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Assisted Tandem Palladium(II)/Palladium(0)-Catalyzed C- and N-Arylations of Quinoxalin-2(1*H*)-ones in Water

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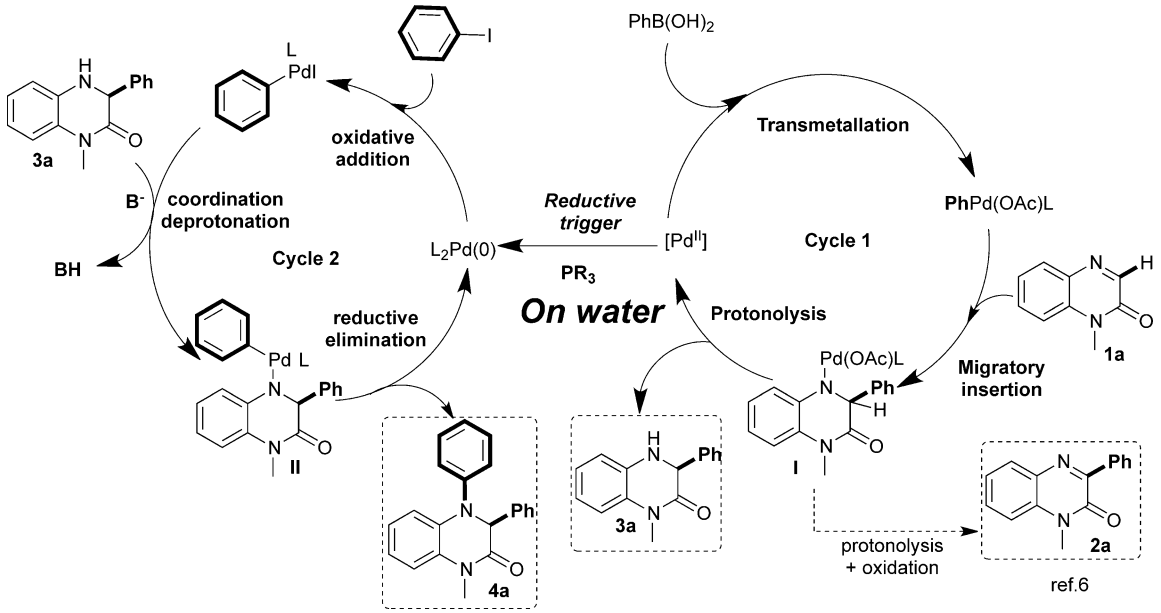
Abstract: A straightforward assisted tandem palladium(II)- and palladium(0)-catalyzed direct C-3 and *N*-4 arylation of quinoxalin-2(1*H*)-ones with boronic acids and aryl halides in water as safe and cheap solvent is reported. This environmentally friendly catalytic protocol is compatible with a wide range of functional groups and allows construction of various biologically important quinoxalin-2(1*H*)-one backbones.

Keywords: assisted tandem catalysis; C-arylation; N-arylation; palladium catalysis; quinoxalinones

Introduction

Quinoxalin-2(1*H*)-ones are present in many compounds of enormous practical importance, ranging from pharmaceutical agents to material science.[1] Tailoring the properties of these compounds to satisfy their specific functions necessitates the development of news synthetic methods. These methods should be capable of regioselectively introducing a variety of substituents bearing diverse functional groups to the desired heterocyclic scaffold in high efficiency within a minimum of steps. Among the strategies able to address this challenge, tandem catalysis, which involves two or more catalytic cycles in a single reactor, is recognized as a powerful tool in several areas of organic chemistry, including natural product synthesis, drug discovery, and processes for constructing heterocycles.[2,3] This approach has emerged as an atom-economic strategy and has several advantages over multistep syntheses, including time- and cost-savings, atom economy, waste reduction and reduced energy consumption.

One of the subfamilies of this strategy is "assisted tandem catalysis," in which one precatalyst was used in different oxidation states to preform two mechanistically distinct bond forming reactions in the presence of a reagent that triggers this change in mechanism.[2] However, in contrast to the much more developed areas of tandem catalysis, reports of assisted tandem catalysis are rare,[4] and to the best of our knowledge, there is only one report based on Pd-assisted tandem catalysis for the construction of two C–C bonds.[4a] Moreover, there are no known examples that employ palladium to form C–C and C–N bonds in two different catalytic cycles. As part of our continuing efforts to develop efficient methods to functionalize heterocycles *via* transition-metal catalysis,[5] we became interested in the possibility of applying our recently disclosed Pd(II)-catalyzed C-3 arylation of quinoxalin-2(1*H*)-one **1a** with arylboronic acids[6] to a new assisted tandem Pd(II) and Pd(0)-catalyzed C-3 and N-4 arylations of this type of heterocycle in a single operation (Scheme 1). The hypothesis was that a reducing agent could be used to trigger the necessary change in mechanism. Thus, in situ reduction of a Pd(II) catalyst which is able to perform reductive C-3 arylation of **1a** (Scheme 1, cycle 1), into a Pd(0) species, by introduction of appropriate ligands such as a phosphine,[7] can effectively catalyze a Buchwald-Hartwig N-4 arylation of **3a** in the presence of an aryl halide (Scheme 1, cycle 2). From the synthetic viewpoint, this coupling should be the shortest and the most efficient route to C3,N4-diarylated dihydroquinoxalin-2(1*H*)-ones **4a** for the purpose of a medicinal chemistry screening program. To the best of our knowledge, there is no report describing the formation of **4** using this strategy. Herein, we report our success on the development of such a protocol.



Scheme 1. Pd(II)-catalyzed C3-arylation and Pd(0)-catalyzed N4-arylation through an assisted tandem process using a reductive trigger.

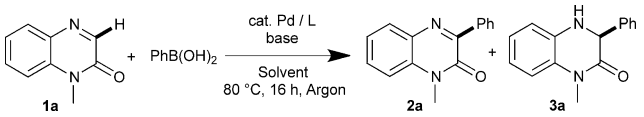
Results and Discussion

To achieve our goal successfully, we initially studied the first step in order to control the exclusive formation of **3a**. Very recently, we reported with a single example that achieving the reaction of **1a** with phenylboronic acid under our optimized conditions [$Pd(OAc)_2$, phenanthroline in DMF at 120 °C, argon atmosphere], enabled the selective formation of 3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one **3a**, however, contaminated with **2a** in a 92/8 ratio (68% yield of **3a**).[6] To circumvent the formation of **2a** in favor of **3a** exclusively, and optimize the yield of **3a**, an extensive screening of various reaction parameters (palladium, ligand and solvent) was conducted (Table 1). Optimal conditions were found to require the use of $Pd(OAc)_2$ (5 mol%), 2,2′-bipyridine (7.5 mol%) in water at 80 °C for 16 h under an argon atmosphere (entry 12). Accordingly, the desired product **3a** was isolated in a 95% yield.

In line of our hypothesis to achieve a tandem process, when the first coupling is complete, subsequent addition of bromobenzene (1.1 equiv), KOH (4 equiv) and Xphos or $P(t\text{Bu})_3{\cdot}HBF_4$ (10 mol%) provided C-3,N-4 diarylated quinoxalin-2(1*H*)-one **4a** in yields up to 84% (Scheme 2, Eq.2). The success of this tandem C–C and C–N bond formation demonstrates that the ligand phosphine added[8] can act as the reductive trigger to form a Pd(0) species from a Pd(II) and can initiate a new reaction for converting **3a** into **4a** through the N-arylation coupling process.

