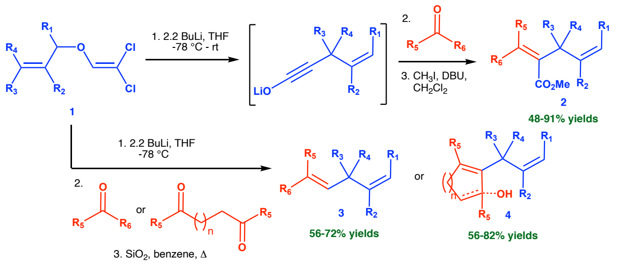
n-Butyllithium-Induced Tandem [3,3]-Sigmatropic Rearrangement and Carbonyl Olefination of Allyl-1,1-Dichlorovinyl Ethers

Aaron Christopher, Dahniel Brandes, Stephen Kelly, and Thomas G. Minehan*

Department of Chemistry and Biochemistry, California State University, Northridge, 18111 Nordhoff Street, Northridge, CA 91330.



ABSTRACT: Exposure of dichlorovinyl ethers **1** to *n*-butyllithium and addition of saturated or unsaturated aldehydes, ketones, or esters at ambient temperature furnishes rearranged α,β-unsaturated carboxylic acids, isolated as their corresponding methyl esters **2** in 48-91% overall yields. Exposure of dichlorovinyl ethers **1** to *n*-butyllithium, addition of aldehydes, ketones, dialdehydes, or diketones at -78 °C, and warming to 80 °C in the presence of SiO$_2$ provides 1,4-dienes **3** or cycloalken-1-ols (or their dehydration products) **4** in 45-72% overall yields.

Ynol ethers (A, Figure 1) and ynolates (B) contain a highly polarized triple bond, which gives them enhanced electrophilic (at C-1) and nucleophilic (at C-2) reactivity.[1,2] As a result of their linear geometry, ynol ethers and ynolates enjoy largely unobstructed approach by nucleophiles or electrophiles in the same or different molecules; furthermore, they can potentially form as many as four new bonds in a single process. However, concerns about the stability of ynol ethers and the non-trivial preparation of ynolates[2] have directed the focus of synthetic chemists toward the ynamide functional group,[3] so that full advantage has not been taken of their useful reactivity patterns with respect to carbon-carbon bond formation.

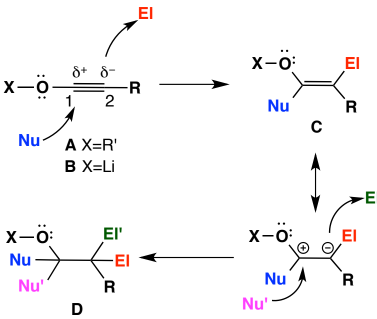
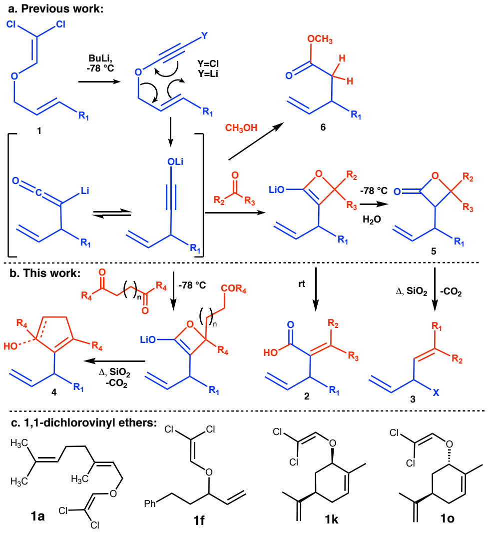


Figure 1. Reactivity of ynol ethers (**A**) and ynolates (**B**) with nucleophiles and electrophiles.

We have previously shown that upon formation at low temperatures, allyl ynol ethers suffer a [3,3]-sigmatropic rearrangement process that gives rise to γ,δ-unsaturated carboxylic acid derivatives after combination with alcohols, amines, or phenols (Figure 2).[4] Allyl-1,1-dichlorovinyl ethers (**1**) served as our initial synthetic precursor of the thermally unstable allyl 1-alkynyl ether intermediate in this process. Thus, treatment of **1** with *n*-butyllithium (2.2 equiv) at -78 °C, followed by reaction quench with methanol, affords 3,4-unsaturated methyl esters **6** in good overall yields. Subsequently it was discovered that quenching the reaction with acetone in place of methanol gave rise to the corresponding rearranged β-lactones **5** (R_2=R_3=Me).[5] These results indicated that the species generated after [3,3]-sigmatropic rearrangement may either undergo protonation and intermolecular nucleophilic ketene trapping with alcohols, or [2+2] cycloaddition with carbonyl compounds and protonation to provide the observed products. A likely candidate for this intermediate species is the lithium ynolate, a functional group that has been shown by Schollkopf[6] to interact with carbonyl compounds at low temperatures to provide β-lactone products in good yields.

Figure 2. a. Previous work, b. current study, and c. substrates

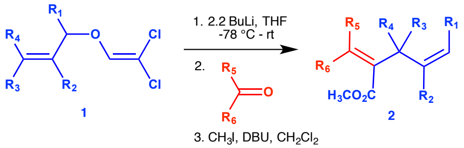


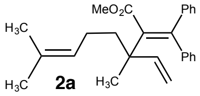
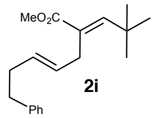
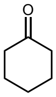
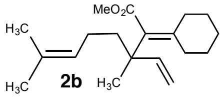
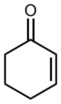
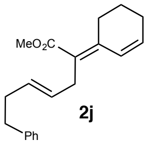
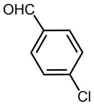
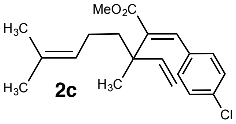
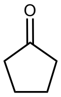
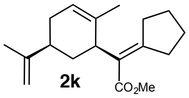
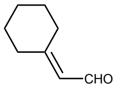
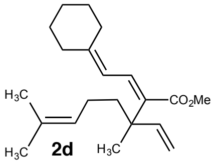
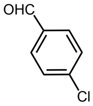
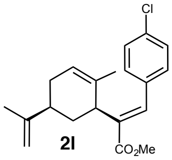
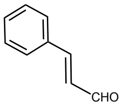
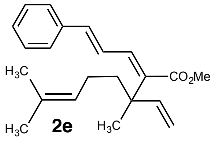
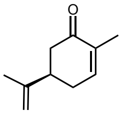
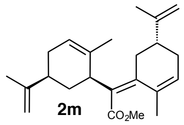
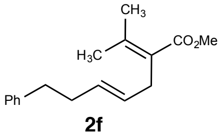
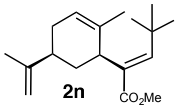
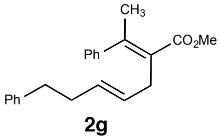
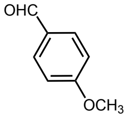
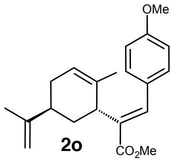
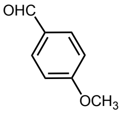
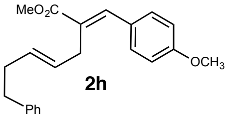
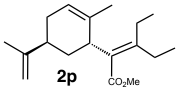
Shindo has also shown that ynolates derived from relatively simple precursors react with carbonyl compounds at room temperature to furnish α,β-unsaturated carboxylic acids.[7,18] In this *Note* we provide details of a tandem sigmatropic rearrangement and carbonyl olefination reaction that can be achieved in a one pot-process by treatment of allyl-1,1-dichlorovinyl ethers with *n*-butyllithium at -78 °C, followed by reaction of the intermediate lithium ynolate with aldehydes, ketones, or esters at room temperature to afford complex carboxylic acids **2**. Furthermore, heating of the intermediate carbonyl-derived β-lactones **5** in the presence of silica gel provides 1,4- dienes **3**. Finally, combination of the intermediate lithium ynolate with diketones or dialdehydes at -78 °C provides rearranged 2-cycloalken-1-ols (or their dehydration products) **4** after warming to 80

°C in the presence of SiO_2. The complexity of diene products available from these processes represents a significant expansion in the scope of Shindo's methodology.

Geranyl-1,1-dichlorovinyl ether, prepared from geranyl formate by reaction with CCl_4/PPh_3,[4a] was exposed to 2.2 equiv *n*-butyllithium at -78 °C in THF, and the mixture was then stirred at this temperature for 15 minutes. The solution was then warmed to 0 °C and stirred for 30 minutes, followed by warming to ambient temperature and addition of 0.9 equiv benzophenone. After 30 minutes, TLC showed the formation of a lower rf spot and the disappearance of benzophenone. Following reaction quench and workup, the crude carboxylic acid was treated with DBU (1.1 equiv) and CH_3I (1.5 equiv) in CH_2Cl_2 (0.25 M) at rt for one hour to provide the rearranged α,β-unsaturated methyl ester **2a** (table 1) in 69% yield after chromatography.

Table 1. Scope of Rearrangement/Olefination Reactions of **1**.

