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Palladium-catalyzed synthesis of 1,2-dihydro-4(3*H*)-carbazolones. Formal total synthesis of murrayaquinone A

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Abstract—Two sequential palladium-catalyzed reactions are the key steps in a novel synthetic route to 1,2-dihydro-4(3*H*)-carbazolones. The steps are an intermolecular Stille cross-coupling followed by a reductive N-heteroannulation. A formal total synthesis of murrayaquinone A, employing this sequence, is reported.

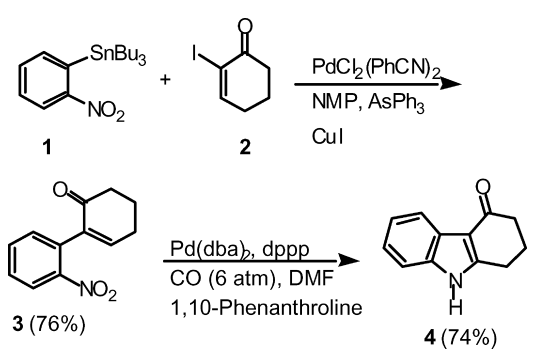
1. Introduction

We have recently described a mild and very efficient palladium-catalyzed route to substituted indoles via a palladium-catalyzed reductive N-heteroannulation of functionalized 2-nitrostyrenes.[1–6] This annulation reaction has been used as the key step to prepare a variety of tricyclic 3,4-fused indoles[7] in addition to some naturally occurring mushroom metabolites.[8]

As an extension of this work, we have communicated a related relatively mild and efficient palladium-catalyzed route to substituted 1,2-dihydro-4(3*H*)-carbazolones.[9] The annulation precursors were prepared by intermolecular Stille cross-couplings.[10] In our initial synthetic sequence, 2-(tri-*n*-butylstannyl)-1-nitrobenzene (**1**) was reacted with 2-iodo-2-cyclohexenone (**2**) in the presence of bis(benzonitrile)palladium dichloride ($PdCl_2(PhCN)_2$, 5 mol%), triphenylarsine ($AsPh_3$, 10 mol%), and copper iodide (10 mol%) in *N*-methylpyrrolidinone (NMP) to give the expected coupling product **3** in good isolated yield. Palladium-catalyzed N-heteroannulation of **3** using palladium bis(dibenzylideneacetone) ($Pd(dba)_2$, 6 mol%), 1,3-bis(diphenylphosphino)propane (dppp, 6 mol%), 1,10-phenanthroline (12 mol%), and CO (6 atm) in dimethylformamide (DMF) at 80°C, furnished the expected 1,2-dihydro-4(3*H*)-carbazolone **4** (Scheme 1).[11]

The polarity of the cross-coupling reagents can readily be switched, i.e. using 2-iodo-1-nitrobenzene and 2-tri-*n*-butyl-2-cyclohexene-1-one (**6**). The required tin reagent was prepared by reaction of the unsaturated bromoketal **5** with 2 equiv. of *tert*-butyllithium followed by addition of *tri-n*-butyltin chloride. The crude reaction mixture was stirred with hydrochloric acid affording the deprotected ketone **6** in high overall yield (Scheme 2). Palladium-catalyzed cross-coupling of **6** with 2-iodo-1-nitrobenzene gave the expected cross coupling product **3** in 71% yield.

Carbazolones have been used as intermediates in total synthesis of a variety of naturally occurring carbazole alkaloids for example, pyrayaquinones A and B, murrayaquinone A, koeniginequinone A,[12] and murrayafoline A.[13] A variety of methods have been utilized to prepare carbazolones. One of the most common methods used is the Fischer indole synthesis. For example, the parent ring-system, 1,2-dihydro-4(3*H*)-carbazolone (**4**), was prepared in 51% yield by reaction of phenylhydrazine with 1,3-cyclohexanedione followed by treatment of the obtained hydrazone with sulfuric acid.[14] Drawbacks of this methodology are the highly acidic reaction conditions and the formation of regioisomeric products when unsymmetrical substrates are used. The synthetic relay seen in Scheme 1 is



Scheme 1.

Keywords: palladium-catalyzed reactions; murrayaquinone A; cross-coupling.
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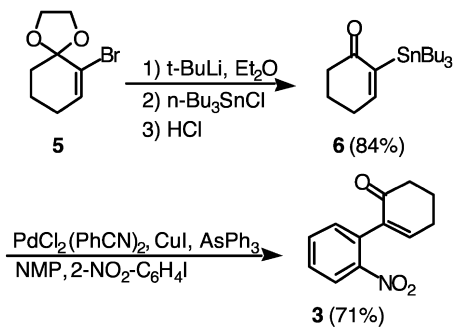


Scheme 2.

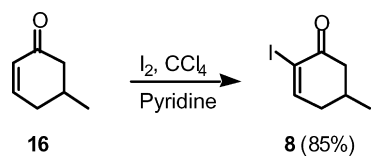
inherently regioselective and tolerates a wide range of functional groups. Herein is reported the full scope of the two-step reaction relay to 1,2-dihydro-4(3*H*)-carbazolones and an application thereof in a formal total synthesis of the carbazole alkaloid murrayaquinone A.

2. Results and discussion

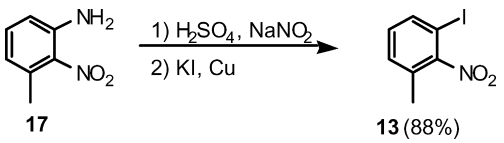
In order to examine the scope and limitation of sequence seen in Scheme 1, a number of cycloalkenones and nitroaromatic compounds were required as starting materials for the cross-coupling reaction. Most of the compounds were commercially available or prepared as previously described in the literature. 2-Iodo-5-methyl-2-cyclohexenone (**8**) was prepared by base mediated iodination of the corresponding cycloalkenone according to Johnson et al. (Scheme 3).[15]

3-Iodo-2-nitrotoluene (**13**) and 4-bromo-2-iodo-1-nitrobenzene (**15**) were prepared by modified literature procedures from the corresponding anilines **17**–**18** (Schemes 4 and 5).

With the starting materials in hand, a variety of substituted 2-(2-nitrophenyl)-2-cycloalkenones (**19**–**27**) were prepared by a palladium-catalyzed Stille type cross-coupling of **1** or **6** with 2-iodo-2-cycloalkenones or aryl halides, respectively. The results are summarized in Table 2. The Stille cross-couplings proceeded uneventfully; however, lower yields of product were observed for the more sterically congested aryl bromides (**12** and **14**) and for vinyl bromide **10**. Some modifications of the reaction conditions were required for the synthesis of compounds **24** and **26**. Although still moderate, the best yield of **26** was obtained by replacing $AsPh_3$ with 1,1′-bis-(diphenylphosphino)ferrocene (dppf) as the ligand. In addition to the expected coupling product **26**, transfer of one of the *n*-butyl groups from **1** to **14** was also observed in some reactions. Compound **24** was prepared using $PdCl_2(PPh_3)_2$ as the catalyst in DMF (110°C) without added ligand. It should be noted that minor amounts



Scheme 3.

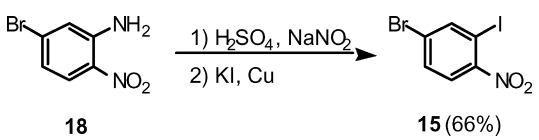


Scheme 4.

(<10%) of homo-coupling products of the tin reagents **1** and **6**, namely 2,2′-dinitrobiphenyl[16] and 2,2′-bis-(2-cyclohexene-1-one),[17,18] were isolated as byproducts in most coupling reactions.

