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Forging C–C Bonds with Hindered Nucleophiles and Carbonyl Electrophiles: Reactivity and Selectivity of Allylic Tin Reagents/*n*-BuLi

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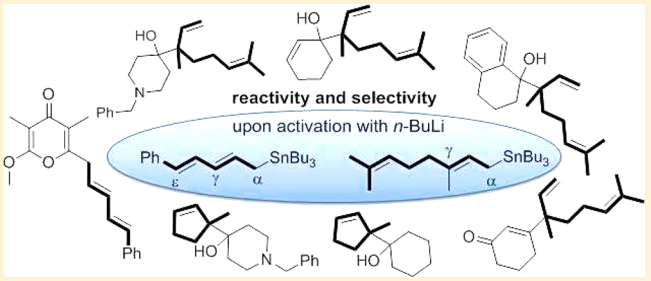
Supporting Information

ABSTRACT: Under activation with *n*-BuLi, trialkylstannanes containing crotyl-, geranyl-, and phenyldienylmethyl appendages were reacted with efficiency and selectivity to various ketone and enone electrophiles with low reactivity. The straightforward process gives access to tertiary alcohols that are vicinal to quaternary carbons. With α,α'-dimethoxy-γ-pyrone, on the other hand, the grafting of a dienyl side chain was effected to prepare dienyl α'-methoxy-γ-pyrone in a stereo- and regioselective and convergent manner. Furthermore, the advantages of this route were highlighted for the preparation of organolithium species at low temperature with the formation of a minimum amount of salts. Synthetic manipulations were demonstrated to illustrate the potential of the chemistry for constructing acyclic and cyclic terpene scaffolds.

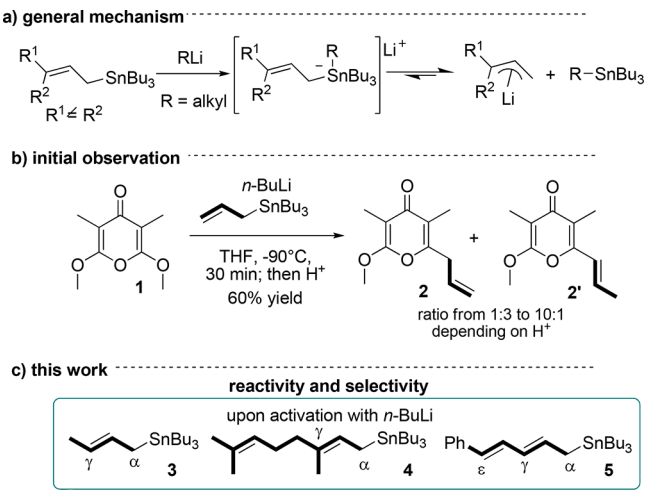


INTRODUCTION

Lithium–tin exchange is a handy method to prepare organolithium reagents, which because of their high reactivity are useful for forging carbon–carbon bonds using hindered nucleophiles.[1] Beyond the addition to carbonyl and imine electrophiles, these reagents were successfully employed in palladium-catalyzed couplings with bromoarenes.[2] The lithium–tin exchange is often performed by treatment of elaborated tetraorgano tin reagents with sacrificial organolithium species (typically *n*-BuLi), which lead to intermediate ate complexes (Scheme 1a).[3] Subsequent fragmentation releases the desired and most stable organolithium products and tetraalkylstannane. In the case of heteroleptic stannates such as those derived from allylic trialkylstannanes, the unsaturated substituent shifts first. Thus, Pulido elegantly relied on tin–ate complexes for the internal and γ-selective delivery of crotyllithium to carbonyl compounds containing a tetraalkylstannane anchor.[4,5] As representative cases of this family of reagents, crotyl- and geranyltributylstannane were however scarcely employed as pronucleophiles upon activation with *n*-BuLi, and little is known of their reactivity and selectivity with enones and ketones. Because many natural products, flagrance ingredients, and organic materials feature terpene (crotyl, prenyl, geranyl, or farnesyl) or dienyl appendages, the chemistry has implications for the formation of C–C bonds with hindered nucleophiles and poorly reactive electrophiles, a difficult and fundamental task.

In the course of a program of total synthesis, we performed the allylation of α,α'-dimethoxy-γ-pyrone **1** into **2** with the combination of allyltributylstannane/*n*-BuLi, which contrasted with allylmagnesium bromide that reacted with **1** following a different pattern (Scheme 1b).[6] Capitalizing on this result, we sought to couple **1** with more hindered allylic appendages, such as crotyl, geranyl, and even dienyl using their stannane counterparts **3**–**5** (Scheme 1c). Additionally, several carbonyl electrophiles were exposed to these species to examine α-, γ-, or ε-selectivity of the couplings. We are pleased to report herein the results of this study illustrating the capacity of stannane reagents to regioselectively transfer terpene appendages to electrophiles having low reactivity.

Scheme 1



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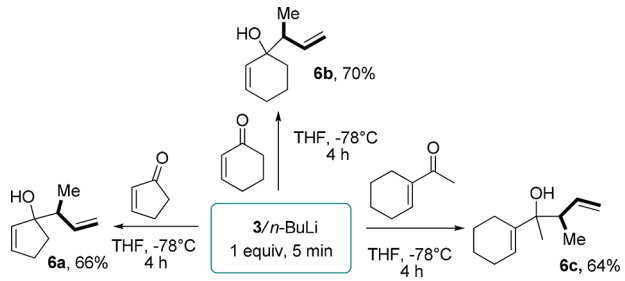
RESULTS AND DISCUSSION

To begin the study, the combination of **3**/*n*-BuLi was tested with α,α'-dimethoxy-γ-pyrone **1**, but the grafting of the crotyl appendage to **1** consistently failed, whether with α- or γ-selectivity.[7] Curious to evaluate reactivity and selectivity of **3** with other carbonyl electrophiles, we employed various enones that have low reactivity, like **1** (Scheme 2). With a

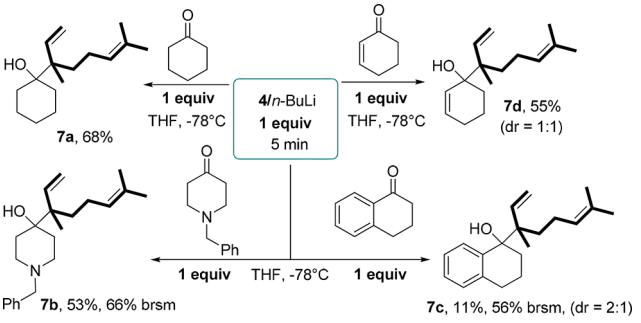
Scheme 2. Hydrocrotylation of Enone Reagents (1:1 dr)



stoichiometric ratio of reagents, the combination (*E*)-**3**/*n*-BuLi proved to be an efficient tool to access allylic alcohols **6a**–**c** (64–70% yields) with excellent γ-selectivity.[8] Similar selectivity was obtained by reaction of crotylmagnesium bromide with enones.[9] In comparison, the combination (*E*)-**3**/*n*-BuLi offers the advantages of generating the nucleophilic species in smooth conditions (at −78 °C) from **3**, a stable pronucleophile, and being convenient for small scale experiment without an excess of reagents. Others strategies were reported to graft the crotyl appendage to such electrophiles with titanocenes or indium species.[10,11] Combined with Lewis acids, crotylboronate was also employed for such a purpose.[12]

