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One-Pot Method for Regioselective Bromination and Sequential Carbon–Carbon Bond-Forming Reactions of Allylic Alcohol Derivatives

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Keywords: Synthetic methods / Elimination / C–C coupling / Cross-coupling / Regioselectivity / Allylic compounds

An efficient one-pot method for the regioselective bromination of allylic alcohol derivatives (two-step reaction sequence) followed by Sonogashira, Negishi, or Suzuki–Miyaura coupling reactions in the same reaction vessel (three-step reaction sequence) has been developed. The key reaction in these one-pot systems is the regioselective DBU-promoted *trans* HBr elimination of vicinal dibromides bearing an adjacent *O*-functional group.

Introduction

Carbon–carbon bond-forming reactions of organometallic reagents are widely used synthetic methods.[1] In particular, palladium-catalyzed cross-coupling reactions such as the Sonogashira,[2] Negishi,[3] and Suzuki–Miyaura couplings[4] are essential for syntheses of complex molecules because they are easy to conduct, they proceed under mild reaction conditions, and they tolerate a wide range of potentially labile functional groups. If such coupling reactions are to be incorporated into one-pot methodologies,[5] however, it is important that the key coupling reactions with the alkenyl halides formed in situ proceed smoothly without damaging the catalyst. Indeed, several one-pot syntheses of 1-bromo-1-alkenes have been reported.[6] However, very little is yet known about the systematic synthesis of 2-bromo-1-alkenes,[7] although a few sporadic examples of such syntheses do exist.[8] In this paper, we disclose the full details of a concise one-pot method for the highly regioselective bromination of allylic alcohol derivatives followed by Sonogashira, Negishi, or Suzuki–Miyaura couplings (i.e., a three-step reaction sequence in one pot).

Results and Discussion

One-Pot Bromination

We recently developed a one-pot reaction for the C-2-selective bromination of allylic alcohol derivatives **1** using optimized Methods A and/or B to give 2-bromo allylic alcohol derivatives **2** in excellent yields (Table 1).[7e] The difference between Methods A and B is the approach used for trapping the pyridinium hydrobromide generated after the addition of bromine from pyridinium tribromide (1.1 equiv.). In Method A, an excess amount of 1,8-diazabicyclo[5.4.0]undec-7-ene (DBU; 3.1 equiv.) serves as an HBr scavenger, whereas in Method B, the addition of potassium carbonate (1.1 equiv.) together with the initial addition of the brominating reagent reduces the amount of DBU required. 1,2-Dichloroethane and acetonitrile were found to be suitable solvents for this two-step reaction sequence, regardless of the method. In general, Method B required a longer reaction time than Method A for the elimination reaction. First, several allylic alcohols (2-propen-1-ol derivatives) protected by substituted phenyl, benzyl, benzoyl, or silyl groups were examined (Table 1, entries 1–20). As explained by Nishiyama et al.[7a–7d,7i,7j] and us,[7e–7h] the yield and regioselectivity of the DBU-promoted elimination appear to be controlled by the inductive electron-withdrawing effects of the neighboring *O*-functional group. However, compounds **2h** and **2m**, bearing relatively electron-donating PMB (*para*-methoxybenzyl) and TIPS (triisopropylsilyl) groups, were obtained in good yields and with satisfactory selectivities (Table 1, entries 10 and 19–20). In the case of **2n**, which has an electron-donating alkyl chain at the adjacent position, the yield and selectivity were somewhat decreased compared with those of **2h** (Table 1, entries 10 and 21). Rewardingly, the reaction of secondary allylic alcohol derivatives **1n**, **1o**, **1q**, **1r**, **1y**, and **1z**, also proceeded with excellent results (Table 1, entries 21–23, 25–26, and 38–41), although tertiary alcohol derivative **2p** was produced in only 34% yield (Table 1, entry 24). Interestingly, the reactions of **1s**–**1x**, bearing internal double bonds, proceeded with high *cis*–*trans* selectivity as a consequence of the *trans* HBr elimination, as well as high regioselectivity (Table 1, entries 27–37). Other significant results can be seen in

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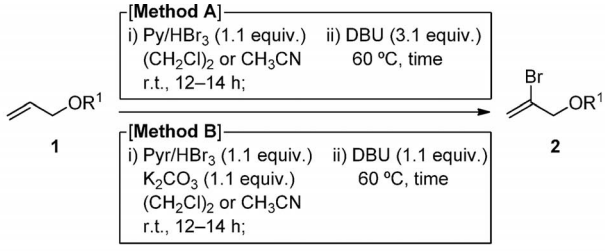
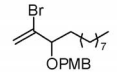
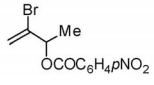
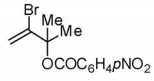
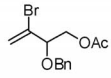
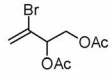
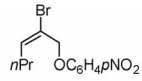
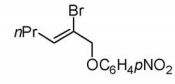
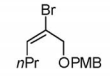
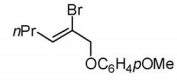
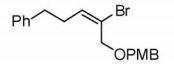
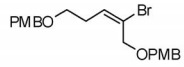
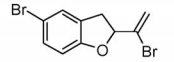
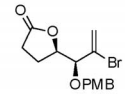
Table 1, entries 36–37, where the positional relationship with the *O*-functional group is important for the regioselectivity. These results suggest that the *O*-functional group at the homoallylic position does not affect the regioselectivity, in contrast to the situation with an *O*-functional group at the allylic position. Furthermore, the reactions of dihydrobenzofuran derivative **1y** and γ-lactone derivative **1z** proceeded highly regioselectively (Table 1, entries 38–41). Thus, we have developed an efficient and concise one-pot method for the regioselective bromination of allylic alcohol derivatives. Our method requires neither drastic conditions, nor extra-dry conditions, nor expensive reagents, nor complex manipulations. This two-step reaction sequence proceeds smoothly even in the presence of sensitive functional groups, and should have broad utility in the synthesis of complex molecules.

Table 1. One-pot bromination of allylic alcohol derivatives.

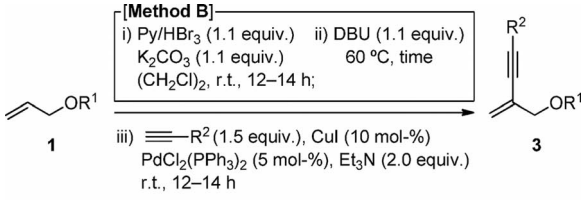


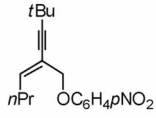
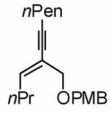
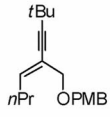
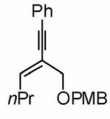
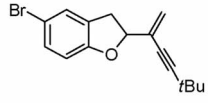
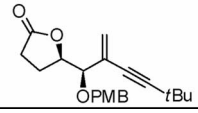
1 **2**

Entry	R^1/ Products **2**		Method	Time /h	Yield /%	Ratio[a]
1	$pO_2NC_6H_4$	(**2a**)	**A**	0.2	99	46 / 1
2			**B**	1.0	91	39 / 1
3	$oO_2NC_6H_4$	(**2b**)	**A**	0.2	91	> 99 / 1
4	$oBrC_6H_4$	(**2c**)	**A**	1.0	94	53 / 1
5	$pMeOC_6H_4$	(**2d**)	**A**	0.5	92	31 / 1
6	$pClC_6H_4$	(**2e**)	**A**	0.5	94	29 / 1
7	$pBrC_6H_4$	(**2f**)	**A**	0.8	95	25 / 1
8	C_6H_5 (Ph)	(**2g**)	**A**	0.5	92	18 / 1
9			**B**	0.8	89	17 / 1
10	$pMeOC_6H_4CH_2$	(**2h**)	**B**	6.5	90	15 / 1
11	$pClC_6H_4CH_2$	(**2i**)	**A**	0.3	96	16 / 1
12			**B**	2.0	93	13 / 1
13	$pO_2NC_6H_4C(O)$	(**2j**)	**A**	0.2	87	31 / 1
14			**B**	6.0	78[b]	28 / 1
15	$pMeOC_6H_4C(O)$	(**2k**)	**A**	0.2	92	20 / 1
16			**B**	3.0	84	15 / 1
17	$pClC_6H_4C(O)$	(**2l**)	**A**	0.8	94	15 / 1
18			**B**	1.8	90	20 / 1
19	TIPS	(**2m**)	**A**	1.0	69[c]	10 / 1
20			**B**	7.0	60[d]	12 / 1
21		(**2n**)	**A**[e]	3.0	82	8 / 1
22		(**2o**)	**A**	0.1	91	49 / 1
23			**B**	6.0	92	40 / 1
24		(**2p**)	**A**	1.0	34	8 / 1
25		(**2q**)	**A**	1.0	90	18 / 1
26		(**2r**)	**A**	1.0	92	> 99 / 1
27		(**2s**)	**A**	1.0	100	> 99 / 1
28			**B**	7.0	95	> 99 / 1
29		(**2t**)	**A**	1.0	97	24 / 1
30			**B**	5.0	99	26 / 1
31		(**2u**)	**A**[e]	1.0	92	20 / 1
32			**B**[e]	2.0	86	30 / 1
33		(**2v**)	**A**	1.5	96	20 / 1
34		(**2w**)	**A**[e]	1.0	93	16 / 1
35			**B**[e]	1.5	91	18 / 1
36		(**2x**)	**A**[e]	4.5	95	17 / 1
37			**B**[e]	6.0	93	20 / 1
38		(**2y**)	**A**	1.5	90	> 99 / 1
39			**B**	1.0	93	> 99 / 1
40		(**2z**)	**A**	0.3	94	57 / 1
41			**B**	4.5	94	21 / 1

[a] The ratio of 2-bromoalkene and 1-bromoalkene was determined by ^{1}H NMR spectroscopy. [b] The dibromoalkane was obtained (9%). [c] The dibromoalkane was obtained (27%). [d] The dibromoalkane was obtained (34%). [e] Acetonitrile was used as solvent.