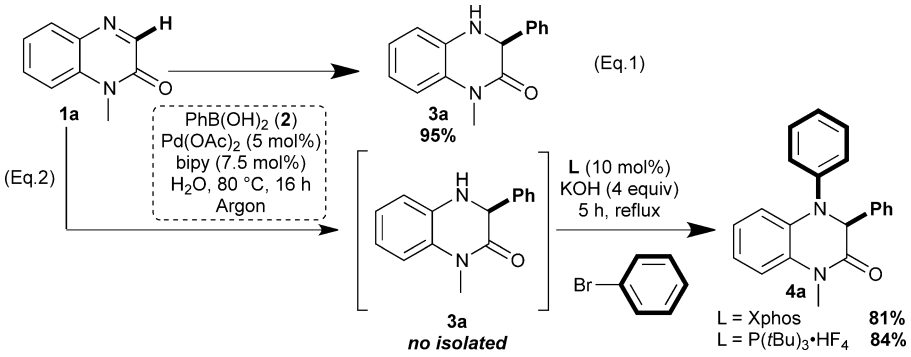
Prompted by these exciting results, we subsequently investigated the substrate scope for this tandem cata-

Table 1. Optimization coupling reaction of **1a** with $PhB(OH)_2$ under various conditions[a]



Entry	Pd.cat	L	Solvent	Conv[g] (%) **2a/1a/3a**
1[a]	$Pd(OAc)_2$	bipy	$MeNO_2$	10/33/57
2[a]	$PdCl_2$(bipy)	-	$MeNO_2$	0/100/0
3[a]	$PdCl_2$(phen)	-	$MeNO_2$	0/100/0
4[a]	$Pd(OAc)_2$	Phen	$MeNO_2$	16/10/74
5[a]	$Pd(OAc)_2$	5(NO_2)Phen	$MeNO_2$	17/5/78
6[a]	$Pd(OAc)_2$	Xphos[b]	$MeNO_2$	0/80/20
7[a]	$Pd(OAc)_2$	bipy	H_2O	10/5/85
8[a]	$Pd(OAc)_2$	bipy	*t*AmOH	0/100/0
9[a]	$Pd(OAc)_2$	bipy	EtOH	0/100/0
10[a]	$Pd(OAc)_2$	5(NO_2)Phen	H_2O	21/0/79
11[c]	$Pd(OAc)_2$	bipy	H_2O	10/4/86
12[d]	**$Pd(OAc)_2$**	**bipy**	**H_2O**	**3/4/93[h]**
13[e]	$Pd(OAc)_2$	bipy	H_2O	5/13/82
14[f]	$Pd(OAc)_2$	bipy	H_2O	7/17/76
15[d]	$Pd(OAc)_2$	bipy	$MeNO_2$	6/4/90[i]

[a] Conditions: quinoxalinone **1a** (0.5 mmol), boronic acid (1.5 equiv), palladium (10 mol%), ligand (10 mol%), solvent (2 mL) under argon at 80 °C for 16 h.
[b] XPhos (20 mol%) was used.
[c] 2,2′-Bipyridine (bipy, 15 mol%) was used.
[d] $Pd(OAc)_2$ (5 mol%) and bipy (7.5 mol%) were used.
[e] $Pd(OAc)_2$ (5 mol%) and bipy (10 mol%) were used.
[f] $Pd(OAc)_2$ (2.5 mol%) and bipy (3.5 mol%) were used.
[g] The ratio was determined by ^{1}H NMR on the crude product.
[h] 95% of isolated product **3a**.
[i] 90% of isolated product **3a**.



Scheme 2. Pd(II)-catalyzed C3-arylation and Pd(0)-catalyzed N4-arylation through an assisted tandem process using phosphine ligand as a reductive trigger.

lytic process by systematically varying the boronic acids, the aryl halides and the quinoxalin-2(1*H*)-one substrates. Gratifyingly, all the tandem C- and N-arylations proceeded cleanly and selectively in good to excellent yields. As illustrated in Scheme 3, a variety of electron-rich and electron-deficient, *para*- and *meta*-substituted aryl boronic acids effectively undergo reaction with quinoxalin-2(1*H*)-one **1a** in concert with bromobenzene in yields up to 95% (products **4a-c** and **4e-h**). In addition, the sterically demanding *ortho* substitution pattern was tolerated toward tandem coupling reaction of **1a**, furnishing compound **4d** having an *ortho* methoxy group. Notably, heteroarene boronic acids such as thiophen-3-ylboronic acid failed in this reaction and starting material **1a** was recovered unchanged. Interestingly, both bromobenzene and chlorobenzene reacted well in this tandem coupling providing **4a** in good yields (81–84%), whereas the yield decreased until 59% when iodobenzene was used as a coupling partner.[9]

As illustrated in Scheme 4, when quinoxalin-2(1*H*)-one **1a** and phenylboronic acid were used as coupling partners, various aryl bromides including those having sensitive functional groups (e.g., esters, enolizable ketones) undergo *N*-arylation in this tandem catalytic process in high yields. Aryl bromides containing *para* and *meta* electron-donating or electron-withdrawing substituents were readily coupled with **1a** and phenylboronic acid to give products **4j–q** in good to excellent yields. Extending this method to the tandem C3-arylation and N4-alkenylation of **1a** was also successful furnishing the desired dihyquinoxalin-2(1*H*)-one **4r** in a good 81% yield.

Finally, this tandem process was successfully expanded to the coupling of a series of quinoxalin-2(1*H*)-ones as well as related heterocycles (e.g., benzo[*g*]quinoxalin-2(1*H*)-one) with various arylboronic acids and aryl/styryl halides (Scheme 5) providing compounds **4s–z**, **4ab** and **4ac** in yields up to 96%.

Conclusions

In conclusion, we successfully developed an efficient and practical catalytic protocol based on Pd(II)- and P(0)-catalyzed tandem process for C-3 and N-4 arylation/alkenylation of various quinoxalin-2(1*H*)-ones with arylboronic acids and aryl/alkenyl halides in a safe and green water reaction media. The protocol exhibited a broad substrate scope with respect to the coupling partners, thus providing an attractive method to access a large molecular diversity of 3-aryl-4-aryl(alkenyl)-dihydroquinoxalin-2(1*H*)-ones **4** of biological interest.