Although the addition of the more hindered pronucleophile **4** to **1** failed upon activation with *n*-BuLi, the hydroalkylation of enone and ketones was more fruitful, furnishing with γ-selectivity various scaffolds embedding vicinal quaternary and tertiary carbons (Scheme 3).[13] Thus, γ-adduct **7a** was obtained

Scheme 3. Hydrogeranylation of Ketone and Enone Reagents

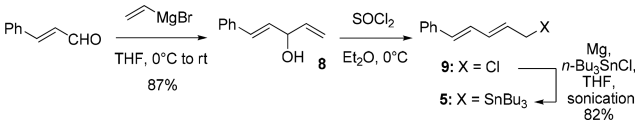


in 68% yield by condensation of **4**/*n*-BuLi with cyclohexanone. So far undocumented, the conversion of the piperidinone pharmacophore[14] into the terpene alkaloid **7b**, as the sole γ-isomer, was carried out in 53% yield (66% brsm). A difficult electrophile such as tetralone was transformed into alcohol **7c** with excellent regioselectivity albeit in 11% yield (56% brsm, 2:1 dr). However, with regard to the literature data, the performance of the coupling remains synthetically useful and pertinent given the versatility of tertiary benzylic alcohols with olefinic appendage as in radical ring expansion.[15] Moreover, 2-cyclohexenone underwent regioselective hydroalkylation upon exposure to **4**/*n*-BuLi giving **7d** in 55% yield. Noteworthy, each reagent was employed in a stoichiometric amount to prepare hindered vicinal carbons through intermolecular coupling.[16]

The stereoselective synthesis of 1,3-diene is a flourishing field of innovation supported by the occurrence of the motif in natural products and in push–pull molecular electronic devices.[17] One of the disconnections consists of the direct transfer of dienyl appendage to carbonyl reagent. Being an unsymmetrical pronucleophile, stannane **5** could produce at least three isomers of position (α-,γ-,ε-) upon reaction, this in addition to isomers of configuration. In the domain, Oppolzer[18] and Nakamura[19] described the addition of lithiated silylated diene to carbonyl compounds with γ- or ε-selectivity. Indium- and aluminum-promoted transfers of symmetrical dienyl appendage, such as pentadiene, were also reported with γ-selectivity by Fallis and Martin, respectively.[20,21]

To our knowledge, the coupling of dienyl stannane to carbonyl compounds was not investigated upon activation with organolithium reagents. Inspired by the related work of Maruyama,[22] the preparation of stannane **5** was undertaken from cinnamaldehyde by treatment with vinylmagnesium bromide giving alcohol **8** (Scheme 4). Exposure to $SOCl_2$

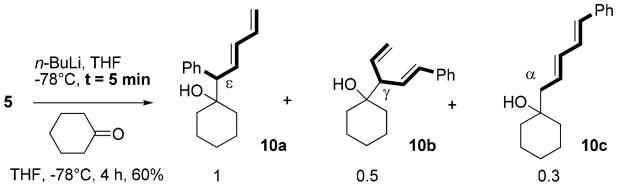
Scheme 4. Preparation of Diene 5



produced the chlorodiene **9** as a single isomer.[23] In what appears to be the first synthesis of stannane **5**, Barbier-type coupling of **9** with Mg and *n*-Bu_3SnCl under sonication gave the desired compound in 82% yield with good selectivity (linear/branched = 5.6:1).[24]

Reacting with cyclohexanone, the combination **5**/*n*-BuLi furnished ε-isomer **10a** as the major product but always in mixture with the γ- and α-products (Scheme 5). In an attempt

Scheme 5. Coupling of Diene 5 with Cyclohexanone



	10a	10b	10c
THF, -78°C, 4 h, 60%	1	0.5	0.3
THF, -90°C, 4 h, 42%	1	0.5	1
t = 0 min			
THF, -78°C, 4 h, 45%	1	0.5	0.2

to steer the selectivity of the coupling, the temperature (from −78 to −90 °C) and the age of the mixture **5**/*n*-BuLi (t = 0–5 min) were modulated, but only minor variations in the outcome were noted.

Pleasingly though, the regioselectivity reached an interesting level with α,α'-dimethoxy-γ-pyrone **1** (Scheme 6). Upon treatment of **5**/*n*-BuLi, the starting material was converted to dienyl *E,E*-**11**/**11′** (31% yield) with complete α-selectivity, a reversal of selectivity that underlines the peculiar behavior of **1** toward nucleophiles. As observed with γ-pyrones **2** and **2′** mentioned at the outset, the mixture of regioisomers **11**/**11′**

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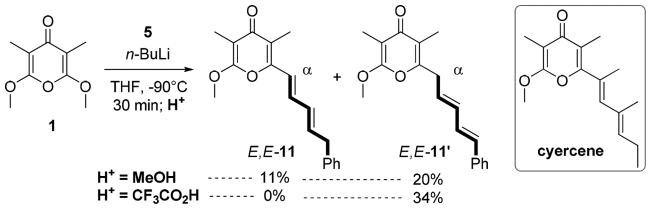
Scheme 6. Coupling of Diene 5 with 1



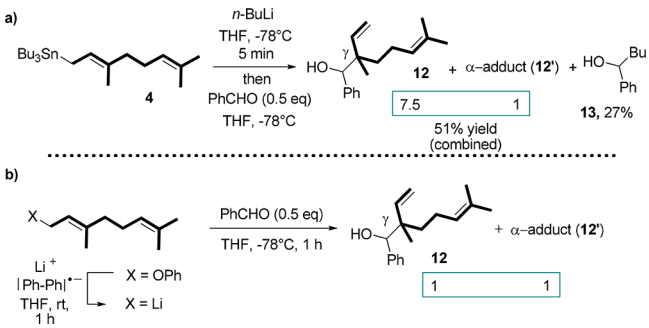
(1:2) was likewise recovered due to the isomerization of *E,E*-**11′** into the conjugated product *E,E*-**11** in basic conditions. With a stronger acid to quench the reaction, such as CF_3CO_2H, a single isomer **11′** was obtained in 34% yield, which given the conciseness of the route remains synthetically useful. Moreover, both *E,E*-**11** and *E,E*-**11′** are therefore technically accessible because the complete isomerization of *E,E*-**11′** → *E,E*-**11** was demonstrated with **2** → **2′**.

In a regio- and stereoselective manner, the chemistry provides a difficult-to-access scaffold ready for further functionalization. In this regard, the structural proximity with cyercene is worthy of note.

