemistry and Chemical Engineering, Xiamen University, Xiamen 361005, Fujian, P. R. China

Supporting Information

ABSTRACT: A copper-catalyzed aminobenzannulation of (*o*-alkynyl)arylketones with amines has been developed. This method features the use of a cheap copper catalyst, the facile annulation involving various amines, and the good functional group tolerance.

Regioselective construction of polysubstituted aromatic compounds is a topic of continued interest due to the prevalence of these structural motifs in natural products, pharmaceuticals, and functional materials. However, classical methods for their synthesis are mainly based on the aromatic substitution, which suffer from relatively low regioselectivity, low efficiency, and harsh conditions. After the pioneering work of Berthelot on thermal cyclotrimerization of acetylene,[1] benzannulation as a synthetically useful strategy for the construction of polysubstituted aromatic compounds has attracted considerable research interest.[2] A large number of efficient benzannulation pathways have been developed,[2] including the transition-metal-catalyzed cyclotrimerization of alkynes,[3] the reaction of chromium Fischer carbene with alkynes (Wulff–Dötz reaction),[4] and the [4 + 2] benzannulation of vinylketenes,[5] *o*-alkynyl benzaldehydes,[6] or enynes with alkynes, etc.[7,8]

Recently, the benzannulations of α-acetylenic aryl ketone derivatives, such as their silyl enol ethers or β-ketoesters, via regioselective intramolecular electrophilic 6-*endo*-dig carbocyclizations have provided a series of efficient pathways for the synthesis of polysubstituted naphthalenes.[9−11] Thereafter, analogous aminobenzannulation reactions of α-acetylenic (hetero)aryl ketones with secondary amines were also developed for the construction of amino-substituted aromatic compounds.[12,13] In 2001, Herndon reported the palladium-catalyzed Sonogashira coupling, followed by cyclization between *o*-bromoacetophenone and 1-hexyne in diethylamine or pyrrolidine as solvents (Scheme 1a).[12a] Later, Belmont developed a metal-free pyrrolidine-triggered aminobenzannulation reaction of α-acetylenic heteroaryl ketones, which were used for the construction of amino-substituted acridines, quinolones, dibenzofurans, and carbazoles (Scheme 1b).[13] However, examples of aminobenzannulation involving primary amines are rare perhaps because they react with ketones preferentially forming the corresponding imines instead of enamines. Moreover, only methyl ketone substrates were included in these transformations.[13b] Therefore, more general and practical processes for aminobenzannulation of α-acetylenic aryl ketones need to be developed.

As a class of unique aromatic molecules, α-aminonaphthalene and its derivatives have been widely used in dye manufacturing, polymer science, etc.[8e,10b,14,15] Recently, the photophysics of several α-aminonaphthalene derivatives have also attracted much attention.[16] Therefore, as a continuation of our research on copper-mediated cyclization reactions of *o*-alkynylbenzaldimines,[17] we envisioned the synthesis of α-aminonaphthalenes via copper-catalyzed aminobenzannulation of α-acetylenic aryl ketones with various amines. Herein, we report on the realization of this transformation (Scheme 1c).

Initially, the reaction of 2-(phenylethynyl)acetophenone (**1a**) with 1 equiv of aniline (**2a**) in the presence of 5 mol % $Cu(OAc)_2·H_2O$ in toluene was conducted at 130 °C in air for 12 h. To our surprise, the carbannulation product naphthalene-1-amine **3aa** was isolated in 24% yield (Table 1, entry 1). When the amount of aniline was increased to 1.5 or 2 equiv, **3aa** could be isolated in higher yields (67% and 72%, entries 2 and 3). The reaction performed at 100 °C gave **3aa** in relatively lower yield (61%, entry 4). When the reaction was carried out under an argon atmosphere, **3aa** could be obtained almost quantitatively (>99%, entry 5). Decreasing the amount of $Cu(OAc)_2·H_2O$ to 2.5 mol % still led to an excellent yield of **3aa** (96%, entry 6). However, by further decreasing the catalyst loading to 1.0 mol %, **3aa** could be isolated in only 57% yield (entry 7). Notably, no aminobenzannulation product was observed in the absence of $Cu(OAc)_2·H_2O$ (entry 8). Thereafter, several solvents, such as *t*-Am-OH, PhCl, DMF, and 1,4-dioxane, were screened, and toluene proved the best choice (entries 9−12). Furthermore, several metal catalysts including $CuCl_2$, $Cu(OTf)_2$, anhydrous $Cu(OAc)_2$, CuOAc, CuI, $Pd(OAc)_2$, $Zn(OAc)_2$, and $Fe(OAc)_2$ were tested, which could also catalyze the transformation, albeit with inferior yields (entries 13−20).

Having the optimized reaction conditions in hand, the scope of this transformation was investigated with various amines (Table 2). Several *para*-substituted arylamines proceeded well and both electron-rich and electron-deficient substituents were

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Scheme 1. Aminobenzannulation of α-Acetylenic Aryl Ketones

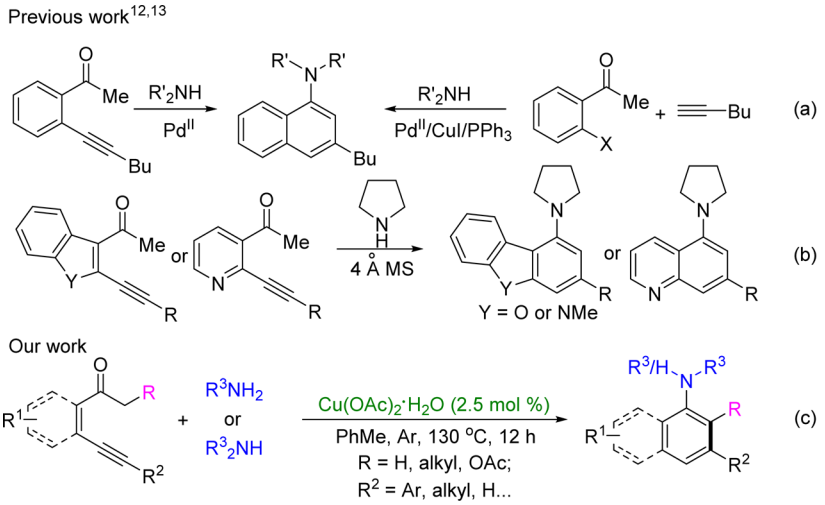
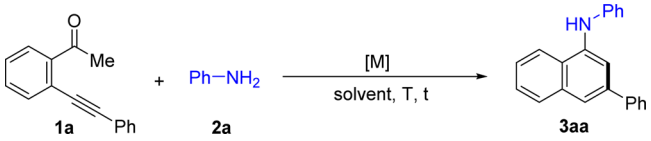


Table 1. Optimization of the Reaction Conditions[a]

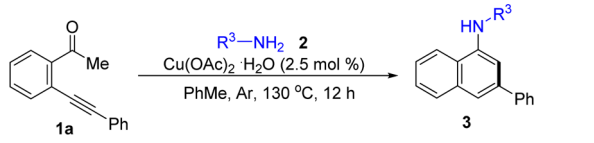


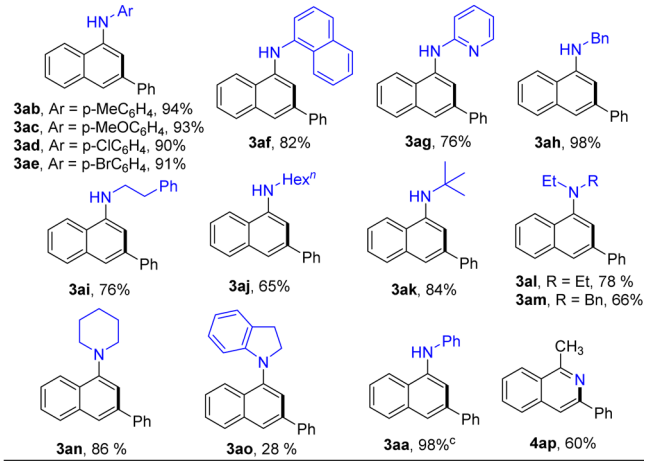
entry	[M] (mol %)	solvent	air/Ar	yield (%)[b]
1[c]	$Cu(OAc)_2·H_2O$ (5.0)	PhMe	air	24
2[d]	$Cu(OAc)_2·H_2O$ (5.0)	PhMe	air	67
3	$Cu(OAc)_2·H_2O$ (5.0)	PhMe	air	72
4[e]	$Cu(OAc)_2·H_2O$ (5.0)	PhMe	air	61
5	$Cu(OAc)_2·H_2O$ (5.0)	PhMe	Ar	>99
6	$Cu(OAc)_2·H_2O$ (2.5)	PhMe	Ar	96
7	$Cu(OAc)_2·H_2O$ (1.0)	PhMe	Ar	57
8		PhMe	Ar	0
9	$Cu(OAc)_2·H_2O$ (2.5)	*t*-Am-OH	Ar	93
10	$Cu(OAc)_2·H_2O$ (2.5)	PhCl	Ar	82
11	$Cu(OAc)_2·H_2O$ (2.5)	DMF	Ar	71
12	$Cu(OAc)_2·H_2O$ (2.5)	1,4-dioxane	Ar	41
13	$CuCl_2$ (2.5)	PhMe	Ar	52
14	$Cu(OTf)_2$ (2.5)	PhMe	Ar	77
15	$Cu(OAc)_2$ (2.5)	PhMe	Ar	86
16	CuOAc (2.5)	PhMe	Ar	89
17	CuI (2.5)	PhMe	Ar	11
18	$Pd(OAc)_2$ (2.5)	PhMe	Ar	69
19	$Zn(OAc)_2$ (2.5)	PhMe	Ar	35
20	$Fe(OAc)_2$ (2.5)	PhMe	Ar	trace