Table 2. One-pot Sonogashira coupling of allylic alcohol derivatives.



Entry	Products **3**			Yield /%
	R^1	R^2		
1	$pO_2NC_6H_4$	*n*Pen	(**3a**)	31
2	$pO_2NC_6H_4$	*t*Bu	(**3b**)	29
3	$pMeOC_6H_4$	*n*Pen	(**3c**)	84
4	$pMeOC_6H_4$	*t*Bu	(**3d**)	91
5	$pMeOC_6H_4$	C_6H_5	(**3e**)	81
6	$pMeOC_6H_4$	$pMeOC_6H_4$	(**3f**)	70
7	C_6H_5 (Ph)	*n*Pen	(**3g**)	93
8	C_6H_5 (Ph)	*t*Bu	(**3h**)	94
9[a]	$pMeOC_6H_4CH_2$ (PMB)	*n*Pen	(**3i**)	89
10[a]	$pMeOC_6H_4CH_2$ (PMB)	*t*Bu	(**3j**)	97
11[a]	$pMeOC_6H_4CH_2$ (PMB)	CH_2CH_2OH	(**3k**)	78
12			(**3l**)	28[b][c]
13[a][d]			(**3m**)	96
14[a][d]			(**3n**)	92
15[a][d]			(**3o**)	84
16[e]			(**3p**)	77
17			(**3q**)	82

[a] 4.0 equiv. of Et_3N was used. [b] Determined by ^1H NMR spectroscopy using 1,4-bis(trimethylsilyl)benzene as internal standard. [c] Intermediate **2s** was obtained (46%). [d] Acetonitrile was used as solvent. Sonogashira coupling was performed at 60 °C. [e] 3.0 equiv. of 3,3-dimethyl-1-butyne was used.

One-Pot Sonogashira Coupling

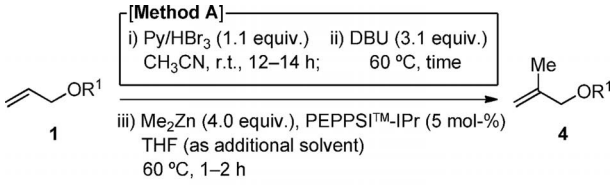
Next, we focused on developing a one-pot sequential method based on the one-pot bromination as described above, and including a Sonogashira coupling reaction. A key factor for the success of this three-step eaction sequence is the activity of the transition metal catalyst under the one-pot reaction conditions. After trial and error, we found that Sonogashira coupling under standard conditions proceeded without any difficulty in one pot following a bromination by Method B (Table 2).[7e,9] This result implies, as we anticipated, that the reaction conditions used for the one-pot bromination do not affect the subsequent palladium-catalyzed C–C bond-forming reaction. As shown in Table 2, entries 1–15, structurally simplified allylic alcohol derivatives **1** were readily converted into the corresponding enynes (i.e., **3**), except for those bearing a 4-nitrophenyl group (Table 2, entries 1, 2, and 12). Remarkably, trisubstituted enynes **3l**–**3o**, which are difficult to synthesize, were obtained with high stereoselectivities (Table 2, entries 12–15). The dihydrobenzofuran derivative **3p** was also synthesized in 77% yield, although 3.0 equiv. of the alkyne unit, 3,3-dimethyl-1-butyne, was required (Table 2, entry 16). In addition, during the course of our investigation, we noticed that the efficiency of the palladium-catalyzed C–C bond-forming reaction, the third step in the one-pot sequence, was largely dependent on the coupling reaction conditions. That is to say, an increase in the amount of palladium catalyst and an elevated temperature tended to cause undesired side-reactions resulting from an allylic ionization process of the *O*-functional group by the transition metal.[10] Note that allylic alcohol derivatives **1** containing an acyl group (= R^1) could not be used in this one-pot methodology when the Sonogashira coupling reaction was conducted with $PdCl_2(PPh_3)_2$ (5 mol-%) at room temperature.

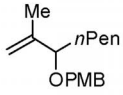
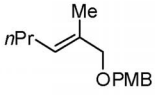
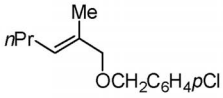
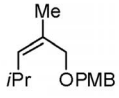
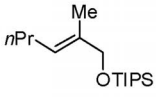
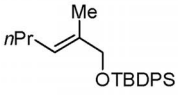
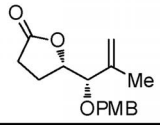
One-Pot Negishi Coupling (Methylation)

After our success with the one-pot Sonogashira coupling, we next developed a one-pot reaction sequence including a Negishi coupling reaction, in particular for the introduction of methyl groups (Table 3). In this case, a two-step bromination by Method A followed by Negishi coupling using dimethylzinc (4.0 equiv.) and precatalyst PEPPSI™-IPr[11] (5 mol-%) with the addition of THF at 60 °C gave the best results.[12] The addition of THF was necessary to allow the mixing of the acetonitrile with the dimethylzinc hexane solution. In this reaction, allylic alcohol derivatives **1** that were protected by substituted benzyl, silyl, or alkyl groups were efficiently transformed into the desired compounds (i.e., **4**), whereas intermediates derived from substrates **1** bearing electron-withdrawing acyl and aryl groups (= R^1) immediately decomposed in the Pd-mediated third step. Nevertheless, **4a**, containing a 4-methoxyphenyl group, was produced in moderate yield when 6.0 equiv. of dimethylzinc was used (Table 3, entry 1). Notably, though, in addition to structurally simple terminal allylic alcohol derivatives, disubstituted allylic alcohols were also converted smoothly

into β-methallyl alcohol derivatives **4h**–**4l** (Table 3, entries 8–12). In addition, γ-lactone product **4m** (Table 3, entry 13) was recently utilized in our total synthetic study of (+)-heteroplexisolide E.[13] Therefore, this three-step methylation sequence can become an efficient method for transforming allylic alcohols **1** into β-methallyl alcohol derivatives **4**.

Table 3. One-pot Negishi coupling (methylation) of allylic alcohol derivatives (TBDPS = *tert*-butyldiphenylsilyl).



Entry	R^1/ Products **4**		Yield /%
1[a]	*p*MeOC$_6$H$_4$	(**4a**)	48
2	*p*MeOC$_6$H$_4$CH$_2$ (PMB)	(**4b**)	80
3	C$_6$H$_5$CH$_2$ (Bn)	(**4c**)	76
4	*p*ClC$_6$H$_4$CH$_2$	(**4d**)	81
5	TBDPS	(**4e**)	79
6	*p*MeOC$_6$H$_4$CH$_2$CH$_2$	(**4f**)	81
7		(**4g**)	82
8		(**4h**)	88
9		(**4i**)	78
10		(**4j**)	74
11		(**4k**)	70
12		(**4l**)	84
13		(**4m**)	82

[a] 6.0 equiv. of Me_2Zn was used.

One-Pot Suzuki–Miyaura Coupling

Next, a one-pot reaction sequence including a Suzuki–Miyaura coupling reaction was developed (Table 4). In this case, a two-step bromination by Method B followed by a Suzuki–Miyaura coupling using an organoboronic acid (3.0 equiv.) and $Pd(PPh_3)_4$ (10 mol-%) with the addition of a 4:1 mixture of dimethylformamide and water at 100 °C gave the best results.[14] In this coupling reaction, it was also observed that allylic alcohol derivatives **1** bearing substituted benzyl or silyl groups (= R^1) were efficiently transformed into the expected compounds (i.e., **5**), whereas intermediates derived from substrates **1** with acyl and aryl groups (= R^1) immediately decomposed in the third step. With respect to the organoboronic acids, not only substituted phenylboronic acids, but also heteroarylboronic acids, styrylboronic acid, and naphthylboronic acid could be used in this one-pot methodology (Table 4, entries 16–20, 25, and 27). In addition, the yields of organotrifluoroborate-based Suzuki–Miyaura coupling reactions[15] either equaled or surpassed those of the reactions with similar organoboronic acids (Table 4, entries 2, 8, and 14).

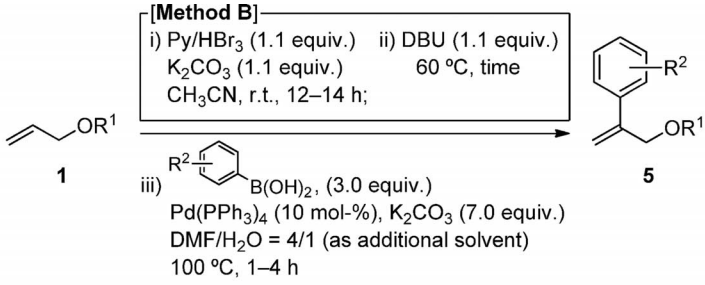
Conclusions

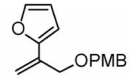
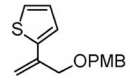
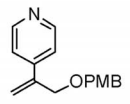
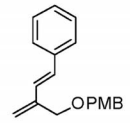
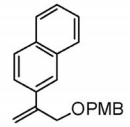
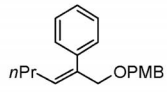
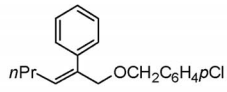
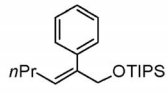
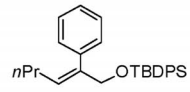
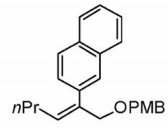
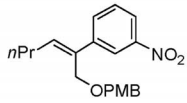
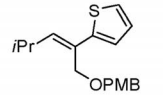
In summary, we have developed one-pot methods for the regioselective bromination of allylic alcohol derivatives (two-step reaction sequence) followed by Pd-catalyzed carbon–carbon bond-formation in the same pot (three-step reaction sequence). These synthetic approaches should be applicable to the total synthesis of natural products and for use in modern drug-discovery research. The most noteworthy point of this study is that the coupling reactions in the third step, which are catalyzed by transition metals, proceed in the same reaction vessel. We believe that this one-pot methodology based on the C-2-selective bromination of allylic alcohol derivatives could be applied to other C–C coupling reactions, and hence, it could become an effective reaction for the transformation of disubstituted "straight" alkenes into trisubstituted alkenes such as those with a "Y-shaped" junction.