The conditions of the N-heteroannulation warrant some comment. The results of a brief study of the influence of catalyst, ligand(s), temperature, solvent, and CO pressure are summarized in Table 1. Initial attempts to cyclize **3** to **4** using palladium diacetate (6 mol%), triphenylphosphine (24 mol%), and carbon monoxide (4 atm) in acetonitrile at 70°C, reaction conditions previously employed for the preparation of a large variety of indoles,[1] surprisingly, gave only recovered starting material (entry 1, Table 1). A moderate yield of product was observed at upon elevating the temperature and CO pressure, however a fair amount of starting material still remained (entry 2, Table 1). Changing the solvent to DMF produced a similar yield of **4** with complete disappearance of **3** (entry 3, Table 1). Combinations of $Pd(OAc)_2$-dppp, $Pd(OAc)_2$-1,10-phenanthroline, $Pd(dba)_2$-dppp, and $Pd(dba)_2$-1,10-phenathroline resulted in the formation of the expected product with somewhat better results using $Pd(dba)_2$ (entries 4–7, Table 1). Finally, a combination of the two bidentate ligands dppp (12 mol%) and 1,10-phenanthroline (12 mol%), in the presence of $Pd(dba)_2$, under 6 atm of CO in (DMF) at 80°C gave the expected 1,2-dihydro-4(3*H*)-carbazolone **4** in 74% yield (entry 8, Table 1). It should be noted that palladium-phenanthroline complexes have been shown to be particularly active catalysts for the reductive carbonylation of nitrobenzenes to give isocyanates.[19] The reason for the increased efficiency of the annulation in the presence of two different bidentate ligands is presently unclear.

Using the above conditions, palladium-catalyzed N-heteroannulation of **19**–**27** gave the expected 2,3-fused indoles **31**–**39** in 52–89% isolated yield (Table 2). The monohydrate of 1,10-phenanthroline was used in all reactions with no apparent detrimental effect compared to our initial reaction seen in Scheme 1. The reactions were monitored by TLC until all starting material had been consumed, and most of the reductive cyclizations were complete in 1–3 days. However, substrate **27** required an extended period of 8 days to go to completion. The yield of the 6-bromocarbazolone **39** was also significantly lower compared to the other cyclizations. A 5-bromo substituent has previously been problematic in this type of reaction. For example, attempted cyclization of 5-bromo-2-nitrostyrene yielded only recovered starting material.[15] It is interesting to note that no



Scheme 5.

Table 1. Catalysts for transformation of **3** to **4**

Entry[a]	Catalyst	Ligand(s)	Solvent	pCO (atm)	Temperature (°C)	3 (%)	4 (%)
1	$Pd(OAc)_2$	PPh_3	MeCN	4	70	43	n.o
2	$Pd(OAc)_2$	PPh_3	MeCN	6	80	50	45
3	$Pd(OAc)_2$	PPh_3	DMF	6	80	n.o	43
4	$Pd(OAc)_2$	dppp	DMF	6	80	n.o	35
5	$Pd(OAc)_2$	1,10-Phen	DMF	6	80	n.o	43
6	$Pd(dba)_2$	dppp	DMF	6	80	n.o	58
7	$Pd(dba)_2$	1,10-Phen	DMF	6	80	39	52
8	$Pd(dba)_2$	dppp/1,10-Phen	DMF	6	80	n.o	74

[a] All reactions were performed on a 0.5 mmol scale for 20 h. 1,10-Phen=1,10-Phenanthroline; DPPP=bis(diphenylphosphino)propane; n.o=not observed.

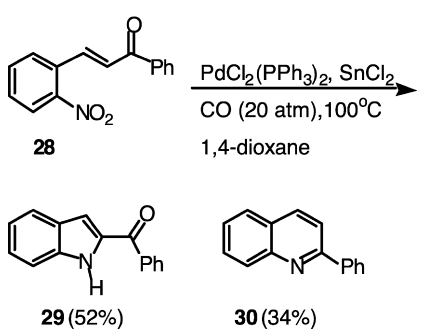
formal condensation with the ketone functionality occurred. This type of annulation was observed by Watanabe et al. upon palladium-catalyzed N-heteroannulation of **28** affording both the expected indole **29** and a significant amount of quinoline **30** (Scheme 6).[3] Related nitrogen–carbonyl carbon reactions of *N*-(2-nitrobenzoyl)amides have also been reported.[20]

Five- to seven-membered rings were readily fused to the indole skeleton (entries 1–3). The annulation reaction appears to be relatively unaffected by electron-withdrawing or electron-donating substituents on the aromatic ring. As can be seen in entries 5 and 8, both methoxy and methyl ester functionalized benzene rings work well. Substituents adjacent to the alkene or the nitro group of the aromatic ring also do not appear to affect the yield of the reaction (entries 6–7). Similar results were obtained in our previous studies of the formation of indoles by reductive N-heteroannulation.[9]

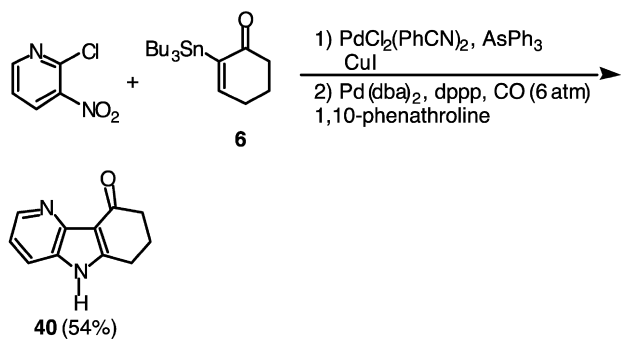
Nitropyridines can also be used as precursor. Palladium-catalyzed cross-coupling of 2-chloro-3-nitropyridine with α-tin substituted alkenone **6** gave a low yield of impure coupling product after workup and chromatographic purification (Scheme 7). The coupling product was found to be unstable and readily decomposed into a myriad of intractable products upon attempted further purification on silica gel or alumina. However, annulation of the crude reaction mixture furnished the expected 5-aza-carbazolone **40** in 54% yield over two steps. This compares very favorably with the only previous synthesis, starting from 3-amino-2-chloropyridine, affording **40** in 23% yield over two steps.[21]

In addition to the cross-coupling products **19**–**27**, two additional 2-(2-nitrophenyl)-2-cyclohexenones were prepared according to literature procedures.[22] The dione **41** was prepared by aromatic nucleophilic substitution employing 2-iodo-1-nitrobenzene and 1,3-cyclohexanedione, and methylation of **41** with dimethylsulfate gave the annulation precursor **42** (Scheme 8). N-heteroannulation of dienone **41** and enol ether **42** produced carbazolone **4** in acceptable yields under the standard reaction conditions. However, longer reaction times (90–96 h) were required for the cyclizations to go to completion.

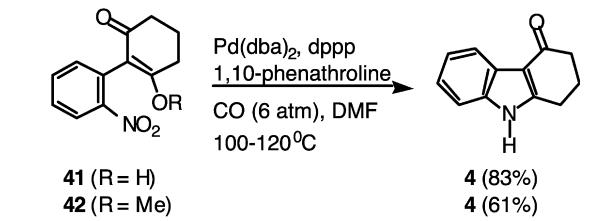
We decided to examine a potentially general route to carbazoloquinone alkaloids. Murrayaquinone A was selected as the initial target molecule (Scheme 8).[12,23,24,25] In the event, iodination of 6-methyl-2-cyclohexenone (**43**) gave 2-iodo-6-methyl-2-cyclohexenone (**44**). Stille cross-coupling of **44** with arylstannane **1** gave annulation precursor **45** in high isolated yield. The reductive cyclization of **45** also proceeded uneventfully affording carbazolone **46** in an excellent yield (97%). Dehydrogenation of carbazolone **46** using 10% Pd/C in a mixture of diphenyl ether and 1,2,4-trimethylbenzene at 230°C furnished 3-methyl-4-hydroxycarbazole **47**. As was previously shown by Bringmann et al. addition of a small amount of 1,2,4-trimethylbenzene was crucial for the dehydrogenation to occur.[26] A number of carbazolequinone alkaloids have been efficiently synthesized via oxidation of 1- or 4-hydroxycarbazoles. For example, oxidation of 4-hydroxy-3-methylcarbazole (**47**), using Fremy's salt ($(KSO_3)_2NO$) to



Scheme 6.