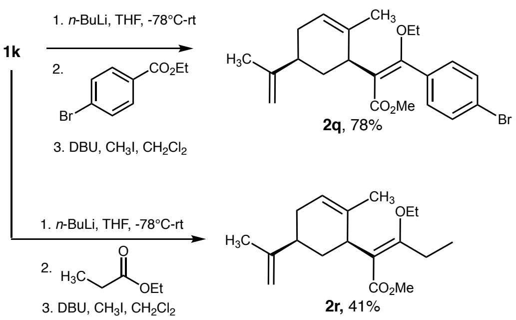


entry	1	RR'C=O	2	Yield $\mathbf{2}^{a}$	Entry	1	RR'C=O	2	Yield $\mathbf{2}^{a}$
1	**1a**	Ph_2CO	 **2a**	69	9	**1f**	*t*-BuCHO	 **2i**	76
2	**1a**		 **2b**	48	10	**1f**		 **2j**	49[c]
3	**1a**		 **2c**	85	11	**1k**		 **2k**	71
4	**1a**		 **2d**	82	12	**1k**		 **2l**	89
5	**1a**		 **2e**	90	13	**1k**		 **2m**	59[d]
6	**1f**	$(CH_3)_2CO$	 **2f**	65	14	**1k**	*t*-BuCHO	 **2n**	65
7	**1f**	$PhCOCH_3$	 **2g**	82[b]	15	**1o**		 **2o**	82
8	**1f**		 **2h**	58	16	**1o**	Et_2CO	 **2p**	91

[a] Isolated yield after column chromatography. [b] Obtained as a 6.6:1 mixture of *E*:*Z* stereoisomers. [c] Obtained as a 1.2:1 mixture of *E*:*Z* stereoisomers. [d] Obtained as ~1:1 Mixture of *E*:*Z* stereoisomers.

Allyl-1,1-dichlorovinyl ethers **1f**, **1k**,[4a] and **1o**[4a] (Figure 2) were prepared similarly to **1a** and tested in the rearrangement/olefination process. As can be seen from table 1, a wide variety of carbonyl compounds may be employed in this reaction, including cycloalkanones (entries 2 and 11), dialkyl ketones (entries 6 and 16), aryl-alkyl ketones (entry 7, product obtained as a 6.6:1 mixture of *E* and *Z* isomers) α,β-unsaturated aldehydes (entries 4 and 5, products obtained as >95:5 *E:Z* mixture of olefin isomers), α,β-unsaturated ketones (entries 10 and 13, products obtained as ~1.2:1 *E*:*Z* mixture of olefin isomers), electron-deficient aromatic aldehydes (entries 3 and 12, products obtained as >95:5 *E:Z* mixture of olefin isomers), electron rich aromatic aldehydes (entries 8 and 15, products obtained as >95:5 *E:Z* mixture of olefin isomers) and α–quaternary aliphatic aldehydes (entries 9 and 14, product obtained as >95:5 *E:Z* mixture of olefin isomers). Good to excellent yields were obtained in most cases, with moderate yields encountered only when cyclohexanone (entry 2) or 2-cyclohexen-1-one (entry 10) were employed as carbonyl substrates. The olefin geometries obtained may be adequately explained by Shindo's model for torquoselective olefination of carbonyl compounds, in which electron-accepting carbonyl substituents rotate toward the carboxylic acid moiety due to an $n \rightarrow \sigma^*$ stereoelectonic interaction in the transition state for β-lactone enolate ring-opening.[7c,2a,2b]

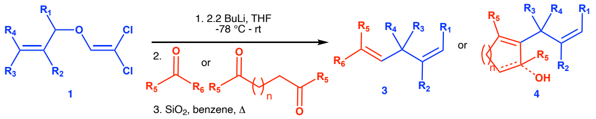
Next we endeavored to apply this process to the preparation of enol ethers using esters as the carbonyl component (Scheme 1). Subjection of dichlorovinyl ether **1k** to 2.2 equiv of BuLi at -78 °C, followed by warming to 0 °C for 30 minutes and addition of ethyl-4-bromobenzoate at room temperature gave rise to the *E*-configured methyl ester **2q** in 78% yield after esterification with DBU and CH_3I in CH_2Cl_2. Reaction with ethyl propionate instead provided ester **2r** in a moderate 42% yield, in accordance with the observation of Shindo[8] on the reactivity of ynolates toward aliphatic esters.

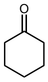
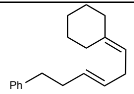
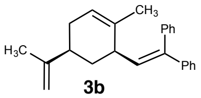
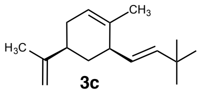
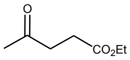
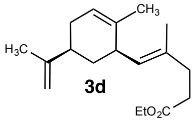
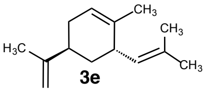
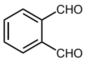
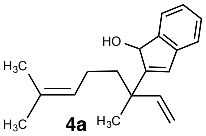
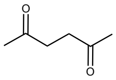
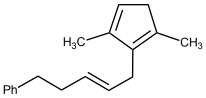
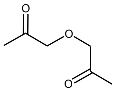
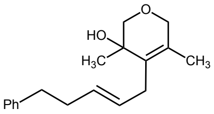
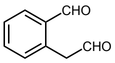
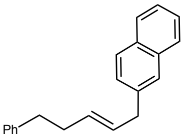


Scheme 1. Rearrangement and ester olefination reactions.

The β-lactones obtained at low temperatures upon interaction of ynolates with ketones may be isolated and subjected directly to decarboxylation under mildly acidic conditions (silica gel in benzene, heat) to provide trisubstituted olefins as products (table 2, entries 1, 2, 4 and 5).[6,9] Interestingly, interaction of the α–quaternary aldehyde pivaldehyde (entry 3) with the ynolate derived from **1k** also provided an isolable β-lactone which was decarboxylated by refluxing in *sym*-collidine for 4 hours to provide the *E*-disubstituted olefin **3c** in 56% overall yield.[10]

Table 2. Scope of Rearrangement/Olefination/ Decarboxylation reactions of **1**.

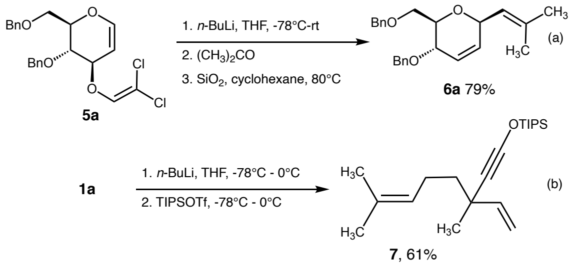


entry	1	RR'C=O	3/4	Yield **3/4**[a]
1	**1f**		 **3a**	61
2	**1k**	Ph_2CO	 **3b**	72
3	**1k**	*t*-BuCHO	 **3c**	56[b]
4	**1k**		 **3d**	70[c]
5	**1o**	$(CH_3)_2CO$	 **3e**	59
6	**1a**		 **4a**	65
7	**1f**		 **4b**	82
8	**1f**		 **4c**	56
9	**1f**		 **4d**	61[d]

[a] Isolated yields after column chromatography. [b] Decarboxylation by refluxing in *sym*-collidine (0.1 M) for 4 h.[c] Obtained as a 1.1:1 mixture of *E*:*Z* stereosiomers. [d] Obtained by dehydration of crude decarboxylation product in Ac_2O/ 1 mol% DMAP at 85 °C for 3h.

Finally, Shindo has shown that combination of ynolates with γ– or δ–ketoesters at low temperatures, followed by decarboxylation of the isolated β-lactone intermediate, gives rise to cycloalkenone products.[11] An initial attempt at this process utilizing the ynolate derived from dichlorovinyl ether **1k** and ethyl levulinate (table 2, entry 4) gave no evidence of the expected enone product but rather provided a 70 % yield of alkene **3d** as a ~1:1 mixture of *E*:*Z* stereoisomers. As a result, we turned our attention to phthalic dicarboxaldehyde as the dicarbonyl component and found that reaction with the ynolate derived from **1a** provided indenol **4a** in 65% yield after heating the crude reaction mixture to 80 °C in benzene for one hour in the presence of silica gel. Application of the same conditions to the ynolate derived from **1f** and acetonyl acetone gave cyclopentadiene **4b** in 82% yield, resulting from acid-promoted dehydration of the intermediate tertiary allylic alcohol. The six-membered 2-cycloalken-1-ol **4c** (entry 8) could be prepared analogously in 56% yield from **1f** and the corresponding dione.[21] Finally, combining the ynolate intermediate derived from **1f** with 2-(2-oxoethyl) benzaldehyde[22] gave naphthalene **4d** in 61% yield after dehydration of the crude decarboxylation product in Ac_2O at 85°C for 3 h.[12,13]

Utilizing the carbohydrate-derived ynol ether **5a**[4a], this method may be applied to the stereoselective synthesis of *C*-vinyl-$\Delta^{2,3}$-glycosides (Scheme 2a).[14-17] Thus, exposure of **5a** to 2.2 equiv *n*-BuLi at -78 °C for 45 minutes, followed by acetone addition and reaction quench gave a crude β-lactone, which was decarboxylated by heating in cyclohexane with silica gel for one hour to provide the β-vinyl glycoside **6a** in 79% yield. Finally, evidence that a lithium ynolate is produced as an intermediate after [3,3]-sigmatropic rearrangement of the *in situ*-formed allyl (lithio)alkynyl ether is seen in the fact that quenching the reaction of **1f** with 2.2 equiv *n*-BuLi in THF at -78 °C with TIPSOTf instead of carbonyl compounds gives a 61% yield of the rearranged triisopropylsilyl ynol ether **7** (Scheme 2b).