Even though aldehydes are well-covered electrophiles in the literature, we were interested in assessing the γ-selectivity of the combination of geranylstannane **4**/*n*-BuLi with them. As for why, we noted that, prepared by another route, geranyllithium produces α-and γ-isomers by reaction with PhCHO. We were then curious to compare the performance of **4**/*n*-BuLi with this electrophile.[25]

To that end, **4** was reacted with *n*-BuLi for 5 min, and PhCHO (0.5 equiv) was subsequently added at −78 °C (Scheme 7a). Expected benzylic alcohol **12** was recovered in

Scheme 7. Hydroalkylation of PhCHO

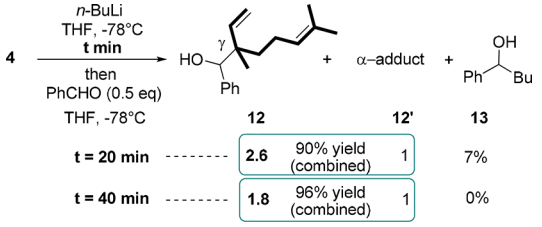


51% yield with a significant level of γ-selectivity (7.5:1, **12**/**12′**). Incidentally, alcohol **13** was isolated in 27% yield, suggesting that the addition of *n*-BuLi to PhCHO competed with the addition to **4**. Because side-products of such were not observed with ketones and enones, this understanding made sense.

More surprising was the γ-selectivity of the reaction in view of the literature data describing no selectivity for the reaction of PhCHO with geranyllithium. When this nucleophile was prepared from geranylphenoxide and Li°, we consistently produced a mixture of alcohols **12** and **12′** (1:1) upon reaction with PhCHO (Scheme 7b).

There was therefore an intriguing discrepancy of selectivity between the two methods. Leaving this point aside for a moment, we first attempted to diminish the amount of alcohol **13**. To that end, the mixture **4**/*n*-BuLi was purposely aged for 20 min at −78 °C (Scheme 8) before adding PhCHO (0.5 equiv). As a result, the production of **13** was decreased to 7%

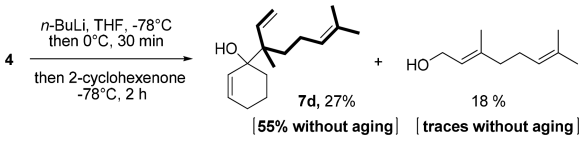
Scheme 8. Influence of the Nucleophile Aging on the Ratio of α- and γ-Isomers



yield, and isomeric alcohols (α- and γ-) **12** and **12′** were produced in 90% yield with diminished γ-selectivity (**12**:**12′**, 2.6:1). Aging further the mixture of **4**/*n*-BuLi for 40 min suppressed the side-product **13** and raised the yield of **12**/**12′** to 96% while further depleting the γ-selectivity to 1.8:1 (**12**:**12′**).

Aging the mixture of **4**/*n*-BuLi resulted in the expected suppression of alcohol **13**, but the concomitant erosion of the selectivity was puzzling. We tried to amplify the phenomena associated with the aging by warming the mixture **4**/*n*-BuLi from −78 to 0 °C (Scheme 9). After 30 min at this temperature, the mixture was returned to −78 °C before the introduction of the electrophile.

Scheme 9



Proceeding this way with 2-cyclohexenone formed γ-isomer **7d** in only 27% yield, whereas it was obtained in 55% yield without aging. In contrast with the previous experiment with PhCHO, the γ-selectivity was not scrambled, but the formation of geraniol in 18% yield was noted at the expense of **7d**. Probably the result of the oxidation of geranyllithium, geraniol was spotted as traces in the crude of the experiments carried out without aging. To some extent, the presence of alkoxide salts was suspected to subtly impact the selectivity of the nucleophilic species with a reactive electrophile such as PhCHO. It is indeed established that polar lithium alkoxides alter the reactivity of organolithium reagents by promoting the formation of heteroaggregates $(ROLi)_x(RLi)_y$ at the expense of homogeneous ones $(RLi)_x$.[26]

Alkoxide salts are actually difficult to avoid in such processes because variable amounts of *n*-BuOLi salts contaminate commercial solutions of *n*-BuLi upon reaction with residual oxygen. It is therefore conceivable that alkoxide salts, whether *n*-BuOLi or lithium geraniol oxide, can form complexes with geranyllithium, affecting the selectivity of this nucleophile toward aldehydes. Inferring that aging, high temperature (> −78 °C), and amounts of PhOLi (produced by reductive lithiation of geranylphenylether, Scheme 7b) are factors and salts accelerating the formation of these complexes, this explanation may account for the low selectivity detailed in Schemes 7b and 8.

Drawing a practical lesson, ate intermediates rapidly form organolithium species, whereas the concomitant production and interference of alkoxide salts remain minimal due to the low temperature at which the process takes place. As noted in

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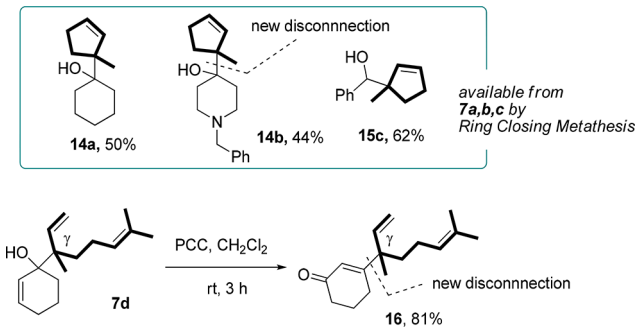
Schemes 8 and 9 with aldehydes and ketone, these factors impact the outcome of the reaction.

To demonstrate the versatility of the prepared substrates, we carried out ring closing metathesis of the olefinic adducts **7a−c** to attain hindered cyclopentenes **14a,b** and **15c** in fair yields (44−62%, not optimized) upon treatment with Grubbs catalyst second generation (Scheme 10). From a retrosynthetic perspective, the disconnection of cyclopentadienyl with carbonyl compounds as illustrated with **14a,b** is not trivial. To our knowledge, a single route was reported by Knochel in which the cyclopentadienyl motif was grafted to aldehydes by a zinc-ene cyclization strategy.[27] With the 2-step route described herein, the cyclopentadienyl motif is assembled to ketones, resulting in the efficient preparation of simple alkaloids with a terpene motif such as **14b**.

Scheme 10



Another appealing extension of this work consisted of the synthesis of hindered enone **16** from **7d** in 81% yield. The route relies on an oxidative rearrangement of tertiary allylic alcohol promoted by pyridinium chlorochromate (PCC).[28] Of note is the new disconnection in which quaternary carbons are connected to enone, which is warranted by the γ-selectivity of the geranyl transfer. Hinging on geranyl cuprates to access such an enone connected to quaternary carbons would be complicated by the α-selectivity displayed by these reagents as reported by Lipshutz.[8b]

Although a well-known strategy, the formation of organolithium species from various hindered allylic stannanes has been under-scrutinized in terms of reactivity and selectivity with enone and ketone electrophiles. This work sheds some light on the field while briefly illustrating the synthetic versatility of the obtained adducts with compounds **14−16**. Furthermore, mechanistic examination suggested that aging the nucleophilic species was detrimental for the γ-selectivity with aldehyde, which emphasized the advantages of using allylic stannanes to rapidly and smoothly generate organolithium species. Given the broad use of these species, as mentioned at the outset of the article, these observations are pertinent in various fields.

At the origin of the study, the desymmetrization of α,α'-dimethoxy-γ-pyrone **1** that was envisaged with crotyl (**3**) or geranyl nucleophiles (**4**) failed, probably due to their steric hindrance. On the other hand, the combination dienylstannane **5**/*n*-BuLi allowed the grafting to **1** of the dienyl side chain with regio- and configurational selectivity in a convergent manner.