Experimental Section

General Methods: Melting points were determined with a Yanaco MP melting point apparatus. Infrared spectra were recorded with a Horiba FT-710 spectrophotometer. ^{1}H and ^{13}C NMR spectroscopic data were obtained with Bruker Avance 600, JEOL JNM-LA 500, or JEOL JNM-AL 300 instruments. Chemical shifts are quoted in ppm using tetramethylsilane (δ = 0 ppm) as the reference for ^{1}H NMR spectroscopy, and $CDCl_3$ (δ = 77.0 ppm) for ^{13}C NMR spectroscopy. Mass spectra were measured with a Bruker

Table 4. One-pot Suzuki–Miyaura coupling of allylic alcohol derivatives.



Entry	Products **5** R^1	R^2		Yield /%
1	$C_6H_5CH_2$ (Bn)	H	(**5a**)	58
2				66[a]
3	$C_6H_5CH_2$ (Bn)	4-NO_2	(**5b**)	59
4	$C_6H_5CH_2$ (Bn)	4-CN	(**5c**)	56
5	$C_6H_5CH_2$ (Bn)	4-Cl	(**5d**)	72
6	$C_6H_5CH_2$ (Bn)	4-Et	(**5e**)	52
7	*p*$MeOC_6H_4CH_2$ (PMB)	H	(**5f**)	74
8				75[a]
9	*p*$MeOC_6H_4CH_2$ (PMB)	4-NO_2	(**5g**)	86
10	*p*$MeOC_6H_4CH_2$ (PMB)	3-NO_2	(**5h**)	85
11	*p*$MeOC_6H_4CH_2$ (PMB)	4-CN	(**5i**)	64
12	*p*$MeOC_6H_4CH_2$ (PMB)	4-Cl	(**5j**)	67
13	*p*$MeOC_6H_4CH_2$ (PMB)	4-Et	(**5k**)	65
14				66[a]
15	TIPS	H	(**5l**)	62
16			(**5m**)	67
17			(**5n**)	70
18			(**5o**)	52
19			(**5p**)	63
20			(**5q**)	67
21			(**5r**)	81
22			(**5s**)	64
23			(**5t**)	88
24			(**5u**)	78
25			(**5v**)	73
26			(**5w**)	55
27			(**5x**)	73

[a] Potassium trifluoroborate salts (R^2-BF_3K; 3.0 equiv.) were used in place of the organoboronic acids, PEPPSI™-IPr (3 mol-%), and potassium carbonate (5.0 equiv.) with the addition of MeOH at 75 °C.

Daltonics microTOF-NR focus spectrometer. Column chromatography was carried out on silica gel (Kanto Chemical Co. or Merck Co. Ltd). All reactions were performed under an argon atmosphere. 2-Bromo allylic alcohol derivatives **2a**–**2m**, **2o**–**2p**, **2r**–**2t**, **2v**, and **2y**–**2z** are known compounds, and their analytical data have been reported.[16] Enynes **3a**–**3i**, **3l**, and **3p**–**3q** are known compounds, and their analytical data have been reported.[17] β-Methallyl alcohol derivatives **4a**–**4c**, **4e**, and **4m** are known compounds, and their ana-

lytical data have been reported.[18] Arenes **5a** and **5f** are known compounds, and their analytical data have been reported.[19]

General Procedures for the Synthesis of 2-Bromo Allylic Alcohol Derivatives 2

Method A: A mixture of allylic alcohol derivative **1** (1.0 equiv.) and pyridinium tribromide (1.1 equiv.) in $(CH_2Cl)_2$ or CH_3CN was stirred at room temperature for 12–14 h. DBU (3.1 equiv.) was added to the reaction mixture at 0 °C, and the system was then heated to 60 °C. The reaction was quenched with NH_4Cl (saturated aq.) or HCl (1 M aq.), and the mixture was extracted with $CHCl_3$ or ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give 2-bromo allylic alcohol derivative **2**.

Method B: A mixture of allylic alcohol derivative **1** (1.0 equiv.), pyridinium tribromide (1.1 equiv.), and potassium carbonate (1.1 equiv.) in $(CH_2Cl)_2$ or CH_3CN was stirred at room temperature for 12–14 h. DBU (1.1 equiv.) was added to the reaction mixture at 0 °C, and the system was then heated to 60 °C. The reaction was quenched with NH_4Cl (saturated aq.) or HCl (1 M aq.), and the reaction mixture was extracted with $CHCl_3$ or ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give 2-bromo allylic alcohol derivative **2**.

General Procedure for the Synthesis of Enynes 3. One-Pot Sonogashira Coupling: After reaction following Method B, copper iodide (10 mol-%), $PdCl_2(PPh_3)_2$ (5 mol-%), triethylamine (2.0 equiv.), and alkyne (1.5 equiv.) were added to the reaction mixture at 0 °C without evaporation, and the mixture was stirred at room temperature for 12–14 h. The reaction was quenched with NH_4Cl (saturated aq.) or HCl (1 M aq.) at 0 °C, and the reaction mixture was extracted with $CHCl_3$ or ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give enyne **3**.

Enyne 3a. Typical Procedure: A mixture of **1a** (117.0 mg, 0.653 mmol), pyridinium tribromide (229.6 mg, 0.718 mmol), and potassium carbonate (99.3 mg, 0.718 mmol) in $(CH_2Cl)_2$ (2 mL) was stirred at room temperature for 12 h. DBU (0.105 mL, 0.705 mmol) was added to the reaction mixture at 0 °C, and the mixture was then stirred at 60 °C for 1 h. After confirming the consumption of the dibromide by TLC, copper iodide (12.4 mg, 0.0653 mmol), $PdCl_2(PPh_3)_2$ (23.0 mg, 0.0327 mmol), triethylamine (0.182 mL, 1.31 mmol), and 1-heptyne (0.129 mL, 0.980 mmol) were added to the reaction mixture at 0 °C without evaporation, and the mixture was stirred at room temperature for 12 h. The reaction was quenched with NH_4Cl (saturated aq.; 10 mL) at 0 °C, and the mixture was extracted with $CHCl_3$ (3 × 10 mL). The combined organic extracts were dried with Na_2SO_4 and concentrated in vacuo, and the residue was purified by silica gel column chromatography (hexane/ethyl acetate = 8:1) to give **3a** (55.6 mg, 31%) as a pale yellow oil.

General Procedure for the Synthesis of β-Methallyl Alcohol Derivatives 4. One-Pot Negishi Coupling: After reaction following Method A, THF, PEPPSI™-IPr (5 mol-%), and dimethylzinc (1.0 M in hexane; 4.0 equiv.) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 60 °C for 1–2 h. The reaction was quenched with H_2O at 0 °C, and the mixture was extracted with ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give β-methallyl alcohol derivative **4**.

β-Methallyl Alcohol Derivative 4a. Typical Procedure: A mixture of **1a** (59.1 mg, 0.360 mmol) and pyridinium tribromide (126.6 mg, 0.396 mmol) in CH_3CN (2.3 mL) was stirred at room temperature for 12 h. DBU (0.167 mL, 1.12 mmol) was added to the reaction mixture at 0 °C, and the mixture was then stirred at 60 °C for 4 h. After confirming the consumption of the dibromide by TLC, THF (1.2 mL), PEPPSI™-IPr (12.2 mg, 0.018 mmol), and dimethylzinc (1.0 M in hexane; 1.98 mL, 2.16 mmol) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 60 °C for 2 h. The reaction was quenched with H_2O (10 mL) at 0 °C, and the mixture was extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were dried with Na_2SO_4 and concentrated in vacuo, and the residue was purified by silica gel column chromatography (hexane/ethyl acetate = 15:1) to give **4a** (30.7 mg, 48%) as a pale yellow oil.

General Procedure for the Synthesis of Arenes 5. One-Pot Suzuki–Miyaura Coupling: After reaction following Method B, DMF/H_2O (4:1), $Pd(PPh_3)_4$ (10 mol-%), potassium carbonate (7.0 equiv.), and organoboronic acid (3.0 equiv.) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 100 °C for 1–4 h. The reaction was quenched with NH_4Cl (saturated aq.) or HCl (1 M aq.) at 0 °C, and the mixture was extracted with ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give the corresponding arene compound **5**.

Arene Compound 5a. Typical Procedure: A mixture of **1a** (13.3 mg, 0.0897 mmol), pyridinium tribromide (31.6 mg, 0.0988 mmol), and potassium carbonate (14.4 mg, 0.104 mmol) in CH_3CN (0.43 mL) was stirred at room temperature for 12 h. DBU (0.015 mL, 0.100 mmol) was added to the reaction mixture at 0 °C, and the mixture was then stirred at 60 °C for 1.5 h. After confirming the consumption of the dibromide by TLC, DMF/H_2O (4:1, 0.9 mL), $Pd(PPh_3)_4$ (8.6 mg, 0.0086 mmol), potassium carbonate (85.8 mg, 0.622 mmol), and phenylboronic acid (33.1 mg, 0.273 mmol) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 100 °C for 1 h. The reaction was quenched with NH_4Cl (saturated aq.; 10 mL) at 0 °C, and the mixture was extracted with ethyl acetate (3 × 10 mL). The combined organic extracts were dried with Na_2SO_4 and concentrated in vacuo, and the residue was purified by silica gel column chromatography (hexane/ethyl acetate = 40:1) to give **5a** (11.6 mg, 58%) as a colorless oil.