Scheme 2. a. Stereospecific reaction of **5a**. b. Synthesis of ynol ether **7**.

In summary, we have demonstrated that allyl-1,1-dichlorovinyl ethers undergo stereospecific *n*-BuLi-induced sigmatropic rearrangements to allylic ynolates, which react with carbonyl compounds to provide products containing di-, tri-, and tetrasubstituted olefins. The use of dicarbonyl compounds in this process allows the preparation of products containing up to four new carbon-carbon bonds and a new carbo-or heterocyclic ring. The use of 2.2 equiv of *n*-butyllithium to form the ynolate intermediate in this process provides a milder alternative to the use of excess amounts of the extremely strong and pyrophoric base *tert*-butyllithium or the inconvenient lithium/naphthalene procedure[23] for the formation of ynolates from brominated[19] or non-brominated[20] esters.

EXPERIMENTAL SECTION

General Experimental Procedures. The reagents and solvents used in this study were purchased and used without additional purification. Distilled water was used in all experiments. Organic extracts were dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo* (20-30mm Hg). Chromatography refers to silica gel chromatography (silica gel 60, 230-400 mesh). All glassware used in the reactions described below were dried with a heat gun under vacuum and flushed with argon gas at rt before addition of reagents and solvents. Heating of reactions was performed on an oil bath equipped with a thermostat. ^1H and $^{13}C\{^1H\}$ NMR spectra were obtained in $CDCl_3$ at 400 MHz and 100 MHz using TMS (Me_4Si) as internal standard. Chemical shifts (δ) are reported in ppm downfield from TMS.

General Procedure A: Preparation of rearranged methyl esters **2a-2r** from dichlorovinyl ethers **1**: To solution of dichlorovinyl ether **1** (1 mmol, 1 equiv) in THF (0.3 M) at -78 °C was added a solution of *n*-BuLi (2.2 mmol, 2.2 equiv; 2.3 M in cyclohexane) dropwise. The mixture was stirred for 20 minutes at -78 °C and was placed in a 0 °C ice bath. After stirring for 30 minutes, the reaction mixture was warmed to room temperature for 30 minutes, and then the ketone, aldehyde, or ester (0.9 mmol, 0.9 equiv) was added. Upon stirring at rt for an additional hour, the mixture was quenched with a solution of saturated ammonium chloride (10 mL). Ether (10 mL) was added, and the layers were separated. The aqueous layer was then extracted with ether (2 x 20 mL). The combined organic extracts were washed once with saturated aqueous NaCl (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure to give a crude oil. The oil (~0.9 mmol, 1 equiv) was dissolved in CH_2Cl_2 (3 mL) and DBU (1.1 mmol, 1.2 equiv) and CH_3I (1.5 mmol, 1.6 equiv) were added, and the mixture was stirred for 2 hours. A solution of saturated sodium bicarbonate (10 mL) and ether (10 mL) were added, and the layers were separated. The aqueous layer was then extracted with ether (2 x 20 mL). The combined organic extracts were washed once with saturated aqueous NaCl (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure to give a crude oil. Purification by flash chromatography (20:1 → 10:1 hexanes: Et_2O) afforded rearranged methyl esters **2a**-**2r**.

General Procedure B: Preparation of skipped dienes **3a-e** and **6a** and cycloalken-1-ols (or their dehydration products) **4a-d** from dichlorovinyl ethers **1**: To solution of dichlorovinyl ether **1** (1 mmol, 1 equiv) in THF (0.15 M) at -78 °C was added a solution of *n*-BuLi (2.2 mmol, 2.2 equiv; 2.3 M in cyclohexane) dropwise. The mixture stirred for 45 minutes at -78 °C and then aldehyde, ketone, dialdehyde, or diketone (0.8 mmol, 0.8 equiv) in THF (1 mL) was added. The mixture stirred for 45 minutes at -78 °C and then saturated $NaHCO_3$ solution (5 mL) was added. The reaction mixture was warmed to room temperature and ether (10 mL) was added and the layers were separated. The aqueous layer was then extracted with ether (2 x 20 mL). The combined organic extracts were washed once with saturated aqueous NaCl (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure to give a crude oil. The oil (~0.8 mmol, 1 equiv) was dissolved in cyclohexane (3 mL) and silica gel (100 mg, 1.7 mmol, 2.1 equiv; 100-200 mesh chromatographic silica gel) was added. The mixture was heated at reflux for 1 hour and then cooled to room temperature. The mixture was loaded directly onto a silica gel column and purification by flash chromatography (20:1 → 10:1 hexanes: Et_2O) afforded rearranged compounds **3** and **4**.

(*E*)-1-((2,2-dichlorovinyl)oxy)-3,7-dimethylocta-2,6-diene (1a): Known compound synthesized by the procedure outlined in reference 4a.

(3-((2,2-dichlorovinyl)oxy)pent-4-en-1-yl)benzene (1f): synthesized by the procedure outlined in reference 4a: 5-phenyl-1-penten-3-ol (synthesized by the procedure outlined in reference 24, 1 g, 6.16 mmol) was dissolved in pyridine (10 mL) and cooled to 0 °C. Formic acetic anhydride (synthesized by the procedure outlined in reference 4a, 5 mL, 63.4 mmol, 10.3 equiv) was added and the mixture was stirred at 0 °C for one hour. Toluene (20 mL) was added and the mixture was concentrated *in vacuo*; this process was repeated two times with two additional 20 mL portions of toluene. The crude oil was dissolved in THF (61.6 mL) and triphenylphosphine (4.84 g, 18.4 mmol, 3 equiv) was added. The mixture was heated to 60 °C under argon and carbon tetrachloride (6.2 mL, 64 mmol, 10.4 equiv) was added dropwise by syringe pump over 8 hours. The mixture was cooled to room temperature and diluted with ether (20 mL) and saturated sodium bicarbonate solution (20 mL). The layers were separated, and the aqueous phase was further extracted with three 20 mL portions of ether. The combined organics were washed once with saturated sodium chloride solution (20 mL), dried over anhydrous sodium sulfate, and concentrated *in vacuo*. Purification of the residue by flash chromatography (SiO_2, 100:1→20:1 Hexanes:EtOAc) afforded **1f** (801 mg, 3.12 mmol, 51%) as a colorless oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.32 (m, 2H); 7.21 (m, 3H); 6.56 (s, 1H); 5.82 (dd, *J*=7.1, 10.6 Hz, 1H); 5.34 (d, *J*=1.2 Hz, 1H); 5.32 (dt, *J*=1.2, 10.1 Hz, 1H); 4.16 (m, 1H); 2.78 (q, *J*=5.8 Hz, 2H); 2.08 (m, 1H); 1.97 (m, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 141.7, 141.0, 136.7, 128.5, 128.4, 126.0, 118.6, 104.4, 83.3, 36.3, 31.1. IR (film): 3027 cm^{-1}, 2988, 2931, 2869, 1639, 1604. **Note**: dichlorovinyl ethers such as **1a**, **1f**, **1k**, and **1o** give unsatisfactory results on exact mass analysis due to degradation processes occurring in the mass spectrometer. A possible mechanism may involve thermal rearrangement of the allyl-dichlorovinyl ether and subsequent decomposition of the resultant aldehyde. Even using the soft ionization technique of ESI-MS did not provide the expected molecular ion. See supporting information in reference 4a and: Morimoto, T.; Sekiya, M. A New, General Route to γ,δ-Unsaturated α,α-Dichloroketones from Allyl-2,2,2-Trichloroethyl Ethers via the [3,3]-Sigmatropic Rearrangement of Intermediary 2,2-Dichlorovinyl Ethers. *Synthesis* **1981**, 308-310.

(4*R*, 6*R*)-6-((2,2-dichlorovinyl)oxy)-1-methyl-4-(prop-1-en-2-yl)cyclohex-1-ene (1k): Known compound synthesized by the procedure outlined in reference 4a.

(4*R*, 6*S*)-6-((2,2-dichlorovinyl)oxy)-1-methyl-4-(prop-1-en-2-yl)cyclohex-1-ene (1k): Known compound synthesized by the procedure outlined in reference 4a.

Methyl 2-(diphenylmethylene)-3,7-dimethyl-3-vinyloct-6-enoate (2a) Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1 hexanes:EtOAc) afforded **2a** (258 mg, 0.69 mmol, 69%) as a pale yellow oil. ^{1}H NMR (400 MHz,

$CDCl_3$) δ 7.26-7.16 (m, 10 H); 5.90-5.83 (dd, *J*=17.4, 10.7 Hz, 1H); 5.02 (m, 1H); 4.85 (d, *J*=17.5 Hz, 1H); 4.74 (d, *J*=10.7 Hz, 1H); 3.35 (s, 3H); 2.09 (m, 2H); 1.69 (s, 3H); 1.63 (s, 3H); 1.54-1.44 (m, 2H); 1.20 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.4, 145.3, 143.1, 141.1, 140.5, 131.2, 128.7, 128.1, 127.9, 127.7, 127.0, 126.9, 124.6, 111.1, 51.0, 44.4, 40.0, 25.7, 24.7, 23.4, 17.7. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{26}H_{31}O_2$ 375.2324; found 375.2298. IR (film): 2967, 2922, 2862, 2844, 1721, 1635, 1596 cm^{-1}.