[a]Reaction condtions: **1a** (0.2 mmol), **2a** (0.4 mmol), [M], solvent (1.5 mL), 130 °C, sealed, 12 h. [b]Isolated yield of **3aa**. [c]**2a** (0.2 mmol). [d]**2a** (0.3 mmol). [e]100 °C.

tolerated (**3ab**–**3ae**).[18] Other aromatic amines, such as α-naphthylamine and 2-aminopyridine, also reacted with **1a**, forming the corresponding annulation products in good yields (**3af** and **3ag**). Interestingly, the reaction of benzylamine **2h** with **1a** gave rise to the desired product **3ah** in 98% yield. Furthermore, other aliphatic amines were also suitable substrates, including sterically bulky *tert*-butylamine (**3ai**–**3ak**). Under the standard conditions, a series of secondary amines also reacted smoothly with 2-(phenylethynyl)-acetophenone (**1a**), affording the corresponding products in moderate to good yields (**3al**–**3ao**).[19] We have also checked

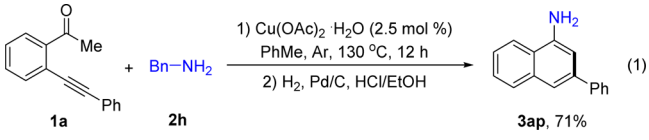
Table 2. Investigation of Scope in Amines[a,b]





[a]Reaction condtions: **1a** (0.2 mmol), **2** (0.4 mmol), $Cu(OAc)_2·H_2O$ (2.5 mol %), PhMe (1.5 mL), Ar, 130 °C, sealed, 12 h. [b]Isolated yield. [c]Yield of 4 mmol scale reaction (1.19 g of **3aa**).

the scalability of the reaction with the 4.0 mmol scale synthesis of **3aa** in 98% yield (1.19 g). Notably, the reaction between amonia **2p** and **1a** could only afford the corresponding imino-cyclization product **4ap** in 60% yield.[20] Therefore, to achieve the corresponding 1-amino-3-phenyl-naphthalene (**3ap**), we conducted the aminobenzannulation of **1a** with benzylamine **2h**, followed by efficient N-debenzylation under mild conditions, which produced the desired product **3ap** in 71% yield (eq 1).



Subsequently, the scope of α-acetylenic aryl ketones **1** was studied (Table 3). Various substituents including both aromatic

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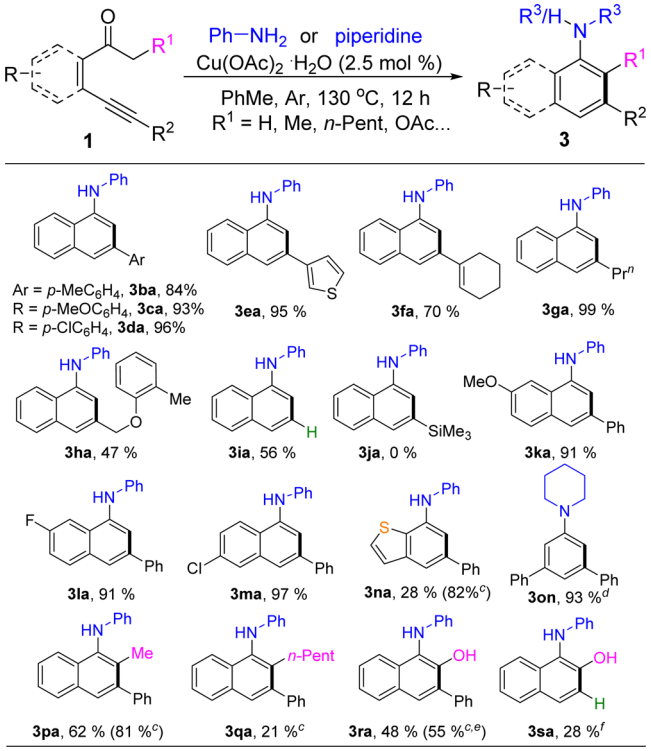
Table 3. Investigation of Scope in (*o*-Alkynyl)arylketones[a,b]

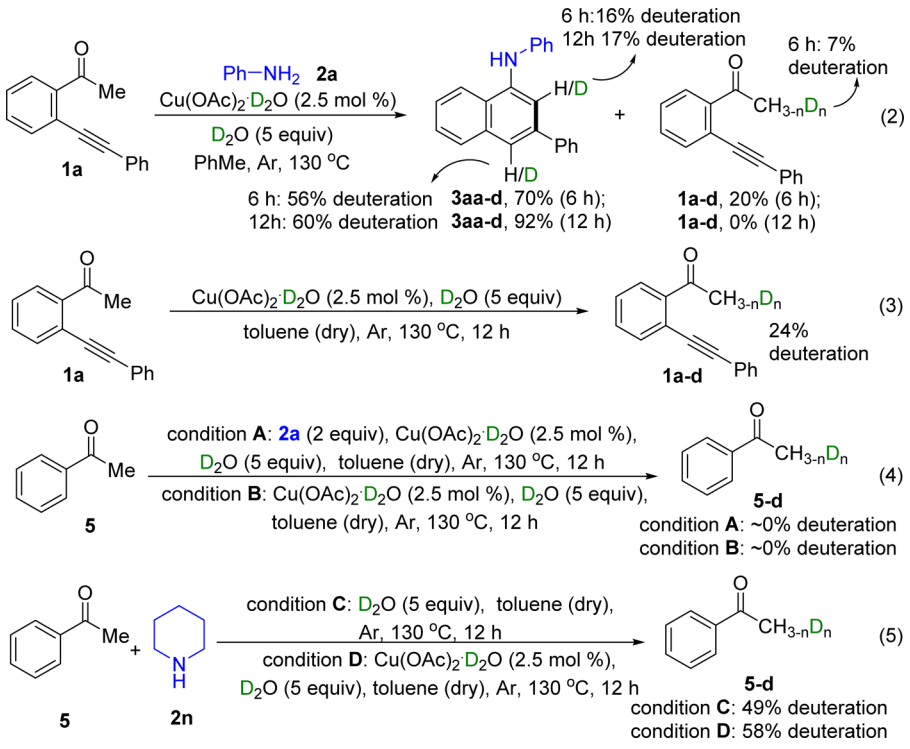


[a]Reaction condtions: **1** (0.2 mmol), **2** (0.4 mmol), $Cu(OAc)_2·H_2O$ (2.5 mol %), PhMe (1.5 mL), Ar, 130 °C, sealed, 12 h. [b]Isolated yield. [c]$Cu(OAc)_2·H_2O$ (7.5 mol %). [d]100 °C. [e]$PhNH_2$ (3 equiv). [f]KF (1.02 equiv), AcOH (1.3 equiv).

and aliphatic substituents on the alkynyl group were well tolerated (**3ba**−**3ha**). The reaction of terminal alkyne **1i** with aniline **2a** could afford the corresponding annulation product **3ia** in 56% yield. However, the annulation of **1j** involving the trimethylsilyl-substituted alkynyl group with aniline **2a** was not observed. Moreover, both electron-donating and electron-withdrawing groups on the phenyl ring have little effect on the reaction (**3ka**−**3ma**). Notably, 1-(3-(phenylethynyl)-thiophen-2-yl)ethan-1-one (**1n**) could also react with **2a**, giving the desired product **3na** in 28% yield. Increasing the amount of $Cu(OAc)_2·H_2O$ to 7.5 mol % led to the formation of **3na** in 82% yield. Interestingly, the reaction of (*Z*)-4,6-diphenylhex-3-en-5-yn-2-one (**1o**) with piperidine (**2n**) worked smoothly at 100 °C, affording 1-([1,1′:3′,1″-terphenyl]-5′-yl)piperidine (**3on**) in 93% yield.[21] Besides methylketone, aryl ethylketone **1p** and even aryl *n*-hexyl ketone **1q** could also react with aniline, affording the desired products, albeit in relatively lower yields (**3pa** and **3qa**). Notably, 2-oxo-2-(2-(phenylethynyl)-phenyl)ethyl acetate (**1r**) also reacted with aniline under the standard conditions, affording 3-phenyl-1-(phenylamino)-naphthalen-2-ol (**3ra**) as major product.[18] The acetyl group was removed during the reaction process. Similarly, 2-oxo-2-(2-((trimethylsilyl)ethynyl)phenyl)ethyl acetate (**1s**) reacted with aniline through the addition of KF and AcOH, which gave rise to the corresponding 1-(phenylamino)naphthalen-2-ol (**3sa**) in 28% yield. Traditionally, the *ortho*-aminated naphthols are synthesized through nitration/reduction, which suffered from harsh conditions and limited generality.[22]