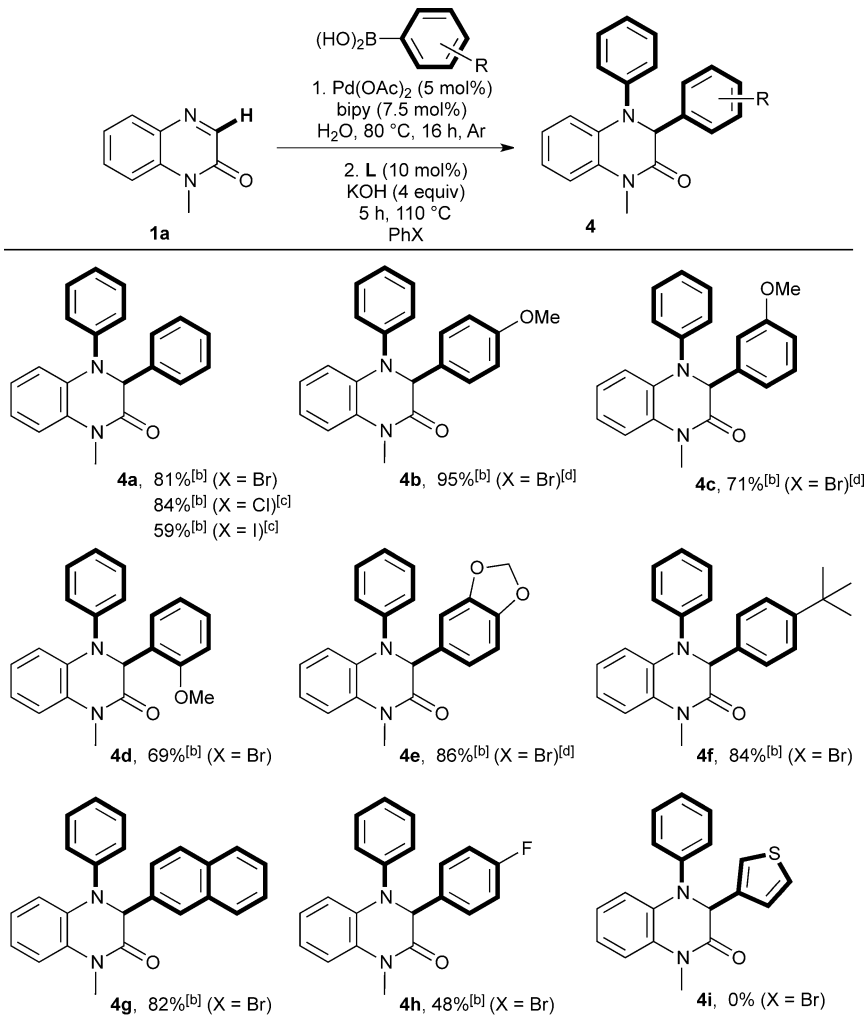
Experimental Section

General experimental methods

The compounds were all identified by usual physical methods, that is, ^{1}H NMR, ^{13}C NMR (J-MOD), IR, MS (ESI). ^{1}H and ^{13}C NMR spectra were measured in $CDCl_3$ or $[D_6]$DMSO with either Bruker Avance-300. ^{1}H chemical shifts are reported in ppm from an internal standard TMS or of residual chloroform (7.27 ppm). The following abreviation are used: m (multiplet), s (singlet), bs (broad singlet), d (doublet), t (triplet) dd (doublet of doublet), td (triplet of doublet), q (quadruplet), qui (quintuplet), sex (sextuplet). ^{13}C chemical shifts are reported in ppm from the central peak of deuteriochloroform (77.14). IR spectra were measured on a Bruker Vector 22 spectrophotometer. MS were recorded on a Micromass spectrometer. Analytical TLC was performed on Merck precoated silica gel 60F plates. Merck silica gel 60 (0,015–0,040 mm) was used for column chromatography. Melting points were recorded on a Büchi B-450 apparatus and are uncorrected.

General procedure for the tandem reaction between quinoxalin-2(1*H*)-ones, arylboronic acids and aryl halides:

A resealable 2–5 mL Pyrex reaction vessel was charged with the solid reactant(s): $Pd(OAc)_2$ (5.0 mol%), bipyridine (7.5 mol%), quinoxalinone **1** (1 equiv) and boronic acid (1.5



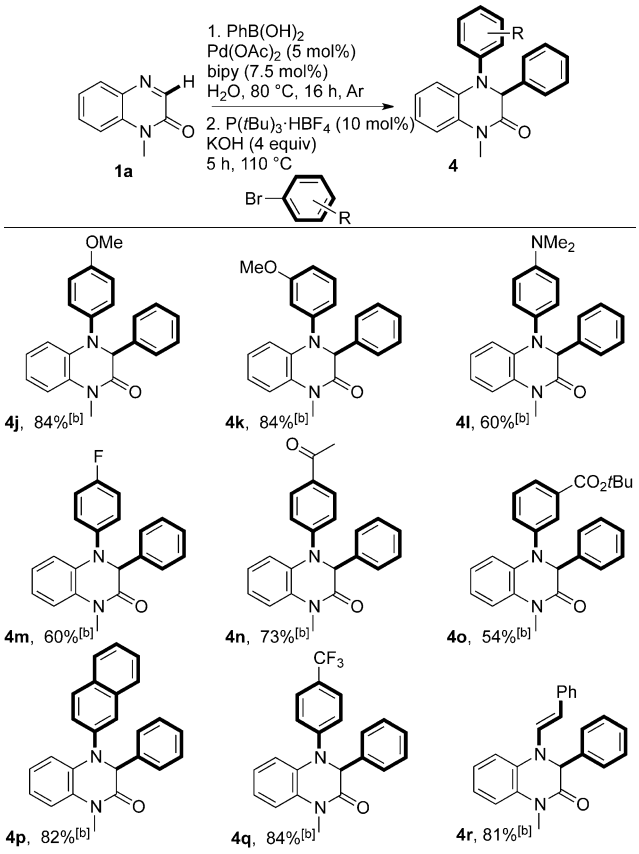
[a] Conditions: quinoxalinone **1a** (0.5 mmol), boronic acid (1.5 equiv), $Pd(OAc)_2$ (5 mol%), bipy. (7.5 mol%), H_2O (2 mL) under argon at 80 °C for 16 h. Then phenyl halide (2 equiv), Xphos (10 mol%), KOH (4 equiv), reflux, 5 h.
[b] Yield of isolated product.
[c] $P(tBu)_3 \cdot HBF_4$ (10 mol%) was used.
[d] $Pd(OAc)_2$ (5 mol%) were added in the second half of the tandem coupling.

Scheme 3. Scope of boronic acids coupling with quinoxalin-2(1*H*)-one **1a** and phenyl halides under tandem Pd(II) and Pd(0) catalysis[a]

or 2 equiv). After argon flushing, water (2 mL) was added and the reaction vessel was sealed with a Teflon screwcap. The reaction was stirred at 80 °C for 14 h. Then the ligand Xphos or $P(tBu)_3 \cdot HBF_4$ (10 mol%), KOH (4 equiv) and aryl halide (2 equiv) were added in the reaction mixture and the reaction was stirred at 110 °C for 5 h. The resulting suspension was cooled to room temperature. Dichloromethane was added. The organic layer was filtered through celite and evaporated under reduced pressure. The residue was purified by flash chromatography over silica gel to afford the desired product.

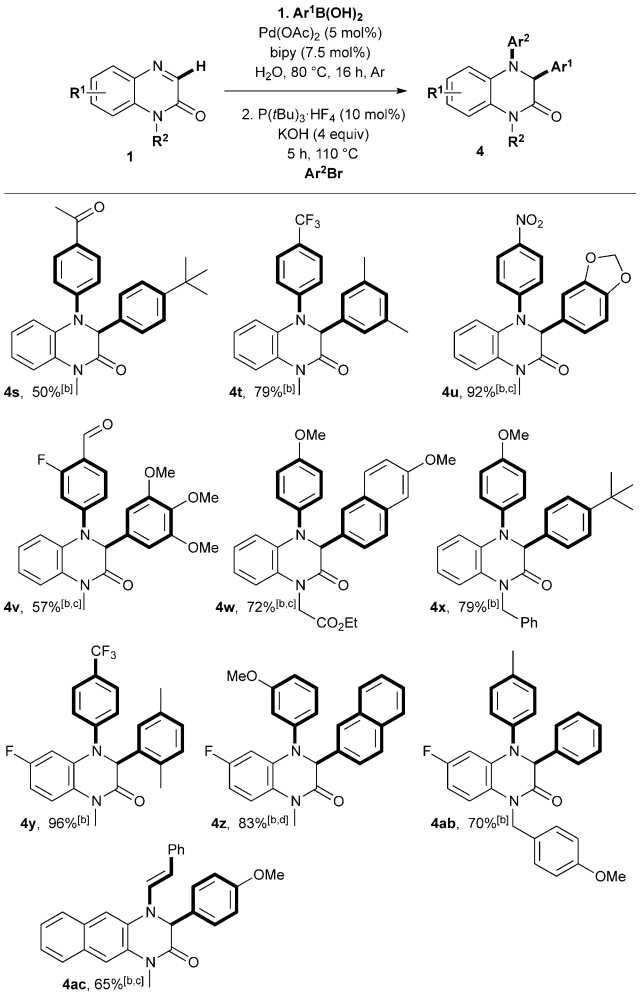
Analytical Data for substituted quinolin-2(1*H*)-ones 4

1-Methyl-3,4-diphenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4a): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then phenyl halide (2 equiv) were mixed (ligand Xphos was added when bromobenzene was used and $P(tBu)_3 \cdot HBF_4$ was added when iodo or chlorobenzene was used in the second half of the tandem procedure). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4a** (132 mg, 0.42 mmol, 84%) as a pale yellow solid. R_f 0.37 (cyclohexane/ethyl acetate 90:10); mp 119 °C (recrystallised from isopropyl ether to give white crystals); ^1H NMR (300 MHz, $CDCl_3$) δ 7.47–7.40 (m, 3H), 7.31–7.26 (m, 5H), 7.18 (d, $J = 8.1$ Hz, 2H), 7.07–6.96 (m, 4H), 5.67 (s, 1H), 3.43 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.5, 145.3, 136.9, 132.6, 130.9, 129.4 (2C), 128.8 (2C), 128.0, 126.4 (2C), 123.7, 123.0, 121.6, 120.3 (2C), 118.3, 115.9, 65.9, 29.7; IR (film) ν (cm^{-1}) 1673, 1590, 1503, 1387; HRMS (ESI^+): *m/z* calculated for $C_{21}H_{18}N_2ONa$ $[M+Na]^+$ 337.1317; found 337.1312.