Methyl 2-cyclohexylidene-3,7-dimethyl-3-vinyloct-6-enoate (2b): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2b** (139 mg, 0.48 mmol, 48%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 6.00 (dd, *J*=17.5, 10.7 Hz, 1 H); 5.10-5.08 (m, 2H); 5.04-5.00 (d, *J*=10.9 Hz, 1H); 3.72 (s, 3H); 2.28 (m, 2H); 2.06-2.02 (m, 4H); 1.69 (s, 3H); 1.61 (s, 3H); 1.61-1.53 (m, 8 H); 1.18 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 171.8, 146.9, 141.1, 132.3, 131.2, 124.8, 111.1, 51.0, 42.6, 40.2, 34.9, 31.1, 28.4, 27.0, 26.3, 25.7, 25.5, 23.2, 17.6. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{19}H_{31}O_2$ 291.2324; found 291.2315. IR (film): 2981, 2974, 2893, 2844, 1724, 1633 cm^{-1}.

Methyl (*E*)-2-(4-chlorobenzylidene)-3,7-dimethyl-3-vinyloxt-6-enoate (2c): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2c** (282 mg, 0.85 mmol, 85%) as a light yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.27 (d, *J*=8.8 Hz, 3H); 7.15 (d, *J*=7.8 Hz, 2H); 5.87 (dd, *J*= 17.3, 10.7 Hz, 1H); 4.95-4.93 (m, 2H); 4.89-4.82 (d, *J*=10.7 Hz, 1H); 3.79 (s, 3H); 1.90-1-84 (q, *J*=7.8 Hz, 2H); 1.65 (s, 3H); 1.65-1.54 (m, 2H); 1.55 (s, 3H); 1.25 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 145.7, 142.3, 135.3, 133.2, 131.4, 130.1, 127.7, 124.3, 111.6, 51.8, 44.5, 40.4, 25.6, 25.0, 23.3, 17.5. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{20}H_{26}ClO_2$ 333.1621; found 333.1620. IR (film): 2969, 1782, 1634, 1599 cm^{-1}.

Methyl (*E*)-2-(2-cyclohexylideneethylidene)-3,7-dimethyl-3-vinyloct-6-enoate (2d): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→4:1 hexanes:EtOAc) afforded **2d** (258 mg, 0.82 mmol, 82%) as a viscous colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.02 (d, *J*= 12.0 Hz, 1H); 6.38 (d, *J*=11.9 Hz, 1H); 6.11 (dd, *J*=17.6, 10.7 Hz, 1H); 5.09 (m, 3H); 5.04 (d, *J*=4.5 Hz, 1H); 3.72 (s, 3H); 2.32 (m, 2H); 2.16 (m, 2H); 1.93-1.80 (m, 3 H); 1.69 (s, 3H); 1.68-1.56 (m, 9H); 1.36 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.9, 150.3, 147.4, 135.6, 131.8, 131.1, 124.7, 118.1, 110.6, 51.3, 43.8, 40.6, 38.1, 28.8, 28.5, 27.7, 26.6, 25.7, 25.6, 23.4, 17.4. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{21}H_{33}O_2$ 317.2481; found 317.2477. IR (film): 2981, 2966, 2923, 2863, 2844, 1712, 1632 cm^{-1}.

Methyl (*E*)-3,7-dimethyl-2-((*E*)-3-phenylallylidene)-3-vinyloct-6-enoate (2e): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1 hexanes:EtOAc) afforded **2e** (294 mg, 0.90 mmol, 90%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.48-7.29 (m, 6H); 6.93 (d, *J*=11.6 Hz, 1H); 6.70 (d, *J*=10.1 Hz, 1H); 6.27 (dd, *J*=17.6, 11.0Hz, 1H); 5.24-5.19 (m, 2H); 5.11 (m, 1H); 3.79 (s, 3H); 2.00 (m, 4H); 1.69 (s, 3H); 1.59 (s, 3H); 1.46 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 170.3, 147.8, 138.6, 138.1, 136.8, 131.4, 128.7, 128.4, 126.8, 124.9, 124.4, 111.0, 51.6, 44.5, 40.6, 26.1, 25.6, 23.6, 17.6. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{22}H_{29}O_2$ 325.2168; found 325.2163. IR (film): 2981, 2949, 2938, 2865, 2844, 1711, 1621, 1585 cm^{-1}.

Methyl (E)-7-phenyl-2-(propan-2-ylidene)hept-3-enoate (2f): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1

hexanes:EtOAc) afforded **2f** (167 mg, 0.65 mmol, 65%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.29 (m, 2H); 7.19 (m, 3H); 5.46 (m, 2H); 3.74 (s, 3H); 3.02 (d, *J*=4.5 Hz, 2H); 2.69 (t, *J*=3.5 Hz, 2H); 2.33 (m, 2H); 2.03 (s, 3H); 2.03 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.7, 144.2, 142.0, 130.3, 128.4, 128.2, 127.4, 125.7, 125.7, 51.2, 36.0, 34.3, 32.8, 30.3, 23.1, 22.0. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{17}H_{23}O_2$ 259.1698; found 259.1692. IR (film): 2981, 2949, 2865, 2844, 1713, 1636, 1603 cm^{-1}.

Methyl (2*E*, 4*E*)-7-phenyl-2-(1-phenylethylidene)hept-4-enoate) (*E*-2g) and Methyl (2*Z*, 4*E*)-7-phenyl-2-(1-phenylethylidene)hept-4-enoate) (*Z*-2g): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1 hexanes:EtOAc) afforded a 6.6:1 ratio of *E*-**2g** (228 mg, 0.71 mmol, 71%) and *Z*-**2g** (34.5 mg, 0.11 mmol, 11%) as pale yellow oils. *E*-**2g**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.33 (m, 5 H); 7.20 (m, 5H); 5.54 (m, 2H); 3.39 (s, 3H); 3.16 (d, *J*=5.5 Hz, 2H); 2.70 (t, *J*=7.5 Hz, 2H); 2.37 (m, 2H); 2.10 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 170.5, 143.9, 143.7, 141.9, 131.0, 129.0, 128.5, 128.4, 128.3, 128.0, 127.1, 126.8, 126.4, 125.7, 51.2, 35.9, 34.3, 33.5, 21.2. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{22}H_{25}O_2$ 321.1855; found 321.1849. IR: 2988, 2947, 2870, 1715, 1627, 1600 cm^{-1}. *Z*-**2g**: ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.35 (m, 5 H); 7.18 (m, 5H); 5.40 (m, 2H); 3.80 (s, 3H); 2.86 (m, 2H); 2.66 (t, *J*=7.5 Hz, 2H); 2.31 (m, 2H); 2.26 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.9,145.5, 142.8, 141.9, 130.9, 128.4, 128.3, 128.2, 127.9, 127.2, 127.0, 125.7, 51.4, 35.9, 34.3, 34.2, 23.4. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{22}H_{25}O_2$ 321.1855; found 321.1838. IR (film): 2988, 2947, 2870, 1715, 1627, 1600 cm^{-1}.

Methyl (*E*)-2-((*E*)-4-methoxybenzylidene)-7-phenylhept-4-enoate (2h): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1

hexanes:EtOAc) afforded **2h** (195 mg, 0.58 mmol, 58%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.73 (s, 1H); 7.39 (d, *J*=7.8 Hz, 2H); 7.28 (m, 2H); 7.19 (m, 3H); 6.92 (d, *J*=8.1 Hz, 2H); 5.59 (m, 2H); 3.86 (s, 3H); 3.82 (s, 3H); 3.26 (d, *J*=3.8 Hz, 2H); 2.72 (t, *J*=7.3 Hz, 2H); 2.41 (m, 2H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.9, 159.9, 141.9, 139.7, 131.2, 130.6, 128.6, 128.5, 128.2, 128.0, 127.6, 125.7, 113.9, 55.3, 51.9, 35.9, 34.3, 30.4. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{22}H_{25}O_3$ 337.1804; found 337.1798. IR (film): 2981, 2941, 2893, 2844, 1706, 1627, 1604 cm^{-1}.

Methyl (2*E*, *4E)*-2-(2,2-dimethylpropylidene)-7-phenylhept-4-enoate (2i): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2i** (217 mg, 0.76 mmol, 76%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.30 (m, 2H); 7.19 (m, 3H); 6.84 (s, 1H); 5.49 (m, 2H); 3.74 (s, 3H); 3.17 (s, 2H); 2.69 (t, *J*=7.6 Hz, 2H); 2.33 (m, 2H); 1.20 (s, 9H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.2, 151.8, 142.0, 130.5, 129.2, 128.4, 128.2, 128.1, 125.7, 51.7, 35.9, 34.4, 33.4, 30.5, 30.3, 29.8. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{19}H_{27}O_2$ 287.2011; found 287.2008 $(M+Na)^+$. IR (film): 2952, 2869, 1713, 1636, 1604 cm^{-1}.