The process hinges upon substituted allyltributylstannanes that are readily prepared, stable, and easily activated with ordinary *n*-BuLi. The side-product of the chemistry, tetrabutylstannane, does not display particularly high toxicity.[29] These considerations should help tin-ate complexes to be seen as useful intermediates in the synthetic quiver to transfer hindered terpene appendages.

EXPERIMENTAL SECTION

General Remarks. All reactions were performed in oven-dried glassware. THF and Et_2O were dried and purified following standard procedure. All reagents were purchased from Alfa Aesar, Sigma-Aldrich, or TCI Europe and were used without further purification. Commercial solutions (Aldrich) of *n*-BuLi were titrated against *N*-benzylbenzamide (1 mmol) at −40 °C in THF. ^{1}H and ^{13}C NMR spectra were recorded in deuterated chloroform on a Bruker DRX 300 MHz spectrometer and were referenced to residual chloroform (7.26 ppm, ^{1}H; 77.36 ppm, ^{13}C). The chemical shifts (δ) are expressed in parts per million (ppm), and coupling constants are indicated in hertz (Hz). Abbreviations for signal coupling are as follows: s = singlet, d = doublet, dd = doublet of doublets, t = triplet, q = quartet, quin = quintet, m = multiplet, br = broad signal. High-resolution mass spectra (HRMS) were performed on Q-TOF Micro WATERS by electrospray ionization (ESI) and electronic impact (EI). Infrared (IR) spectra were recorded with a PerkinElmer 16 PC FT-IR ATR spectrometer using the pure product (oil or solid). Thin layer chromatography (TLC) was run on precoated aluminum plates of silica gel 60 F-254 (Merck). Flash column chromatography was performed on silica gel column (Merck silica gel, 40−63 μm) using air pressure. The purity of the compounds was assessed by ^{1}H and ^{13}C NMR spectroscopy. As the stannanes and alcohols prepared in this study were either very apolar or very polar, some impurities were noted in their spectra.

Allyltributylstannane [24850-33-7]. Although commercially available, allyltributylstannane was prepared in large quantities as follows. To a solution of tributyltin chloride (10 mL, 36.9 mmol, 1.0 equiv) in Et_2O (300 mL) cooled at 0 °C and stirred under argon was added allylmagnesium bromide (37 mL, 36.9 mmol, 1.0 equiv, *C* = 1 M in Et_2O), and the resulting cloudy solution was stirred for 1 h at 0 °C. After quenching with NH_4Cl (20 mL), the solution was extracted with Et_2O (3 × 40 mL). Combined organic layers were brined (50 mL) and dried on $MgSO_4$. The volatiles were removed under reduced pressure to give crude allyltributylstannane (colorless oil), which was used without further purification. ^{1}H NMR (300 MHz, $CDCl_3$): δ 6.07−5.86 (m, 1H), 4.86−4.58 (m, 2H), 1.77 (d, *J* = 8.6 Hz, 2H), 1.60−1.41 (m, 6H), 1.30 (dq, *J* = 14.2, 7.1 Hz, 6H), 0.88 (dd, *J* = 14.8, 7.5 Hz, 15H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 138.3, 109.3, 29.3, 27.5, 16.3, 13.9, 9.3.

(*E*)-Crotyltributylstannane (3).[30] To a solution of *trans*-crotyl alcohol (4.3 g, 60 mmol, 1 equiv) in anhydrous Et_2O (200 mL) was added PBr_3 (5.7 mL, 60 mmol) at 0 °C. The solution was stirred for 1 h at this temperature. The mixture was diluted with Et_2O (50 mL) and treated with $NaHCO_3$ until pH 7. After extraction with Et_2O (3 × 20 mL), the combined organic layers were dried with $MgSO_4$, and the solvent was removed under vacuum (*Caution!* Crotyl bromide is volatile) to give the crude bromide, which was used without further purification. To a solution of freshly prepared LDA (127 mL, 1.2 equiv, 38.1 mmol, 0.3 M in THF) was added *n*-Bu_3SnH (8.5 mL, 31.7 mmol, 1 equiv) at −78 °C. The solution was stirred at −20 °C for 1 h, and crotyl bromide (5.1 g, 38.1 mmol, 1.2 equiv) was added neat at −40 °C. The mixture was stirred at −20 °C for 1 h. After quenching with NH_4Cl (20 mL), the solution was extracted with Et_2O (3 × 50 mL). Combined organic layers were brined and dried on $MgSO_4$. The volatiles were removed under reduced pressure to give an oil that was purified by distillation (Kugelrohr, bp = 112 °C under 0.5 mmHg) to give 6.0 g of (*Z*)-**3** product as a colorless oil in 46% yield (2 steps). R_f: 0.99 (cyclohexane). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.53 (m, 1H), 5.28−5.07 (m, 1H), 1.74−1.40 (m, 10H), 1.36−1.24 (m, 7H), 0.96−0.77 (m, 15H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 130.1, 119.9, 29.2, 27.3, 17.8, 14.1, 13.7, 9.1.

Geranyltributylstannane (4).[31] To a solution of geraniol (2.8 g, 18.1 mmol, 1 equiv) in Et_2O (100 mL) was added PBr_3 (1.7 mL, 18.1 mmol) at 0 °C. The solution was stirred for 1 h at this temperature. The mixture was diluted in Et_2O (50 mL) and carefully treated with sat. solution $NaHCO_3$ until pH 7. After extraction, the combined

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organic layers were dried with $MgSO_4$, and the solvent was removed under vacuum to give geranyl bromide, which was used without further purification. To a solution of freshly prepared LDA (30 mL, 8.9 mmol, 1.2 equiv, 0.3 M in THF) was added Bu_3SnH (2 mL, 7.4 mmol, 1 equiv) at −78 °C. The solution was stirred at −20 °C for 1 h, and geranyl bromide (1.9 g, 8.9 mmol, 1.2 equiv) was added neat at −40 °C. The mixture was stirred at −20 °C for 2 h. After quenching with NH_4Cl (20 mL), the solution was extracted with Et_2O (3 × 50 mL). Combined organic layers were brined and dried on $MgSO_4$. The volatiles were removed under reduced pressure to give a residue that was purified by flash chromatography (cyclohexane) to give 1.9 g (50% yield) of **4** as a colorless oil. R_f: 0.9 (cyclohexane). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.25 (t, J = 9.0 Hz, 1H), 5.03 (t, J = 6.7 Hz, 1H), 2.04−1.85 (m, 4H), 1.62−1.33 (m, 18H), 1.23 (m, 6H), 0.82 (t, J = 7.3 Hz, 11H), 0.79−0.73 (m, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 131.0, 129.1, 124.7, 122.9, 39.9, 29.2, 27.4, 27.1, 25.7, 17.6, 15.6, 13.69, 10.6, 9.4. IR (υ/cm^{-1}, neat): 2956, 2922, 2872, 2853, 1456, 1376, 1070, 863, 686, 592, 503.