[a] Conditions: quinoxalinone **1a** (0.5 mmol), phenylboronic acid (1.5 or 2 equiv), $Pd(OAc)_2$ (5 mol%), bipy. (7.5 mol%), H_2O (2 mL) under argon at 80 °C for 16 h. Then aryl bromide (2 equiv), $P(tBu)_3{\cdot}HBF_4$ (10 mol%), KOH (4 equiv), reflux, 5h.
[b] Yield of isolated product.

Scheme 4. Scope of aryl halides coupling with quinoxalin-2(1*H*)-one **1a** and phenylboronic acid under tandem Pd(II) and Pd(0) catalysis[a]



[a] Conditions: quinoxalinone **1** (0.5 mmol), boronic acid (1.5 equiv), $Pd(OAc)_2$ (5 mol%), bipy. (7.5 mol%), H_2O (2 mL) under argon at 80 °C for 16 h. Then aryl bromide (2 equiv), $P(tBu)_3{\cdot}HBF_4$ (10 mol%), KOH (4 equiv), reflux, 5 h.
[b] Yield of isolated product.
[c] $Pd(OAc)_2$ (5 mol%) were added in the second half of the tandem coupling.
[d] 3-Chloroanisole was used as the electrophile in the second half of the tandem coupling.

Scheme 5. Scope of quinoxalin-2(1*H*)-ones coupling with boronic acids and aryl/alkenyl halides under tandem Pd(II) and Pd(0) catalysis[a]

3-(4-Methoxyphenyl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4b): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 4-methoxyphenylboronic acid (114 mg, 0.75 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10 to 80:20) to afford the desired product **4b** (162 mg, 0.47 mmol, 94%) as a white solid. R_f 0.24 (cyclohexane/ethyl acetate 90:10); mp 115 °C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.37 (m, 5H), 7.15 (d, J = 7.8 Hz, 2H), 7.04–6.93 (m, 4H), 6.78 (d, J = 8.7 Hz, 2H), 5.57 (s, 1H), 3.72 (s, 3H), 3.41 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.8, 159.4, 145.3, 132.7, 130.9, 129.4 (2C), 128.9, 127.6 (2C), 123.7, 123.0, 121.5, 120.3 (2C), 118.2, 115.8, 114.2 (2C), 65.4, 55.3, 29.6; IR (film) ν(cm^{-1}) 1669, 1505, 1386, 1249; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{20}N_2O_2Na$ $[M+Na]^+$ 367.1422; found 367.1434.

3-(3-Methoxyphenyl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4c): Following the general procedure (Xphos ligand was used), 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 3-methoxyphenylboronic acid (114 mg, 0.75 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed. The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4c** (123 mg, 0.36 mmol, 71%) as a white solid. R_f 0.23 (cyclohexane/ethyl acetate 90:10); mp 126–127 °C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.38 (d, J = 7.2 Hz, 1H), 7.30–7.25 (m, 2H), 7.17 (d, J = 8.1 Hz, 2H), 7.06–6.96 (m, 6H), 6.77 (dd, J = 2.7–8.4 Hz, 1H), 5.60 (s, 1H), 3.69 (s, 3H), 3.42 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.5, 160.0, 145.3, 138.6, 132.8, 131.0, 129.9, 129.5 (2C), 123.8, 123.1, 121.7, 120.4 (2C), 118.7, 118.3, 115.9, 113.8, 111.8, 65.9, 55.3, 29.8; IR (film) ν(cm^{-1}) 1671, 1584, 1503, 1386; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{20}N_2O_2Na$ $[M+Na]^+$ 367.1422; found 367.1424.

3-(2-Methoxyphenyl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4d): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 2-methoxyphenylboronic acid (114 mg, 0.75 mmol) and then bro-

mobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10) to afford the desired product **4d** (123 mg, 0.36 mmol, 71%) as a white solid. R_f 0.16 (cyclohexane/ethyl acetate 90:10); mp 106°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.27–7.19 (m, 3H), 7.13–6.89 (m, 9H), 6.72 (t, J=7.5 Hz, 1H), 6.00 (s, 1H), 3.84 (s, 3H), 3.47 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 166.2, 156.8, 145.5, 134.0, 131.1, 129.7, 129.3 (2C), 128.0, 127.7, 123.6 (2C), 122.3 (2C), 121.0 (2C), 118.1, 115.2, 111.7, 60.3, 56.0, 29.5; IR (film) ν(cm^{-1}) 1669, 1586, 1503, 1385, 1249; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{20}N_2O_2Na$ $[M+Na]^+$ 367.1422; found 367.1420.

3-(Benzo[*d*][1,3]dioxol-5-yl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1H)-one (4e): Following the general procedure, 1-methylquinoxalin-2(1H)-one **1a** (80 mg, 0.5 mmol), benzo[*d*][1,3]dioxol-5-ylboronic acid (124.5 mg, 0.75 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4e** (154 mg, 0.43 mmol, 86%) as a white solid. R_f 0.27 (cyclohexane/ethyl acetate 90:10); mp 138°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.36–7.25 (m, 3H), 7.15 (d, J=8.1 Hz, 2H), 7.06–6.96 (m, 4H), 6.91–6.86 (m, 2H), 6.68 (d, J=8.1 Hz, 1H), 5.89 (s, 2H), 5.52 (s, 1H), 3.43 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.5, 148.1, 147.5, 145.3, 132.6, 130.8 (2C), 129.5 (2C), 123.8, 123.1, 121.7, 120.4 (2C), 119.8, 118.3, 115.9, 108.5, 107.1, 101.2, 65.7, 29.7; IR (film) ν(cm^{-1}) 1669, 1589, 1503, 1388, 1236; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{19}N_2O_3$ $[M+H]^+$ 359.1396; found 359.1400.

3-(4-*tert*-Butylphenyl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4f): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 4-*tert*-butylphenylboronic acid (178 mg, 1.0 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4f** (155 mg, 0.42 mmol, 84%) as a white solid. R_f 0.45 (cyclohexane/ethyl acetate 90:10); mp 213°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.39 (d, J=7.8 Hz, 1H), 7.33 (d, J=8.7 Hz, 2H), 7.30–7.25 (m, 4H), 7.16 (d, J=7.8 Hz, 2H), 7.05–6.96 (m, 4H), 5.60 (s, 1H), 3.42 (s, 3H), 1.26 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.7, 150.9, 145.5, 133.9, 132.8, 131.0, 129.4 (2C), 126.0 (2C), 125.8 (2C), 123.7, 122.9, 121.5, 120.3 (2C), 118.3, 115.9, 65.7, 34.6, 31.4 (3C), 29.7; IR (film) ν(cm^{-1}) 1676, 1589, 1503, 1386; HRMS (ESI$^+$): *m/z* calculated for $C_{25}H_{26}N_2ONa$ $[M+Na]^+$ 393.1943; found 393.1930.