Several deuterium labeling experiments were performed to understand the mechanism (Scheme 2). Initially, the reaction of **1a** with **2a** in the presence of 2.5 mol % $Cu(OAc)_2·D_2O$ and 5 equiv of D_2O in toluene at 130 °C for 12 h provided the corresponding product **3aa-d** in 92% yield with deuterium incorporation at C-2 (17% deuteration) and C-4 (60% deuteration) position. When the reaction was performed under the same conditions for only 6 h, **3aa-d** was isolated in

Scheme 2. Mechanism Study



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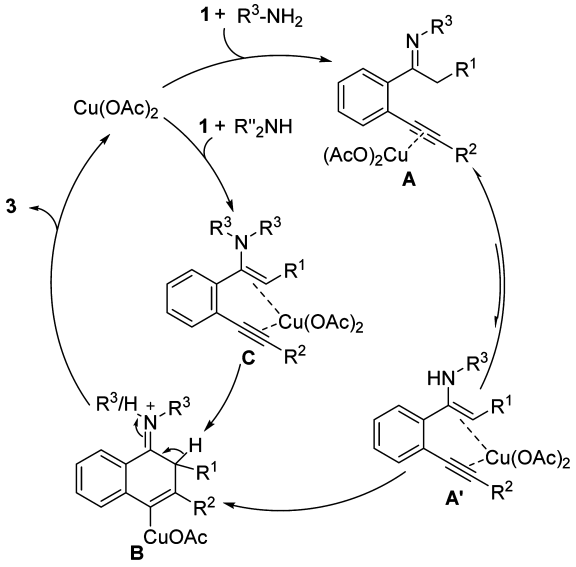
70% yield with similar deuteration results (eq 2). Notably, 20% of the starting compound **1a** was recovered and 7% deuteration of the methyl group was observed. Furthermore, it was also found that treatment of **1a** with 2.5 mol % $Cu(OAc)_2·D_2O$ in the presence of 5 equiv of D_2O in toluene at 130 °C for 12 h led to 24% deuteration of the methyl group (eq 3; also see the Supporting Information). However, both the reactions of simple acetophenone (**5**) with and without aniline (**2a**) under similar reaction conditions could not give the deuterated acetophenone (**5-d**) (eq 4; also see the Supporting Information). All of these results indicated that the coordination ability of copper and the directing effect of the alkynyl group could facilitate the keto−enol or imine−enamine tautomerization. On the contrary, the reaction of **5** with piperidine (**2n**) in the presence of 5 equiv of D_2O produced the deuterated acetophenone (**5-d**) with 49% deuteration of the methyl group. Moreover, the addition of 2.5 mol % of $Cu(OAc)_2$ led to a higher deuteration ratio (58%, eq 5). Thereafter, the reaction of **1a** with piperidine (**2n**) in the absence of $Cu(OAc)_2·H_2O$ was also carried out at 130 °C for 12 h, and only a trace amount of annulation product **3an** was observed (see the Supporting Information). These results indicated the dual roles of $Cu(OAc)_2·H_2O$ in the annulation of **1a** with secondary amines.

On the basis of the above results, a tentative mechanism for the aminobenzannulations of (*o*-alkynyl)arylketone **1** with primary and secondary amines was proposed (Scheme 3). First,

Scheme 3. Proposed Mechanism



the condensation of (*o*-alkynyl)arylketone **1** with primary amine R^3NH_2 leads to the formation of an imine intermediate which may coordinate with $Cu(OAc)_2$ to form the intermediate **A**. The Cu(II)-promoted tautomerization of imine **A** to enamine **A′**, followed by 6-*endo*-dig carbocyclization, afforded the intermediate **B**.[23,24] On the other hand, secondary amine $R^3{}_2NH$ reacted with **1** directly, affording the enamine intermediate **C**, which may also undergo Cu(II)-mediated 6-*endo*-dig carbocyclization to form intermediate **B**. Finally, the protonolysis of intermediated **B** gave the desired product **3**.

In conclusion, we have developed an efficient copper-catalyzed aminobenzannulation reaction of α-acetylenic (hetero)aryl ketones with primary and secondary amines. A series of amino-substituted aromatic compounds, especially α-aminonaphthalenes, could be synthesized through this transformation. The mechanistic studies indicated that, for the reaction of primary amines, the presence of both an *ortho*-alkynyl group and Cu(II) facilitated the imine−enamine tautomerization, which is essential for the following 6-*endo*-dig carbocyclizations.

EXPERIMENTAL SECTION

General Information. All commercial reagents were used without further purification. The (*o*-alkynyl)arylketones were prepared according to the literature.[25] ^1H and ^{13}C NMR spectra were recorded at 500 MHz in $CDCl_3$, CD_2Cl_2, or DMSO-d_6 solutions. High-resolution mass spectra were recorded on an FT-MS instrument using the ESI technique.

General Procedures for the Synthesis of α-Aminonaphthalenes. To a 15 mL tube were added (*o*-alkynyl)arylketone **1** (0.2 mmol), amine **2** (0.4 mmol), $Cu(OAc)_2·H_2O$ (0.005 mmol), and 1.5 mL of degassed toluene under an Ar atmosphere. Then, the tube was sealed with a Teflon lined cap, and the resulting mixture was stirred at 130 °C for 12 h. Finally, the reaction mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1) to give desired product **3**.

N,3-diphenylnaphthalen-1-amine (***3aa***). Light yellow solid; mp 95−97 °C; yield: 96% (57 mg); ^1H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.97 (d, *J* = 8.1 Hz, 1H), 7.83 (s, 1H), 7.76−7.71 (m, 3H), 7.61−7.56 (m, 1H), 7.55−7.49 (m, 3H), 7.45−7.40 (m, 1H), 7.37−7.32 (m, 2H), 7.12 (dd, *J* = 8.5, 0.9 Hz, 2H), 7.00 (t, *J* = 7.4 Hz, 1H), 6.05 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.7, 141.1, 139.4, 139.0, 135.1, 129.6, 129.0, 128.9, 127.5, 127.5, 126.9, 126.7, 125.8, 121.8, 120.9, 120.8, 117.6, 115.3; HRMS (ESI), *m*/*z* calcd. For $C_{22}H_{17}NNa$ [(M + Na)$^+$] 318.1259, found 318.1254.

3-Phenyl-N-(p-tolyl)naphthalen-1-amine (***3ab***). Light yellow liquid; yield: 94% (58 mg); ^1H NMR (500 MHz, $CDCl_3$) δ 8.09 (d, *J* = 8.5 Hz, 1H), 8.01 (d, *J* = 8.1 Hz, 1H), 7.83 (s, 1H), 7.78 (dt, *J* = 8.2, 1.7 Hz, 2H), 7.71 (d, *J* = 1.7 Hz, 1H), 7.62 (ddd, *J* = 8.1, 6.9, 1.1 Hz, 1H), 7.58−7.52 (m, 3H), 7.49−7.44 (m, 1H), 7.22 (d, *J* = 8.0 Hz, 2H), 7.15−7.08 (m, 2H), 6.03 (brs, 1H), 2.45 (s, 3H). ^{13}C NMR (126 MHz, $CDCl_3$) δ 141.7, 141.3, 140.2, 139.0, 135.1, 130.7, 130.1, 129.0, 128.9, 127.5, 126.6, 126.3, 125.6, 121.5, 120.0, 118.8, 113.5, 20.8; HRMS (ESI), *m*/*z* calcd. For $C_{23}H_{19}NNa$ [(M + Na)$^+$] 332.1415, found 332.1411.

N-(4-Methoxyphenyl)-3-phenylnaphthalen-1-amine (***3ac***). Light yellow liquid; yield: 93% (61 mg); ^1H NMR (500 MHz, CD_2Cl_2) δ 8.07 (d, *J* = 8.4 Hz, 1H), 7.99 (d, *J* = 8.0 Hz, 1H), 7.78−7.73 (m, 3H), 7.61 (ddd, *J* = 8.1, 6.8, 1.2 Hz, 1H), 7.58−7.50 (m, 3H), 7.49 (d, *J* = 1.7 Hz, 1H), 7.46−7.40 (m, 1H), 7.24−7.18 (m, 2H), 7.02−6.96 (m, 2H), 6.10 (brs, 1H), 3.87 (s, 3H); ^{13}C NMR (126 MHz, CD_2Cl_2) δ 155.4, 141.7, 141.3, 138.9, 136.7, 135.1, 128.9, 128.8, 127.4, 127.3, 126.5, 125.4, 125.1, 122.2, 121.0, 118.6, 114.8, 110.7, 55.5; HRMS (ESI), *m*/*z* calcd. For $C_{23}H_{19}NNaO$ [(M + Na)$^+$] 348.1364, found 348.1362.