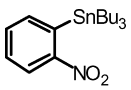
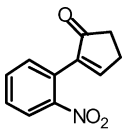
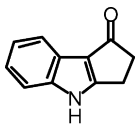
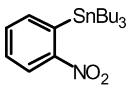
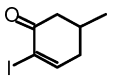
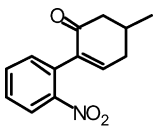
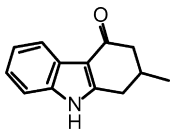
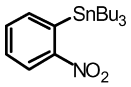
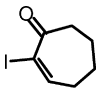
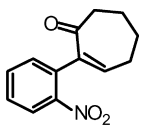
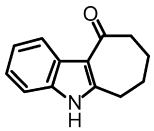
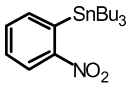
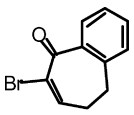
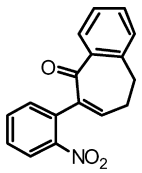
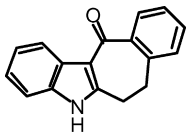
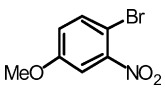
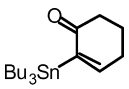
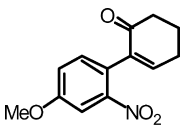
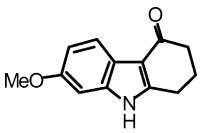
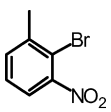
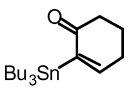
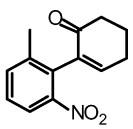
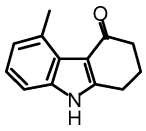
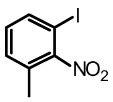
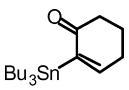
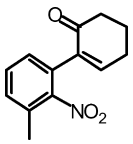
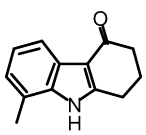
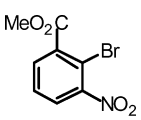
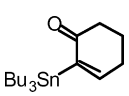
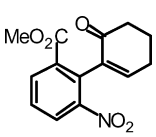
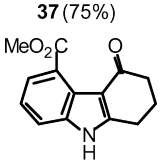
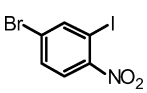
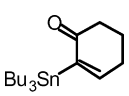
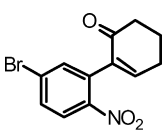
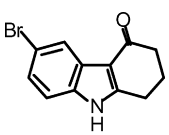


Scheme 7.

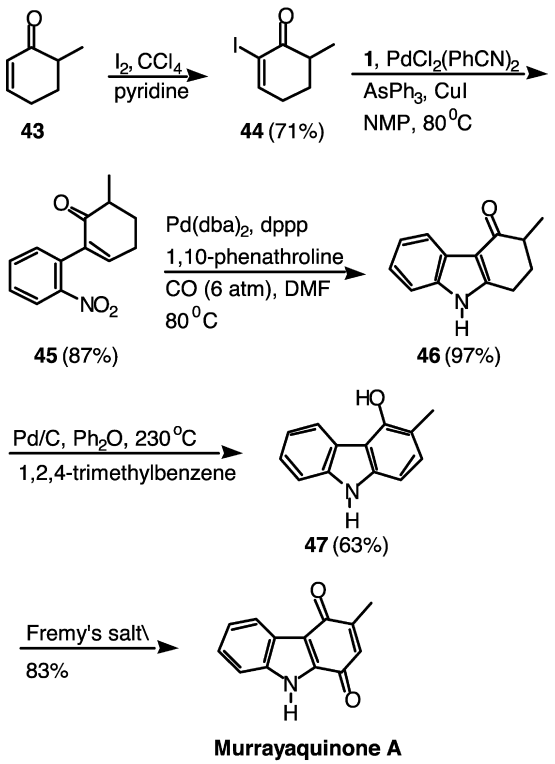


Scheme 8.

Table 2. Stille cross-coupling and N-heteroannulation forming carbazolones

Entry	Nitrobenzene	Alkenone	Coupling Product[a,b]	Carbazolone[a,b]
1	 **1**	 **7**	 **19** (65%)	 **31** (86%)
2	 **1**	 **8**	 **20** (74%)	 **32** (89%)
3	 **1**	 **9**	 **21** (68%)	 **33** (66%)
4	 **1**	 **10**	 **22** (46%)	 **34** (86%)
5	 **11**	 **6**	 **23** (67%)	 **35** (89%)
6	 **12**	 **6**	 **24** (31%)	 **36** (79%)
7	 **13**	 **6**	 **25** (62%)	 **37** (75%)
8	 **14**	 **6**	 **26** (44%)	 **38** (75%)
9	 **15**	 **6**	 **27** (56%)	 **39** (52%)

[a] See Section 3 for detailed procedures.
[b] Isolated yields in parenthesis.



Scheme 9.

murrayaquinone A in good yield has been reported in the literature (Scheme 9).[27,28] The presented synthesis of the murrayaquinone A precursor **47** was completed in only four steps from 6-methyl-2-cyclohexen-1-one with an overall yield of 38%. As a comparison, the previous synthesis of **47** by Miki et al.[26] was achieved in nine steps from dimethyl indole-2,3-dicarboxylate with an overall of yield of less than 16%.

In summary, a novel route to tricyclic substituted 2,3-fused indoles in general and carbazolones in particular has been developed. The route was applied to a formal total synthesis of murrayaquinone A. Further applications in total synthesis are presently being pursued in our laboratories.

3. Experimental

3.1. General procedures

All NMR spectra were determined in $CDCl_3$ at 270 MHz (^1H NMR) and 67.5 MHz (^{13}C NMR). The chemical shifts are expressed in δ values relative to Me_4Si (0.0 ppm, ^1H and ^{13}C) or $CDCl_3$ (77.0 ppm, ^{13}C) internal standards. ^1H–^1H coupling constants are reported as calculated from spectra; thus a slight difference between $J_{a,b}$ and $J_{b,a}$ is usually obtained. Results of APT (attached proton test)–^{13}C NMR experiments are shown in parentheses where, relative to $CDCl_3$, (+) denotes CH_3 or CH and (−) denotes CH_2 or C.

Benzene and diethyl ether were distilled from sodium benzophenone ketyl prior to use. Hexanes, dichloromethane, and ethyl acetate were distilled from calcium hydride. Chemicals prepared according to literature procedures have been footnoted the first time used; all other reagents were obtained from commercial sources and used as received. All reactions were performed under an argon atmosphere in oven-dried glassware unless otherwise stated. Solvents were removed from reaction mixtures and products on a rotary evaporator at water aspirator pressure. Elemental Analyses were performed by Atlantic Microlab, Inc., Norcross, GA. High Resolution Mass Spectra (HRMS) were performed at University of California Riverside Mass Spectrometry Center.