1-Methyl-3-(naphthalen-2-yl)-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4g): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 2-naphtylboronic acid (129 mg, 0.75 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4g** (141 mg, 0.39 mmol, 77%) as a white solid. R_f 0.35 (cyclohexane/ethyl acetate 90:10); mp 120–121°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.84–7.76 (m, 3H), 7.72–7.69 (m, 1H), 7.61 (dd, J=1.8–8.7 Hz, 1H), 7.48 (d, J=7.8 Hz, 1H), 7.44–7.41 (m, 2H), 7.29 (t, J=8.4 Hz, 2H), 7.21 (d, J=7.8 Hz, 2H), 7.07–7.02 (m, 2H), 6.98–6.96 (m, 2H), 5.81 (s, 1H), 3.44 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.5, 145.4, 134.4, 133.3, 133.1, 132.7, 130.9, 129.5 (2C), 128.7, 128.3, 127.7, 126.3, 126.3, 125.5, 124.3, 123.9, 123.1, 121.7, 120.4 (2C), 118.4, 116.0, 66.1, 29.8; IR (film) ν(cm^{-1}) 1717, 1672, 1504, 1396; HRMS (ESI$^+$): *m/z* calculated for $C_{25}H_{20}N_2ONa$ $[M+Na]^+$ 387.1473; found 387.1470.

3-(4-Fluorophenyl)-1-methyl-4-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4h): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 4-fluorophenylboronic acid (140 mg, 1.0 mmol) and then bromobenzene (110 μL, 2 equiv) were mixed (Xphos ligand was used). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4h** (79.5 mg, 0.24 mmol, 48%) as a white solid. R_f 0.37 (cyclohexane/ethyl acetate 90:10); mp 133°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.46–7.42 (m, 2H), 7.35–7.28 (m, 3H), 7.18–7.12 (m, 3H), 7.08–6.98 (m, 5H), 5.61 (s, 1H), 3.40 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.6, 163.3 (d, J=243 Hz), 146.3, 134.1 (d, J=3.0 Hz), 132.9, 132.2, 130.3 (2C), 129.2 (2C, d, J=8.3 Hz), 124.3, 123.8, 122.9, 120.8 (2C), 119.4, 116.8, 116.3 (2C, d, J=21 Hz), 66.0, 29.6; IR (film) ν(cm^{-1}) 1666, 1588, 1503, 1386, 1223; HRMS (ESI$^+$): *m/z* calculated for $C_{21}H_{18}N_2OF$ $[M+H]^+$ 333.1403; found 333.1399.

4-(4-Methoxyphenyl)-1-methyl-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4j): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 1-bromo-4-methoxybenzene (125 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4j** (144 mg, 0.42 mmol, 84%) as a white solid. R_f 0.26 (cyclohexane/ethyl acetate 90:10); mp 115°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42–7.39 (m, 2H), 7.28–7.25 (m, 3H), 7.16 (d, J=7.8 Hz, 1H), 7.09 (d, J=8.7 Hz, 2H), 7.02–6.91 (m, 3H), 6.84 (d, J=9.0 Hz, 2H), 5.52 (s, 1H), 3.80 (s, 3H), 3.44 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.3, 156.2, 138.4, 137.7, 133.9, 130.0, 128.8 (2C), 128.0, 126.6 (2C), 123.8, 123.4 (2C), 120.5, 116.9, 115.6, 114.8 (2C), 66.6, 55.6, 29.7; IR (film) ν(cm^{-1}) 1669, 1505, 1388, 1245; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{20}N_2O_2Na$ $[M+Na]^+$ 367.1422; found 367.1419.

4-(3-Methoxyphenyl)-1-methyl-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4k): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 1-chloro-3-methoxybenzene (123 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4k** (137 mg, 0.40 mmol, 80%) as a white solid. R_f 0.26 (cyclohexane/ethyl acetate 90:10); mp 105–106°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.42–7.37 (m, 3H), 7.31–7.23 (m, 4H), 7.14 (dd, J=2.1–7.2 HZ, 1H), 7.01–6.97 (m, 2H), 6.79–6.71

(m, 2H), 6.64 (dd, J=2.4–8.4 Hz, 1H), 5.61 (s, 1H), 3.73 (s, 3H), 3.42 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.7, 161.6, 147.6, 138.0, 132.9, 132.2, 131.0, 129.4 (2C), 128.7, 127.1 (2C), 124.2, 122.8, 119.7, 116.7, 113.0, 108.9, 106.8, 66.5, 55.5, 29.6; IR (film) ν(cm^{-1}) 1673, 1591, 1504, 1386, 1208; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{20}N_2O_2Na$ [M+Na]$^+$ 367.1422; found 367.1421.

4-(4-(Dimethylamino)phenyl)-1-methyl-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4l): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 4-bromo-*N*,*N*-dimethylaniline (201 mg, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10 to 85:15) to afford the desired product **4l** (108 mg, 0.30 mmol, 60%) as a pale yellow solid. R_f 0.17 (cyclohexane/ethyl acetate 90:10); mp 149–150 °C (recrystallised from isopropyl ether to give off-white crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.37–7.34 (m, 2H), 7.30–7.24 (m, 3H), 7.10–7.07 (m, 1H), 7.01–6.85 (m, 5H), 6.72 (d, J=9.0 Hz, 2H), 5.37 (s, 1H), 3.40 (s, 3H), 2.91 (s, 6H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.3, 149.0, 139.5, 135.42, 135.36, 130.8, 129.4 (2C), 128.7, 127.5 (2C), 124.8 (2C), 124.2, 120.8, 117.0, 116.3, 114.2 (2C), 67.7, 40.9 (2C), 29.5; IR (film) ν(cm^{-1}) 1670, 1518, 1389; HRMS (ESI$^+$): *m/z* calculated for $C_{23}H_{24}N_3O$ [M+H]$^+$ 358.1919; found 358.1919.

4-(4-Fluorophenyl)-1-methyl-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4m): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 1-bromo-4-fluorobenzene (110 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4m** (100 mg, 0.30 mmol, 60%) as a white solid. R_f 0.33 (cyclohexane/ethyl acetate 90:10); mp 127–128 °C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 8.42 (m, 2H), 7.89 (d, J=8.1 Hz, 1H), 7.56–7.51 (m, 1H), 7.37–7.27 (m, 2H), 7.13 (t, J=8.7 Hz, 2H), 3.72 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 164.2 (d, J=250 Hz), 154.7, 152.6, 133.3, 133.0, 132.2, 132.0, 131.9, 130.4 (2C), 123.8, 115.1 (2C, d, J=22.8 Hz), 113.6, 29.3; ^{19}F NMR (188 MHz, $CDCl_3$) δ −119.6; IR (film) ν(cm^{-1}) 1670, 1504, 1387, 1218; HRMS (ESI$^+$): *m/z* calculated for $C_{21}H_{17}N_2OFNa$ [M+Na]$^+$ 355.1223; found 355.1227.

4-(4-Acetylphenyl)-1-methyl-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4n): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 4′-bromoacetophenone (123 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4n** (130 mg, 0.36 mmol, 73%) as a pale yellow solid. R_f 0.11 (cyclohexane/ethyl acetate 90:10); mp 144–145 °C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.95 (d, J=8.7 Hz, 2H), 7.54–7.51 (m, 1H), 7.44–7.41 (m, 2H), 7.32–7.26 (m, 5H), 7.21–7.17 (m, 1H), 7.12–7.08 (m, 2H), 5.78 (s, 1H), 3.43 (s, 3H), 2.51 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 196.0, 165.8, 150.3, 136.9, 133.1, 132.0, 131.4, 130.9 (2C), 129.6 (2C), 128.9, 127.0 (2C), 124.4, 124.3, 121.1, 118.6 (2C), 117.1, 65.9, 29.7, 26.4; IR (film) ν(cm^{-1}) 1674, 1587, 1510, 1386, 1266; HRMS (ESI$^+$): *m/z* calculated for $C_{23}H_{21}N_2O_2$ [M+H]$^+$ 357.1603; found 357.1599.