Tributyl[(2*E*,4*E*)-5-phenylpenta-2,4-dien-1-yl]stannane (5).[32] To alcohol **8**[33] (1.5 g, 9.31 mmol, 1 equiv) in solution in anhydrous Et_2O (100 mL) was added $SOCl_2$ (1.35 mL, 18.7 mmol, 2 equiv) at 0 °C. The solution was stirred for 2 h at this temperature and then quenched with sat. $NaHCO_3$ solution until pH 7 before extraction with Et_2O. The combined organic layers were brined, dried ($MgSO_4$), filtered, and concentrated under reduced pressure. Crude chlorodiene **9** was used without any further purification as it was found instable. ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.37−7.13 (m, 5H), 6.70 (dd, J = 15.6, 10.4 Hz, 1H), 6.52 (d, J = 15.7 Hz, 1H), 6.39 (dd, J = 14.9, 10.4 Hz, 1H), 5.85 (dt, J = 14.8, 7.3 Hz, 1H), 4.10 (dd, J = 7.3, 0.7 Hz, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 136.9, 134.8, 134.4, 128.8 (2C), 128.6, 128.1, 127.4, 126.7 (2C), 45.3. In a Schlenk tube under argon, charged with magnesium turning (0.16 g, 6.62 mmol, 1.3 equiv), a piece of iodine and n-Bu_3SnCl (1.65 g, 5.1 mmol, 1 equiv) in anhydrous THF (5 mL) were added at 0 °C. Under sonication, crude **9** (1 g, 5.6 mmol, 1.1 equiv, diluted in 5 mL of anhydrous THF) was added to the mixture over 45 min. Once the addition was completed, sonication was continued for 15 min at 0 °C, and then H_2O was added to the mixture. The aqueous layer was extracted with Et_2O (3 × 100 mL). Organic layers were brined and dried on Na_2SO_4. The reaction mixture was purified by quick filtration under silica gel (washing with cyclohexane) to give stannane **5** (2 g, 82% of combined yield with linear and branched products; ratio = 5.6:1, l/b) as a colorless oil. R_f = 0.95 (cyclohexane). Data for the linear isomer: ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.35−7.26 (m, 2H), 7.19 (m, 2H), 7.08 (m, 1H), 6.66 (dd, J = 15.6, 9.4 Hz, 1H), 6.22 (d, J = 15.6 Hz, 1H), 5.96 (d, J = 9.1 Hz, 1H), 1.83 (d, J = 7.6 Hz, 2H), 1.42 (m, 6H), 1.23 (m, 6H), 0.81 (m, 16H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 138.3, 136.3, 130.2, 128.6 (2C), 128.5, 126.8, 126.4, 125.8, 29.2, 27.4, 17.5 (3C), 13.7 (3C), 9.6 (3C). IR (υ/cm^{-1}, neat): 3022, 2955, 2922, 2850, 1627, 1594, 1462, 1071, 980, 689, 498. HRMS (EI, M$^+$) for $C_{23}H_{38}Sn$ calcd, 434.1995; found, 434.1981.

General Procedure for the Hydroxyalkylation of Enones and Ketones. To a solution of **3** or **4** (1 equiv) in anhydrous THF (C = 0.1 M), was added n-BuLi (1 equiv, C = 1.6 M in hexane) at −78 °C under an argon atmosphere. The solution was stirred for 5 min at this temperature, and the electrophile (1 equiv) was added neat. The solution was stirred at this temperature until the completion of the reaction. Then, quenching was performed with sat. solution NH_4Cl, and the reaction mixture was extracted with Et_2O (3×). The combined organic layers were washed with brine, dried ($MgSO_4$), filtered, and concentrated. The alcohols were purified by flash chromatography on silica gel.

1-(1-Methyl-2-propenyl)-2-cyclopenten-1-ol (6a).[10] The reaction of **3** (420 mg, 1.2 mmol, 1 equiv), n-BuLi (0.763 mL, 1.2 mmol), and cyclopentenone (100 mg, 1.2 mmol) in THF (12 mL) gave **6a** after 2 h of reaction (109 mg, 66% yield) as a colorless oil after purification (cyclohexane/AcOEt 9:1). R_f: 0.3 (cyclohexane/AcOEt, 9:1). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97−5.74 (m, 2H), 5.71−5.61 (m, 1H), 5.18−5.02 (m, 2H), 2.58−2.34 (m, 2H), 2.34−2.13 (m, 1H), 2.13−1.99 (m, 1H), 1.87−1.68 (m, 2H), 1.03 (d, J = 6.9 Hz, 1.5H), 1.00 (d, J = 6.9 Hz, 1.5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 140.4, 140.4, 135.1, 134.7, 134.5, 134.4, 116.1, 116.0, 87.8, 87.8, 47.1, 47.1, 35.6, 34.8, 31.6, 31.4, 15.3, 14.6. IR (υ/cm^{-1}, neat): 3400, 3052, 2964, 2935, 2850, 1633, 1452, 1416, 1280, 1175, 1018, 950, 930, 754. MS (CI, isobutane) for $[M - OH]^+$ C_9H_{13} calcd, 121; found, 121.

1-(1-Methyl-2-propenyl)-2-cyclohexen-1-ol (6b).[10] The reaction of **3** (359 mg, 1.04 mmol, 1 equiv), n-BuLi (0.65 mL, 1.04 mmol), and 2-cyclohexenone (100 mg, 1.04 mmol) in THF (10 mL) gave alcohol **6b** after 2 h of reaction (111 mg, 70% yield, 1:1 dr determined by ^{1}H NMR) as a colorless oil after purification (9:1 cyclohexane/AcOEt). R_f: 0.35 (9:1 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$) 2 diastereoisomers (1:1): δ 5.91−5.71 (m, 2H), 5.69−5.55 (m, 1H), 5.16−4.96 (m, 2H), 2.33−2.19 (m, 1H), 2.15−1.86 (m, 2H), 1.78−1.55 (m, 4H), 1.05 (d, J = 6.9 Hz, 1.5H), 1.00 (d, J = 7.0 Hz, 1.5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 140.2, 140.2, 131.5, 131.4, 131.4, 130.9, 116.4, 115.7, 71.0 (2C), 48.4, 47.5, 32.6, 31.9, 25.4 (2C), 18.8, 18.6, 15.1, 13.8. IR (υ/cm^{-1}, neat): 3375, 3019, 2931, 2862, 1703, 1649, 1456, 1169, 977, 961, 907, 732, 515, 562, 471. MS (CI, isobutane) for $[M - OH]^+$ $C_{10}H_{15}$ calcd, 135; found, 135.