3.1.1. 2-(tri-*n*-Butylstannyl)-2-cyclohexen-1-one (6).[29] *tert*-Butyllithium (34.5 mL, 1.7 M in hexanes, 58.7 mmol) was added dropwise to a solution of 6-bromo-1,4-dioxaspiro[4,5]dec-6-ene (**5**)[30] (6.00 g, 27.4 mmol) in diethyl ether (480 mL) cooled to −78°C. After 30 min, tri-*n*-butyltin chloride (8.2 mL, 30.2 mmol) was added slowly, and the reaction mixture stirred an additional 30 min at −78°C. The reaction mixture was allowed to warm to ambient temperature followed by slow addition of HCl (10%, aq., 200 mL). The resulting reaction mixture was stirred for 3 h. After dilution with diethyl ether (500 mL), the reaction mixture was washed successively with water (500 mL), NH_4OH (10%, aq., 500 mL), and water (500 mL). The organic phase was dried ($MgSO_4$), filtered, and the solvent was removed at reduced pressure. The crude product was purified by chromatography (hexanes/EtOAc, 95:5) to give **6** (8.38 g, 21.8 mmol, 79%) as a clear, colorless oil.

3.1.2. 2-Iodo-5-methyl-2-cyclohexen-1-one (8). To a solution of 5-methyl-2-cyclohexen-1-one (**16**)[31] (502 mg, 4.55 mmol) in 20 mL of 1:1 CCl_4/pyridine cooled to 0°C was added dropwise, a solution of iodine (2.30 g, 9.04 mmol) in 20 mL of 1:1 CCl_4/pyridine. The reaction mixture was allowed to warm to ambient temperature overnight. The reaction mixture was diluted with ether (100 mL) and washed successively with water (40 mL), HCl (5%, aq., 2×40 mL), water (40 mL), and $Na_2S_2O_3$ (20%, aq., 40 mL). The organic phase was dried ($MgSO_4$), filtered, and the solvent was removed at reduced pressure. Purification of the crude product by chromatography (hexanes/EtOAc, 9:1) gave **8** (911 mg, 3.86 mmol, 85%) as a pale yellow solid. Mp 39–40°C; IR 2955, 1682, 1590 cm^{-1}; ^1H NMR δ 1.08 (d, J=5.9 Hz, 3H), 2.11–2.53 (m, 4H), 2.69–2.83 (m, 1H), 7.72 (dd, J=5.9, 2.9 Hz, 1H); ^{13}C NMR δ 20.6 (−), 30.4 (−), 37.9 (+), 45.0 (+), 103.5 (+), 158.6 (−), 192.5 (+); CG-MS (EI) m/z 236 (M^+); HRMS (EI) calcd for C_7H_9IO (M^+) 235.9698, found 235.9703.

3.1.3. 2-Iodo-6-methyl-2-cyclohexen-1-one (44). To a solution of 6-methyl-2-cyclohexen-1-one (**43**)[31] (441 mg, 4.00 mmol) in 20 mL of 1:1 CCl_4/pyridine cooled to 0°C was added dropwise a solution of iodine (2.09 g, 8.23 mmol) dissolved in 20 mL of 1:1 CCl_4/pyridine with stirring. The reaction was allowed to warm to ambient temperature overnight. The reaction mixture was diluted with ether (100 mL) and washed successively with water (40 mL), HCl (5%, aq., 2×40 mL), water (40 mL), and $Na_2S_2O_3$ (20%, aq., 40 mL). The organic phase was dried ($MgSO_4$), filtered, and the solvent was removed at reduced pressure. The crude product was purified by chromatography (hexanes/EtOAc, 9:1) to give **44** (675 mg,

2.86 mmol, 71%) as a pale yellow oil; IR 2929, 1682, 1594, 1454 cm^{-1}; ^1H NMR δ 1.21 (d, J=6.7 Hz, 3H), 1.75–1.91 (m, 1H), 2.06–2.18 (m, 1H), 2.35–2.68 (m, 3H), 7.68–7.73 (m, 1H); ^{13}C NMR δ 15.2 (−), 29.0 (+), 29.9 (+), 40.7 (−), 102.8 (+), 158.3 (−), 193.9 (+); GC-MS (M^+) m/z 236 (M^+); HRMS (EI) calcd for C_7H_9IO (M^+) 235.9698, found 235.9688.

3.1.4. 3-Iodo-2-nitrotoluene (13).[32] To a mixture of 3-methyl-2-nitroaniline (**17**)[16] (502 mg, 3.30 mmol), ice-water (4 mL), and H_2SO_4 (conc., 0.2 mL), cooled in an ice bath, was added a solution of $NaNO_2$ (251 mg, 3.64 mmol) in water (1 mL) very slowly (~1 drop/min). After the addition, the reaction mixture was stirred for 20 min and additional H_2SO_4 (conc., ~0.07 mL) was added. The reaction mixture was poured slowly into an ice-cold solution of KI (656 mg, 3.95 mL) in water (1 mL). After a few minutes, copper powder (4 mg, 0.06 mmol) was added, and the reaction mixture was heated slowly to 80°C over 30 min. The mixture was allowed to cool to ambient temperature, extracted with CH_2Cl_2 (3×50 mL), washed with $Na_2S_2O_3$ (20%, aq., 50 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by chromatography (hexanes/EtOAc, 8:2) to give **13** (764 mg, 2.90 mmol, 88%) as a yellow-orange solid.

3.1.5. 4-Bromo-2-iodo-1-nitrobenzene (15).[33] To a mixture of 5-bromo-2-nitroaniline (**18**)[34] (198 mg, 0.91 mmol), ice-water (5 mL), and H_2SO_4 (conc., 0.2 mL) cooled to 0°C was added a solution of $NaNO_2$ (70.2 mg, 1.02 mL) very slowly (~1 drop/min). The reaction mixture was stirred for 1.5 h at ambient temperature, and was then added very slowly to an ice-cold solution of KI (190 mg, 1.14 mmol) in water (1 mL). After a few minutes copper powder (2 mg, 0.03 mmol) was added, and the reaction mixture was heated slowly to 80°C over 20 min. The reaction mixture was allowed to cool to ambient temperature and was extracted with CH_2Cl_2 (3×50 mL). The combined organic phases were washed with $Na_2S_2O_3$ (10%, aq., 50 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. The crude product was purified by chromatography (hexanes/EtOAc, 9:1) to give **15** (182 mg, 0.55 mmol, 61%) as a yellow solid. Mp 77–79°C; IR 1563, 1518, 1335 cm^{-1}; ^1H NMR δ (dd, J=8.5, 2.0 Hz, 1H), 7.77 (d, J=8.5 Hz, 1H), 8.22 (d, J=2.0 Hz, 1H); ^{13}C NMR δ 87.4 (+), 126.4(−), 127.7 (+), 132.2 (−), 144.1 (−), 151.7 (+).

3.1.6. 2-(2-Nitrophenyl)-2-cyclohexen-1-one (3).[22] To a solution of 2-iodo-2-cyclohexen-1-one (**2**)[35] (808 mg, 3.64 mmol) and 2-(tri-*n*-butylstannyl)-1-nitrobenzene (**1**)[36] (1.80 g, 4.34 mmol) in *N*-methylpyrrolidinone (NMP, 4 mL) was added $PdCl_2(PhCN)_2$ (77.5 mg, 0.20 mmol), Ph_3As (117 mg, 0.40 mmol), and CuI (77.2 mg, 0.40 mmol). The reaction mixture was heated at 80°C for 20 h. The reaction mixture was diluted with EtOAc (100 mL) and washed successively with NH_4OH (10%, aq., 3×30 mL) and H_2O (2×30 mL). The aqueous portions were combined and extracted with EtOAc (50 mL). The organic phases were combined, dried ($MgSO_4$), filtered, and concentrated under reduced pressure. Purification of the crude product by chromatography (hexanes/EtOAc, 9:1) gave **3** (603 mg, 2.77 mmol, 76%) as a pale yellow solid.