***tert*-Butyl 3-(4-methyl-3-oxo-2-phenyl-3,4-dihydroquinoxalin-1(2*H*)-yl)benzoate (4o):** Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then *tert*-butyl 3-chlorobenzoate (212.5 mg, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4o** (111 mg, 0.27 mmol, 54%) as a white solid. R_f 0.29 (cyclohexane/ethyl acetate 90:10); mp 159 °C (recrystallised from isopropyl ether to give off-white crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.79–7.78 (m, 1H), 7.64–7.61 (m, 1H), 7.45–7.35 (m, 5H), 7.33–7.26 (m, 3H), 7.18–7.15 (m, 1H), 7.07–7.03 (m, 2H), 5.64 (s, 1H), 3.42 (s, 3H), 1.52 (s, 9H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.63, 165.59, 146.5, 137.8, 134.2, 132.7, 132.4, 130.3, 129.6 (2C), 128.9, 127.1 (2C), 124.7, 124.3, 124.2, 123.3, 121.2, 119.4, 116.9, 81.5, 66.5, 29.6, 28.2 (3C); IR (film) ν(cm^{-1}) 1712, 1674, 1504, 1388, 1303; HRMS (ESI$^+$): *m/z* calculated for $C_{26}H_{26}N_2O_3Na$ [M+Na]$^+$ 437.1841; found 437.1843.

1-Methyl-4-(naphthalen-2-yl)-3-phenyl-3,4-dihydroquinoxalin-2(1*H*)-one (4p): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 2-bromo-naphtalene (207 mg, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4p** (148.5 mg, 0.41 mmol, 82%) as a white solid. R_f 0.30 (cyclohexane/ethyl acetate 90:10); mp 168 °C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.80–7.75 (m, 2H), 7.63 (d, J=7.5 Hz, 1H), 7.55–7.47 (m, 3H), 7.45–7.29 (m, 7H), 7.09–7.00 (m, 3H), 5.84 (s, 1H), 3.46 (s, 3H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.5, 142.9, 136.7, 134.5, 132.4, 131.0, 129.0, 128.9 (2C), 128.1, 127.7, 127.1, 126.7, 126.4 (2C), 124.7, 123.8, 121.9, 121.1, 118.4, 115.9, 115.8, 66.1, 29.7; IR (film) ν(cm^{-1}) 1673, 1505, 1391; HRMS (ESI$^+$): *m/z* calculated for $C_{25}H_{20}N_2ONa$ [M+Na]$^+$ 387.1473; found 387.1474.

1-Methyl-3-phenyl-4-(4-(trifluoromethyl)phenyl)-3,4-dihydroquinoxalin-2(1*H*)-one (4q): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 1-bromo-4-(trifluoromethyl)benzene (140 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4q** (160 mg, 0.42 mmol, 84%) as a white solid. mp 128 °C (recrystallised from isopropyl ether to give white crystals); R_f 0.34 (cyclohexane/ethyl acetate 90:10); ^{1}H NMR (400 MHz, acetone d-6) δ 7.64 (d, J=8.8 Hz, 2H), 7.54–7.51 (m, 1H), 7.42 (d, J=7.2 Hz, 2H), 7.36 (d, J=8.4 Hz, 2H), 7.32–7.24 (m, 3H), 7.20–7.18 (m, 1H), 7.11–7.07 (m, 2H), 5.76 (s, 1H), 3.43 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.8, 149.8, 136.9, 133.1, 131.5, 129.6 (2C), 128.9, 127.5 (q, J=3.50 Hz), 127.0 (2C), 124.4 (2C), 123.8 (q, J=32 Hz), 120.8, 119.5 (2C), 117.1, 66.0, 29.6; ^{19}F NMR (188 MHz, acetone d-6) δ −60.3; IR (film) ν(cm^{-1}) 1672, 1503, 1326, 1268, 1106, 1067; HRMS

(ESI$^+$): *m/z* calculated for $C_{22}H_{18}N_2OF_3$ $[M+H]^+$ 383.1371; found 383.1371.

(*E*)-1-Methyl-3-phenyl-4-styryl-3,4-dihydroquinoxalin-2(1*H*)-one (4r): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then bromostyrene (129 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4r** (138 mg, 0.41 mmol, 81%) as a pale yellow solid. R_f 0.33 (Cyclohexane/ethyl acetate 90:10); mp 158°C (recrystallised from isopropyl ether to give pale yellow crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.59 (d, J= 14.4 Hz, 1H), 7.40–7.34 (m, 5H), 7.31–7.05 (m, 9H), 5.97 (d, J=14.4 Hz, 1H), 5.77 (s, 1H), 3.41 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 164.9, 138.7, 137.0, 132.4, 131.2 (2C), 130.8, 129.5 (2C), 129.3 (2C), 128.8, 127.1 (2C), 126.1, 125.8 (2C), 124.9, 122.9, 117.3, 116.2, 107.7, 63.1, 29.5; IR (film) ν(cm^{-1}) 1673, 1639, 1594, 1509, 1394; HRMS (ESI$^+$): *m/z* calculated for $C_{23}H_{20}N_2ONa$ $[M+Na]^+$ 363.1473; found 363.1471.

4-(4-Acetylphenyl)-3-(4-*tert*-butylphenyl)-1-methyl-3,4-dihydroquinoxalin-2(1*H*)-one (4s): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 4-*tert*-butylphenylboronic acid (178 mg, 1.00 mmol) and then 4′-bromoacetophenone (123 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10 to 85:15) to afford the desired product **4s** (103 mg, 0.25 mmol, 50%) as a yellow solid. R_f 0.16 (cyclohexane/ethyl acetate 90:10); mp 220°C (recrystallised from isopropyl ether to give pale yellow crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.94 (d, J=8.7 Hz, 2H), 7.54–7.51 (m, 1H), 7.34 (s, 4H), 7.26 (d, J= 8.7 Hz, 2H), 7.20–7.17 (m, 1H), 7.11–7.08 (m, 2H), 5.73 (s, 1H), 3.42 (s, 3H), 2.51 (s, 3H), 1.25 (s, 9H); ^{13}C NMR (75 MHz, acetone d-6) δ 196.0, 165.9, 151.7, 150.3, 133.8, 133.1, 131.9, 131.5, 130.9 (2C), 126.8 (2C), 126.5 (2C), 124.35, 124.3, 121.0, 118.6 (2C), 117.1, 65.7, 35.0, 31.5 (3C), 29.6, 26.4; IR (film) ν(cm^{-1}) 1672, 1586, 1504, 1419, 1264; HRMS (ESI$^+$): *m/z* calculated for $C_{27}H_{28}N_2O_2Na$ $[M+Na]^+$ 435.2048; found 435.2047.

3-(3,5-Dimethylphenyl)-1-methyl-4-(4-(trifluoromethyl)-phenyl)-3,4-dihydroquinoxalin-2(1*H*)-one (4t): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 3,5-dimethylphenylboronic acid (150 mg, 1.00 mmol) and then 1-bromo-4-trifluoromethylbenzene (140 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4t** (163 mg, 0.40 mmol, 79%) as a white solid. R_f 0.39 (cyclohexane/ethyl acetate 90:10); mp 209°C (recrystallised from isopropyl ether to give white crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 7.63 (d, J= 8.7 Hz, 2H), 7.54–7.50 (m, 1H), 7.35 (d, J=8.7 Hz, 2H), 7.20–7.16 (m, 1H), 7.12–7.06 (m, 1H), 7.03 (s, 2H), 6.89 (s, 1H), 5.67 (s, 1H), 3.42 (s, 3H), 2.18 (s, 6H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.8, 149.8, 139.1 (2C), 136.8, 133.2, 131.6, 130.4, 127.5 (2C, q, J=3.6 Hz), 125.5 (q, J= 254 Hz), 124.7 (2C), 124.33, 124.32, 123.7 (q, J=32 Hz), 120.7, 119.4 (2C), 117.1, 65.9, 29.6, 21.4 (2C); IR (film) ν(cm^{-1}) 1677, 1504, 1386, 1326, 1118; HRMS (ESI$^+$): *m/z* calculated for $C_{24}H_{21}N_2OF_3Na$ $[M+Na]^+$ 433.1504; found 433.1498.