2-(Cyclohex-1-en-1-yl)-3-methylpent-4-en-2-ol (6c).[12a] The reaction of **3** (310 mg, 0.9 mmol, 1 equiv), n-BuLi (0.562 mL, 0.9 mmol), and 1-acetyl-1-cyclohexene (100 mg, 0.9 mmol) in THF (9 mL) gave alcohol **6c** after 4 h of reaction (103 mg, 64%) as a colorless oil after purification (9:1 cyclohexane/AcOEt). R_f: 0.56 (9:1 cyclohexane/AcOEt) 2 diastereoisomers (1:1): ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.97−5.74 (m, 1H), 5.71−5.61 (m, 1H), 5.18−5.02 (m, 2H), 2.52−2.40 (m, 0.5H), 2.35 (m, 0.5 H), 2.06 (m, 2.5H), 2.01−1.90 (m, 1.5H), 1.59 (m, 4H), 1.22 (s, 3H), 0.97 (d, J = 6.9 Hz, 1.5H), 0.91 (d, J = 6.9 Hz, 1.5H). ^{13}C NMR (75 MHz, CDCl3): δ 142.1, 142.0, 140.6, 140.3, 121.2, 120.3, 116.0, 115.6, 76.4, 76.3, 44.9, 44.2, 25.9, 25.3, 25.2, 25.2, 24.7, 23.4, 23.2, 23.2, 22.5 (2C), 14.5, 14.0. IR (υ/cm^{-1}, neat): 3476, 2927, 1709, 1635, 1449, 1368, 1139, 1000, 909, 844, 586, 459. MS (CI, isobutane, m/z 163) $[M - OH]^+$ for $C_{12}H_{20}$ calcd, 163; found, 163.

1-(3,7-Dimethylocta-1,6-dien-3-yl)cyclohexanol (7a).[13a] The reaction of **4** (240 mg, 0.55 mmol, 1 equiv), n-BuLi (0.34 mL, 0.55 mmol), and cyclohexanone (54 mg, 0.55 mmol) in THF (5 mL) gave alcohol **7a** after 4 h of reaction (87 mg, 68%) as a colorless oil after purification (cyclohexane/AcOEt, 95:5). R_f: 0.56 (9:1 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.86 (m, 1H), 5.21 (dd, J = 10.9, 1.6 Hz, 1H), 5.14−5.06 (m, 1H), 5.02 (dd, J = 17.7, 1.6 Hz, 1H), 1.80 (m, 2H), 1.67 (s, 3H), 1.62−1.34 (m, 14H), 1.26 (m, 1H), 1.01 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 143.9, 131.2, 125.3, 115.5, 74.9, 47.8, 34.9, 31.9, 31.1, 26.0, 25.8, 23.5, 22.2, 22.0, 17.7, 16.2. IR (υ/cm^{-1}, neat): 3493.3, 3080.0, 2929.9, 1856.9, 1633.3, 1448.3, 1413.3, 1375.9, 1257.5, 1124.9, 1044.6, 962.7, 909.9, 839.8, 503.4. MS (CI, isobutane, m/z 219) $[M - OH]^+$ for $C_{16}H_{27}$ calcd, 219; found, 219.

1-Benzyl-4-[(6*E*)-3-methylocta-1,6-dien-3-yl]piperidin-4-ol (7b). The reaction of **4** (146 mg, 0.26 mmol, 1 equiv), n-BuLi (0.16 mL, 0.26 mmol), and N-benzylpiperidone (50 mg, 0.26 mmol) in THF (3 mL) gave alcohol **7b** after 4 h of reaction (11 mg, 53%, 80% conversion) as a colorless oil after purification (8:2 CH_2Cl_2/acetone). R_f: 0.05 (9:1 CH_2Cl_2/acetone). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.24 (m, 5H), 5.77 (dd, J = 17.6, 10.9 Hz, 1H), 5.17 (dd, J = 10.9, 1.0 Hz, 1H), 5.07−4.87 (m, 2H), 3.46 (brs, 2H), 2.73−2.55 (m, 2H), 2.23 (t, J = 11.8 Hz, 2H), 2.11 (s, 1H), 1.85−1.67 (m, 4H), 1.61 (s, 3H), 1.51 (s, 3H), 1.38 (m, 4H), 0.96 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 143.3, 138.4, 131.4, 129.3 (2C), 128.3 (2C), 127.1, 125.1, 116.1, 73.2, 63.2, 49.7, 49.4, 47.4, 34.8, 31.9, 31.2, 25.8, 23.4, 17.7, 16.2. IR (υ/cm^{-1}, neat): 3369, 2928, 1636, 1454, 1375, 1107, 1001, 911, 810, 737, 698, 604, 461. HRMS (ESI) $[M + H]^+$ for $C_{22}H_{34}NO$ calcd, 328.2638; found, 328.2640.

1-(3,7-Dimethylocta-1,6-dien-3-yl)-1,2,3,4-tetrahydronaphtalen-1-ol (7c). The reaction of **4** (146 mg, 0.34 mmol, 1 equiv), n-BuLi (0.21 mL, 0.34 mmol), and α-tetralone (50 mg, 0.34 mmol) in THF (3.5 mL) gave alcohol **7c** after 8 h of reaction (11 mg, 11% and 56% brsm, 25% conversion) as a colorless oil after purification (95:5 cyclohexane/AcOEt). R_f: 0.5 (9:1 cyclohexane/AcOEt) 2 diastereoisomers (2:1): ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.58 (m, 0.7H),

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7.46−7.39 (m, 1H, 0.3H), 7.12−7.03 (m, 2H), 7.02−6.96 (m, 1H), 6.03−5.78 (m, 1H), 5.31−4.83 (m, 3H), 2.72−2.40 (m, 2H), 2.28−2.01 (m, 1H), 1.99−1.62 (m, 4H), 1.57 (m, 3H), 1.49−1.44 (m, 3H), 1.20 (m, 3H), 0.96 (s, 1H), 0.89 (s, 2H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 144.2, 143.8, 140.6, 140.1, 139.8, 139.7, 139.6, 139.5, 131.0, 129.0, 128.4, 128.2, 126.7, 126.6, 125.2, 125.2, 125.1, 124.99, 115.51, 115.0, 76.3, 75.6, 49.5 (2C), 36.9, 36.2, 35.1, 34.6, 30.9, 30.9, 25.7, 25.7, 23.6, 23.4, 21.0, 20.8, 17.66, 17.6, 17.0, 16.9. IR (υ/cm^{-1}, neat): 3467, 2928, 1634, 1448, 1375, 1011, 909, 749, 670, 454. HRMS (EI) M^+ for $C_{20}H_{28}O$ calcd, 284.2140; found, 284.2146.

1-(3,7-Dimethylocta-1,6-dien-3-yl)cyclohex-2-en-1-ol (7d). The reaction of **4** (222 mg, 0.52 mmol, 1 equiv), *n*-BuLi (0.325 mL, 0.52 mmol), and 2-cyclohexenone (49 μL, 0.52 mmol) in THF (5 mL) gave alcohol **7d** after 4 h of reaction (66 mg, 55%) as a colorless oil after purification (95:5 cyclohexane/AcOEt). R_f: 0.52 (9:1 cyclohexane/AcOEt) 2 diastereoisomers (1:1): ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.98−5.84 (m, 2H), 5.80−5.70 (m, 1H), 5.26−5.18 (m, 1H), 5.13−4.98 (m, 2H), 2.06−1.95 (m, 1H), 1.90 (m, 3H), 1.71−1.62 (m, 7H), 1.59−1.56 (m, 4H), 1.48−1.36 (m, 2H), 1.02 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 143.5, 143.0, 132.0, 131.5, 131.2, 131.1, 129.8, 129.7, 125.3, 125.2, 115.7, 115.1, 73.2, 72.9, 47.0, 47.0, 34.7, 34.4, 31.12, 30.80, 25.8 (2C), 25.3, 25.3, 23.4, 23.3, 19.1, 18.9, 17.7 (2C), 16.4 (2C). IR (υ/cm^{-1}, neat): 3467, 2931, 2873, 1707, 1633, 1438, 1375, 1168, 1078, 1013, 944, 910, 816, 734, 532. HRMS (EI) M^+ for $C_{16}H_{26}O$ calcd, 234.2017; found, 234.2015.