N-(4-Chlorophenyl)-3-phenylnaphthalen-1-amine (***3ad***). White solid; mp 130−132 °C; yield: 90% (60 mg); ^1H NMR (500 MHz, $CDCl_3$) δ 8.01 (d, *J* = 8.7 Hz, 1H), 7.98−7.95 (m, 1H), 7.85 (s, 1H), 7.74−7.70 (m, 2H), 7.66 (d, *J* = 1.7 Hz, 1H), 7.58 (ddd, *J* = 8.1, 6.8, 1.2 Hz, 1H), 7.55−7.49 (m, 3H), 7.45−7.41 (m, 1H), 7.28−7.24 (m, 2H), 7.00−6.95 (m, 2H), 5.96 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.5, 140.9, 138.90, 138.87, 135.0, 129.4, 129.0, 128.9, 127.6, 127.3, 127.0, 126.7, 125.9, 125.2, 121.7, 121.4, 118.5, 116.0; HRMS (ESI), *m*/*z* calcd. For $C_{22}H_{16}ClNNa$ [(M + Na)$^+$] 352.0869, found 352.0865.

N-(4-Bromophenyl)-3-phenylnaphthalen-1-amine (***3ae***). Light yellow solid; mp 140−141 °C; yield: 91% (68 mg); ^1H NMR (500 MHz, $CDCl_3$) δ 8.00 (d, *J* = 8.3 Hz, 1H), 7.97 (d, *J* = 8.1 Hz, 1H), 7.86 (s, 1H), 7.76−7.69 (m, 2H), 7.67 (d, *J* = 1.5 Hz, 1H), 7.58 (t, *J* = 7.5 Hz, 1H), 7.50−7.53 (m, 3H), 7.43 (t, *J* = 7.4 Hz, 1H), 7.38−7.40 (m, 2H), 6.91 (d, *J* = 8.8 Hz, 2H), 5.95 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.09, 140.83, 138.89, 138.64, 135.05, 132.28,

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128.98, 128.93, 127.58, 127.34, 127.13, 126.75, 125.96, 121.78, 121.61, 118.71, 116.37, 112.27; HRMS (ESI), m/z calcd. For $C_{22}H_{17}BrN$ [(M + H)$^+$] 374.0544, found 374.0546.

N-(Naphthalen-1-yl)-3-phenylnaphthalen-1-amine (**3af**). Light yellow liquid; yield: 82% (57 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.20 (d, J = 8.4 Hz, 1H), 8.14 (d, J = 8.4 Hz, 1H), 8.03 (d, J = 8.2 Hz, 1H), 7.98 (d, J = 7.7 Hz, 1H), 7.85 (s, 1H), 7.70−7.66 (m, 2H), 7.66−7.52 (m, 5H), 7.50−7.45 (m, 2H), 7.45−7.38 (m, 3H), 7.19 (dd, J = 7.5, 0.8 Hz, 1H), 6.47 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 141.2, 140.8, 140.2, 139.1, 135.1, 134.8, 129.1, 128.83, 128.76, 127.43, 127.40, 127.0, 126.7, 126.31, 126.25, 126.20, 125.81, 125.78, 122.6, 121.81, 121.78, 120.4, 115.6, 115.0; HRMS (ESI), m/z calcd. For $C_{26}H_{19}NNa$ [(M + Na)$^+$] 368.1415, found 368.1413.

N-(3-Phenylnaphthalen-1-yl)pyridin-2-amine (**3ag**). Light yellow solid; mp 197−199 °C; yield: 76% (45 mg); ^{1}H NMR (500 MHz, DMSO) δ 9.03 (s, 1H), 8.29 (s, 1H), 8.23 (d, J = 7.0 Hz, 1H), 8.15 (s, 1H), 8.00 (d, J = 6.7 Hz, 1H), 7.94 (s, 1H), 7.79 (d, J = 6.5 Hz, 2H), 7.58−7.51 (m, 5H), 7.40 (d, J = 5.9 Hz, 1H), 7.02 (d, J = 7.7 Hz, 1H), 6.75 (s, 1H); ^{13}C NMR (126 MHz, DMSO) δ 157.7, 148.0, 140.8, 138.1, 137.9, 137.8, 134.9, 129.5, 129.1, 128.0, 127.4, 127.2, 126.8, 125.9, 123.2, 120.9, 117.7, 115.0, 110.8; HRMS (ESI), m/z calcd. For $C_{21}H_{16}N_2Na$ [(M + Na)$^+$] 319.1211, found 319.1208.

N-Benzyl-3-phenylnaphthalen-1-amine (**3ah**). Light yellow liquid; yield: 98% (61 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97 (d, J = 8.1 Hz, 1H), 7.89 (d, J = 8.4 Hz, 1H), 7.80−7.78 (m, 2H), 7.61−7.54 (m, 6H), 7.54−7.42 (m, 5H), 7.02 (d, J = 1.5 Hz, 1H), 4.83 (s, 1H), 4.63 (s, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.74, 142.15, 139.50, 139.13, 134.72, 129.16, 128.88, 128.82, 127.97, 127.60, 127.54, 127.32, 126.33, 124.94, 122.85, 119.98, 116.05, 104.63, 48.80; HRMS (ESI), m/z calcd. For $C_{23}H_{19}NNa$ [(M + Na)$^+$] 332.1415, found 332.1411.

N-Phenethyl-3-phenylnaphthalen-1-amine (**3ai**). Light yellow liquid; yield: 76% (49 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94−7.90 (m, 1H), 7.82 (dt, J = 8.1, 1.6 Hz, 2H), 7.76 (d, J = 8.5 Hz, 1H), 7.57−7.51 (m, 4H), 7.50−7.40 (m, 4H), 7.39−7.32 (m, 3H), 7.00 (d, J = 1.4 Hz, 1H), 4.55 (brs, 1H), 3.70 (t, J = 7.0 Hz, 2H), 3.18 (t, J = 7.0 Hz, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 143.7, 142.2, 139.5, 139.3, 134.7, 129.1, 128.9, 128.8, 128.8, 127.5, 127.3, 126.7, 126.2, 124.8, 122.9, 119.8, 115.8, 104.3, 45.3, 35.5; HRMS (ESI), m/z calcd. For $C_{24}H_{21}NNa$ [(M + Na)$^+$] 346.1572, found 346.1570.

N-(3-Phenylnaphthalen-1-yl)hexanamide (**3aj**). Light yellow liquid; yield: 65% (39 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.94 (d, J = 8.0 Hz, 1H), 7.88 (d, J = 8.3 Hz, 1H), 7.84−7.86 (m, 2H), 7.50−7.59 (m, 5H), 7.47 (t, J = 7.4 Hz, 1H), 6.96 (s, 1H), 4.45 (brs, 1H), 3.42 (t, J = 7.1 Hz, 2H), 1.95−1.80 (m, 2H), 1.66−1.54 (m, 2H), 1.54−1.42 (m, 4H), 1.05 (t, J = 6.9 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.1, 142.3, 139.6, 134.7, 129.1, 128.8, 127.6, 127.3, 126.2, 124.7, 122.8, 119.8, 115.5, 104.0, 44.4, 31.8, 29.5, 27.2, 22.8, 14.2; HRMS (ESI), m/z calcd. For $C_{22}H_{25}NNa$ [(M + Na)$^+$] 326.1885, found 326.1880.

N-(tert-Butyl)-3-phenylnaphthalen-1-amine (**3ak**). Light yellow solid; mp 101−104 °C; yield: 84% (47 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.90−7.95 (m, 2H), 7.82−7.84 (m 2H), 7.60−7.49 (m, 5H), 7.49−7.44 (m, 1H), 7.31 (d, J = 1.4 Hz, 1H), 4.38 (brs, 1H), 1.63 (s, 9H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.3, 139.0, 135.0, 129.3, 128.8, 127.5, 127.2, 126.0, 124.9, 124.7, 120.4, 116.2, 109.6, 51.8, 30.1; HRMS (ESI), m/z calcd. For $C_{20}H_{22}N$ [(M + H)$^+$] 276.1752, found 276.1748.

N,N-Diethyl-3-phenylnaphthalen-1-amine (**3al**).[12b] Light yellow liquid; yield: 78% (45 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.46−8.38 (m, 1H), 8.00−7.93 (m, 1H), 7.86 (s, 1H), 7.84−7.77 (m, 2H), 7.61−7.55 (m, 4H), 7.50 (d, J = 1.5 Hz, 1H), 7.49−7.45 (m, 1H), 3.37 (q, J = 7.0 Hz, 4H), 1.21 (t, J = 7.1 Hz, 6H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 148.5, 141.8, 138.4, 135.2, 130.5, 128.9, 128.6, 127.5, 127.3, 126.2, 125.3, 124.3, 121.4, 117.9, 47.8, 12.4.

N-Benzyl-N-ethyl-3-phenylnaphthalen-1-amine (**3am**). Light yellow liquid; yield: 66% (45 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.53−8.46 (m, 1H), 7.98−7.91 (m, 1H), 7.82 (s, 1H), 7.77−7.69 (m, 2H), 7.53−7.58 (m, 4H), 7.49−7.50 (m, 2H), 7.46−7.42 (m, 2H), 7.38−7.41 (m, 2H), 7.31 (t, J = 7.3 Hz, 1H), 4.46 (s, 2H), 3.31 (q, J = 7.0 Hz, 2H), 1.16 (t, J = 7.0 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 148.3, 141.7, 139.1, 138.3, 135.2, 129.7, 128.8, 128.7, 128.4, 128.3, 127.5, 127.3, 127.0, 126.2, 125.4, 124.0, 121.5, 118.1, 58.2, 47.1, 11.8; HRMS (ESI), m/z calcd. For $C_{25}H_{24}N$ [(M + H)$^+$] 338.1909, found 338.1904.