General Procedure for the Synthesis of Arenes 5. One-Pot Organotrifluoroborate-Based Suzuki–Miyaura Coupling: After reaction following Method B, MeOH, PEPPSI™-IPr (3 mol-%), potassium carbonate (5.0 equiv.), and potassium trifluoroborate salt (3.0 equiv.) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 75 °C for 6–10 h. The reaction was quenched with NH_4Cl (saturated aq.) or HCl (1 M aq.) at 0 °C, and the mixture was extracted with ethyl acetate. The organic phase was concentrated in vacuo, and the residue was purified by silica gel column chromatography to give the corresponding arene **5**.

Arene 5f. Typical Procedure: A mixture of **1f** (38.0 mg, 0.213 mmol), pyridinium tribromide (73.4 mg, 0.230 mmol), and potassium carbonate (32.2 mg, 0.230 mmol) in CH_3CN (0.43 mL) was stirred at room temperature for 12 h. DBU (0.035 mL, 0.234 mmol) was added to the reaction mixture at 0 °C, and the mixture was then stirred at 60 °C for 1.5 h. After confirming the consumption of the dibromide by TLC, MeOH (1.7 mL), PEPPSI™-IPr (4.3 mg, 0.0063 mmol), potassium carbonate (146.5 mg, 1.06 mmol), and potassium phenyltrifluoroborate salt (119.3 mg, 0.648 mmol) were added to the reaction mixture at 0 °C without evaporation, and the mixture was then stirred at 75 °C for

6 h. The reaction was quenched with NH_4Cl (saturated aq.; 10 mL) at 0 °C, and the reaction mixture was extracted with ethyl acetate (3× 10 mL). The combined organic extracts were dried with Na_2SO_4 and concentrated in vacuo, and the residue was purified by silica gel column chromatography (hexane/ethyl acetate = 15:1) to give **5f** (40.4 mg, 75%) as a colorless oil.

2-Bromo Allylic Alcohol 2n: IR (neat): $\tilde{\nu}$ = 2924, 2854, 1620, 1512, 1458, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.88 (t, J = 7.2 Hz, 3 H), 1.08–1.81 (m, 16 H), 3.72 (t, J = 6.7 Hz, 1 H), 3.80 (s, 3 H), 4.22 (d, J = 11.1 Hz, 1 H), 4.56 (d, J = 11.1 Hz, 1 H), 5.68 (s, 1 H), 5.85 (s, 1 H), 6.87 (d, J = 8.6 Hz, 2 H), 7.26 (d, J = 8.6 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.1, 22.7, 25.2, 29.27, 29.30, 29.48, 29.51, 31.9, 34.0, 55.2, 69.9, 82.1, 113.8 (×2), 118.7, 129.3, 129.6 (×2), 135.7, 159.3 ppm. HRMS (ESI): calcd. for $C_{20}H_{31}BrO_2Na$ [M + Na]$^+$ 405.1400; found 405.1401.

2-Bromo Allylic Alcohol 2q: IR (neat): $\tilde{\nu}$ = 3032, 2954, 2870, 1743, 1628, 1373, 1234 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 2.04 (s, 3 H), 4.11 (dd, J = 6.1, 5.2 Hz, 1 H), 4.20 (dd, J = 11.3, 5.2 Hz, 1 H), 4.24 (dd, J = 11.3, 6.1 Hz, 1 H), 4.38 (d, J = 11.9 Hz, 1 H), 4.69 (d, J = 11.9 Hz, 1 H), 5.80 (m, 1 H), 6.02 (m, 1 H), 7.27–7.38 (m, 5 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 20.7, 64.8, 70.7, 80.0, 120.8, 127.87, 127.89 (×2), 128.4 (×2), 130.3, 137.2, 170.5 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{13}H_{15}BrO_3Na$ [M + Na]$^+$ 231.0097; found 231.0096.

2-Bromo Allylic Alcohol 2u: IR (neat): $\tilde{\nu}$ = 2954, 2862, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.5 Hz, 3 H), 1.41 (qt, J = 7.5, 7.4 Hz, 2 H), 2.03 (dt, J = 7.7, 7.4 Hz, 2 H), 3.80 (s, 3 H), 4.21 (s, 2 H), 4.46 (s, 2 H), 6.13 (t, J = 7.7 Hz, 1 H), 6.88 (d, J = 8.3 Hz, 2 H), 7.29 (d, J = 8.3 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.5, 22.4, 31.7, 55.2, 68.7, 71.1, 113.7 (×2), 121.2, 129.5 (×2), 129.9, 137.2, 159.3 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{14}H_{19}BrO_2Na$ [M + Na]$^+$ 321.0461; found 321.0461.

2-Bromo Allylic Alcohol 2w: IR (neat): $\tilde{\nu}$ = 3026, 2933, 2856, 1612, 1514, 1248 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 2.37 (dt, J = 7.7, 7.7 Hz, 2 H), 2.68 (t, J = 7.7 Hz, 2 H), 3.80 (s, 3 H), 4.09 (s, 2 H), 4.36 (s, 2 H), 6.16 (t, J = 7.7 Hz, 1 H), 6.87 (d, J = 7.5 Hz, 2 H), 7.11 (d, J = 7.5 Hz, 2 H), 7.19 (t, J = 7.1 Hz, 1 H), 7.23–7.30 (m, 4 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 31.6, 35.3, 55.3, 68.7, 71.0, 113.8 (×2), 122.0, 126.2, 128.4 (×2), 128.45 (×2), 128.50 (×2), 129.8, 135.9, 140.6, 159.3 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{19}H_{21}BrO_2Na$ [M + Na]$^+$ 383.0623; found 383.0617.

2-Bromo Allylic Alcohol 2x: IR (neat): $\tilde{\nu}$ = 2999, 2856, 1612, 1514, 1464, 1302, 1248 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 2.36 (dt, J = 7.8, 6.6 Hz, 2 H), 3.44 (t, J = 6.6 Hz, 2 H), 3.80 (s, 3 H), 3.80 (s, 3 H), 4.21 (s, 2 H), 4.41 (s, 2 H), 4.43 (s, 2 H), 6.18 (t, J = 7.8 Hz, 1 H), 6.84–6.89 (m, 4 H), 7.23 (d, J = 8.4 Hz, 2 H), 7.27 (d, J = 9.5 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 30.4, 55.3 (×2), 68.4, 68.9 (×2), 71.1, 72.7, 113.8 (×4), 122.8, 129.2 (×2), 129.5 (×2), 133.5 (×2), 159.2, 159.3 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{21}H_{25}BrO_4Na$ [M + Na]$^+$ 443.0834; found 443.0828.

Enyne 3j: IR (neat): $\tilde{\nu}$ = 2970, 2862, 2214, 1612, 1512, 1458, 1358, 1296, 1250 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.25 (s, 9 H), 3.80 (s, 3 H), 3.97 (s, 2 H), 4.49 (s, 2 H), 5.41 (m, 1 H), 5.46 (m, 1 H), 6.88 (d, J = 8.6 Hz, 2 H), 7.29 (d, J = 8.6 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 27.8, 30.9 (×3), 55.3, 71.7, 72.1, 81.5, 99.4, 113.7 (×2), 120.0, 128.9, 129.3 (×2), 130.4, 159.2 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{17}H_{22}O_2Na$ [M + Na]$^+$ 281.1512; found 281.1517.

Enyne 3k: IR (neat): $\tilde{\nu}$ = 3402, 3001, 2939, 2908, 2862, 2222, 1612, 1512, 1466, 1250 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 2.41 (br. s, 1 H), 2.57 (t, J = 6.3 Hz, 2 H), 3.70 (m, 2 H), 3.80 (s, 3 H), 3.98 (s, 2 H), 4.47 (s, 2 H), 5.44–5.51 (m, 1 H), 5.44–5.51 (m, 1 H), 6.88 (d, J = 8.7 Hz, 2 H), 7.27 (d, J = 8.7 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 23.6, 55.2, 60.8, 71.6, 71.9, 80.6, 87.7, 113.7 (×2), 121.5, 128.4, 129.4 (×2), 129.9, 159.2 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{15}H_{18}O_3Na$ [M + Na]$^+$ 269.1148; found 269.1149.

Enyne 3m: IR (neat): $\tilde{\nu}$ = 3001, 2954, 2931, 2862, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.89 (t, J = 7.4 Hz, 3 H), 0.90 (t, J = 7.1 Hz, 3 H), 1.35 (m, 6 H), 1.55 (m, 2 H), 2.08 (dt, J = 7.4, 7.4 Hz, 2 H), 2.31 (t, J = 7.1 Hz, 2 H), 3.81 (s, 3 H), 4.03 (s, 2 H), 4.47 (s, 2 H), 6.00 (t, J = 7.4 Hz, 1 H), 6.87 (d, J = 8.4 Hz, 2 H), 7.29 (d, J = 8.4 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 14.0, 19.4, 22.2, 22.5, 28.6, 30.3, 31.1, 55.3, 66.9, 71.4, 81.4, 88.1, 113.7 (×2), 120.6, 129.4 (×2), 130.6, 140.8, 159.1 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{21}H_{30}O_2Na$ [M + Na]$^+$ 337.2138; found 337.2133.

Enyne 3n: IR (neat): $\tilde{\nu}$ = 2962, 2870, 2360, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.90 (t, J = 7.4 Hz, 3 H), 1.26 (s, 9 H), 1.39 (tq, J = 7.4, 7.4 Hz, 2 H), 2.09 (dt, J = 7.8, 7.4 Hz, 2 H), 3.81 (s, 3 H), 4.03 (s, 2 H), 4.48 (s, 2 H), 5.99 (t, J = 7.8 Hz, 1 H), 6.87 (d, J = 8.7 Hz, 2 H), 7.30 (d, J = 8.7 Hz, 2 H) ppm. ^{13}C NMR (75 MHz, $CDCl_3$): δ = 13.8, 22.5, 27.8, 30.4, 31.1 (×3), 55.3, 67.1, 71.3, 79.9, 96.2, 113.6 (×2), 120.5, 129.4 (×2), 130.6, 140.7, 159.1 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{20}H_{28}O_2Na$ [M + Na]$^+$ 323.1982; found 323.1987.