Methyl (2*E*, 4*E*)-2-(cyclohex-2-en-1-ylidene)-7-phenylhept-4-enoate (2j): Prepared according to General Procedure A: Purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2j** (145 mg, 0.49 mmol, 49%, as an inseparable 1.2:1 mixture of *E* and *Z* stereoisomers) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.31 (m, 2H); 7.20 (m, 3H); 6.98 (d, *J*=9.9 Hz, 0.7 H); 6.46 (d, *J*=9.9 Hz, 0.3H); 6.18 (m, 0.4 H); 6.08 (m, 0.6 H); 5.49 (m, 2H); 3.77 (s, 3H); 3.13, 3.08 (s, 2H); 2.74-2.67 (m, 3H); 2.42-2.33 (m, 3H); 2.20 (m, 2H); 1.76 (m, 2H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 169.7, 169.4, 142.9, 142.7, 142.0, 141.9, 136.2, 134.3, 130.5, 128.5, 128.4, 128.2, 127.7, 127.1, 126.6, 125.7, 125.7, 125.6, 124.3, 124.1, 51.4, 51.3, 36.0, 34.3, 32.3, 31.5, 28.5, 27.1, 25.8, 22.6, 22.3. HRMS (ESI-TOF) m/z: [M+H]+ calculd for $C_{20}H_{25}O_2$ 297.1855; found 297.1851. IR (film): 3027, 2924, 2854, 1706, 1617, 1581 cm^{-1}.

Methyl 2-cyclopentylidene-2-((1*S*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl) acetate (2k): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2k** (194 mg, 0.71 mmol, 71%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.49 (m, 1H); 4.71 (s, 2H); 3.70 (s, 3H); 2.70 (m, 2H); 2.42 (m, 2H); 2.27 (m, 1H); 2.18-1.99 (m, 2H); 1.74 (s, 3H); 1.80-1.61 (m, 7H); 1.54 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 149.9, 135.1, 121.4, 108.4, 50.8, 41.9, 40.2, 37.4, 34.5, 33.8, 32.6, 32.1, 32.0, 29.7, 26.5, 25.9, 21.2, 20.7. HRMS (ESI-TOF) m/z: [M+H]$^+$ calcd for $C_{18}H_{27}O_2$ 275.2011; found 275.2008. IR (film): 2936, 2844, 1709, 1644 cm^{-1}. $[\alpha]_D^{25}$= -18.5 (c= 0.08, CH_2Cl_2).

Methyl (*E*)-3-(4-chlorophenyl)-2-((1*S*,5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl) acrylate (2l): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1 hexanes:EtOAc) afforded **2l** (293 mg, 0.89 mmol, 89%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.75 (s, 1H); 7.39 (d, *J*=7.9 Hz, 2H); 7.25 (m, 2H); 5.52 (m, 1H); 4.73 (m, 2H); 3.81 (s, 3H); 2.21 (m, 1H); 2.09-2.04 (m, 3H); 1.75 (s, 3H); 1.78-1.74 (m, 2H); 1.52 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 149.6, 139.6, 134.1, 130.2, 129.9, 128.7, 128.5, 121.9, 121.2, 108.7, 51.7, 37.6, 36.4, 33.7, 32.0, 29.6, 29.4, 21.5, 20.6. HRMS (ESI-TOF) m/z: [M+H]$^+$ calcd for $C_{20}H_{24}ClO_2$ 331.1465; found 331.1461. IR (film): 2981, 2966, 2938, 2865, 2844, 1714, 1645, 1592 cm^{-1}. $[\alpha]_D^{25}$= +88.6 (c= 0.01, CH_2Cl_2).

Methyl (*Z*)-2-((1*S*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)-2-((*R*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-ylidene)acetate (2m): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→5:1 hexanes:EtOAc) afforded **2m** (153 mg, 0.59 mmol, 59%, as a ~1:1 *E*:*Z* mixture of stereoisomers) as a yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 5.73 (m, 1H); 5.67 (m, 1H); 5.59 (m, 1H); 5.51 (m, 1H); 4.77 (s, 3H); 4.72 (m, 5H); 3.75 (s, 3H); 3.68 (s, 3H); 3.59 (m, 1H); 3.11 (m, 1H); 2.90 (d, *J*=13.0 Hz, 1H); 2.82 (d, *J*=11.5 Hz, 1H); 2.38-2.0 (m, 12H); 2.05-1.96 (m, 4H); 1.79-1.69 (m, 25H); 1.56 (q, *J*=12.2 Hz, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 173.6, 171.2, 149.6, 149.3, 148.7, 148.6, 140.5, 138.5, 135.8, 133.9, 132.3, 130.9, 130.8, 130.5, 130.4, 128.9, 123.9, 121.9, 109.4, 108.9, 108.8, 108.6, 77.1, 51.8, 51.1, 45.6, 42.9, 41.8, 41.6, 41.4, 34.8, 33.8, 32.8, 32.3, 31.7, 31.6, 30.7, 21.4, 21.2, 21.1, 21.0, 20.8, 20.7, 20.6, 20.5, 20.4. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{23}H_{33}O_2$ 341.2481; found 341.2477. IR (film): 2967, 2939, 2921, 2866, 2844, 1720, 1644 cm^{-1}.

Methyl (*E*)-4,4-dimethyl-2-((1*S*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)pent-2-enoate (2n): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→10:1 hexanes:EtOAc) afforded **2n** (179 mg, 0.65 mmol, 65%) as a yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 6.89 (s, 1H); 5.51 (m, 1H); 4.72 (m, 2H); 3.69 (s, 3H); 2.25 (m, 1H); 2.09-2.00 (m, 2H); 1.97 (q, *J*=11.3 Hz, 2H); 1.74 (m, 4H); 1.55 (s, 3H); 1.23 (s, 9H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 168.0, 152.9, 149.8, 134.3, 134.0, 121.4, 108.5, 51.3, 42.0, 40.7, 34.0, 32.9, 31.0, 30.9, 29.7, 24.5, 21.5, 20.6. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{18}H_{29}O_2$ 277.2168; found 277.2163. IR (film): 2978, 2870, 1716, 1644 cm^{-1}. $[\alpha]_D^{25}$= -14.2 (c= 0.05, CH_2Cl_2).

Methy (*E*)-3-(4-methoxyphenyl)-2-((1*R*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl acrylate (2o): Prepared according to General Procedure A: Purification of the residue by flash chromatography (SiO_2, 20:1→4:1 hexanes:EtOAc) afforded **2o** (286 mg, 0.82 mmol, 82%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 7.69 (s, 1H); 7.33 (d, *J*=8.4 Hz, 2H); 6.92 (d, *J*=8.8 Hz, 2H); 5.52 (m, 1H); 4.79 (s, 1H); 4.73 (s, 1H); 3.85 (s, 3H); 3.78 (s, 3H); 3.60 (m, 1H); 2.57 (m, 1H); 2.38-2.32 (m, 1H); 2.16-2.05 (m, 2H); 1.90 (m, 1H); 1.77 (s, 3H); 1.48 (s, 3H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 168.5, 159.6, 148.1, 140.1, 134.5, 133.8, 130.8, 128.1, 120.8, 113.8, 109.3, 108.6, 55.3, 51.6, 37.7, 36.3, 32.1, 29.5, 21.9, 21.8. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{21}H_{27}O_3$ 327.1960; found 327.1956. IR (film): 2981, 2966, 2950, 2922, 1867, 2844, 1710, 1643, 1605 cm^{-1}. $[\alpha]_D^{25}$= -36.0 (c= 0.07, CH_2Cl_2).

Methyl 3-ethyl-2-((1*R*, 5*S*)-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)pent-2-enoate (2p): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO_2, 20:1→4:1 hexanes:EtOAc) afforded **2p** (238 mg, 0.91 mmol, 91%) as a yellow oil. ^{1}H NMR (400 MHz, $CDCl_3$) δ 5.53 (m, 1H); 4.75 (s, 1H); 4.69 (s, 1H); 3.68 (s, 3H); 3.17 (m, 1H); 2.31 (m, 1H); 2.28-2.01 (m, 4H); 1.89-1.74 (m, 2H); 1.78 (s, 3H); 1.67 (s, 3H); 1.03 (q, *J*=7.5 Hz, 6H). ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$) δ 171.2, 149.2, 145.0, 133.8, 132.0, 122.7,108.6, 51.0, 38.8, 36.8, 33.8, 30.0, 27.1, 23.2, 22.2, 21.2, 13.3. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{17}H_{27}O_2$ 263.2011; found 263.1992. IR (film): 2967, 2938, 2922, 1873, 2844, 1723, 1644 cm^{-1}. $[\alpha]_D^{25}$= +35.4 (c= 0.07, CH_2Cl_2).

Methyl (*E*)-3-(4-bromophenyl)-3-ethoxy-2-(1*S*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)acrylate (2q): Prepared according to General Procedure A: Purification of the residue by flash chromatography (SiO_2, 20:1→4:1 hexanes:EtOAc) afforded **2q** (326 mg, 0.78 mmol, 78%)

as a yellow oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.53 (d, *J*=8.5 Hz, 2H); 7.19 (d, *J*=8.4 Hz, 2H); 5.54 (m, 1H); 4.75 (dd, *J*=4.5, 0.8 Hz, 2H); 3.67 (m, 2H); 3.39 (s, 3H); 2.29 (m, 1H); 2.08-2.01 (m, 2H); 1.89 (m, 1H); 1.81 (m, 2H); 1.81 (s, 3H); 1.77 (s, 3H); 1.22 (t, *J*=7.0 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) δ 169.3, 149.9, 135.0, 134.2, 131.4, 131.3, 130.2, 130.1, 128.3,123.0, 108.5, 65.4, 51.0, 41.9, 33.7, 30.8, 21.5, 20.8, 15.2. HRMS (ESI-TOF) m/z: [M+H] calcd for $C_{22}H_{28}BrO_3$ 419.1222; found 419.1223. IR (film): 2973, 2938, 2922, 2866, 2844, 1713, 1643, 1621, 1586 cm^{-1}. $[\alpha]_D^{25}$= -32.1 (c= 0.04, CH_2Cl_2).