Compound **3** was also prepared in a similar fashion described above using 2-(tri-*n*-butylstannyl)-2-cyclohexenone (**6**) (931 mg, 2.42 mmol), 1-iodo-2-nitrobenzene (502 mg, 2.01 mmol), $PdCl_2(PhCN)_2$ (38.5 mg, 0.10 mmol), Ph_3As (70.1 mg, 0.22 mmol), CuI (41.9 mg, 0.22 mmol), and NMP (4 mL) to give **3** (309 mg, 1.42 mmol, 71%) after purification.

3.1.7. 2-(2-Nitrophenyl)-2-cyclopenten-1-one (19).[22] As described for **3**, reaction of 2-iodo-2-cyclopenten-1-one (**7**)[35] (290 mg, 1.40 mmol) with 1-(tri-*n*-butylstannyl)-2-nitrobenzene (**1**) (643 mg, 1.56 mmol), $PdCl_2(PhCN)_2$ (26.7 mg, 0.07 mmol), Ph_3As (43.7 mg, 0.14 mmol), CuI (29.2 mg, 0.15 mmol), and NMP (2.8 mL) for 20 h gave, after chromatography (EtOAc/hexanes, 2:8), **19** (183 mg, 0.90 mmol, 65%) as a pale yellow solid. Mp 94.5–96.5°C; IR 1697, 1518, 1349 cm^{-1}; ^1H NMR δ 2.56–2.60 (m, 2H), 2.78–2.83 (m, 2H), 7.32 (dd, J=7.5, 1.6 Hz, 1H), 7.49 (td, J=7.5, 1.4 Hz, 1H), 7.61 (td, J=7.5, 1.4 Hz, 1H), 7.69 (t, J=2.8 Hz, 1H), 8.02 (dd, J=8.1, 2.6 Hz, 1H); ^{13}C NMR δ 27.0 (+), 34.5 (+), 124.3 (−), 127.1 (+), 129.1 (−), 131.2 (−), 133.0 (−), 143.7 (+), 148.2 (+), 159.0 (−), 205.3 (+); Anal. calcd for $C_{11}H_9NO_3$: C, 65.02; H, 4.46, found: C, 65.15; H, 4.46.

3.1.8. 5-Methyl-2-(2-nitrophenyl)-2-cyclohexen-1-one (20). As described for **3**, reaction of 2-iodo-5-methyl-2-cyclohexen-1-one (**8**) (241 mg, 1.02 mmol) with 1-(tri-*n*-butylstannyl)-2-nitrobenzene (**1**) (455 mg, 1.10 mmol), $PdCl_2(PhCN)_2$ (20.6 mg, 0.05 mmol), Ph_3As (31.6 mg, 0.10 mmol), CuI (19.1 mg, 0.10 mmol), and NMP (1 mL) for 24 h gave, after chromatography (EtOAc/hexanes, 1:9 followed by 2:8), **20** (175 mg, 0.75 mmol, 74%) as a pale yellow solid. Mp 107–109°C; IR 1672, 1517, 1340 cm^{-1}; ^1H NMR δ 1.03 (d, J=8.1 Hz, 3H), 2.10–2.35 (m, 3H), 2.44–2.59 (m, 2H), 6.90 (dd, J=5.5, 2.8 Hz, 1H), 7.16 (dd, J=7.5, 1.6 Hz, 1H), 7.35 (td, J=6.4, 1.6 Hz, 1H), 7.49 (td, J=7.3, 1.2 Hz, 1H), 7.88 (dd, J=8.1, 1.2 Hz, 1H); ^{13}C NMR δ 20.9 (−), 29.9 (−), 34.3 (+), 46.1 (+), 123.9 (−), 128.6 (−), 131.5 (−), 131.7 (+), 133.2 (−), 138.8 (+), 146.0 (−), 148.4 (+), 196.5 (+); GC-MS (EI) m/z 185 (M^+-NO_2); HRMS (DEI) calcd for $C_{13}H_{13}NO_3$ (MH^+) 232.0974, found 232.0965.

3.1.9. 2-(2-Nitrophenyl)-2-cyclohepten-1-one (21). As described for **3**, reaction of 2-iodo-2-cyclohepten-1-one (**9**)[37] (389 mg, 1.65 mmol) with 1-(tri-*n*-butylstannyl)-2-nitrobenzene (**1**) (820 mg, 1.99 mmol), $PdCl_2(PhCN)_2$ (31.9 mg, 0.08 mmol), Ph_3As (51.7 mg, 0.16 mmol), CuI (31.2 mg, 0.16 mmol), and NMP (1.6 mL) for 72 h gave, after chromatography (benzene/CH_2Cl_2, 19:1), **21** (259 mg, 1.12 mmol, 68%) as a pale yellow solid. Mp 83–85°C; IR 1665, 1517, 1340 cm^{-1}; ^1H NMR δ 1.81–1.99 (m, 4H), 2.53–2.61 (m, 2H), 2.74–2.80 (m, 2H), 6.74 (t, J=6.5 Hz, 1H), 7.28 (dd, J=7.5, 1.6 Hz, 1H), 7.43 (td, J=8.1, 1.6 Hz, 1H), 7.58 (td, J=7.5, 1.6 Hz, 1H) 8.00 (dd, J=8.1, 1.2 Hz, 1H); ^{13}C NMR δ 21.0 (+), 25.0 (+), 27.8 (+), 42.4 (+), 124.2 (−), 128.5 (−), 132.6 (−), 133.5 (−), 135.1 (+), 142.9 (+), 143.1 (−), 147.2 (+), 202.5 (+); GC-MS (EI) m/z 186 (M^+-NO_2+H); HRMS (EI) calcd for $C_{13}H_{13}NO_3$ (M^+) 231.0895, found 231.0895.

3.1.10. 8,9-Dihydro-5*H*-6-(2-nitrophenyl)-benzocyclohepten-5-one (22). As described for **3**, reaction of

6-bromo-8,9-dihydro-5H-benzocyclohepten-5-one (**10**)[38] (250 mg, 1.06 mmol) with 1-(tri-*n*-butylstannyl)-2-nitrobenzene (**1**) (496 mg, 1.20 mmol), $PdCl_2(PhCN)_2$ (21.5 mg, 0.06 mmol), Ph_3As (34.1 mg, 0.11 mmol), CuI (21.0 mg, 0.11 mmol), and NMP (1 mL) for 40 h gave, after chromatography (EtOAc/hexanes, 1:9 followed by 2:8), **22** (183 mg, 0.90 mmol, 65%) as an orange oil; IR 3408, 2941, 1665, 1517, 1340 cm^{-1}; ^1H NMR δ 2.78 (q, J=5.1 Hz, 2H), 3.14 (t, J=5.1 Hz, 2H), 6.81 (t, J=5.1 Hz, 1H), 7.19–7.70 (m, 7H), 8.07 (dd, J=8.1, 2.9 Hz, 1H); ^{13}C NMR δ 30.6 (+), 33.7 (+), 124.3 (−), 127.0 (−), 128.2 (−), 128.6 (−), 129.9 (−), 132.1 (−), 132.5 (−), 133.4 (−), 136.2 (+), 139.1 (+), 140.9 (+), 141.5 (+), 144.2 (−), 148.1 (+), 194.2 (+); GC-MS (M^+) m/z 233 (M^+-NO_2); HRMS (DEI) calcd for $C_{14}H_{15}NO_4$ (MH^+) 280.0974, found 280.0964.