1-(3-Phenylnaphthalen-1-yl)piperidine (**3an**).[12b] Light yellow solid; mp 87−88 °C; yield: 86% (50 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.33−8.25 (m, 1H), 7.97−7.90 (m, 1H), 7.84−7.76 (m, 3H), 7.59−7.51 (m, 4H), 7.47−7.42 (m, 1H), 7.40 (d, J = 1.5 Hz, 1H), 3.20 (brs, 4H), 1.95 (dt, J = 10.8, 5.4 Hz, 4H), 1.75 (brs, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 151.6, 141.8, 138.7, 135.0, 128.8, 128.7, 128.4, 127.5, 127.3, 126.2, 125.3, 123.8, 121.0, 114.5, 54.8, 26.8, 24.7.

1-(3-Phenylnaphthalen-1-yl)indoline (**3ao**). Light yellow solid; mp 121−123 °C; yield: 28% (18 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.17 (d, J = 8.4 Hz, 1H), 8.02−7.96 (m, 2H), 7.78 (d, J = 1.6 Hz, 1H), 7.76−7.71 (m, 2H), 7.61−7.55 (m, 1H), 7.54−7.49 (m, 3H), 7.44−7.39 (m, 1H), 7.29 (d, J = 5.1 Hz, 1H), 7.02 (t, J = 7.6 Hz, 1H), 6.80 (t, J = 7.4 Hz, 1H), 6.40 (d, J = 7.9 Hz, 1H), 4.09 (d, J = 57.7 Hz, 2H), 3.49−3.10 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 151.1, 142.9, 140.9, 139.0, 135.1, 130.5, 129.6, 128.9, 128.7, 127.5, 127.4, 127.2, 126.7, 125.8, 124.7, 124.1, 123.5, 119.7, 118.4, 109.1, 55.7, 29.1; HRMS (ESI), m/z calcd. For $C_{24}H_{20}N$ [(M + H)$^+$] 322.1596, found 322.1593.

1-Methyl-3-phenylisoquinoline (**4ap**).[19] Light yellow oil; yield: 60% (26 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.20−8.13 (m, 3H), 7.95 (s, 1H), 7.88 (d, J = 8.2 Hz, 1H), 7.69 (ddd, J = 8.1, 6.9, 1.1 Hz, 1H), 7.59 (ddd, J = 8.2, 6.9, 1.2 Hz, 1H), 7.56−7.50 (m, 2H), 7.46−7.41 (m, 1H), 3.07 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 158.6, 150.1, 139.9, 136.8, 130.0, 128.7, 128.3, 127.6, 127.0, 126.8, 126.6, 125.6, 115.2, 22.7.

N-Phenyl-3-(p-tolyl)naphthalen-1-amine (**3ba**). Light yellow liquid; yield: 84% (52 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, J = 8.4 Hz, 1H), 7.99 (d, J = 8.1 Hz, 1H), 7.86 (s, 1H), 7.76 (d, J = 1.5 Hz, 1H), 7.68 (d, J = 8.1 Hz, 2H), 7.60 (t, J = 7.4 Hz, 1H), 7.56−7.50 (m, 1H), 7.40−7.31 (m, 4H), 7.13 (d, J = 7.6 Hz, 2H), 7.03 (t, J = 7.4 Hz, 1H), 6.04 (brs, 1H), 2.50 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.8, 139.3, 138.9, 138.2, 137.3, 135.1, 129.6, 129.5, 128.9, 127.3, 126.9, 126.6, 125.6, 121.8, 120.7, 120.6, 117.6, 115.4, 21.2; HRMS (ESI), m/z calcd. For $C_{23}H_{19}NNa$ [(M + Na)$^+$] 332.1415, found 332.1410.

3-(4-Methoxyphenyl)-N-phenylnaphthalen-1-amine (**3ca**). Light yellow liquid; yield: 93% (61 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.07 (d, J = 8.4 Hz, 1H), 7.97 (d, J = 8.1 Hz, 1H), 7.81 (s, 1H), 7.72 (d, J = 1.5 Hz, 1H), 7.71−7.66 (m, 2H), 7.58 (t, J = 7.5 Hz, 1H), 7.54−7.48 (m, 1H), 7.37 (t, J = 7.9 Hz, 2H), 7.12 (d, J = 7.7 Hz, 2H), 7.09−7.05 (m, 2H), 7.03 (t, J = 7.4 Hz, 1H), 6.03 (brs, 1H), 3.92 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 159.4, 144.8, 139.3, 138.5, 135.2, 133.6, 129.5, 128.8, 128.4, 126.7, 126.6, 125.5, 121.8, 120.6, 120.2, 117.5, 115.3, 114.4, 55.4; HRMS (ESI), m/z calcd. For $C_{23}H_{19}NNaO$ [(M + Na)$^+$] 348.1364, found 348.1360.

3-(4-Chlorophenyl)-N-phenylnaphthalen-1-amine (**3da**). Light yellow solid; mp 109−111 °C; yield: 96% (64 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.05 (d, J = 8.3 Hz, 1H), 7.95 (d, J = 8.1 Hz, 1H), 7.76 (s, 1H), 7.61−7.64 (m, 3H), 7.58 (t, J = 7.4 Hz, 1H), 7.53 (t, J = 7.0 Hz, 1H), 7.46 (d, J = 8.5 Hz, 2H), 7.35 (t, J = 7.9 Hz, 2H), 7.11 (d, J = 7.7 Hz, 2H), 7.02 (t, J = 7.4 Hz, 1H), 6.03 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.4, 139.6, 139.5, 137.6, 135.0, 133.5, 129.6, 129.0, 129.0, 128.6, 126.8, 126.0, 121.7, 121.0, 120.6, 117.8, 114.4; HRMS (ESI), m/z calcd. For $C_{22}H_{17}ClN$ [(M + H)$^+$] 330.1050, found 330.1045.

N-Phenyl-3-(thiophen-3-yl)naphthalen-1-amine (**3ea**). Light yellow solid; mp 135−138 °C; yield: 95% (57 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.03 (d, J = 8.6 Hz, 1H), 7.92 (d, J = 8.1 Hz, 1H), 7.81 (s, 1H), 7.70 (d, J = 1.6 Hz, 1H), 7.57−7.47 (m, 4H), 7.44 (dd, J = 5.0, 2.9 Hz, 1H), 7.36−7.30 (m, 2H), 7.11−7.07 (m, 2H), 6.99 (tt, J = 7.5, 1.1 Hz, 1H), 6.00 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.7, 142.3, 139.4, 135.1, 133.5, 129.6, 128.8, 127.0, 126.7, 126.5, 126.4, 125.7, 121.8, 120.83, 120.77, 120.0, 117.6, 114.8; HRMS (ESI), m/z calcd. For $C_{20}H_{15}NNaS$ [(M + Na)$^+$] 324.0823, found 324.0818.

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J. Org. Chem. 2016, 81, 1696−1703

*3-(Cyclohex-1-en-1-yl)-N-phenylnaphthalen-1-amine (**3fa**).* Light yellow solid; mp 108−110 °C; yield: 70% (42 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.99 (d, J = 8.3 Hz, 1H), 7.88 (d, J = 8.1 Hz, 1H), 7.62−7.56 (m, 2H), 7.51 (ddd, J = 8.1, 6.8, 1.2 Hz, 1H), 7.45 (ddd, J = 8.2, 6.8, 1.3 Hz, 1H), 7.28−7.33 (m, 2H), 7.05−7.00 (m, 2H), 6.95 (tt, J = 7.4, 1.1 Hz, 1H), 6.27 (ddd, J = 5.6, 3.9, 1.5 Hz, 1H), 5.92 (brs, 1H), 2.60−2.51 (m, 2H), 2.33−2.25 (m, 2H), 1.91−1.83 (m, 2H), 1.71−1.76 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.2, 140.2, 138.3, 136.3, 134.9, 129.4, 128.7, 127.2, 126.3, 125.6, 125.2, 121.8, 120.2, 118.8, 117.0, 114.6, 27.4, 26.0, 23.1, 22.2; HRMS (ESI), m/z calcd. For $C_{22}H_{21}NNa$ [(M + Na)$^+$] 322.1572, found 322.1565.

*N-Phenyl-3-propylnaphthalen-1-amine (**3ga**).* Light yellow liquid; yield: 99% (52 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.04 (d, J = 8.4 Hz, 1H), 7.88 (d, J = 8.1 Hz, 1H), 7.58−7.52 (m, 1H), 7.51−7.43 (m, 2H), 7.39−7.31 (m, 3H), 7.05−7.07 (m, 2H), 7.00 (t, J = 7.3 Hz, 1H), 5.95 (brs, 1H), 2.83−2.74 (m, 2H), 1.86−1.75 (m, 2H), 1.07 (t, J = 7.3 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 145.1, 140.7, 138.5, 135.0, 129.4, 128.1, 126.5, 126.2, 124.9, 121.9, 121.8, 120.3, 117.8, 117.2, 38.4, 24.5, 14.0; HRMS (ESI), m/z calcd. For $C_{19}H_{19}NNa$ [(M + Na)$^+$] 284.1415, found 284.1412.