Methyl (*E*)-ethoxy-2-((1*S*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)pent-2-enoate (2r): Prepared according to General Procedure A: purification of the residue by flash chromatography (SiO$_2$, 20:1→4:1 hexanes:EtOAc) afforded **2r** (118 mg, 0.41 mmol, 41%) as a pale yellow syrup. ^{1}H NMR (400 MHz, CDCl$_3$) δ 5.43 (m, 1H); 4.71 (m, 2H); 3.96 (m, 2H); 3.69 (s, 3H); 2.67 (m, 2H); 2.27 (m, 1H); 2.09-1.92 (m, 2H); 1.74 (s, 3H); 1.74-1.63 (m, 3H); 1.53 (s, 3H); 1.29 (t, *J*= 7.0 Hz, 3H); 1.16 (t, *J*=7.4 Hz, 3H). ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) δ 150.4, 136.1, 120.6, 108.1, 62.8, 50.9, 42.1, 37.5, 30.9, 21.9, 21.1, 20.7, 19.2, 15.2, 12.7. HR MS (ESI-TOF) m/z: [M+H]$^+$ calcd for $C_{18}H_{29}O_3$ 293.2117; found 293.2114. IR (film): 2966, 2937, 1700, 1644, 1604 cm^{-1}. $[\alpha]_D^{25}$= -63.6 (c= 0.01, CH_2Cl_2).

(*E*)-(6-cyclohexylidenehex-3-en-1-yl)benzene (3a): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO$_2$, 100:1 → 20:1 hexanes:EtOAc) afforded **3a** (145 mg, 0.61 mmol, 61%) as a yellow oil. ^{1}H NMR (400 MHz, CDCl$_3$) δ 7.31 (m, 2H); 7.22 (m, 3H); 5.52-5.46 (m, 2H); 5.10 (t, *J*=6.7 Hz, 1H); 2.70 (m, 4H); 2.34 (m, 2H); 2.13 (m, 4H); 1.56 (m, 6H). ^{13}C{^{1}H} NMR (100 MHz, CDCl$_3$) δ 142.2, 140.4, 129.8, 129.3, 128.5, 128.2, 125.6, 119.0, 37.1, 36.1, 34.5, 30.2, 28.6, 27.8, 26.9. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{18}H_{25}$ 241.1956; found 241.1951. IR (film): 3026, 2923, 2852, 1604 cm^{-1}.

2-((1*R*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)ethene-1,1-diyl)dibenzene (3b): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, 100:1 → 20:1 hexanes:EtOAc) afforded **3b** (226 mg, 0.72 mmol, 72%) as a yellow oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.46-7.42 (t, *J*=8.2 Hz, 2H); 7.39 (d, *J*=5.1 Hz, 1H); 7.31-7.25 (m, 7H); 5.95 (d, *J*= 10.6 Hz, 1H); 5.55 (m, 1H); 4.77 (m, 2H); 3.01 (m, 1H); 2.13-2.07 (m, 2H); 2.00-1.86 (m, 2H); 1.77 (s, 3H); 1.71 (s, 3H); 1.52 (m, 1H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 149.9, 142.3, 141.8, 140.2, 135.5, 133.6, 129.7, 128.3, 128.1, 127.0, 126.9, 126.8, 122.2, 108.6, 41.4, 40.8, 35.6, 31.1, 22.1, 20.6. HRMS (ESI-TOF) m/x: $[M+H]^+$ calcd for $C_{24}H_{27}$ 315.2113; found 315.2102. IR (film): 2966, 2922, 2866, 2845, 1644, 1598 cm^{-1}. $[\alpha]_D^{25}$= +6.0 (c= 0.002, CH_2Cl_2).

(4*S*, 6*R*)-6-((*E*)-3,3-dimethylbut-1-en-1-yl)-1-methyl-4-(prop-1-en-2-yl)cyclohex-1-ene (3c): Prepared according to General Procedure B, except that the reflux in benzene with silica gel step was replaced with reflux in *sym*-collidine (0.1 M) for 4 hours, followed by cooling to room temperature, dilution with hexanes (10 mL) and extraction with 0.5 M HCl (3 x 10 mL). The organic layer was dried over anhydrous Na_2SO_4, filtered, and concentrated *in vacuo*. Purification of the residue by flash chromatography (SiO_2, hexanes) afforded **3c** (122 mg, 0.56 mmol, 56%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 5.51 (d, *J*=15.5 Hz, 1H); 5.50 (m, 1H); 5.11 (dd, *J*=15.4, 9.2 Hz, 1H); 4.73 (m, 2H); 2.71 (m, 1H); 2.24 (m, 1H) 2.23 (m, 1H); 1.97 (m, 1H); 1.85 (m 1H); 1.75 (s, 3H); 1.61 (s, 3H); 1.34 (m, 1H); 1.02 (s, 9H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 150.0, 142.4, 135.9, 128.3, 121.8, 108.4, 45.2, 41.4, 36.6, 32.7, 31.2, 29.8, 21.7, 20.7. HRMS

(ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{16}H_{27}$ 219.2113; found 219.2097. IR (film): 2958, 2866, 1644 cm^{-1}. $[\alpha]_D^{25}$= -7.0 (c= 0.001, CH_2Cl_2).

Ethyl (*E* and *Z*)-4-methyl-5-((1*R*, 5*S*)-2-methyl-5-(prop-1-en-2-yl)cyclohex-2-en-1-yl)pent-4-enoate (3d): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, 100:1 → 20:1 hexanes:EtOAc) afforded **3d** (193 mg, 0.70 mmol, 70%, as a ~1:1 mixture of E and Z stereoisomers) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 5.50 (m, 1H); 4.95 (dd, *J*=1.1, 10 Hz, 1H); 4.71 (s, 2H); 4.21 (q, *J*=7.2 Hz, 2H); 3.10 (m, 1H); 2.49-2.34 (m, 4H); 2.21 (m, 1H); 2.18-2.02 (m, 1H); 1.94-1.90 (m, 1H); 1.79-1.73 (m, 2H); 1.78 (s, 6H); 1.57 (m, 3H); 1.28 (t, *J*=6.3 Hz, 3H). $^3C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 173.3, 149.9, 135.9, 133.5, 130.7, 129.4, 108.4, 60.3, 41.1, 36.0, 34.7, 33.2, 31.1, 27.1, 23.0, 21.6, 20.6, 14.2. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{18}H_{29}O_2$ 277.2168,; found 277.2166. IR (film): 2949, 2922, 2893, 2844, 1736, 1644 cm^{-1}.

(4*S*, 6*S*)-1-methyl-6-(2-methylprop-1-en-1-yl)-4-(prop-1-en-2-yl)cyclohex-1-ene (3e): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, 100:1 → 20:1 hexanes:EtOAc) afforded **3e** (112 mg, 0.59 mmol, 59%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 5.42 (m, 1H); 5.22 (m, 1H); 4.71 (m, 2H); 2.93 (m, 1H); 2.37 (m, 1H); 1.95 (m, 1H); 1.78 (s, 3H); 1.75 (s, 3H); 1.72 (s, 3H); 1.79-1.62 (m, 3H); 1.64 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 150.2, 136.6, 131.2, 128.3, 121.0, 108.4, 38.3, 36.5, 34.4, 31.0, 25.9, 22.2, 20.8, 18.0. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{14}H_{23}$ 191.1800; found 191.1794. IR (film): 2966, 2921, 2865, 2844, 1645 cm^{-1}. $[\alpha]_D^{25}$= +71.3 (c= 0.02, CH_2Cl_2).

2-(3,7-dimethylocta-1,6-dien-3-yl)-1*H*-inden-1-ol (4a): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, 100:1 → 20:1 hexanes:EtOAc) afforded **4a** (174 mg, 0.65 mmol, 65%, as a 1:1 mixture of diastereomers) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.47 (d, *J*=7.4 Hz, 1H); 7.27 (d, *J*=8.4 Hz, 1H); 7.24-7.15 (m, 2H); 6.50 (d, *J*=9.9 Hz, 1H); 6.18, 6.09 (dd, *J*=17.5, 10.6 Hz, 1H); 5.18 (m, 4H); 1.99-1.87 (m, 3H); 1.80-1.76 (m, 2H); 1.75 (s, 3H); 1.70, 1.69 (s, 3H); 1.59, 1.44 (s, 3H) $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 156.7, 156.5, 146.2, 146.1, 145.4, 141.9, 141.8, 131.6, 131.5, 128.4, 127.5, 126.8, 125.3, 124.6, 124.5, 123.0, 120.5, 112.5, 112.3, 42.8, 42.7, 39.9, 39.7, 25.6, 23.6, 23.2, 23.1, 22.7, 17.6. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{19}H_{25}O$ 269.1905; found 269.1891. IR (film): 3377, 2967, 2922, 2865, 2844, 1736, 1634, 1609 cm^{-1}.