3-(Benzo[*d*][1,3]dioxol-5-yl)-1-methyl-4-(4-nitrophenyl)-3,4-dihydroquinoxalin-2(1*H*)-one (4u): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), benzo[*d*][1,3]dioxol-5-ylboronic acid (124.5 mg, 0.75 mmol) and then 1-bromo-4-nitrobenzene (202 mg, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10 to 80:20) to afford the desired product **4u** (185 mg, 0.46 mmol, 92%) as a yellow solid. R_f 0.13 (cyclohexane/ethyl acetate 90:10); mp 211–212°C (recrystallised from ethyl acetate to give yellow crystals); ^{1}H NMR (300 MHz, acetone d-6) δ 8.20 (d, J= 9.0 Hz, 2H), 7.60 (dd, J=1.8–7.5 Hz, 1H), 7.38 (d, J= 9.0 Hz, 2H), 7.28–7.11 (m, 3H), 6.89–6.87 (m, 2H), 6.76 (d, J=8.7 Hz, 1H), 5.96 (s, 2H), 5.77 (s, 1H), 3.45 (s, 3H); ^{13}C NMR (75 MHz, acetone d-6) δ 165.8, 152.0, 149.2, 148.6, 142.4, 133.5, 130.4, 129.8, 126.4 (2C), 125.5, 124.5, 121.8, 120.4, 118.6 (2C), 117.3, 109.2, 107.3, 102.4, 65.6, 29.7; IR (film) ν(cm^{-1}) 1675, 1584, 1503, 1325, 1240; HRMS (ESI$^+$): *m/z* calculated for $C_{22}H_{18}N_3O_5$ $[M+H]^+$ 404.1246; found 404.1242.

2-Fluoro-4-(4-methyl-3-oxo-2-(3,4,5-trimethoxyphenyl)-3,4-dihydroquinoxalin-1(2*H*)-yl)benzaldehyde (4v): Following the general procedure, 1-methylquinoxalin-2(1*H*)-one **1a** (80 mg, 0.5 mmol), 3,4,5-trimethoxyphenylboronic acid (178 mg, 1.00 mmol) and then 1-bromo-4-methoxybenzene (125 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 80:20) to afford the desired product **4v** (183 mg, 0.38 mmol, 77%) as a white solid. R_f 0.10 (cyclohexane/ethyl acetate 80:20); mp 196°C (recrystallised from ethyl acetate to give pale yellow crystals); ^{1}H NMR (300 MHz, DMSO d-6) δ 10.05 (s, 1H), 7.76 (t, J=8.4 Hz, 1H), 7.62 (d, J=7.8 Hz, 1H), 7.28 (d, J= 7.8 Hz, 1H), 7.23–7.12 (m, 3H), 7.07–7.03 (m, 1H), 6.56 (s, 2H), 5.89 (s, 1H), 3.61 (s, 6H), 3.59 (s, 3H), 3.37 (s, 3H); ^{13}C NMR (75 MHz, [D$_6$]DMSO) δ 185.6 (d, J=3.75 Hz), 165.0, 164.8 (d, J=255 Hz), 153.0 (2C), 151.9 (d, J=12 Hz), 137.2, 132.2, 130.7 (d, J=3 Hz), 130.1, 129.0, 124.9, 123.7, 121.3, 117.3 (d, J=9 Hz), 116.8, 113.7, 104.2 (d, J=25 Hz), 103.2 (2C), 63.8, 59.9, 55.7 (2C), 29.3; IR (film) ν(cm^{-1}) 1683, 1616, 1507, 1384; HRMS (ESI$^+$): *m/z* calculated for $C_{25}H_{23}N_2O_5FNa$ $[M+Na]^+$ 473.1489; found 473.1491.

Ethyl 2-(3-(6-methoxynaphthalen-2-yl)-4-(4-methoxyphenyl)-2-oxo-3,4-dihydroquinoxalin-1(2*H*)-yl)acetate (4w): Following the general procedure, ethyl 2-(2-oxoquinoxalin-1(2*H*)-yl)acetate **1b** (116 mg, 0.5 mmol), 6-methoxynaphthalen-2-ylboronic acid (151.5 mg, 0.75 mmol) and then 1-bromo-4-methoxybenzene (125 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 90:10 to 85:15) to afford the desired product **4w** pure at 86% (180 mg, 0.31 mmol, 61%) as a yellow solid. R_f 0.13 (cyclohexane/ethyl acetate 90:10), ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.79 (s, 1H), 7.73 (d, J=8.7 Hz, 1H), 7.66 (d, J=8.7 Hz, 1H), 7.51 (dd, J=1.8–8.7 Hz, 1H), 7.24 (d, J=2.7 Hz, 1H), 7.17–7.08 (m, 4H), 7.01–6.86 (m, 5H), 5.62 (s, 1H), 5.98 (d, J=17.5 Hz, 1H), 4.65 (d, J=17.5 Hz, 1H), 4.13 (q, J=7.2 Hz, 2H), 3.88 (s, 3H), 3.77 (s, 3H), 1.13 (t, J=7.2 Hz, 3H); ^{13}C NMR (75 MHz, [D$_6$]acetone) δ

168.9, 166.0, 159.0, 157.4, 139.6, 135.3, 134.8, 133.5, 130.9, 130.3, 129.5, 128.1, 126.7, 126.1, 124.7 (2C), 124.6, 121.8, 119.9, 118.7, 116.3, 115.6 (2C), 106.5, 67.5, 61.8, 55.8, 55.7, 44.8, 14.4; IR (film) $\nu(cm^{-1})$ 1752, 1672, 1509, 1393, 1266, 1245; HRMS (ESI^+): *m/z* calculated for $C_{25}H_{17}N_2O$ $[M+H]^+$ 497.2071; found 497.2063.

1-Benzyl-3-(4-tert-butylphenyl)-4-(4-methoxyphenyl)-3,4-dihydroquinoxalin-2(1*H*)-one (4x): Following the general procedure, 1-benzylquinoxalin-2(1*H*)-one **1c** (118 mg, 0.5 mmol), 4-tert-butylphenylboronic acid (178 mg, 1.00 mmol) and then 1-bromo-4-methoxybenzene (125 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4x** (183 mg, 0.38 mmol, 77%) as a white solid. R_f 0.40 (cyclohexane/ethyl acetate 90:10); mp 80 °C (recrystallised from isopropyl ether to give white crystals); ^1H NMR (300 MHz, $CDCl_3$) δ 7.37–7.28 (m, 4H), 7.19–7.12 (m, 6H), 7.02–6.99 (m, 2H), 6.95–6.90 (m, 1H), 6.86–6.75 (m, 4H), 5.59 (s, 1H), 5.54 (d, $J=16.2$ Hz, 1H), 4.90 (d, $J=16.2$ Hz, 1H), 3.80 (s, 3H), 1.29 (s, 9H), ^{13}C NMR (75 MHz, $CDCl_3$) δ 165.3, 156.2, 151.1, 138.7, 136.7, 134.2, 134.1, 129.4, 128.8 (2C), 127.2, 126.3 (2C), 126.2 (2C), 125.8 (2C), 123.8, 123.4 (2C), 120.5, 117.1, 116.3, 114.8 (2C), 66.4, 55.7, 45.9, 34.7, 31.4 (3C); IR (film) $\nu(cm^{-1})$ 1676, 1509, 1395, 1244; HRMS (ESI^+): *m/z* calculated for $C_{32}H_{32}N_2O_2Na$ $[M+Na]^+$ 499.2361; found 499.2358.