*N-Phenyl-3-((o-tolyloxy)methyl)naphthalen-1-amine (**3ha**).* Light yellow liquid; yield: 47% (32 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.06 (d, J = 8.2 Hz, 1H), 7.93 (d, J = 8.0 Hz, 1H), 7.66 (s, 1H), 7.52−7.59 (m, 3H), 7.35 (t, J = 7.6 Hz, 2H), 7.26 (d, J = 7.2 Hz, 1H), 7.22 (t, J = 7.8 Hz, 1H), 7.10 (d, J = 8.5 Hz, 2H), 7.02 (t, J = 7.8 Hz, 1H), 6.97 (t, J = 7.1 Hz, 2H), 6.04 (brs, 1H), 5.23 (s, 2H), 2.38 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 156.9, 144.3, 139.4, 135.5, 134.7, 130.8, 129.5, 128.7, 127.2, 127.0, 126.8, 126.5, 125.8, 121.6, 120.9, 120.7, 120.5, 118.0, 113.9, 111.6, 70.0, 16.5; HRMS (ESI), m/z calcd. For $C_{24}H_{21}NNaO$ [(M + Na)$^+$] 362.1521, found 362.1518.

*N-Phenylnaphthalen-1-amine (**3ia**).*[23e] Light yellow solid; mp 61−65 °C; yield: 56% (25 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.08 (d, J = 8.2 Hz, 1H), 7.95−7.90 (m, 1H), 7.63 (d, J = 7.7 Hz, 1H), 7.57−7.51 (m, 2H), 7.45 (t, J = 7.6 Hz, 1H), 7.43 (dd, J = 7.4, 1.6 Hz, 1H), 7.35−7.30 (m, 2H), 7.06−7.04 (m, 2H), 7.00−6.95 (m, 1H), 5.97 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.9, 138.9, 134.8, 129.4, 128.6, 127.8, 126.2, 126.1, 125.7, 123.0, 121.9, 120.5, 117.5, 116.0.

*7-Methoxy-N,3-diphenylnaphthalen-1-amine (**3ka**).* Light yellow liquid; yield: 91% (59 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.87 (d, J = 8.9 Hz, 1H), 7.81 (s, 1H), 7.70−7.72 (m, 3H), 7.52−7.46 (m, 2H), 7.39 (t, J = 7.4 Hz, 1H), 7.35−7.29 (m, 3H), 7.25 (dd, J = 8.9, 2.5 Hz, 1H), 7.04−7.06 (m, 2H), 6.96 (t, J = 7.3 Hz, 1H), 5.86 (brs, 1H), 3.91 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 158.0, 145.2, 141.0, 138.2, 136.6, 130.5, 129.4, 128.8, 128.7, 127.2, 121.4, 120.3, 119.2, 117.4, 117.0, 100.8, 55.4; HRMS (ESI), m/z calcd. For $C_{23}H_{19}NNaO$ [(M + Na)$^+$] 348.1364, found 348.1360.

*7-Fluoro-N,3-diphenylnaphthalen-1-amine (**3la**).* Light yellow liquid; yield: 91% (57 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.93 (dd, J = 8.9, 5.7 Hz, 1H), 7.81 (s, 1H), 7.73 (s, 1H), 7.67−7.73 (m, 3H), 7.49 (t, J = 7.7 Hz, 2H), 7.40 (t, J = 7.4 Hz, 1H), 7.37−7.29 (m, 3H), 7.06 (d, J = 8.1 Hz, 2H), 6.98 (t, J = 7.4 Hz, 1H), 5.83 (s, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 160.8 (d, J = 246.0 Hz), 144.5, 140.6, 138.9 (d, J = 5.5 Hz), 138.1 (d, J = 2.7 Hz), 131.9, 131.2 (d, J = 8.8 Hz), 129.4, 128.8, 128.0 (d, J = 8.2 Hz), 127.4, 127.2, 120.9, 120.6, 117.2, 116.78, 116.77 (d, J = 25.3 Hz), 105.8 (d, J = 22.1 Hz); HRMS (ESI), m/z calcd. For $C_{22}H_{17}FN$ [(M + H)$^+$] 314.1345, found 314.1339.

*6-Chloro-N,3-diphenylnaphthalen-1-amine (**3ma**).* Light yellow liquid; yield: 97% (64 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.97 (d, J = 9.0 Hz, 1H), 7.91 (d, J = 2.1 Hz, 1H), 7.67−7.69 (m, 3H), 7.66 (d, J = 1.6 Hz, 1H), 7.53−7.47 (m, 2H), 7.45−7.39 (m, 2H), 7.36−7.30 (m, 2H), 7.10−7.05 (m, 2H), 7.00 (tt, J = 7.5, 1.0 Hz, 1H), 5.98 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 144.3, 140.6, 140.3, 139.6, 135.8, 132.5, 129.6, 129.0, 127.8, 127.5, 127.4, 126.4, 125.1, 123.7, 121.1, 119.9, 117.8, 115.5; HRMS (ESI), m/z calcd. For $C_{22}H_{17}ClN$ [(M + H)$^+$] 330.1050, found 330.1050.

*N,5-Diphenyl-3a,7a-dihydrobenzo[b]thiophen-7-amine (**3na**).* Light yellow solid; mp 95−97 °C; yield: 82% (50 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, J = 1.4 Hz, 1H), 7.68−7.63 (m, 2H), 7.53 (d, J = 1.3 Hz, 1H), 7.50−7.44 (m, 4H), 7.41−7.33 (m, 3H), 7.17−7.19 (m, 2H), 7.03 (t, J = 7.4 Hz, 1H), 5.76 (brs, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.8, 141.8, 141.5, 139.3, 138.2, 130.5, 129.5, 128.8, 127.5, 127.2, 126.1, 125.2, 121.5, 118.5, 116.2, 112.2; HRMS (ESI), m/z calcd. For $C_{20}H_{15}NNaS$ [(M + Na)$^+$] 324.0823, found 324.0817.

*1-([1,1′:3′,1″-Terphenyl]-5′-yl)piperidine (**3on**).* Light yellow solid; mp 108−111 °C; yield: 93% (58 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.76 (d, J = 7.2 Hz, 4H), 7.55 (t, J = 7.6 Hz, 4H), 7.46 (t, J = 7.4 Hz, 2H), 7.39 (s, 1H), 7.27 (s, 2H), 3.42−3.37 (t, J = 5.4 Hz, 4H), 1.90−1.83 (m, 4H), 1.72 (m, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 153.1, 142.7, 142.1, 128.8, 127.5, 127.4, 117.7, 114.7, 51.0, 26.0, 24.5; HRMS (ESI), m/z calcd. For $C_{23}H_{24}N$ [(M + H)$^+$] 314.1909, found 314.1903.

*2-Methyl-N,3-diphenylnaphthalen-1-amine (**3pa**).* Light yellow solid; mp 167−170 °C; yield: 81% (50 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.10 (d, J = 8.1 Hz, 1H), 7.95 (d, J = 7.7 Hz, 1H), 7.81 (s, 1H), 7.59−7.47 (m, 7H), 7.30−7.25 (m, 2H), 6.88 (t, J = 7.3 Hz, 1H), 6.69 (d, J = 7.9 Hz, 2H), 5.66 (brs, 1H), 2.38 (s, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 147.0, 142.1, 141.9, 135.1, 132.8, 131.6, 130.8, 129.5, 129.4, 128.3, 127.1, 127.0, 126.4, 125.8, 123.6, 118.4, 113.8, 16.6; HRMS (ESI), m/z calcd. For $C_{23}H_{20}N$ [(M + H)$^+$] 310.1596, found 310.1592.

*2-Pentyl-N,3-diphenylnaphthalen-1-amine (**3qa**).* Light yellow liquid; yield: 21% (16 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 8.00 (d, J = 8.2 Hz, 1H), 7.85 (d, J = 7.6 Hz, 1H), 7.67 (s, 1H), 7.51−7.37 (m, 7H), 7.17 (t, J = 7.9 Hz, 2H), 6.78 (t, J = 7.3 Hz, 1H), 6.61 (d, J = 7.7 Hz, 2H), 5.63 (brs, 1H), 2.77−2.64 (m, 2H), 1.36−1.32 (m, 2H), 1.10−1.08 (m, 4H), 0.72 (t, J = 7.0 Hz, 3H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 147.7, 142.1, 141.8, 136.7, 134.8, 132.7, 130.9, 129.4, 129.2, 128.1, 128.0, 127.5, 127.0, 126.2, 125.7, 124.0, 118.2, 113.8, 31.8, 30.0, 29.1, 22.0, 13.8; HRMS (ESI), m/z calcd. For $C_{27}H_{27}NNa$ [(M + Na)$^+$] 388.2041, found 388.2039.