(*E*)-(5-(2,5-diemthylcyclopenta-1,4-diene-1-yl)pent-3-en-1-yl)benzene (4b): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, hexanes) afforded **4b** (147 mg, 0.82 mmol, 82%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.32 (t, *J*=7.6 Hz, 3H); 7.21 (d, *J*= 8.32 Hz, 2H); 5.87 (s, 1H); 5.48 (t, *J*=5.4 Hz, 2H); 3.00 (s, 2H); 2.84 (s, 2H); 2.70 (m, 2H); 2.35 (m, 2H); 1.98 (s, 3H); 1.94 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 143.9, 142.1, 138.1, 137.8, 129.7, 128.6, 128.4, 128.2, 125.7, 123.5,43.8, 36.0, 34.3, 28.8, 14.3, 13.6. HRMS (ESI) calculated for $C_{18}H_{23}$ 239.1800, found 239.1797 $(M+H)^+$. IR: 2966 cm^{-1}, 2922, 2865, 2844, 1641, 1606.

(*E*)-3,5-dimethyl-4-(5-phenylpent-2-en-1-yl)-3,6-dihydro-2H-pyran-3-ol (4c): Prepared according to General Procedure B: purification of the residue by flash chromatography (SiO_2, hexanes → 5:1 hexanes:EtOAc) afforded **4c** (152 mg, 0.56 mmol, 56%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.30-7.26 (m, 2H); 7.20-7.16 (m, 3H); 5.46 (t, *J*=4.7 Hz, 2H); 3.99 (d, *J*=0.8

Hz, 2H); 3.64 (d, *J*=11.2 Hz, 1H); 3.50 (d, *J*=11.2 Hz, 1H); 2.87 (q, *J*=13.7 Hz, 2H); 2.67 (t, *J*=7.4 Hz, 2H); 2.37-2.32 (m, 2H); 1.91 (br s, 1H); 1.54 (s, 3H); 1.19 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$)δ 141.8, 131.9, 129.9, 129.1, 128.4, 128.3, 128.2, 125.7, 76.2, 70.0, 68.3, 35.9, 34.1, 29.6, 22.2, 14.2. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{18}H_{25}O_2$ 273.1855; found 273.1849. IR (film): 3391 cm^{-1}, 3026, 2923, 2844, 1716, 1603 cm^{-1}.

(E)-2-(5-phenylpent-2-en-1-yl)naphthalene (4d): Prepared according to General Procedure B with the addition of the following step: the crude decarboxylation reaction was filtered through a plug of celite to remove silica gel and concentrated *in vacuo*. The residue was dissolved in Ac_2O (3 mL) and DMAP (1 mg, 0.008 mmol) was added. The mixture was heated at 85°C for 3 hours before concentration *in vacuo*. Purification of the residue by flash chromatography (SiO_2, hexanes) afforded **4d** (166 mg, 0.61 mmol, 61%) as a pale oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.85-7.81 (m, 3H); 7.59 (s, 1H); 7.50-7.44 (m, 2H); 7.33-7.28 (m, 3H); 7.24-7.21 (m, 3H); 5.74-5.59 (m, 2H); 3.52 (d, *J*=6.5 Hz, 2H); 2.77 (t, *J*=7.4 Hz, 2H); 2.44 (q, *J*=6.7 Hz, 2H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 141.9, 138.4, 133.6, 132.0, 131.3, 129.4, 128.5, 128.2, 127.8, 127.6, 127.5, 127.4, 126.4, 125.8, 125.7,125.1, 39.1,35.9, 34.3. HRMS (ESI-TOF) m/z: $[M-H]^+$ calcd for $C_{21}H_{19}$ 271.1492; found 271.1496. IR (film): 3024 cm^{-1}, 2921, 2845, 1633, 1601 cm^{-1}.

(2*R*, 3*S*, 6*R*)-3-(benzyloxy)-2-((benzyloxy)methyl)-6-(2-methylprop-1-en-1-yl)-3,6-dihydro-2H-pyran (6a): Prepared according to General Procedure B from **5a**[4]: purification of the residue by flash chromatography (SiO_2, hexanes→10:1 Hexanes:EtOAc) afforded **6a** (288 mg, 0.79 mmol, 79%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 7.42-7.25 (m, 10H); 5.93 (dd, *J*=10.1, 1.9 Hz, 1H); 5.71 (dt, *J*=10.2, 1.5 Hz, 1H); 5.19 (dt, *J*= 8.6, 1.3 Hz, 1H); 4.92 (dd, *J*=5.8, 1.3 Hz, 1H); 4.67-4.61 (m, 3H); 4.50 (d, *J*= 11.4 Hz, 1H); 4.10 (m, 1H); 3.81 (m, 1H); 3.74-3.69 (m, 2H); 1.77

(s, 3H); 1.75 (s, 3H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 138.4, 138.1, 136.4, 131.6, 128.4, 128.3, 127.9,127.7, 127.5, 125.8, 124.1, 76.7, 73.4, 72.5, 71.1, 70.6, 69.8, 25.8, 18.4. HRMS (ESI-TOF) m/z: $[M+Na]^+$ calcd for $C_{24}H_{28}NaO_3$ 387.1936; found 387.1932. IR (film): 3030, 2973, 2922, 1864, 2844, 1676 cm^{-1}. $[\alpha]_D^{25}$= +54.7 (c= 0.03, CH_2Cl_2).

((3,7-dimethyl-3-vinyloct-6-en-1-yn-1-yl)oxy)triisopropylsilane (7): To solution of allyl-1,1-dichlorovinyl ether **1a** (248 mg, 1 mmol) in THF (3.3 mL, 0.3 M) at -78 °C was added dropwise a solution of *n*-BuLi (0.95 mL, 2.2 mmol, 2.2 equiv; 2.3 M in cyclohexane). The mixture was allowed to stir for 20 minutes at -78 °C and was then placed in a 0 °C ice bath. After stirring for 30 minutes, the reaction mixture was cooled to -78 °C and TIPSOTf (0.3 mL, 1.1 equiv) was added. The mixture was allowed to stir for 20 minutes at -78 °C and was then placed in a 0 °C ice bath. After stirring for 30 minutes, the reaction mixture was re-cooled to -78 °C and saturated $NaHCO_3$ solution (10 mL) was added. Ether (10 mL) was added, and the layers were separated. The aqueous layer was then extracted with ether (2 x 20 mL). The combined organic extracts were washed once with saturated aqueous NaCl (20 mL), dried over anhydrous Na_2SO_4, and concentrated under reduced pressure to give a crude oil. Purification of the residue by flash chromatography (SiO_2, hexanes/1% Et_3N) afforded **7** (288 mg, 0.61 mmol, 61%) as a colorless oil. ^1H NMR (400 MHz, $CDCl_3$) δ 5.74 (dd, *J*=16.9, 10.1 Hz, 1H); 5.36 (dd, *J*=16.9, 1.8 Hz, 1H); 5.14 (t, *J*= 1.4 Hz, 1H); 5.01 (dd, *J*=10.1, 1.9, Hz, 1H); 2.16-1.96 (m, 2H); 1.71 (s, 3H); 1.63 (s, 3H); 1.43 (m, 2H); 1.35 (m, 3H); 1.33 (s, 3H); 1.25-1.17 (m, 18 H). $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$) δ 145.3, 131.0, 124.6, 111.6, 90.3, 63.1, 42.8, 38.0, 34.2, 29.0, 25.3, 24.3, 17.7, 17.4, 17.2, 17.1, 11.8. HRMS (ESI-TOF) m/z: $[M+H]^+$ calcd for $C_{21}H_{39}OSi$ 335.2770; found 335.2765. IR (film): 2946, 2924, 2868, 2270, 1638 cm^{-1}.

ASSOCIATED CONTENT

Supporting Information.

The Supporting Information is available free of charge at

^{1}H and ^{13}C NMR spectra for all compounds in Tables 1 and 2 and Schemes 1 and 2.

AUTHOR INFORMATION

Corresponding Author

Thomas Minehan – *Department of Chemistry and Biochemistry, California State University Northridge, Northridge CA 91330, United States.* orcid.org/0000-0002-7791-0091; Email: thomas.minehan@csun.edu

Authors

Aaron Christopher - *Department of Chemistry and Biochemistry, California State University Northridge, Northridge CA 91330, United States.*

Dahniel Brandes - *Department of Chemistry and Biochemistry, California State University Northridge, Northridge CA 91330, United States.*

Stephen Kelly - *Department of Chemistry and Biochemistry, California State University Northridge, Northridge CA 91330, United States.*

Notes

The authors declare no competing financial interest

ACKNOWLEDGMENT

We acknowledge the National Science Foundation (CHE-2003261) and Organic Syntheses (Wayland-Noland Undergraduate Research Award) for their generous support of this research program.