Enyne 3o: IR (neat): $\tilde{\nu}$ = 3000, 2954, 2931, 2862, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.93 (t, J = 7.4 Hz, 3 H), 1.45 (tq, J = 7.4, 7.4 Hz, 2 H), 2.17 (dt, J = 7.7, 7.4 Hz, 2 H), 3.80 (s, 3 H), 4.14 (s, 2 H), 4.53 (s, 2 H), 6.20 (t, J = 7.7 Hz, 1 H), 6.87 (d, J = 8.8 Hz, 2 H), 7.27–7.34 (m, 5 H), 7.40–7.46 (m, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 22.5, 30.6, 55.3, 66.8, 71.5, 87.4, 90.6, 113.7 (×2), 120.4, 123.7, 127.8, 128.2 (×2), 129.5 (×2), 130.4, 131.5 (×2), 142.7, 159.2 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{22}H_{24}O_2Na$ [M + Na]$^+$ 343.1669; found 343.1670.

β-Methallyl Alcohol 4d: IR (neat): $\tilde{\nu}$ = 3078, 2978, 2924, 2854, 2360, 1658, 1597, 1489, 1450, 1358 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.76 (s, 3 H), 3.93 (s, 2 H), 4.46 (s, 2 H), 4.93 (m, 1 H), 4.99 (m, 1 H), 7.27–7.35 (m, 4 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 19.5, 71.0, 74.2, 112.5, 128.5 (×2), 128.9 (×2), 133.2, 136.9, 142.0 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{11}H_{13}ClONa$ [M + Na]$^+$ 219.0547; found 219.0545.

β-Methallyl Alcohol 4f: IR (neat): $\tilde{\nu}$ = 2939, 2854, 2337, 1720, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.70 (s, 3 H), 2.84 (t, J = 7.2 Hz, 2 H), 3.58 (t, J = 7.2 Hz, 2 H), 3.79 (s, 3 H), 3.89 (s, 2 H), 4.87 (m, 1 H), 4.93 (m, 1 H), 6.83 (d, J = 8.7 Hz, 2 H), 7.14 (d, J = 8.7 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 19.4, 35.4, 55.2, 71.2, 74.8, 111.9, 113.7 (×2), 129.8 (×2), 131.1, 142.4, 158.0 ppm. HRMS (ESI): [M + Na]$^+$ calcd. for $C_{13}H_{18}O_2Na$ [M + Na]$^+$ 229.1199; found 229.1198.

β-Methallyl Alcohol 4g: IR (neat): $\tilde{\nu}$ = 2931, 2854, 1612, 1512, 1458, 1373, 1304, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.86 (t, J = 6.9 Hz, 3 H), 1.14–1.50 (m, 7 H), 1.62 (m, 1 H), 1.69 (s, 3 H), 3.68 (t, J = 6.9 Hz, 1 H), 3.80 (s, 3 H), 4.17 (d, J = 11.5 Hz, 1 H), 4.43 (d, J = 11.5 Hz, 1 H), 4.89 (m, 1 H), 4.96 (m, 1 H), 6.87 (d, J = 8.3 Hz, 2 H), 7.25 (d, J = 8.3 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.0, 16.5, 22.6, 25.5, 31.7, 33.6, 55.3, 69.5, 83.0, 113.5, 113.7 (×2), 129.3 (×2), 131.0, 144.9, 159.0 ppm.

HRMS (ESI): $[M + Na]^+$ calcd. for $C_{17}H_{26}O_2Na$ $[M + Na]^+$ 285.1825; found 285.1822.

β-Methallyl Alcohol 4h: IR (neat): $\tilde{\nu}$ = 2954, 2862, 1712, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.91 (t, J = 7.4 Hz, 3 H), 1.39 (qt, J = 7.4, 7.3 Hz, 2 H), 1.67 (s, 3 H), 2.03 (dt, J = 7.8, 7.3 Hz, 2 H), 3.80 (s, 3 H), 3.88 (s, 2 H), 4.38 (s, 2 H), 5.42 (m, 1 H), 6.87 (d, J = 8.5 Hz, 2 H), 7.26 (d, J = 8.5 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 13.9, 22.7, 29.8, 55.3, 71.0, 76.1, 113.7 (×2), 128.6, 129.3 (×2), 130.8, 132.1, 159.1 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{15}H_{22}O_2Na$ $[M + Na]^+$ 257.1512; found 257.1512.

β-Methallyl Alcohol 4i: IR (neat): $\tilde{\nu}$ = 2962, 2931, 2862, 2360, 2337, 1489, 1458, 1358 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.91 (t, J = 7.4 Hz, 3 H), 1.39 (tq, J = 7.5, 7.4 Hz, 2 H), 1.67 (s, 3 H), 2.03 (dt, J = 7.9, 7.5 Hz, 3 H), 3.89 (s, 2 H), 4.41 (s, 2 H), 5.37–5.47 (m, 1 H), 7.22–7.34 (m, 4 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 14.1, 14.2, 22.9, 30.0, 70.7, 77.5, 128.7 (×2), 129.2, 129.3 (×2), 132.1, 133.4, 137.4 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{14}H_{19}ClONa$ $[M + Na]^+$ 261.1017; found 261.1019.

β-Methallyl Alcohol 4j: IR (neat): $\tilde{\nu}$ = 2954, 2862, 1612, 1512, 1458, 1250 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.93 (d, J = 8.2 Hz, 3 H), 0.93 (d, J = 8.2 Hz, 3 H), 1.75 (s, 3 H), 2.48–2.60 (m, 1 H), 3.08 (s, 3 H), 4.00 (s, 2 H), 4.38 (s, 2 H), 5.20 (d, J = 9.5 Hz, 1 H), 6.88 (d, J = 7.7 Hz, 2 H), 7.27 (d, J = 7.7 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 21.3, 23.5 (×2), 26.9, 55.3, 68.4, 71.2, 113.7 (×2), 129.2 (×2), 129.6, 130.8, 137.4, 159.1 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{15}H_{22}O_2Na$ $[M + Na]^+$ 257.1512; found 257.1509.

β-Methallyl Alcohol 4k: IR (neat): $\tilde{\nu}$ = 2947, 2862, 2360, 2337, 1466, 1381, 1257 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.90 (t, J = 7.3 Hz, 3 H), 1.05–1.15 (m, 21 H), 1.37 (tq, J = 7.3, 7.3 Hz, 2 H), 1.60 (s, 3 H), 2.01 (dt, J = 7.9, 7.3 Hz, 2 H), 4.09 (s, 2 H), 5.41–5.46 (m, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 12.1 (×3), 13.4, 13.8, 18.0 (×6), 22.8, 29.6, 68.6, 124.1, 134.4 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{16}H_{34}OSiNa$ $[M + Na]^+$ 293.2271; found 293.2270.

β-Methallyl Alcohol 4l: IR (neat): $\tilde{\nu}$ = 3070, 2954, 2931, 2862, 1466, 1427, 1389, 1365, 1265, 1111, 1065 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 0.90 (t, J = 7.3 Hz, 3 H), 1.04–1.07 (m, 9 H), 1.37 (tq, J = 7.3, 7.3 Hz, 2 H), 1.60 (s, 3 H), 2.01 (dt, J = 7.6, 7.3 Hz, 2 H), 4.06 (s, 2 H), 5.41–5.47 (m, 1 H), 7.32–7.44 (m, 6 H), 7.63–7.74 (m, 4 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.5, 13.8, 19.3, 22.8, 26.8 (×3), 29.5, 69.1, 124.6, 127.6 (×4), 129.5 (×2), 133.9, 134.0 (×2), 135.6 (×4) ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{23}H_{32}OSiNa$ $[M + Na]^+$ 375.2115; found 375.2115.

Arene 5b: IR (neat): $\tilde{\nu}$ = 3070, 3032, 2924, 2854, 1597, 1520, 1342, 1111, 1080 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.40–4.43 (m, 2 H), 4.56 (s, 2 H), 5.55 (m, 1 H), 5.71 (m, 1 H), 7.22–7.37 (m, 5 H), 7.62 (d, J = 8.9 Hz, 2 H), 8.18 (d, J = 8.9 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 71.7, 72.2, 118.5, 123.6 (×2), 127.0 (×2), 127.9 (×3), 128.5 (×2), 140.8, 142.4, 142.7, 145.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{16}H_{15}NO_3Na$ $[M + Na]^+$ 292.0944; found 292.0942.

Arene 5c: IR (neat): $\tilde{\nu}$ = 3085, 3062, 3032, 2862, 2229, 1604, 1504, 1119, 1080 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 4.40 (s, 2 H), 4.54 (s, 2 H), 5.51 (s, 1 H), 5.66 (s, 1 H), 7.27–7.38 (m, 5 H), 7.56 (d, J = 8.3 Hz, 2 H), 7.62 (d, J = 8.3 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 71.6, 72.1, 111.3, 117.8, 118.8, 126.8 (×2), 127.8 (×3), 128.4 (×2), 132.2 (×2), 137.7, 142.9, 143.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{17}H_{15}NONa$ $[M + Na]^+$ 272.1046; found 272.1045.

Arene 5d: IR (neat): $\tilde{\nu}$ = 2924, 2854, 1628, 1497, 1095 cm^{-1}. ^1H NMR (500 MHz, $CDCl_3$): δ = 4.37 (s, 2 H), 4.54 (s, 2 H), 5.37 (s, 1 H), 5.54 (s, 1 H), 7.22–7.37 (m, 7 H), 7.40 (d, J = 8.3 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 71.91, 71.94, 115.2, 127.5 (×2), 127.7, 127.8 (×2), 128.4 (×2), 128.5 (×2), 133.6, 137.1, 138.0, 143.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{16}H_{15}ClONa$ $[M + Na]^+$ 281.0704; found 281.0706.