3.1.11. 2-(4-Methoxy-2-nitrophenyl)-2-cyclohexen-1-one (23). As described for **3**, reaction of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (183 mg, 0.48 mmol) with 1-bromo-2-nitro-4-methoxybenzene (**11**)[39] (103 mg, 0.44 mmol), $PdCl_2(PhCN)_2$ (8.2 mg, 0.02 mmol), 1,1′-bis(diphenylphosphino)ferrocene (24.1 mg, 0.04 mmol), CuI (8.9 mg, 0.04 mmol), and NMP (1 mL) for 3 days gave, after chromatography (EtOAc/hexanes, 2:8 followed by 3:7), **23** (73.4 mg, 0.30 mmol, 67%) as a yellow-orange solid. Mp 63–65°C; IR 1682, 1531, 1357, 1234 cm^{-1}; ^1H NMR δ 2.14 (pentet, J=5.9 Hz, 2H), 2.52–2.60 (m, 4H), 3.85 (s, 3H), 6.96 (t, J=4.1 Hz, 1H), 7.1–7.16 (m, 2H), 7.55 (d, J=3.9 Hz, 1H); ^{13}C NMR δ 22.6 (+), 26.2 (+), 38.3 (+), 55.8 (−), 109.1 (−), 119.5 (−), 124.1 (+), 132.4 (−), 139.0 (+), 146.2 (−), 149.0 (+), 159.5 (+), 196.8 (+); GC-MS (EI) m/z 247 (M^+), 201 (M^+-NO_2); HRMS (EI) calcd for $C_{13}H_{13}NO_3$ (M^+) 247.0845, found 247.0849.

3.1.12. 2-(6-Methyl-2-nitrophenyl)-2-cyclohexen-1-one (24). As described for **3**, reaction of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (351 mg, 0.91 mmol) with 2-bromo-3-nitrotoluene (**12**) (177 mg, 0.82 mmol), $PdCl_2(PPh_3)_2$ (27.7 mg, 0.04 mmol), and DMF (5 mL) at 110°C for 26 h gave, after chromatography (EtOAc/hexanes, 2:8), **24** (58.2 mg, 0.25 mmol, 31%) as a pale yellow solid. Mp 79–80°C; IR 1671, 1520, 1356 cm^{-1}; ^1H NMR δ 2.09–2.20 (m, 2H), 2.22 (s, 3H), 2.51 (q, J=5.7 Hz, 2H), 2.57–2.74 (m, 2H), 6.72 (t, J=4.2 Hz, 1H), 7.33 (t, J=7.8 Hz, 1H), 7.46 (d, J=7.5 Hz, 1H), 7.78 (d, J=8.1 Hz, 1H); ^{13}C NMR δ 20.0 (−), 22.5 (+), 26.0 (+), 38.2 (+), 121.6 (−), 127.9 (−), 131.4 (+), 134.4 (−), 137.2 (+), 138.3 (+), 146.8 (−), 149.4 (+), 196.8 (+); GC-MS (EI) m/z 231 (M^+), 185 (M^+-NO_2); HRMS (EI) calcd for $C_{13}H_{13}NO_3$ (M^+) 231.0895, found 231.0902.

3.1.13. 2-(3-Methyl-2-nitrophenyl)-2-cyclohexen-1-one (25). As described for **3**, reaction of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (385 mg, 1.00 mmol) with 3-iodo-2-nitrotoluene (**13**) (215 mg, 0.82 mmol), $PdCl_2(PhCN)_2$ (15.7 mg, 0.04 mmol), Ph_3As (25.3 mg, 0.08 mmol), CuI (16.1 mg, 0.08 mmol), and NMP (2.5 mL) for 2 days gave, after chromatography (EtOAc/hexanes, 1:9 followed by 2:8), **25** (117 mg, 0.51 mmol, 62%) as a pale yellow solid. Mp 129–131°C; IR 1677, 1523, 1362 cm^{-1}; ^1H NMR δ 2.10 (pentet, J=6.2 Hz, 2H), 2.39 (s, 3H), 2.48–2.58 (m, 4H), 6.99 (t, J=4.3 Hz, 1H), 7.07 (d, J=7.6 Hz, 1H), 7.26 (d, J=7.8 Hz, 1H), 7.37 (t, J=7.5 Hz, 1H); ^{13}C NMR δ 18.5 (−), 22.5 (+), 26.3 (+), 38.3 (+), 128.9 (−), 130.4 (−), 130.6 (+), 130.7 (+), 131.2 (−), 137.8 (+), 148.6 (−), 150.3 (+), 196.5 (+); GC-MS (EI) m/z 231 (M^+), 185 (M^+-NO_2); HRMS (EI) calcd for $C_{13}H_{13}NO_3$ (M^+) 231.0895, found 231.0898.

3.1.14. 2-(6-Carbomethoxy-2-nitrophenyl)-2-cyclohexen-1-one (26). As described for **3**, reaction of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (887 mg, 2.30 mmol) with 1-carbomethoxy-2-bromo-3-nitrobenzene (**14**)[16] (501 mg, 1.92 mmol), $PdCl_2(PhCN)_2$ (38.2 mg, 0.10 mmol), Ph_3As (59.8 mg, 0.20 mmol), CuI (39.7 mg, 0.20 mmol), and NMP (4 mL) for 96 h gave, after chromatography (EtOAc/hexanes, 2:8), **26** (233 mg, 0.84 mmol, 44%) as a yellow-orange solid. Mp 86.5–88.5°C; IR 1730, 1681, 1531, 1357, 1294, 1273 cm^{-1}; ^1H NMR δ 2.15 (pentet, J=6.3 Hz, 2H), 2.47 (q, J=5.3 Hz, 2H), 2.63 (t, J=6.3 Hz, 2H), 6.66 (t, J=4.1 Hz, 1H), 7.53 (t, J=7.9 Hz, 1H), 7.99 (d, J=8.1 Hz, 1H), 8.12 (d, J=7.9 Hz, 1H); ^{13}C NMR δ 22.2 (+), 26.0 (+), 38.0 (+), 52.3 (−), 126.9 (−), 128.5 (−), 132.5 (+), 132.7 (+), 133.8 (−), 136.9 (+), 144.6 (−), 150.3 (+), 165.4 (+), 196.3 (+); GC-MS (EI) m/z 275 (M^+), 229 (M^+-NO_2); HRMS (EI) calcd for $C_{14}H_{15}NO_4$ (M^+) 275.0794, found 275.0804.

This reaction was performed a number of times and methyl 2-butyl-3-nitrobenzoate (tentatively assigned) was usually obtained as an inseparable byproduct. Partial spectral data for the byproduct: ^1H NMR δ 0.91 (t, J=7.3 Hz, 3H), 1.25–1.42 (m, 4H), 1.64 (pentet, J=6.9 Hz, 2H), 3.63 (s, 3H), 7.68 (t, J=7.9 Hz, 1H), 8.28 (m, 1H). Partial ^{13}C NMR δ 13.4 (−), 17.4 (+), 26.6 (+), 27.6 (+), 52.4 (−), 127.7 (−), 128.8 (−), 134.7 (−).