3-(2,5-Dimethylphenyl)-6-fluoro-1-methyl-4-(4-(trifluoromethyl)phenyl)-3,4-dihydroquinoxalin-2(1*H*)-one (4y): Following the general procedure, 6-fluoro-1-methylquinoxalin-2(1*H*)-one **1d** (89 mg, 0.5 mmol), 2,5-dimethylphenylboronic acid (150 mg, 1.0 mmol) and then 1-bromo-4-trifluoromethylbenzene (140 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4y** (205 mg, 0.48 mmol, 96%) as a white solid. R_f 0.29 (cyclohexane/ethyl acetate 90:10); mp 152–153 °C (recrystallised from isopropyl ether to give white crystals); ^1H NMR (300 MHz, $[D_6]$acetone) δ 7.67 (d, $J=8.7$ Hz, 2H), 7.33–7.25 (m, 3H), 7.14 (d, $J=7.8$ Hz, 1H), 7.01–6.96 (m, 2H), 6.90–6.83 (m, 2H), 5.79 (s, 1H), 3.41 (s, 3H), 2.61 (s, 3H), 2.05 (s, 3H); ^{13}C NMR (75 MHz, $[D_6]$acetone) δ 165.3, 160.0 (d, $J=239$ Hz), 148.9, 137.8, 136.5, 135.0 (d, $J=10$ Hz), 134.2, 132.2, 129.8, 127.6 (q, $J=3.6$ Hz), 127.4, 125.6 (q, $J=33$ Hz), 125.5 (q, $J=288$ Hz), 122.2 (2C), 118.0 (d, $J=10$ Hz), 109.1 (d, $J=23$ Hz), 105.3 (d, $J=27$ Hz), 63.5, 29.8, 21.1, 19.9; ^{19}F NMR (188 MHz, $CDCl_3$) δ −60.6, −118.1; IR (film) $\nu(cm^{-1})$ 1675, 1606, 1517, 1327, 1115; HRMS (ESI^+): *m/z* calculated for $C_{24}H_{20}N_2OF_4Na$ $[M+Na]^+$ 451.1409; found 451.1410.

6-Fluoro-4-(3-methoxyphenyl)-1-methyl-3-(naphthalen-2-yl)-3,4-dihydroquinoxalin-2(1*H*)-one (4z): Following the general procedure, 6-fluoro-1-methylquinoxalin-2(1*H*)-one **1d** (89 mg, 0.5 mmol), naphthalen-2-ylboronic acid (129 mg, 0.75 mmol) and then 1-chloro-3-methoxybenzene (123 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4z** (172 mg, 0.42 mmol, 83%) as a white solid. R_f 0.22 (cyclohexane/ethyl acetate 90:10); mp 203 °C (recrystallised from isopropyl ether to give white crystals); ^1H NMR (300 MHz, $[D_6]$acetone) δ 7.90–7.80 (m, 4H), 7.62–7.59 (m, 1H), 7.52–7.45 (m, 2H), 7.28 (t, $J=8.1$ HZ, 1H), 7.19–7.11 (m, 2H), 6.87–6.70 (m, 4H), 5.78 (s, 1H), 3.73 (s, 3H), 3.44 (s, 3H); ^{13}C NMR (75 MHz, $[D_6]$acetone) δ 165.1, 161.5, 160.1 (d, $J=259$ Hz), 146.9, 135.5 (2C), 135.0 (d, $J=10$ Hz), 134.2, 134.0, 131.3, 129.5, 128.9, 128.5, 127.3, 127.2, 126.3, 125.1, 117.9 (d, $J=10$ Hz), 114.1, 110.1, 108.6 (d, $J=23$ Hz), 107.9, 105.9 (d, $J=27$ Hz), 66.8, 55.6, 30.1; IR (film) $\nu(cm^{-1})$ 1677, 1599, 1512, 1394, 1214; HRMS (ESI^+): *m/z* calculated for $C_{26}H_{21}N_2O_2FNa$ $[M+Na]^+$ 435.1485; found 435.1490.

6-Fluoro-1-(4-methoxybenzyl)-3-phenyl-4-*p*-tolyl-3,4-dihydroquinoxalin-2(1*H*)-one (4ab): Following the general procedure, 6-fluoro-1-(4-methoxybenzyl)quinoxalin-2(1*H*)-one **1e** (142 mg, 0.5 mmol), phenylboronic acid (91.5 mg, 0.75 mmol) and then 1-bromo-4-methylbenzene (123 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5) to afford the desired product **4ab** (159 mg, 0.35 mmol, 70%) as a white solid. R_f 0.35 (cyclohexane/ethyl acetate 90:10); mp 203 °C (recrystallised from isopropyl ether to give white crystals); ^1H NMR (300 MHz, $[D_6]$acetone) δ 7.46–7.43 (m, 2H), 7.37–7.31 (m, 3H), 7.20 (d, $J=8.4$ Hz, 2H), 7.13–7.08 (m, 4H), 7.01 (dd, $J=5.4$–9.0 Hz, 1H), 6.91 (dd, $J=2.7$–10.5 Hz, 1H), 6.79 (d, $J=8.4$ Hz, 2H), 6.57 (td, $J=3.0$–8.4 Hz, 1H), 5.63 (s, 1H), 5.34 (d, $J=15.9$ Hz, 1H), 5.05 (d, $J=15.9$ Hz, 1H), 3.74 (s, 3H), 2.32 (s, 3H); ^{13}C NMR (75 MHz, $[D_6]$acetone) δ 165.1, 160.0 (d, $J=239$ Hz), 159.9, 143.1, 138.1, 135.9 (d, $J=10$ Hz), 134.6, 131.0 (2C), 129.6 (2C), 129.0, 128.7 (2C), 127.2 (2C), 127.1, 122.4 (2C), 118.5 (d, $J=10$ Hz), 114.9 (2C), 107.9 (d, $J=23$ Hz), 105.1 (d, $J=26$ Hz), 67.0, 55.5, 45.6, 20.8; ^{19}F NMR (188 MHz, $CDCl_3$) δ −118.3; IR (film) $\nu(cm^{-1})$ 1669, 1512, 1248; HRMS (ESI^+): *m/z* calculated for $C_{29}H_{25}N_2O_2FNa$ $[M+Na]^+$ 475.1798; found 475.1808.

(*E*)-3-(4-Methoxyphenyl)-1-methyl-4-styryl-3,4-dihydrobenzo[*g*]quinoxalin-2(1*H*)-one 4ac: Following the general procedure, 1-methyl-3,4-dihydrobenzo[*g*]quinoxalin-2(1*H*)-one **1f** (105 mg, 0.5 mmol), 4-methoxyphenylboronic acid (114 mg, 0.75 mmol) and then bromostyrene (129 μL, 2 equiv) were mixed ($P(tBu)_3{\cdot}HBF_4$ was used as the ligand). The residue was purified by flash chromatography over silica gel (cyclohexane/ethyl acetate 95:5 to 90:10) to afford the desired product **4ac** (136 mg, 0.32 mmol, 65%) as a yellow oil, R_f 0.17 (cyclohexane/ethyl acetate 90:10), ^1H NMR (300 MHz, $[D_6]$acetone) δ 7.87–7.80 (m, 2H), 7.73 (s, 1H), 7.69 (d, $J=14.1$ Hz, 1H), 7.55 (s, 1H), 7.43–7.23 (m, 8H), 7.13–7.08 (m, 1H), 6.80 (d, $J=8.7$ Hz, 2H), 6.04 (d, $J=14.1$ Hz, 1H), 5.75 (s, 1H), 3.68 (s, 3H), 3.50 (s, 3H); ^{13}C NMR (75 MHz, $[D_6]$acetone) δ 165.9, 160.5, 138.7, 132.6, 131.9, 131.5, 131.1, 130.6, 129.4 (2C), 129.1, 128.5 (2C), 128.1, 127.3, 126.3 (2C), 126.0 (2C), 125.4, 115.0 (2C), 112.93, 112.89, 109.0, 62.8, 55.5, 29.8; IR (film) $\nu(cm^{-1})$ 1678, 1599, 1511, 1481, 1250; HRMS (ESI^+): *m/z* calculated for $C_{26}H_{21}N_2O_2FNa$ $[M+Na]^+$ 421.19011; found 421.1909.

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Assisted Tandem Palladium(II)/Palladium(0)-Catalyzed C- and N-Arylations of Quinoxalin-2(1*H*)-ones in Water

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