REFERENCES

(1) For reviews of the chemistry of ynol ethers and the methods for the synthesis of ynol ethers, see: (a) Brandsma, L., Bos, H.J., and Arens, J.F. In *The Chemistry of Acetylenes;* Viehe, H.G., Ed.; Marcel Dekker: New York, 1969, pp. 751-860. (b) Stang, P.J. and Zhdankin, V.V. In *The Chemistry of Triple-Bonded Functional Groups*; Patai, S., Ed.; John Wiley & Sons: New York, 1994; chapter 19. (c) Witulski, B.; Alayrac, C. Product Subclass 2: 1-(organooxy)alk-1-ynes and 1-(heterodoxy)alk-1-ynes. *Sci. Synth.* **2005**, *24*, 933-956. (d) Minehan, T.G. Tandem Bond Forming Reactions of 1-Alkynyl Ethers. *Acc. Chem. Res.* **2016**, *49*, 1168-1181. (e) Liu, F.; Liu, C.; Liu, W.; Ding, Z.; Ma, H.; Serram, N. P.; Xu, L.; Mu, Y.; Huang, X.; Li, L. New Sesquiterpenoids from *Eugenia jambolana* Seeds and their Anti-microbial Activities. *J. Agric. Food Chem.* **2017**, *65*, 10214-10222.

(2) For reviews of the synthetic utility of ynolates, see: (a) Shindo, M.; Matsumoto, K. *Top. Curr. Chem.* Stereoselective Synthesis of Tetrasubstituted Alkenes via Torquoselectivity-Controlled Olefination of Carbonyl Compounds with Ynolates. **2012**, *327*, 1-32. (b) Shindo, M. Synthetic Uses of Ynolates. *Tetrahedron* **2007**, *63*, 10-36. (c) Shindo, M. and Matsumoto, K. Recent Advances in the Chemistry of Metal Ynolates; Patai's Chemistry of Functional Groups; Zabicky, J., Ed.; John Wiley and Sons, Ltd.: Chicester, UK, 2016;

Vol. 2. (d) Julia, M.; Pfeuty Saint-Jalmes, V.; Verpeaux, J.-N. Oxidation of Carbanions with *tert*-Butyl Peroxide. *Synlett* **1993**, *1993*, 233-234.

(3) For recent reviews of ynamide chemistry, see: (a) DeKorver, K. A.; Li, H.; Lohse, A. G.; Hayashi, R.; Lu, Z.; Zhang, Y.; Hsung, R. P. Ynamides: A Modern Functional Group for the New Millennium. *Chem. Rev.* **2010**, *110*, 5064-5106. (b) Evano, G.; Coste, A.; Jouvin, K. Ynamides: Versatile Tools in Organic Synthesis. *Angew. Chem., Int. Ed.* **2010**, *49*, 2840-2859.

(4) a) Christopher, A.; Brandes, B.; Kelly, S.; Minehan, T.G. Low Temperature *n*-Butyllithium Induced Rearrangement of Allyl-1,1-Dichlorovinyl Ethers. *Org. Lett.* **2006**, *8*, 451-454. (b) Sosa, J.R.; Tudjarian, A.A.; Minehan, T.G. Synthesis of Alkynyl Ethers and Low-Temperature Sigmatropic Rearrangement of Allyl and Benzyl Alkynyl Ethers. *Org. Lett.* **2008**, *10*, 5091-5094.

(5) Christopher, A.; Brandes, D.; Kelly, S.; Minehan, T. G. Low Temperature *n*-Butyllithium-Induced [3,3]-Sigmatropic Rearrangement/Electrophile Trapping of Allyl-1,1-Dichlorovinyl ethers. Synthesis of β, γ, and δ-Lactones. *Org. Biomol. Chem.* **2013**, *11*, 7658-7661.

(6) (a) Schollkopf, U.; Hoppe, I. Lithium Phenylethynolate and Its Reaction with Carbonyl Compounds to Give β-Lactones. *Angew. Chem. Int. Ed. Engl.* **1975**, *14*, 765. (b) Hoppe, I.; Schollkopf, U. Uber Lithiumalkinolate und Lithiierte Ketene. *Liebigs Ann. Chem.* **1979**, 219-226.

(7) (a) Shindo, M.; Sato, Y.; Shishido, K. A Highly Stereoselective Synthesis of Tri- and Tetra-substituted Olefins via Ynolates. *Tetrahedron Lett.* **1998**, *39*, 4857-4860. (b) Shindo, M.;

Sato, Y.; Yoshikawa, T.; Koretsune, R.; Shishido, K. Stereoselective Olefination of Unfunctionalized Ketones via Ynolates. *J. Org. Chem.* **2004**, *69*, 3912-3916. (c) Shindo, M.; Sato, Y.; Shishido, K. Stereoelectronic Effect on Stereoselective Olefination of Ketones Providing Tetrasubstituted Olefins via Ynolates. *J. Org. Chem.* **2000**, *65*, 5443-5445.

(8) Shindo, M.; Kita, T.; Kumagai, T; Matsumoto, K.; Shishido, K. Synthesis of Tetrasubstituted and Functionalized Enol Ethers by *E*-Selective Olefination of Esters with Ynolates. *J. Am. Chem. Soc.* **2006**, *128*, 1062-1063.

(9) Danheiser, R. L.; Nowick, J. S.; Lee, J. H.; Miller, R. F.; Huboux, A. H. Synthesis of β-Lactones and Alkenes via Thiol Esters. *Org. Synth.* **1996**, *73*, 61-72.

(10) Pallenberg, A. J.; Dobhal, M. P.; Pandey, R. K. Efficient Synthesis of Pyropheophorbide-a and Its Derivatives. *Org. Proc. Res. Dev.* **2004**, *8*, 287-290.

(11) Shindo, M.; Sato, Y.; Shishido, K. A Novel Tandem [2+2] Cycloaddition-Dieckmann Condensation: Facile One-Pot Process to Obtain 2,3-Disubstituted-2-cycloalkenones from Ynolates. *J. Am. Chem. Soc.* **1999**, *121*, 6507-6508.

(12) Crump, S. L.; Netka, J.; Rickborn, B. Preparation of Isobenzofuran-Aryne Cycloadducts. *J. Org. Chem.* **1985**, *50*, 2746-2750.

(13) Moss, R. J.; Rickborn, B. Stereochemistry of the Hydride Reduction of 7-Oxabicyclo[2.2.1]heptanes. *J. Org. Chem.* **1985**, *50*, 1381-1384.

(14) Price, S.; Edwards, S., Wu, T., Minehan, T. Synthesis of *C*-aryl-$\Delta^{2,3}$-glycopyranosides via Uncatalyzed Addition of Triarylindium Reagents to Glycals. *Tetrahedron Lett.* **2004**, *45*, 5197-5201.

(15) Han, P.-R.; Liu, J.; Liao, J.-X.; Tu, Y.-H.; Sun, J.-S. Reagent-Controlled Divergent Synthesis of *C*-Glycosides. *J. Org. Chem* **1985**, *85*, 11449-11464.

(16) (a) Moineau, C.; Bolitt, V.; Sinou, D. Stereospecific Synthesis of α- and β-*C*-aryl-Δ^2-glycopyranosides from *p-tert*-butylphenyl α-*O*-Δ^2-glycospyranoside via Grignard Reagents. *J. Chem. Soc., Chem. Commun.* **1995**, *11,* 1103-1104. (b) Moineau, C.; Bolitt, V.; Sinou, D. Synthesis of α- and β-*C*-Aryl Δ^2-Glycopyranosides from *p-tert*-Butyl Δ^2-Glycopyranosides via Grignard Reagents. *J. Org. Chem.* **1998**, *63,* 582-591.

(17) Moineau, C.; Bolitt, V.; Sinou, D. Sterochemistry in Palladium and Nickel-Catalyzed Addition of Phenylmagnesium Bromide to Unsaturated Carbohydrates. *J. Organomet. Chem.* **1998**, *567*, 157-162.

(18) Shindo, M. Ynolates as Functional Carbanions. *Synthesis* **2003**, *15*, 2275-2288.

(19) (a) Shindo, M. A Synthesis of Ynolates via The Cleavage of ester Dianions. *Tetrahedron Lett.* **1997**, *38*, 4433-4436. (b) Shindo, M.; Sato, Y.; Shisido, K. Novel Synthesis of Ynolates via the Cleavage of Ester Dianions: α-Bromo and α,α-Dibromo Esters as Precursors. *Tetrahedron* **1998**, *54* 2411-2422.

(20) Sun, J.; Yoshiiwa, T.; Iwata, T.; Shindo, M. Synthesis of Ynolates via Double Deprotonation of Non-Brominated Esters. *Org. Lett.* **2019**, *21*, 6585-6588.

(21) Goldsmith, D. J.; Dickinson, C. M.; Lewis, A. J. Kinetic and Thermodynamic Enolization of 3-Pyranones. *Heterocycles*, **1987**, *25*, 291-295.

(22) Tassano, E.; Merusic, K.; Buljubasic, I.; Laggner, O.; Reiter, T.; Vogel, A.; Hall, M. Regioselective Biocatalytic Self-Sufficient Tishchenko-type Reaction via Formal Intramolecular Hydride Transfer. *Chem Commun.* **2020**, *56*, 6340-6343.

(23) Yus, M.; Herrera, R.P.; Guijarro, A. On the Mechanism of Arene-Catalyzed Lithiation: The Role of Arene Dianions-Naphthalene Radical Anion versus Naphthalene Dianion. *Chem. Eur. J.* **2002**, *8*, 2574-2584.

(24) McCourt, R. O.; Scanlan, E. M. Atmospheric Oxygen Mediated Radical Hydrothiolation of Alkenes. *Chem. Eur. J.* **2020**, *26*, 15804-15810.