3.1.15. 2-(5-Bromo-2-nitrophenyl)-2-cyclohexen-1-one (27). As described for**3**, reaction of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (459 mg, 1.19 mmol) with 4-bromo-2-iodo-1-nitrobenzene (**15**) (318 mg, 0.97 mmol), $PdCl_2(PhCN)_2$ (18.9 mg, 0.05 mmol), Ph_3As (30.5 mg, 0.10 mmol), CuI (18.2 mg, 0.10 mmol), and NMP (3 mL) for 2 days gave, after chromatography (EtOAc/hexanes, 1:9), **27** (160 mg, 0.54 mmol, 56%) as a yellow-orange solid. Mp 168–169°C; IR 2948, 1668, 1520, 1557, 1520, 1348 cm^{-1}; ^1H NMR δ 2.14 (p, J=5.8 Hz, 2H), 2.52–2.61 (m, 4H), 7.02 (t, J=3.2 Hz, 1H), 7.41 (d, J=3.5 Hz, 1H), 7.59 (dd, J=8.9, 3.4 Hz, 1H), 7.90 (d, J=8.7 Hz, 1H); ^{13}C NMR δ 22.4 (+), 26.2 (+), 38.1 (+), 125.7 (−), 127.9 (+), 131.7 (−), 133.9 (+), 134.4 (−), 134.5 (+), 138.4 (+), 147.3 (−), 196.1 (+); GC-MS (EI) m/z 251 (M^+-NO_2), 249 (M^+-NO_2); HRMS (DEI) calcd for $C_{12}H_{10}BrNO_3$ (M^+) 295.9923, found 295.9915.

3.1.16. 1,2-Dihydrocarbazol-4(3*H*)-one (4).[9] 2-(2-Nitrophenyl)-2-cyclohexen-1-one (**3**) (285 mg, 1.31 mmol), $Pd(dba)_2$ (45.3 mg, 0.08 mmol), dppp (32.5 mg, 0.08 mmol), 1,10-phenanthroline monohydrate (31.2 mg, 0.16 mmol), and DMF (5 mL) were placed in an ACE Glass pressure tube fitted with a pressure head. The tube was pressurized-depressurized with CO to 6 atm 3 times, and the reaction was heated at 80°C under CO (6 atm) for 24 h. The reaction mixture was filtered through a Celite pad, the pad was washed with CH_2Cl_2, and the filtrate was concentrated under high vacuum. The crude product was purified by

chromatography (EtOAc/hexanes, 3:7) to give **4** (180 mg, 0.97 mmol, 74%) as a white powder.

Compound **4** was also prepared using the above procedure except that a mixture of 2-(2-nitrophenyl)-1,3-cyclohexanedione[21] (**41**) (202 mg, 0.87 mmol), $Pd(dba)_2$ (29.7 mg, 0.05 mmol), dppp (22.5 mg, 0.05 mmol), 1,10-phenanthroline monohydrate (23.5 mg, 0.12 mmol), and DMF (5 mL) was heated at 100°C for 90 h to give **4** (133 mg, 0.72 mmol, 83%) after chromatography.

Compound **4** was also prepared using the above procedure except that a mixture of 3-methoxy-2-(2-nitrophenyl)-2-cyclohexen-1-one[21] (**42**) (141 mg, 0.57 mmol), $Pd(dba)_2$ (20.6 mg, 0.04 mmol), dppp (16.3 mg, 0.04 mmol), 1,10-phenanthroline monohydrate (15.4 mg, 0.08 mmol), and DMF (5 mL) was heated at 120°C for 96 h to give **4** (64.5 mg, 0.35 mmol, 61%) after chromatography.

3.1.17. 3,4-Dihydrocyclopent[*b*]indol-1(2*H*)-one (31).[40] As described for **4**, reaction of 2-(2-nitrophenyl)-2-cyclopenten-1-one (**19**) (125 mg, 0.61 mmol) with $Pd(dba)_2$ (21.2 mg, 0.04 mmol), dppp (15.7 mg, 0.04 mmol), 1,10-phenanthroline monohydrate (14.8 mg, 0.07 mmol), and DMF (5 mL) for 3 days gave, after chromatography (EtOAc/hexanes, 1:1 followed by EtOAc), **31** (90.4 mg, 0.53 mmol, 86%) as a white powder.

3.1.18. 2-Methyl-1,2-dihydrocarbazol-4(3*H*)-one (32). As described for **4**, reaction of 5-methyl-2-(2-nitrophenyl)-2-cyclohexenone (**20**) (98.3 mg, 0.42 mmol) with $Pd(dba)_2$ (14.7 mg, 0.03 mmol), dppp (10.5 mg, 0.03 mmol), 1,10-phenanthroline monohydrate (10.2 mg, 0.05 mmol), and DMF (5 mL) for 36 h gave, after chromatography (EtOAc/hexanes, 3:7), **32** (75.1 mg, 0.38 mmol, <89%)[40] as a white powder. Mp 260–261°C; IR (Nujol) 2925, 1630, 1583, 1458, 1376 cm^{-1}; ^1H NMR ($CDCl_3$+DMSO-d_6) δ 1.19 (d, J=6.2 Hz, 3H), 2.22–2.71 (m, 4H), 2.98–3.11 (m, 1H), 7.11–7.21 (m, 2H), 7.32–7.40 (m, 1H), 8.04–8.12 (m, 1H), 11.25 (s, 1H); ^{13}C NMR ($CDCl_3$+DMSO-d_6) δ 20.3 (−), 30.4 (+), 30.7 (−), 45.6 (+), 110.5 (−), 111.1 (+), 119.7 (−), 120.7 (−), 121.6 (−), 123.7 (+), 135.4 (+), 150.8 (+), 192.4 (−).

3.1.19. 6,7,8,9-Tetrahydrocyclohept[*b*]indol-10(5*H*)-one (33).[41] As described for **4**, reaction of 2-(2-nitrophenyl)-2-cycloheptenone (**21**) (136 mg, 0.59 mmol) with $Pd(dba)_2$ (20.4 mg, 0.04 mmol), dppp (14.5 mg, 0.04 mmol), 1,10-phenanthroline monohydrate (14.7 mg, 0.07 mmol), and DMF (5 mL) for 48 h gave, after chromatography (EtOAc/hexanes, 3:7), **33** (77.9 mg, 0.39 mmol, 66%) as a white powder.

3.1.20. 6,7-Dihydrobenzo[4,5]cyclohept-[1,2-*b*]indol-12(5*H*)-one (34).[42] As described for **4**, reaction of **22** (31.5 mg, 0.11 mmol) with $Pd(dba)_2$ (5.1 mg, 0.009 mmol), dppp (3.5 mg, 0.009 mmol), 1,10-phenanthroline monohydrate (3.4 mg, 0.017 mmol), and DMF (3 mL) for 30 h gave, after chromatography (EtOAc/hexanes, 3:7), **34** (24.1 mg, 0.098 mmol, 86%) as a white powder.

3.1.21. 7-Methoxy-1,2-dihydrocarbazol-4(3*H*)-one (35).[43,44] As described for **4**, reaction of 2-(4-methoxy-2-nitrophenyl)-2-cyclohexen-1-one (**23**) (43.5 mg, 0.18 mmol) with $Pd(dba)_2$ (6.3 mg, 0.01 mmol), dppp (4.6 mg, 0.01 mmol), 1,10-phenanthroline monohydrate (4.5 mg, 0.02 mmol), and DMF (5 mL) for 22 h gave, after chromatography (EtOAc/hexanes, 3:7 followed by EtOAc), **35** (33.8 mg, 0.16 mmol, 89%) as a white powder.