*3-Phenyl-1-(phenylamino)naphthalen-2-ol (**3ra**).* Light yellow solid; mp 186−189 °C; yield: 48% (30 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.89- 7.90 (m, 2H), 7.83−7.76 (m, 2H), 7.70 (d, J = 8.2 Hz, 1H), 7.54 (t, J = 7.6 Hz, 2H), 7.37−7.47 (m, 3H), 7.24 (t, J = 7.9 Hz, 2H), 6.91 (t, J = 7.3 Hz, 1H), 6.75 (d, J = 7.8 Hz, 2H), 5.22 (brs, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 150.0, 146.7, 137.7, 131.2, 130.0, 129.6, 129.5, 129.2, 128.9, 128.7, 128.4, 127.7, 126.9, 123.8, 121.6, 120.0, 119.5, 114.6; HRMS (ESI), m/z calcd. For $C_{22}H_{17}NNaO$ [(M + Na)$^+$] 334.1208, found 334.1205.

*1-(Phenylamino)naphthalen-2-ol (**3sa**).* Light yellow solid; mp 156−158 °C; yield: 28% (13 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.84 (d, J = 8.0 Hz, 1H), 7.81 (d, J = 8.9 Hz, 1H), 7.70 (d, J = 8.4 Hz, 1H), 7.43−7.39 (m, 1H), 7.35 (dd, J = 7.9, 4.9 Hz, 2H), 7.21 (t, J = 7.9 Hz, 2H), 6.86 (t, J = 7.3 Hz, 1H), 6.73−6.65 (m, 2H), 6.56 (s, 1H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 152.1, 146.7, 132.1, 129.6, 129.1, 128.6, 127.0, 123.4, 121.4, 119.8, 118.6, 116.9, 114.2; HRMS (ESI), m/z calcd. For $C_{16}H_{13}NNaO$ [(M + Na)$^+$] 258.0895, found 258.0900.

Preparation of 1-Amino-3-phenylnaphthalene. To a 15 mL tube were added 1-(2-(phenylethynyl)phenyl)ethan-1-one **1a** (0.4 mmol), benzylamine **2h** (0.8 mmol), $Cu(OAc)_2{\cdot}H_2O$ (0.01 mmol), and 2.0 mL of degassed toluene under an Ar atmosphere. The tube was sealed with a Teflon lined cap, and the reaction mixture was stirred at 130 °C for 12 h. The resulting mixture was purified by column chromatography on silica gel (petroleum ether/ethyl acetate = 50:1) to give 106 mg of **3ah**. Then, **3ah** (106 mg) and Pd/C (0.1 g, 5% Pd basis) were added to a new 15 mL tube which was filled with H_2. After the addition of 0.5 mL of hydrochloric acid and 5 mL of C_2H_5OH, the resulting mixture was stirred at room temperature for 12 h. After the reaction was complete, 1 M KOH solution was added until the pH was around 8. Then, 5 mL of distilled water and 10 mL of ethyl acetate were added to the reaction mixture, and the aqueous layer was extracted with ethyl acetate (10 mL × 3). The combined organic layers were washed with brine, dried over Na_2SO_4, and concentrated under reduced pressure. Finally, the residue was purified by flash column chromatography on silica gel (petroleum ether/ethyl acetate = 5:1) to obtain the product **3ap** in 71% (62 mg).

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J. Org. Chem. 2016, 81, 1696−1703

*3-Phenylnaphthalen-1-amine (**3ap**).*[19] Gray solid; mp 103−106 °C; yield: 71% (62 mg); ^{1}H NMR (500 MHz, $CDCl_3$) δ 7.95 (d, J = 8.1 Hz, 1H), 7.87 (d, J = 8.3 Hz, 1H), 7.79−7.80 (m, 2H), 7.64 (s, 1H), 7.60−7.54 (m, 3H), 7.52 (ddd, J = 8.1, 6.9, 1.3 Hz, 1H), 7.47 (t, J = 7.4 Hz, 1H), 7.10 (d, J = 1.5 Hz, 1H), 4.13 (brs, 2H); ^{13}C NMR (126 MHz, $CDCl_3$) δ 142.7, 141.5, 139.2, 134.8, 129.0, 128.9, 127.5, 127.4, 126.4, 125.0, 123.1, 120.9, 117.2, 109.4; HRMS (ESI), m/z calcd. For $C_{16}H_{14}N$ [(M + H)$^+$] 220.1126, found 220.1131.

■ ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.joc.5b02340.

Text, figures, and NMR spectra for all new compounds (PDF)

Crystallographic data for compound **3ad** (CIF)

Crystallographic data for compound **3ra** (CIF)

■ AUTHOR INFORMATION

Corresponding Authors

*E-mail: meghjzhang@xmu.edu.cn (H.-J.Z.).

*E-mail: chwtb@xmu.edu.cn (T.-B.W.).

Author Contributions

†M. Zhang and W. Ruan contributed equally to this work.

Notes

The authors declare no competing financial interest.

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■ REFERENCES

(1) (a) Berthelot, M. C. *C. R. Acad. Sci.* **1866**, *62*, 905. (b) Berthelot, M. *Ann. Chim.* **1866**, *9*, 445.

(2) For a review, see: (a) Saito, S.; Yamamoto, Y. *Chem. Rev.* **2000**, *100*, 2901. For one review on the synthesis of substituted naphthalenes, see: (b) de Koning, C. B.; Rousseau, A. L.; van Otterlo, W. A. L. *Tetrahedron* **2003**, *59*, 7.

(3) (a) Reppe, W.; Schwekendiek, W. J. *Justus Liebigs Ann. Chem.* **1948**, *560*, 104. (b) Lautens, M.; Klute, W.; Tam, W. *Chem. Rev.* **1996**, *96*, 49. (c) Galan, B. R.; Rovis, T. *Angew. Chem., Int. Ed.* **2009**, *48*, 2830. (d) Dominguez, G.; Pérez-Castells, J. *Chem. Soc. Rev.* **2011**, *40*, 3430. (e) Heller, B.; Hapke, M. *Chem. Soc. Rev.* **2007**, *36*, 1085. (f) Boñaga, L. V. R.; Zhang, H. C.; Gauthier, D. A.; Reddy, I.; Maryanoff, B. E. *Org. Lett.* **2003**, *5*, 4537. (g) Alvarez, S.; Medina, S.; Dominguez, G.; Pérez-Castells, J. *J. Org. Chem.* **2013**, *78*, 9995.

(4) (a) Dötz, K. H. *Angew. Chem., Int. Ed. Engl.* **1975**, *14*, 644. (b) Dötz, K. H.; Tomuschat, P. *Chem. Soc. Rev.* **1999**, *28*, 187. (c) Minatti, A.; Dötz, K. H. *Top. Organomet. Chem.* **2004**, *13*, 123. (d) Waters, M. L.; Wulff, W. D. *Org. Reat.* **2008**, *70*, 121.

(5) (a) Danheiser, R. L.; Gee, S. K. *J. Org. Chem.* **1984**, *49*, 1672. (b) Danheiser, R. L.; Brisbois, R. G.; Kowalczyk, J. J.; Miller, R. F. *J. Am. Chem. Soc.* **1990**, *112*, 3093. (c) Danheiser, R. L.; Dudley, G. B.; Austin, W. F. In *Science of Synthesis*; Danheiser, R. L., Ed.; Thieme: Stuttgart, Germany, 2006; Vol. *23*, p 493. (d) Lam, T. Y.; Wang, Y.-P.; Danheiser, R. L. *J. Org. Chem.* **2013**, *78*, 9396.

(6) (a) Asao, N.; Takahashi, K.; Lee, S.; Kasahara, T.; Yamamoto, Y. *J. Am. Chem. Soc.* **2002**, *124*, 12650. (b) Asao, N.; Nogami, T.; Lee, S.; Yamamoto, Y. *J. Am. Chem. Soc.* **2003**, *125*, 10921. (c) Asao, N.; Aikawa, H.; Yamamoto, Y. *J. Am. Chem. Soc.* **2004**, *126*, 7458. (d) Barluenga, J.; Vázquez-Villa, H.; Ballesteros, A.; González, J. M. *Org. Lett.* **2003**, *5*, 4121.

(7) (a) Danheiser, R. L.; Gould, A. E.; Fernandez de la Predilla, R.; Helgason, A. L. *J. Org. Chem.* **1994**, *59*, 5514. (b) Saito, S.; Salter, M. M.; Gevorgyan, V.; Tsuboya, N.; Tando, K.; Yamamoto, Y. *J. Am. Chem. Soc.* **1996**, *118*, 3970. (c) Burrell, R. C.; Daoust, K. J.; Bradley, A. Z.; DiRico, K. J.; Johnson, R. P. *J. Am. Chem. Soc.* **1996**, *118*, 4218. (d) Gevorgyan, V.; Takeda, A.; Yamamoto, Y. *J. Am. Chem. Soc.* **1997**, *119*, 11313. (e) Gevorgyan, V.; Yamamoto, Y. *J. Organomet. Chem.* **1999**, *576*, 232. (f) Rubina, M.; Conley, M.; Gevorgyan, V. *J. Am. Chem. Soc.* **2006**, *128*, 5818. (g) Gevorgyan, V.; Zatolochnaya, O. V. In *Transition-Metal-Mediated Aromatic Ring Constructions*; Tanaka, K., Ed.; Wiley: Hoboken, NJ, 2013; Chapter 14, p 355.