Arene 5e: IR (neat): $\tilde{\nu}$ = 3032, 2962, 2931, 2862, 1682, 1512, 1119, 1080 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.24 (t, J = 7.6 Hz, 3 H), 2.65 (q, J = 7.6 Hz, 2 H), 4.40 (m, 2 H), 4.56 (s, 2 H), 5.32 (m, 1 H), 5.53 (m, 1 H), 7.17 (d, J = 8.0 Hz, 2 H), 7.26–7.36 (m, 5 H), 7.40 (d, J = 8.0 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 15.5, 28.5, 71.9, 72.1, 113.7, 126.1 (×2), 127.6, 127.8 (×2), 127.9 (×2), 128.4 (×2), 138.3, 143.9, 144.0, 144.6 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{18}H_{20}ONa$ $[M + Na]^+$ 275.1406; found 275.1405.

Arene 5g: IR (neat): $\tilde{\nu}$ = 2931, 2846, 1597, 1512, 1458, 1342, 1242, 1111, 1072 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.39 (m, 2 H), 4.48 (s, 2 H), 5.53 (m, 1 H), 5.70 (s, 1 H), 6.87 (d, J = 8.7 Hz, 2 H), 7.25 (d, J = 8.7 Hz, 2 H), 7.58–7.64 (m, 2 H), 8.15–8.21 (m, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 71.3, 71.8, 113.9 (×2), 118.4, 123.6 (×2), 127.0 (×2), 129.5 (×2), 129.7, 142.8, 145.2, 159.4, 160.6 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{17}H_{17}NO_4Na$ $[M + Na]^+$ 322.1050; found 322.1047.

Arene 5h: IR (neat): $\tilde{\nu}$ = 2931, 2854, 1612, 1527, 1466, 1350, 1250, 1080 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.39 (m, 2 H), 4.50 (s, 2 H), 5.50 (s, 1 H), 5.67 (s, 1 H), 6.88 (d, J = 8.0 Hz, 2 H), 7.24 (d, J = 8.0 Hz, 2 H), 7.50 (dd, J = 8.0, 8.0 Hz, 1 H), 7.80 (m, 1 H), 8.13 (m, 1 H), 8.33 (dd, J = 2.0, 2.0 Hz, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 71.4, 71.9, 113.9 (×2), 117.4, 121.2, 122.5, 129.2, 129.5 (×2), 129.8, 132.2, 138.1, 140.5, 142.5, 159.4 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{17}H_{17}NO_4Na$ $[M + Na]^+$ 322.1050; found 322.1049.

Arene 5i: IR (neat): $\tilde{\nu}$ = 2931, 2908, 2854, 2229, 1612, 1512, 1458, 1304, 1250, 1080 1034 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.37 (d, J = 1.0 Hz, 2 H), 4.47 (s, 2 H), 5.49 (d, J = 1.0 Hz, 1 H), 5.65 (s, 1 H), 6.87 (d, J = 8.6 Hz, 2 H), 7.21 (d, J = 8.6 Hz, 2 H), 7.55 (d, J = 8.6 Hz, 2 H), 7.62 (d, J = 8.6 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 71.3, 71.8, 113.5, 113.8 (×2), 115.2, 117.8, 126.8 (×2), 129.5 (×2), 129.8, 132.2 (×2), 143.0, 149.4, 159.4 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{18}H_{17}NO_2Na$ $[M + Na]^+$ 302.1151; found 302.1146.

Arene 5j: IR (neat): $\tilde{\nu}$ = 3016, 2839, 1612, 1512, 1304, 1219, 1088, 764 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.34 (m, 2 H), 4.47 (s, 2 H), 5.36 (m, 1 H), 5.53 (m, 1 H), 6.87 (d, J = 8.5 Hz, 2 H), 7.20–7.32 (m, 4 H), 7.40 (d, J = 8.5 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.2, 71.57, 71.58, 113.8 (×2), 115.2, 127.5 (×2), 128.4 (×2), 129.4 (×2), 130.0, 133.6, 137.1, 143.2, 159.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{17}H_{17}ClO_2Na$ $[M + Na]^+$ 311.0809; found 311.0809.

Arene 5k: IR (neat): $\tilde{\nu}$ = 2962, 2854, 1612, 1512, 1458, 1250, 1080 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 1.24 (t, J = 7.6 Hz, 3 H), 2.65 (q, J = 7.6 Hz, 2 H), 3.80 (s, 3 H), 4.37 (m, 2 H), 4.49 (s, 2 H), 5.31 (td, J = 1.3, 1.3 Hz, 1 H), 5.52 (m, 1 H), 6.87 (d, J = 8.7 Hz, 2 H), 7.17 (d, J = 8.2 Hz, 2 H), 7.24 (d, J = 8.7 Hz, 2 H), 7.39 (d, J = 8.2 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 15.5, 28.5, 55.3, 71.5, 71.7, 113.6, 113.7 (×2), 126.0 (×2), 127.8 (×2), 129.4 (×2), 130.3, 136.1, 143.9, 144.1, 159.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{19}H_{22}O_2Na$ $[M + Na]^+$ 305.1512; found 305.1512.

Arene 5l: IR (neat): $\tilde{\nu}$ = 2939, 2862, 1635, 1466, 1257, 1134, 1088 cm^{-1}. ^1H NMR (300 MHz, $CDCl_3$): δ = 0.97–1.17 (m, 21 H),

4.55 (dd, J = 1.7, 1.7 Hz, 2 H), 5.38 (dt, J = 1.7, 1.7 Hz, 1 H), 5.43 (dt, J = 1.7, 1.7 Hz, 1 H), 7.22–7.42 (m, 4 H), 7.55 (m, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 12.1 (×3), 18.0 (×6), 64.8, 111.0, 126.0 (×2), 127.6, 128.3 (×2), 139.3, 147.0 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{18}H_{30}OSiNa$ $[M + Na]^+$ 313.1958; found 313.1961.

Arene 5m: IR (neat): $\tilde{\nu}$ = 3000, 2931, 2908, 2854, 1612, 1589, 1512, 1458, 1358, 1304, 1250, 1173, 1080 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.27 (s, 2 H), 4.48 (s, 2 H), 5.25 (s, 1 H), 5.69 (s, 1 H), 6.37–6.40 (m, 2 H), 6.88 (d, J = 8.6 Hz, 2 H), 7.27 (d, J = 8.6 Hz, 2 H), 7.37 (d, J = 1.2 Hz, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 70.2, 71.5, 107.0, 111.2, 111.7, 113.8 (×2), 129.5 (×2), 130.2, 134.2, 141.9, 152.7, 159.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{15}H_{16}O_3Na$ $[M + Na]^+$ 267.0992; found 267.0992.

Arene 5n: IR (neat): $\tilde{\nu}$ = 2931, 2862, 1612, 1512, 1458, 1296, 1250, 1173, 1111, 1080 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.34 (s, 2 H), 4.51 (s, 2 H), 5.25 (s, 1 H), 5.57 (s, 1 H), 6.88 (d, J = 8.5 Hz, 2 H), 6.98 (dd, J = 4.9, 3.9 Hz, 1 H), 7.14 (d, J = 3.9 Hz, 1 H), 7.19 (d, J = 4.9 Hz, 1 H), 7.27 (d, J = 8.5 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 71.6, 71.8, 113.1, 113.8 (×2), 124.1, 124.5, 127.3, 129.5 (×2), 130.2, 138.2, 142.5, 159.3 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{15}H_{16}O_2SNa$ $[M + Na]^+$ 283.0763; found 283.0760.

Arene 5o: IR (neat): $\tilde{\nu}$ = 3001, 2931, 2854, 1712, 1604, 1512, 1458, 1304, 1250, 1173, 1080 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.36 (s, 2 H), 4.49 (s, 2 H), 5.52 (s, 1 H), 5.74 (s, 1 H), 6.88 (d, J = 8.5 Hz, 2 H), 7.23 (d, J = 8.5 Hz, 2 H), 7.35 (d, J = 5.8 Hz, 2 H), 8.56 (d, J = 5.8 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 70.9, 71.8, 113.8 (×2), 117.9, 120.7 (×2), 129.5 (×2), 129.8, 142.3, 140.6, 149.9 (×2), 159.4 ppm. HRMS (ESI): $[M + H]^+$ calcd. for $C_{16}H_{18}NO_2$: 256.1332; found 256.1334.

Arene 5p: m.p. 66.2–66.5 °C. IR (neat): $\tilde{\nu}$ = 3024, 2954, 2931, 2854, 1612, 1512, 1450, 1304, 1250, 1126, 1103, 1034 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.81 (s, 3 H), 4.28 (s, 2 H), 4.50 (s, 2 H), 5.33 (s, 1 H), 5.34 (s, 1 H), 6.69 (d, J = 16.9 Hz, 1 H), 6.81 (d, J = 16.9 Hz, 1 H), 6.89 (d, J = 8.2 Hz, 2 H), 7.23 (dd, J = 7.0, 7.0 Hz, 1 H), 7.28–7.34 (m, 4 H), 7.41 (d, J = 8.2 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 70.0, 71.7, 113.8 (×2), 118.0, 126.5 (×2), 127.6, 128.5, 128.6 (×2), 129.2, 129.5 (×2), 130.4, 134.3, 137.2, 142.4 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{19}H_{20}O_2Na$ $[M + Na]^+$ 303.1356; found 303.1352.

Arene 5q: m.p. 68.3–71.4 °C. IR (neat): $\tilde{\nu}$ = 2854, 1612, 1589, 1512, 1450, 1358, 1250, 1180, 1103, 1065, 1026 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 3.80 (s, 3 H), 4.50 (s, 2 H), 4.53 (s, 2 H), 5.46 (s, 1 H), 5.69 (s, 1 H), 6.87 (d, J = 8.4 Hz, 2 H), 7.26 (d, J = 8.4 Hz, 2 H), 7.40–7.49 (m, 2 H), 7.63 (d, J = 8.4 Hz, 1 H), 7.76–7.83 (m, 3 H), 7.89 (s, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 55.3, 71.6, 71.8, 113.8 (×2), 115.1, 124.4, 125.0, 125.9, 126.1, 127.5, 127.8, 128.3, 129.4 (×2), 130.3, 133.0, 133.4, 136.0, 144.1, 159.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{21}H_{20}O_2Na$ $[M + Na]^+$ 327.1356; found 327.1352.