2-Methoxy-3,5-dimethyl-6-[(2*E*,4*E*)-5-phenylpenta-2,4-dien-1-yl]-4*H*-pyran-4-one (11). A 250 mL, single-necked, round-bottom flask equipped with a magnetic stirring bar was charged with **5** (471 mg, 1.1 mmol, 2 equiv) and **1** (100 mg, 0.55 mmol, 1 equiv) in anhydrous THF (10 mL). *n*-BuLi (0.69 mL, 1.1 mmoL, 2 equiv, *C* = 1.6 M in hexane) was added at −90 °C. The solution became red and was stirred for 30 min at this temperature before addition of MeOH (0.11 mL, 2.72 mmol, 5 equiv) at −90 °C. The bath was removed, and the solution was allowed to reach a temperature of 20 °C. The mixture was quenched with sat. NH_4Cl and extracted with Et_2O (3 × 10 mL). The combined organic layers were brined, dried ($MgSO_4$), filtered, and concentrated under reduced pressure. The reaction mixture was purified by flash chromatography (7:3 cyclohexane/AcOEt) to give the products **11**/**11′** (49 mg, 31% combined yield with a ratio 2:1). Complete selectivity toward **11′** (34%) can be obtained by transferring with cannula the cold reaction mixture (−90 °C) to a solution of CF_3CO_2H (3 equiv) in Et_2O at −78 °C.

Data for **11**: R_f = 0.40 (6:4 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.32−7.19 (m, 5H), 6.86 (dd, *J* = 15.3, 10.3 Hz, 1H), 6.42 (d_{AB}, *J* = 15.3 Hz, 1H), 6.32−6.08 (m, 2H), 4.01 (s, 3), 3.52 (d, *J* = 6.6 Hz, 2H), 2.02 (s, 3H), 1.86 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 180.9, 161.7, 152.1, 139.2, 138.7, 133.4, 130.4, 128.7 (2C), 128.6 (2C), 126.4, 119.8, 118.7, 99.6, 55.3, 39.3, 9.5, 6.9. IR (υ/cm^{-1}, neat): 2955, 2925, 1660, 1574, 1377, 1332, 1257, 1164, 983, 733, 690, 475. HRMS (ESI) *m*/*z* for $C_{19}H_{21}O_3$ $(M + H)^+$, 297.1491; calcd, 297.1491. Data for **11′**: R_f = 0.3 (6:4 cyclohexane/AcOEt).

^{1}H NMR (300 MHz, $CDCl_3$): δ 7.34−7.24 (m, 5H), 6.68 (dd, *J* = 15.6, 10.3 Hz, 1H), 6.45 (d, *J* = 15.7 Hz, 1H), 6.23 (appdd, *J* = 15.1, 10.3 Hz, 1H), 5.76 (dt, *J* = 14.4, 6.6 Hz, 1H), 3.87 (s, 3H), 3.35 (appd, *J* = 6.6 Hz, 2H), 1.90 (s, 3H), 1.79 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 181.2, 162.4, 155.7, 137.1, 133.7, 132.6, 128.8 (2C), 128.1, 127.8, 126.7, 126.5 (2C), 119.1, 99.7, 55.5, 34.4, 10.0, 7.0. IR (υ/cm^{-1}, neat): 2956, 2925, 1663; 1575, 1464, 1412, 1251, 1165, 983, 732, 694, 476. HRMS (ESI) *m*/*z* for $C_{19}H_{21}O_3$ $(M + H)^+$, 297.1492; calcd, 297.1491.

Study of the Hydroalkylation of PhCHO. To a solution of **4** (402 mg, 0.94 mmol, 2 equiv) in anhydrous THF (5 mL) was added *n*-BuLi (0. 59 mL, 0. 94 mmol, 1 equiv, *C* = 1.6 M in hexane) at −78 °C. The solution was stirred for 5 min at this temperature before the introduction of PhCHO (48 μL, 0.47 mmol, 1 equiv). The solution was then stirred at this temperature for 30 min. The mixture was quenched with sat. NH_4Cl solution and extracted with Et_2O (3 × 10 mL). The combined organic layers were washed with brine (10 mL), dried ($MgSO_4$), filtered, and concentrated under reduced pressure. The crude was purified by flash chromatography (95:5 cyclohexane/AcOEt) followed by preparative TLC (95:5 cyclohexane/AcOEt) to separate the two isomers.

2-Ethyl-2,6-dimethyl-1-phenylhept-5-en-1-ol (12).[25] R_f: 0.57 (9:1 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$) 2 diastereoisomers (1:1): δ 7.34−7.25 (m, 5H), 5.83 (m, 1H), 5.15 (m, 3H), 4.44 (m, 1H), 2.07−1.94 (m, 1H), 1.86 (m, 2H), 1.65 (s, 3H), 1.55 (s, 3H), 1.46−1.19 (m, 2H), 1.08 (s, 1.5H), 0.93 (s, 1.5H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 144.0, 142.8, 141.4, 140.6, 131.4, 131.3, 128.2, 127.9, 127.6, 127.6, 127.5, 127.4, 124.9, 124.8, 115.9, 115.2, 80.9, 80.2, 46.0, 45.4, 37.7, 36.5, 25.8, 22.9, 19.0, 17.7, 16.3. IR (υ/cm^{-1}, neat): 3469, 2927, 2857, 2838, 1703, 1636, 1449, 1367, 1139, 1001, 909, 845, 586 cm^{-1}. MS (CI, isobutane, *m*/*z* 227) $[M - OH]^+$ for $C_{17}H_{23}$ calcd, 227; found, 227.

(3*E*)-4,8-Dimethyl-1-phenylnona-3,7-dien-1-ol (12′).[25] R_f: 0.5 (9:1 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$) δ 7.44−7.25 (m, 5H), 5.17 (t, *J* = 7.4 Hz, 1H), 5.07 (m, 1H), 4.75−4.62 (m, 1H), 2.47 (m, 2H), 2.06 (m, 4H), 1.69 (s, 3H), 1.61 (s, 6H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 143.9, 139.3, 131.5, 128.0 (2C), 127.1, 125.5 (2C), 123.8, 119.3, 73.6, 39.6, 37.9, 26.2, 25.4, 17.4, 15.9. IR (υ/cm^{-1}, neat): 3370, 2965, 2914, 2857, 1874, 1806, 1494, 1450, 1380, 755, 694. MS (CI, isobutane, *m*/*z* 227) $[M-OH]^+$ for $C_{17}H_{23}$ calcd, 227; found, 227.