(8) For selected examples, see: (a) Liedtke, R.; Tenberge, F.; Daniliuc, C. G.; Kehr, G.; Erker, G. *J. Org. Chem.* **2015**, *80*, 2240. (b) Zhu, S.; Xiao, Y.; Guo, Z.; Jiang, H. *Org. Lett.* **2013**, *15*, 898. (c) Viswanathan, G. S.; Wang, M.; Li, C.-J. *Angew. Chem., Int. Ed.* **2002**, *41*, 2138. (d) Dudnik, A. S.; Schwier, T.; Gevorgyan, V. *Org. Lett.* **2008**, *10*, 1465. (e) Chen, Z.; Zeng, W.; Jiang, H.; Liu, L. *Org. Lett.* **2012**, *14*, 5385. For aminobenzannulation, see: (f) Sagar, P.; Fröhlich, R.; Würthwein, E.-U. *Angew. Chem., Int. Ed.* **2004**, *43*, 5694.

(9) (a) Imamura, K.-i.; Yoshikawa, E.; Gevorgyan, V.; Yamamoto, Y. *Tetrahedron Lett.* **1999**, *40*, 4081. (b) Belmont, P.; Andrez, J.-C.; Allan, C. S. M. *Tetrahedron Lett.* **2004**, *45*, 2783. (c) Godet, T.; Belmont, P. *Synlett* **2008**, *2008*, 2513. (d) Dankwardt, J. W. *Tetrahedron Lett.* **2001**, *42*, 5809.

(10) (a) Shukla, S. P.; Tiwari, R.; Verma, A. K. *Tetrahedron* **2012**, *68*, 9035 and references therein. (b) Sakthivel, K.; Srinivasan, K. *J. Org. Chem.* **2014**, *79*, 3244. (c) Youn, S. W.; Kim, B. S.; Jagdale, A. R. *J. Am. Chem. Soc.* **2012**, *134*, 11308. For Pd-catalyzed oxidative annulation of benzoylacetates and internal alkynes, see: (d) Peng, S.; Wang, L.; Wang, J. *Chem.—Eur. J.* **2013**, *19*, 13322 and references therein.

(11) For one example of 5-*exo*-*dig* cyclization of α-acetylenic aryl ketones, see: Yue, D.; Della Cà, N.; Larock, R. *Org. Lett.* **2004**, *6*, 1581.

(12) (a) Herndon, J. M.; Zhang, Y.; Wang, K. *J. Organomet. Chem.* **2001**, *634*, 1. (b) Chen, X.; Jin, J.; Wang, N.; Lu, P.; Wang, Y. *Eur. J. Org. Chem.* **2012**, *2012*, 824. (c) Facoetti, D.; Abbiati, G.; Rossi, E. *Eur. J. Org. Chem.* **2009**, *2009*, 2872.

(13) (a) Belmont, P.; Belhadj, T. *Org. Lett.* **2005**, *7*, 1793. (b) Tiano, M.; Belmont, P. *J. Org. Chem.* **2008**, *73*, 4101.

(14) For several other pathways to aminonaphthalenes, see: (a) Jin, T.; Yang, F.; Yamamoto, Y. *Org. Lett.* **2010**, *12*, 388. (b) Naoe, S.; Suzuki, Y.; Hirano, K.; Inaba, Y.; Oishi, S.; Fujii, N.; Ohno, H. *J. Org. Chem.* **2012**, *77*, 4907. (c) Tatton, M. R.; Simpson, I.; Donohoe, T. J. *Chem. Commun.* **2014**, *50*, 11314. (d) Gou, F.-R.; Huo, P.-F.; Bi, H.-P.; Guan, Z.-H.; Liang, Y.-M. *Org. Lett.* **2009**, *11*, 3418.

(15) (a) Hawe, A.; Sutter, M.; Jiskoot, W. *Pharm. Res.* **2008**, *25*, 1487. (b) Odorisio, P. A.; Chasan, D. E.; Pastor, S. D. Patent US5160647, 1992. (c) Ward, R. S. *Nat. Prod. Rep.* **1999**, *16*, 75. (d) Sharma, S.; Singh, T.; Mittal, R.; Saxena, K. K.; Srivastava, V. K.; Kumar, A. *Arch. Pharm.* **2006**, *339*, 145. (e) Sarkar, S. K.; Jana, M. S.; Mondal, T. K.; Sinha, C. *J. Mol. Struct.* **2013**, *1036*, 28.

(16) (a) Meech, S. R.; O'Connor, D. V.; Phillips, D.; Lee, A. G. *J. Chem. Soc., Faraday Trans. 2* **1983**, *79*, 1563. (b) Suzuki, K.; Tanabe, H.; Tobita, S.; Shizuka, H. *J. Phys. Chem. A* **1997**, *101*, 4496. (c) Zachariasse, K. A.; Grobys, M.; von der Haar, T.; Hebecker, A.; Il'ichev, Y. V.; Morawski, O.; Rückert, I.; Kühnle, W. *J. Photochem. Photobiol., A* **1997**, *105*, 373. (d) Rückert, I.; Demeter, A.; Morawski, O.; Kühnle, W.; Tauer, E.; Zachariasse, K. A. *J. Phys. Chem. A* **1999**, *103*, 1958. (e) Zhang, X.; Liu, C.-H.; Liu, L.-H.; Wu, F.-Y.; Guo, L.; Sun, X.-Y.; Wang, C.-J.; Jiang, Y.-B. *Org. Biomol. Chem.* **2003**, *1*, 728.

(17) Zhang, M.; Zhang, H.-J.; Ruan, W.; Wen, T.-B. *Eur. J. Org. Chem.* **2015**, *2015*, 5914.

(18) For the X-ray crystal structure analyses of **3ad** (CCDC 1409407) and **3ra** (CCDC 1409247), see the Supporting Information.

(19) The reaction between **1a** and **2l** in the presence of 4 Å molecular sieves was performed, and the corresponding product **3al** was not observed (see the Supporting Information).

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J. Org. Chem. 2016, 81, 1696−1703

(20) Dell'Acqua, M.; Abbiati, G.; Arcadi, A.; Rossi, E. *Org. Biomol. Chem.* **2011**, *9*, 7836.
(21) The reaction of **1n** with primary amine **2a** was also performed under standard conditions, which could not give the desired aminobenzannulation product.
(22) Tang, Q.; Zhang, C.; Luo, M. *J. Am. Chem. Soc.* **2008**, *130*, 5840 and references therein.
(23) For selected examples of copper-catalyzed C(sp^3)−H functionalization, see: (a) Ilangovan, A.; Satish, G. *Org. Lett.* **2013**, *15*, 5726. (b) Cai, Z.-J.; Wang, S.-Y.; Ji, S.-J. *Org. Lett.* **2012**, *14*, 6068. (c) Zhang, G.; Miao, J.; Zhao, Y.; Ge, H. *Angew. Chem., Int. Ed.* **2012**, *51*, 8318. (d) Yu, J.; Yang, H.; Jiang, Y.; Fu, H. *Chem.—Eur. J.* **2013**, *19*, 4271. (e) Huang, X.-F.; Salman, M.; Huang, Z.-Z. *Chem.—Eur. J.* **2014**, *20*, 6618. For two reviews, see: (f) Wendlandt, A. E.; Suess, A. M.; Stahl, S. S. *Angew. Chem., Int. Ed.* **2011**, *50*, 11062. (g) Guo, X.-X.; Gu, D.-W.; Wu, Z.; Zhang, W. *Chem. Rev.* **2015**, *115*, 1622.
(24) For analogous α-palladation of imines, see: (a) Shi, Z.; Glorius, F. *Angew. Chem., Int. Ed.* **2012**, *51*, 9220 and references therein. (b) Wei, Y.; Deb, I.; Yoshikai, N. *J. Am. Chem. Soc.* **2012**, *134*, 9098. (c) Hajra, A.; Wei, Y.; Yoshikai, N. *Org. Lett.* **2012**, *14*, 5488. (d) Chen, Z.; Lu, B.; Ding, Z.; Gao, K.; Yoshikai, N. *Org. Lett.* **2013**, *15*, 1966. (e) Girard, S. A.; Hu, X.; Knauber, T.; Zhou, F.; Simon, M. O.; Deng, G. J.; Li, C.-J. *Org. Lett.* **2012**, *14*, 5606. (f) Liu, J.; Zhu, J.; Jiang, H.; Wang, W.; Li, J. *Chem. - Asian J.* **2009**, *4*, 1712.
(25) (a) Too, P. C.; Chiba, S. *Chem. Commun.* **2012**, *48*, 7634. (b) Guo, B.; Zheng, L.; Yang, L.; Hua, R. *J. Org. Chem.* **2014**, *79*, 4352.

DOI: 10.1021/acs.joc.5b02340
J. Org. Chem. 2016, 81, 1696−1703