3.1.22. 5-Methyl-1,2-dihydrocarbazol-4(3*H*)-one (36). As described for **4**, reaction of 2-(6-methyl-2-nitrophenyl)-2-cyclohexen-1-one (**24**) (117 mg, 0.51 mmol) with $Pd(dba)_2$ (17.5 mg, 0.03 mmol), dppp (12.7 mg, 0.03 mmol), 1,10-phenanthroline monohydrate (12.4 mg, 0.06 mmol), and DMF (5 mL) for 36 h gave, after chromatography (EtOAc/hexanes, 3:7), **36** (79.5 mg, 0.40 mmol, 79%) as a white powder. Mp 234–235°C; IR (Nujol) 1711, 1620, 1575 cm^{-1}; ^1H NMR ($CDCl_3$+DMSO-d_6) δ 2.16 (pentet, J=5.9 Hz, 2H), 2.50 (t, J=5.9 Hz, 2H), 2.86 (s, 3H), 2.97 (t, J=5.9 Hz, 2H), 6.88 (d, J=7.2 Hz, 1H), 7.03 (t, J=7.4 Hz, 1H), 7.15 (d, J=8.2 Hz, 1H), 11.47 (s, 1H); ^{13}C NMR ($CDCl_3$+DMSO-d_6) δ 23.3 (−), 23.6 (+), 23.9 (+), 38.9 (+), 109.4 (−), 113.5 (+), 123.2 (−), 123.7 (−), 124.6 (+), 131.7 (+), 137.0 (+), 153.0 (+), 192.1 (+); GC-MS (EI) m/z 199 (M^+); HRMS (EI) calcd for $C_{13}H_{13}NO$ (M^+) 199.0997, found 199.0997.

3.1.23. 8-Methyl-1,2-dihydrocarbazol-4(3*H*)-one (37).[45] As described for **4**, reaction of 2-(3-methyl-2-nitrophenyl)-2-cyclohexen-1-one (**25**) (108 mg, 0.47 mmol) with $Pd(dba)_2$ (16.5 mg, 0.03 mmol), dppp (11.9 mg, 0.03 mmol), 1,10-phenanthroline monohydrate (11.4 mg, 0.06 mmol), and DMF (5 mL) for 144 h gave, after chromatography (EtOAc/hexanes, 3:7 followed by 7:3), **37** (69.8 mg, 0.35 mmol, 75%) as a white powder.

3.1.24. Methyl 1,2-dihydrocarbazol-4(3*H*)-one-5-carboxylate (38).[46] As described for **4**, reaction of 2-(6-carbomethoxy-2-nitrophenyl)-2-cyclohexen-1-one (**26**) (158 mg, 0.57 mmol), with $Pd(dba)_2$ (19.7 mg, 0.03 mmol), dppp (14.2 mg, 0.03 mmol), 1,10-phenanthroline monohydrate (13.6 mg, 0.07 mmol), and DMF (5 mL) for 96 h gave, after chromatography (EtOAc/hexanes, 3:7 followed by EtOAc), **38** (105 mg, 0.43 mmol, 75%) as a white powder.

3.1.25. 6-Bromo-1,2,3,9-tetrahydro-4*H*-carbazol-4-one (39).[47] As described for **4**, reaction of 2-(5-bromo-2-nitrophenyl)-2-cyclohexen-1-one (**27**) (123 mg, 0.42 mmol) with $Pd(dba)_2$ (14.3 mg, 0.025 mmol), dppp (10.4 mg, 0.025 mmol), 1,10-phenanthroline monohydrate (9.9 mg, 0.050 mmol), and DMF (5 mL) for 8 days gave, after chromatography (EtOAc/hexanes, 3:7 followed by 7:3), **39** (56.9 mg, 0.22 mmol, 52%) as a white powder.

3.1.26. 6,7,8,9-Tetrahydro-5*H*-pyrido[3,2-*b*]indol-9-one (40).[21] A mixture of 2-(tri-*n*-butylstannyl)-2-cyclohexen-1-one (**6**) (621 mg, 1.61 mmol), 2-chloro-3-nitropyridine[16] (201 mg, 1.26 mmol), $Pd(dba)_2$ (22.1 mg, 0.038 mmol), Ph_3As (47.1 mg, 0.15 mmol), and toluene (5 mL) was heated at reflux for 20 h. The reaction was diluted with benzene (100 mL) and washed with NH_4OH (10%, aq., 3×50 mL) and H_2O (2×50 mL). The organic phase was dried ($MgSO_4$), filtered, and concentrated under reduced pressure. As described for **4**, the crude product was reacted

without purification with $Pd(dba)_2$ (43.6 mg, 0.075 mmol), dppp (31.2 mg, 0.076 mmol), 1,10-phenanthroline monohydrate (30.1 mg, 0.152 mmol), and DMF (5 mL) for 24 h to give, after chromatography ($CHCl_3$ to $CHCl_3$/MeOH, 9:1), **40** (128 mg, 0.685 mmol, 54%) as a tan solid.

3.1.27. 6-Methyl-2-(2-nitrophenyl)-2-cyclohexen-1-one (45) and 1-nitro-2-(2-nitrophenyl)benzene. As described for **3**, reaction of 2-iodo-6-methyl-2-cyclohexen-1-one (**44**) (305 mg, 1.29 mmol) with1-(tri-*n*-butylstannyl)-2-nitrobenzene (**1**) (412 mg, 1.53 mmol), $PdCl_2(PhCN)_2$ (65 mg, 0.13 mmol), Ph_3As (306 mg, 0.127 mmol), CuI (190.5 mg, 0.129 mmol), and NMP (2.5 mL) for 48 h gave, after chromatography (EtOAc/hexanes, 1:9), an inseparable mixture (288 mg, ca. 9:1 ratio as determined by ^1H NMR) of **45** (ca. 87%) and 1-nitro-2-(2-nitrophenyl)benzene[17,48] (ca. 15%) as a pale yellow oil. Spectral data of **45** from the mixture: IR 2931, 1679, 1524, 1349 cm^{-1}; ^1H NMR δ 1.19 (d, J=6.7 Hz, 3H), 1.82–1.98 (m, 1H), 2.12–2.23 (m, 1H), 2.50–2.67 (m, 3H), 6.96 (td, J=3.6, 2.0 Hz, 1H), 7.26 (dd, J=8.3, 1.6 Hz, 1H), 7.47 (td, J=7.5, 1.6 Hz, 1H), 7.59 (td, J=7.7, 1.6 Hz, 1H), 8.02 (dd, J=8.1, 1.4 Hz, 1H); ^{13}C NMR δ 14.7 (−), 25.5 (+), 30.3 (+), 41.5 (−), 123.9 (−), 128.5 (−), 131.6 (−), 132.1 (+), 133.2 (−), 138.6 (+), 146.0 (−), 148.3 (+), 198.9 (+); GC-MS (EI) *m/z* 231 (M^+), 185 (M^+-NO_2); HRMS (DEI) calcd for $C_{13}H_{13}NO_3$ (MH^+) 232.0974, found 232.0968.

3.1.28. 1,2,3,9-Tetrahydro-3-methyl-4*H*-carbazol-4-one (46).[49] As described for **4**, reaction of 208 mg of the mixture obtained in the previous experiment with $Pd(dba)_2$ (31.0 mg, 0.054 mmol), dppp (22.2 mg, 0.053 mmol), 1,10-phenanthroline monohydrate (21.4 mg, 0.108 mmol), and DMF (5 mL) for 48 h gave, after chromatography (EtOAc/hexanes, 3:7 followed by 7:3), **46** (156 mg, 0.78 mmol, 84% based on **44**) as a white powder.

3.1.29. 4-Hydroxy-3-methyl-9*H*-carbazol (47).[50] A mixture of 3-methyl-1,2-dihydrocarbazol-4(3*H*)-one (**46**) (159 mg, 0.80 mmol), 10% Pd/C (108 mg), diphenyl ether (6 mL), and 1,2,4-trimethylbenzene (0.75 mL) was degassed by bubbling argon through the mixture for 10 min. The reaction mixture was heated at 230°C for 20 h. The reaction was filtered through a short column of silica gel using petroleum ether followed by CH_2Cl_2/formic acid (99.9:0.1) to give **47** (99 mg, 0.50 mmol, 63%) as a white solid.

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