Preparation of Geranyllithium from Geranyloxybenzene. The glassware employed consisted of a one-neck flask connected to a second one-neck flask through a glass bridge equipped with a fritted glass filter. To the first flask were added THF (5 mL) and freshly cut pieces of Li° (40 mg, 6 mmol, 3 equiv) at rt. A solution of geranyloxybenzene (462 mg, 2 mmol, 1 equiv) in anhydrous Et_2O (2 mL) was added dropwise. When a color change was observed, the solution was stirred for an additional 10 min at rt. Then, the solution was transferred into the second flask through the filter using gravity and a positive pressure of argon, and the mother solution was cooled at −78 °C. From the mother solution, 3.5 mL was removed with a syringe and quickly transferred into a flask cooled at −78 °C. PhCHO (100 μL, 1 mmol) was added, and the resulting mixture was stirred for 1 h at this temperature. The mixture was quenched with MeOH and water. After extraction with CH_2Cl_2, the combined organic layers were brined, dried over $MgSO_4$, filtered, and concentrated under reduced pressure. Purification gave **12** and **12′** in equal quantities.

1-(1-Methylcyclopent-2-en-1yl)cyclohexanol (14a). To a sealed tube containing **7a** (30 mg, 0.13 mmol, 1 equiv) in anhydrous toluene (1 mL) was added Grubbs catalyst second generation [246047-72-3] (5 mg, 0.06 mmol, 0.05 equiv) at rt. The solution was stirred at 110 °C until complete conversion of the starting material (24 h). The mixture was then concentrated under reduced pressure and purified by flash chromatography (9:1 cyclohexane/AcOEt) to give alcohol **14a** (12 mg, 50% yield) as a colorless oil. R_f: 0.40 (8:2 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.75 (dt, *J* = 5.7, 2.3 Hz, 1H), 5.62 (dt, *J* = 5.7, 2.2 Hz, 1H), 2.37−2.28 (m, 2H), 2.18−2.04 (m, 2H), 1.70−1.52 (m, 7H), 1.48−1.39 (m, 3H), 1.25 (s, 1H), 1.05 (s, 3H,). ^{13}C NMR (75 MHz, $CDCl_3$): δ 136.4, 131.3, 75.20, 57.6, 32.6, 32.4, 32.3, 31.7, 26.1, 22.5, 21.9, 21.9. IR (υ/cm^{-1}, neat): 3368, 2926, 2854, 1718, 1449, 1078, 836. HRMS (EI) M^+ for $C_{12}H_{20}O$ calcd, 180.1512; found, 180.1517.

1-Benzyl-4-(1-methylcyclopent-2-en-1-yl)piperidin-4-ol (14b). To a sealed tube containing **7b** (20 mg, 0.06 mmol, 1 equiv) in anhydrous toluene (0.5 mL) was added Grubbs catalyst second generation (2.5 mg, 0.003 mmol, 0.05 equiv) at rt. The solution was stirred at 110 °C until complete conversion of the starting material (48 h). The mixture was then concentrated under reduced pressure and purified by flash chromatography (9:1:0.1 CH_2Cl_2/MeOH/$NH_{3\ aq}$) to give alcohol **14b** (9 mg, 44%). R_f: 0.3 (9:1:0.1 CH_2Cl_2/MeOH/$NH_{3\ aq}$). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.37−7.27 (m, 5H), 5.7−5.74 (m, 1H), 5.63−5.54 (m, 1H), 3.56 (br s, 2H), 2.87−2.67 (m, 2H), 2.46−2.24 (m, 4H), 2.18−2.01 (m, 1H), 1.98−1.72 (m, 2H), 1.61−1.37 (m, 4H), 1.06 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 135.9, 132.0, 129.5, 128.4, 127.2, 125.05, 7.4, 57.2, 49.5, 49.3, 32.6, 32.3, 29.8, 22.3. IR (υ/cm^{-1}, neat): 3330, 2927, 2852, 1638, 1448, 1144, 1007, 746, 534. HRMS (ESI) $[M + H]^+$ for $C_{18}H_{26}NO$ calcd, 272.2014; found, 272.2017.

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(1-Methylcyclopent-2-en-1-yl)(phenyl)methanol (15c).[27] To a sealed tube containing **7a** (20 mg, 0.08 mmol, 1 equiv) in anhydrous toluene (1 mL) was added Grubbs catalyst second generation (7 mg, 0.008 mmol, 0.1 equiv) at rt. The solution was stirred at 110 °C until complete conversion of the starting material (24 h). The mixture was concentrated under reduced pressure and purified by flash chromatography (9:1 cyclohexane/AcOEt) to give alcohol **15c** (10 mg, 62% yield) as a colorless oil. R_f: 0.43 (8:2 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$): δ 7.37−7.28 (m, 5H), 5.81 (dd, J = 5.3, 2.8 Hz, 1H), 5.65−5.55 (m, 1H), 4.53 (d, J = 4.8 Hz, 1H), 2.32 (m, 2H), 2.24−2.10 (m, 1H), 2.08−1.94 (m, 1H), 1.55 (s, 1 H, OH), 1.00 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 142.3, 135.4, 132.2, 127.8, 127.6 (2C), 127.2 (2C), 80.8, 34.5, 32.2, 29.7, 23.8. IR (υ/cm^{-1}, neat): 3342, 2925, 2815, 2315, 1710, 1447, 1190, 684, 413. HRMS (EI) M^+ for $C_{13}H_{16}O$ calcd, 188.1201; found, 188.1201.

3-(3,7-Dimethylocta-1,6-dien-3-yl)cyclohex-2-en-1one (16). To a flask containing **7d** (10 mg, 0.042 mmol, 1 equiv) in anhydrous CH_2Cl_2 (0.5 mL) was added pyridinium chlorochromate (18 mg, 0.085 mmol, 2 equiv) at rt, and the reaction mixture was stirred at this temperature for 3 h. The mixture was filtered under Florisil and washed with CH_2Cl_2. After removal of the solvent, the residue was purified by flash chromatography (9:1 cyclohexane/AcOEt) to give enone **16** (8 mg, 81% yield) as a colorless oil. R_f: 0.45 (8:2 cyclohexane/AcOEt). ^{1}H NMR (300 MHz, $CDCl_3$): δ 5.98 (s, 1H), 5.77 (dd, J = 17.5, 10.8 Hz, 1H), 5.18−4.93 (m, 3H), 2.39−2.34 (m, 2H), 2.28 (dd, J = 11.2, 5.6 Hz, 2H), 1.99−1.91 (m, 2H), 1.84 (s, 2H), 1.67 (s, 3H), 1.57 (s, 3H), 1.53−1.42 (m, 2H) 1.20 (s, 3H). ^{13}C NMR (75 MHz, $CDCl_3$): δ 200.5, 170.4, 144.0, 132.0, 125.7, 124.2, 113.9, 46.5, 37.9, 37.8, 26.5, 25.8, 23.4, 23.2, 22.4, 17.8. IR (υ/cm^{-1}, neat): 3424, 2930, 1667, 1454, 1326, 1192, 965, 804, 411. HRMS (EI) M^+ for $C_{16}H_{24}O$ calcd, 232.1827; found, 232.1832.

■ ASSOCIATED CONTENT

Supporting Information

SI contains . The Supporting Information is available free of charge on the ACS Publications website at DOI: 10.1021/acs.organomet.7b00765.

Detailed procedures and copies of ^{1}H and ^{13}C spectra (PDF)

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Notes

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