Arene 5r: IR (neat): $\tilde{\nu}$ = 2954, 2931, 2862, 1612, 1512, 1458, 1250, 1173 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.86 (t, J = 7.3 Hz, 3 H), 1.39 (qt, J = 7.3, 7.3 Hz, 2 H), 2.02 (dt, J = 7.3, 7.3 Hz, 2 H), 3.77 (s, 3 H), 4.18 (s, 2 H), 4.44 (s, 2 H), 5.75 (t, J = 7.3 Hz, 1 H), 6.84 (d, J = 8.7 Hz, 2 H), 7.16–7.35 (m, 7 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 23.0, 30.7, 55.2, 71.3, 74.8, 113.7 (×2), 126.7, 128.0 (×2), 128.6 (×2), 129.3 (×2), 130.5, 130.8, 137.3, 139.2, 159.1 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{20}H_{24}O_2Na$ $[M + Na]^+$ 319.1669; found 319.1670.

Arene 5s: IR (neat): $\tilde{\nu}$ = 3054, 2962, 2931, 2862, 2360, 2337, 1597, 1489, 1458, 1350, 1089 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.86 (t, J = 7.4 Hz, 3 H), 1.39 (qt, J = 7.4, 7.4 Hz, 2 H), 2.03 (dt, J = 7.7, 7.4 Hz, 2 H), 4.14 (s, 2 H), 4.40 (s, 2 H), 5.74 (m, 1 H), 7.10–7.38 (m, 9 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 23.0, 30.7, 70.8, 75.3, 126.8, 128.1 (×2), 128.4 (×2), 128.6 (×2), 129.0 (×2), 131.3, 133.1, 137.0, 137.1, 139.0 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{19}H_{21}ClONa$ $[M + Na]^+$ 323.1173; found 323.1175.

Arene 5t: IR (neat): $\tilde{\nu}$ = 2954, 2862, 2337, 1466, 1381, 1250, 1119 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.85 (t, J = 7.4 Hz, 3 H), 0.99–1.16 (m, 21 H), 1.37 (tq, J = 7.5, 7.4 Hz, 2 H), 1.96 (td, J = 7.5, 7.4 Hz, 2 H), 4.37 (m, 2 H), 5.81 (m, 1 H), 7.08–7.19 (m, 2 H), 7.22–7.36 (m, 3 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 12.1 (×3), 13.8, 18.0 (×6), 23.1, 30.3, 67.3, 126.0, 126.7, 128.0 (×2), 128.7 (×2), 139.4, 139.8 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{21}H_{36}OSiNa$ $[M + Na]^+$ 355.2428; found 355.2427.

Arene 5u: IR (neat): $\tilde{\nu}$ = 3055, 2954, 2854, 2337, 1466, 1365, 1265, 1111 cm^{-1}. ^{1}H NMR (300 MHz, $CDCl_3$): δ = 0.86 (t, J = 7.4 Hz, 3 H), 1.04 (s, 9 H), 1.38 (tq, J = 7.5, 7.4 Hz, 2 H), 1.96 (td, J = 7.5, 7.2 Hz, 2 H), 4.33 (d, J = 1.3 Hz, 2 H), 5.84 (tt, J = 7.2, 1.3 Hz, 1 H), 7.05–7.11 (m, 2 H), 7.18–7.45 (m, 9 H), 7.62–7.68 (m, 4 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 19.3, 23.1, 26.8 (×3), 30.4, 68.0, 126.7, 127.0, 127.6 (×4), 127.9 (×2), 128.8 (×2), 129.5 (×2), 133.7 (×2), 135.6 (×4), 139.2, 139.5 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{28}H_{34}OSiNa$ $[M + Na]^+$ 433.2271; found 437.2271.

Arene 5v: IR (neat): $\tilde{\nu}$ = 2954, 2931, 2862, 1612, 1512, 1458, 1250, 1173, 1095, 1072 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.86 (t, J = 7.3 Hz, 3 H), 1.41 (qt, J = 7.5, 7.3 Hz, 2 H), 2.07 (dt, J = 7.6, 7.5 Hz, 2 H), 3.78 (s, 3 H), 4.27 (s, 2 H), 4.47 (s, 2 H), 5.83 (t, J = 7.6 Hz, 1 H), 6.82 (d, J = 8.6 Hz, 2 H), 7.19 (d, J = 8.6 Hz, 2 H), 7.36 (m, 1 H), 7.42–7.50 (m, 2 H), 7.67 (s, 1 H), 7.76–7.86 (m, 3 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 23.0, 30.8, 55.3, 71.4, 74.9, 113.7 (×2), 125.6, 125.9, 127.1, 127.4, 127.5, 127.6, 127.9, 129.3 (×2), 130.5, 131.5, 132.4, 133.3, 136.8, 137.4, 159.1 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{24}H_{26}O_2Na$ $[M + Na]^+$ 369.1825; found 369.1826.

Arene 5w: IR (neat): $\tilde{\nu}$ = 2954, 2931, 2862, 1612, 1527, 1466, 1350, 1250, 1173, 1080 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 0.96 (t, J = 7.3 Hz, 3 H), 1.50 (qt, J = 7.3, 7.3 Hz, 2 H), 2.24 (dt, J = 7.4, 7.3 Hz, 2 H), 3.81 (s, 3 H), 4.38 (s, 2 H), 4.47 (s, 2 H), 6.10 (t, J = 7.4 Hz, 1 H), 6.87 (d, J = 8.6 Hz, 2 H), 7.23 (d, J = 8.6 Hz, 2 H), 7.45 (dd, J = 8.4, 7.8 Hz, 1 H), 7.74 (d, J = 7.8 Hz, 1 H), 8.08 (dd, J = 8.4, 2.1 Hz, 1 H), 8.28 (s, 1 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 13.8, 22.8, 30.6, 55.3, 65.8, 72.0, 113.9 (×2), 121.2, 121.5, 129.0, 129.5 (×2), 129.9, 132.2, 134.6, 136.1, 143.3, 148.3, 159.3 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{20}H_{23}NO_4Na$ $[M + Na]^+$ 364.1519; found 364.1515.

Arene 5x: IR (neat): $\tilde{\nu}$ = 2962, 2931, 2862, 1612, 1512, 1458, 1365, 1250, 1173, 1080 cm^{-1}. ^{1}H NMR (500 MHz, $CDCl_3$): δ = 1.04 (d, J = 6.5 Hz, 6 H), 2.71 (m, 1 H), 3.80 (s, 3 H), 4.36 (s, 2 H), 4.47 (s, 2 H), 5.94 (d, J = 9.8 Hz, 1 H), 6.87 (d, J = 8.5 Hz, 2 H), 6.95 (dd, J = 4.6, 3.6 Hz, 1 H), 7.07 (d, J = 3.6 Hz, 1 H), 7.11 (d, J = 4.6 Hz, 1 H), 7.25 (d, J = 8.5 Hz, 2 H) ppm. ^{13}C NMR (126 MHz, $CDCl_3$): δ = 23.2 (×2), 27.6, 55.3, 66.5, 71.5, 113.7 (×2), 123.2, 123.3, 127.2, 128.0, 129.5 (×2), 130.4, 139.7, 145.4, 159.2 ppm. HRMS (ESI): $[M + Na]^+$ calcd. for $C_{18}H_{22}O_2SNa$ $[M + Na]^+$ 325.1233; found 325.1230.

Supporting Information (see footnote on the first page of this article): Copies of ^{1}H and ^{13}C NMR spectra of final products.

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[1] a) E. Erdik, *Tetrahedron* **1992**, *48*, 9577–9648; b) T.-Y. Luh, M.-k. Leung, K.-T. Wong, *Chem. Rev.* **2000**, *100*, 3187–3204; c) K. Tamao, T. Hiyama, E. Negishi, *J. Organomet. Chem.* **2002**, *653*, 1–4; d) K. C. Nicolaou, P. G. Bulger, D. Sarlah, *Angew. Chem.* **2005**, *117*, 4516–4563; *Angew. Chem. Int. Ed.* **2005**, *44*, 4442–4489; e) J.-P. Corbet, G. Mignani, *Chem. Rev.* **2006**, *106*, 2651–2710; f) C. C. C. Johansson Seechurn, M. O. Kitching, T. J. Colacot, V. Snieckus, *Angew. Chem.* **2012**, *124*, 5150–5174; *Angew. Chem. Int. Ed.* **2012**, *51*, 5062–5085; g) R. Jana, T. P. Pathak, M. S. Sigman, *Chem. Rev.* **2011**, *111*, 1417–1492.

[2] a) K. Sonogashira, Y. Tohda, N. Hagihara, *Tetrahedron Lett.* **1975**, *16*, 4467–4470; b) K. Sonogashira, *J. Organomet. Chem.* **2002**, *653*, 46–49; c) E. Negishi, L. Anastasia, *Chem. Rev.* **2003**, *105*, 1979–2018; d) R. Chinchilla, C. Nájera, *Chem. Rev.* **2007**, *107*, 874–922.

[3] a) A. O. King, N. Okukado, E. Negishi, *J. Chem. Soc., Chem. Commun.* **1977**, 683–684; b) E. Negishi, A. O. King, N. Okukado, *J. Org. Chem.* **1977**, *42*, 1821–1823; c) E. Negishi, *Acc. Chem. Res.* **1982**, *15*, 340–348; d) P. Knochel, R. D. Singer, *Chem. Rev.* **1993**, *93*, 2117–2188; e) X. Zeng, M. Qian, Q. Hu, E. Negishi, *Angew. Chem.* **2004**, *116*, 2309–2313; *Angew. Chem. Int. Ed.* **2004**, *43*, 2259–2263.

[4] a) N. Miyaura, A. Suzuki, *J. Chem. Soc., Chem. Commun.* **1979**, 86–87; b) N. Miyaura, K. Yamada, A. Suzuki, *Tetrahedron Lett.* **1979**, *20*, 3437–3440; c) N. Miyaura, A. Suzuki, *Chem. Rev.* **1995**, *95*, 2457–2483; d) S. R. Chemler, D. Trauner, S. J. Danishefsky, *Angew. Chem.* **2001**, *113*, 4676–4701; *Angew. Chem. Int. Ed.* **2001**, *40*, 4544–4568; e) R. Martin, S. L. Buchwald, *Acc. Chem. Res.* **2008**, *41*, 1461–1473; f) C. A. Fleckenstein, H. Plenio, *Chem. Soc. Rev.* **2010**, *39*, 694–711.

[5] a) N. Hall, *Science* **1994**, *266*, 32–33; b) K. C. Nicolaou, T. Montagnon, S. A. Snyder, *Chem. Commun.* **2003**, 551–564; c) K. C. Nicolaou, D. J. Edmonds, P. G. Bulger, *Angew. Chem.* **2006**, *118*, 7292–7344; *Angew. Chem. Int. Ed.* **2006**, *45*, 7134–7186; d) H. Ishikawa, T. Suzuki, Y. Hayashi, *Angew. Chem.* **2009**, *121*, 1330; *Angew. Chem. Int. Ed.* **2009**, *48*, 1304–1307; e) C. Grondal, M. Jeanty, D. Enders, *Nat. Chem.* **2010**, *2*, 167–178; f) H. Ishikawa, M. Honma, Y. Hayashi, *Angew. Chem.* **2011**, *123*, 2876–2879; *Angew. Chem. Int. Ed.* **2011**, *50*, 2824–2827; g) M. J. Climent, A. Corma, S. Iborra, *Chem. Rev.* **2011**, *111*, 1072–1133; h) H. Fujioka, K. Yahata, O. Kubo, Y. Sawama, T. Hamada, T. Maegawa, *Angew. Chem.* **2011**, *123*, 12440–12443; *Angew. Chem. Int. Ed.* **2011**, *50*, 12232–12235; i) H. Fujioka, Y. Minamitsuji, T. Moriya, K. Okamoto, O. Kubo, T. Matsushita, K. Murai, *Chem. Asian J.* **2012**, *7*, 1925–1933; j) H. Fujioka, K. Yahata, T. Hamada, O. Kubo, T. Okitsu, Y. Sawama, T. Ohnaka, T. Maegawa, Y. Kita, *Chem. Asian J.* **2012**, *7*, 367–373.

[6] a) C. Kuang, Q. Yang, H. Senboku, M. Tokuda, *Tetrahedron* **2005**, *61*, 4043–4052; b) P. Pawluć, G. Hreczycho, J. Szudkowska, M. Kubicki, B. Marciniec, *Org. Lett.* **2009**, *11*, 3390–3393; c) M.-A. Bazin, M. Jouanne, H. El-Kashef, S. Rault, *Synlett* **2009**, 2789–2794.

[7] For the synthesis of 2-bromo-1-alkenes, see: a) T. Ohgiya, S. Nishiyama, *Chem. Lett.* **2004**, *33*, 1084–1085; b) T. Ohgiya, S. Nishiyama, *Heterocycles* **2004**, *63*, 2349–2354; c) T. Ohgiya, S. Nishiyama, *Tetrahedron Lett.* **2004**, *45*, 8273–8275; d) T. Ohgiya, K. Nakamura, S. Nishiyama, *Bull. Chem. Soc. Jpn.* **2005**, *78*, 1549–1554; e) N. Kutsumura, K. Niwa, T. Saito, *Org. Lett.* **2010**, *12*, 3316–3319; f) N. Kutsumura, K. Kubokawa, T. Saito, *Synlett* **2010**, 2717–2720; g) N. Kutsumura, K. Kubokawa, T. Saito, *Synthesis* **2011**, 2377–2382; h) N. Kutsumura, M. Iijima, S. Toguchi, T. Saito, *Chem. Lett.* **2011**, *40*, 1231–1232. For reviews on the elimination reactions of 1,2-dibromoalkanes, see: i) T. Ohgiya, N. Kutsumura, S. Nishiyama, *J. Synth. Org. Chem. Jpn.* **2008**, *66*, 139–147; j) T. Ohgiya, N. Kutsumura, S. Nishiyama, *Synlett* **2008**, 3091–3105.

[8] a) M. Nakata, H. Enari, M. Kinoshita, *Bull. Chem. Soc. Jpn.* **1982**, *55*, 3283–3296; b) D. Andrei, S. F. Wnuk, *Org. Lett.* **2006**, *8*, 5093–5096.

[9] The yields of the one-pot Sonogashira coupling reactions following Method A were lower than those following Method B.

[10] a) M. G. Organ, M. Miller, *Tetrahedron Lett.* **1997**, *38*, 8181–8184; b) M. G. Organ, M. Miller, Z. Konstantinou, *J. Am. Chem. Soc.* **1998**, *120*, 9283–9290; c) M. G. Organ, E. A. Arvanitis, C. E. Dixon, J. T. Cooper, *J. Am. Chem. Soc.* **2002**, *124*, 1288–1294; d) M. G. Organ, E. A. Arvanitis, A. Villani, Y. Majkut, S. Hynes, *Tetrahedron Lett.* **2003**, *44*, 4403–4406; e) E. Comer, M. G. Organ, S. J. Hynes, *J. Am. Chem. Soc.* **2004**, *126*, 16087–16092.

[11] a) N. Hadei, E. A. B. Kantchev, C. J. O'Brien, M. G. Organ, *Org. Lett.* **2005**, *7*, 3805–3807; b) N. Hadei, E. A. B. Kantchev, C. J. O'Brien, M. G. Organ, *J. Org. Chem.* **2005**, *70*, 8503–8507; c) C. J. O'Brien, E. A. B. Kantchev, G. A. Chass, N. Hadei, A. C. Hopkinson, M. G. Organ, D. H. Setiadi, T.-H. Tang, D.-C. Fang, *Tetrahedron* **2005**, *61*, 9723–9735; d) M. G. Organ, S. Avola, I. Dubovyk, N. Hadei, E. A. B. Kantchev, C. J. O'Brien, C. Valente, *Chem. Eur. J.* **2006**, *12*, 4749–4755; e) C. Valente, M. E. Belowich, N. Hadei, M. G. Organ, *Eur. J. Org. Chem.* **2010**, 4343–4354.

[12] The yields of the one-pot Negishi coupling reactions following Method B were lower than those following Method A.

[13] a) N. Kutsumura, A. Kiriseko, T. Saito, *Tetrahedron Lett.* **2012**, *53*, 3274–3276; b) N. Kutsumura, A. Kiriseko, T. Saito, *Heterocycles* **2012**, *86*, 1367–1378.

[14] The yields of the one-pot Suzuki–Miyaura coupling reactions following Method A were lower than those following Method B.

[15] a) S. Darses, J.-P. Genêt, J.-L. Brayer, J.-P. Demoute, *Tetrahedron Lett.* **1997**, *38*, 4393–4396; b) S. Darses, G. Michaud, J.-P. Genêt, *Eur. J. Org. Chem.* **1999**, 1875–1883; c) G. A. Molander, M. R. Rivero, *Org. Lett.* **2002**, *4*, 107–109; d) G. A. Molander, C. R. Bernardi, *J. Org. Chem.* **2002**, *67*, 8424–8429; e) G. A. Molander, C.-S. Yun, M. Ribagorda, B. Biolatto, *J. Org. Chem.* **2003**, *68*, 5534–5539; f) G. A. Molander, L. A. Felix, *J. Org. Chem.* **2005**, *70*, 3950–3956; g) Y. Yamamoto, S. Takada, N. Miyaura, *Chem. Lett.* **2006**, *35*, 1368–1369.

[16] For **2a**, **2d**, **2e**, **2o**, **2p**, **2s**, and **2t**, see: ref.[7a]; for **2b**, **2i**, **2j**, **2k**, **2l**, and **2m**, see: ref.[7e]; for **2c**, see: S.-E. Yoo, S.-H. Lee, S.-K. Kim, S.-H. Lee, *Bioorg. Med. Chem.* **1997**, *5*, 445–459; for **2f**, see: S. G. Powell, R. Adams, *J. Am. Chem. Soc.* **1920**, *42*, 646–658; for **2g**, see: ref.[10c]; for **2h**, see: E. A. Couladouros, V. P. Vidali, *Chem. Eur. J.* **2004**, *10*, 3822–3835; for **2r**, see: F. Matsuura, R. Peters, M. Anada, S. S. Harried, J. Hao, Y. Kishi, *J. Am. Chem. Soc.* **2006**, *128*, 7463–7465; for **2v**, see: ref.[7f,7g]; for **2y** and **2z**, see: ref.[7j]

[17] For **3a**, **3b**, **3c**, **3d**, **3e**, **3f**, **3g**, **3h**, **3i**, **3l**, **3p**, and **3q**, see: ref.[7e]

[18] For **4a**, see: M. Wolter, G. Nordmann, G. E. Job, S. L. Buchwald, *Org. Lett.* **2002**, *4*, 973–976; for **4b**, see: J. Wennerberg, L. Eklund, M. Polla, T. Frejd, *Chem. Commun.* **1997**, 445–446; for **4c** and **4e**, see: J. Waser, B. Gaspar, H. Nambu, E. M. Carreira, *J. Am. Chem. Soc.* **2006**, *128*, 11693–11712; for **4m**, see: ref.[13]

[19] For **5a**, see: H. Lebel, M. Davi, S. Díez-González, S. P. Nolan, *J. Org. Chem.* **2007**, *72*, 144–149; for **5f**, see: J. Wennerberg, C. Olofsson, T. Frejd, *J. Org. Chem.* **1998**, *63*, 3595–3598.

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