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Stereodivergent synthesis of 1,4-bifunctional compounds by regio- and diastereoselective Pd-catalyzed allylic substitution reaction

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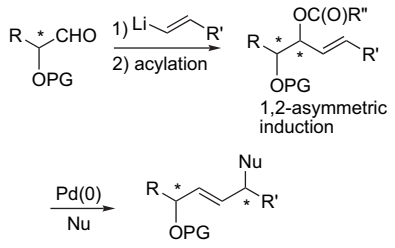
Abstract—Highly stereoselective synthesis of 1,4-bifunctional compounds was accomplished via 1,2-asymmetric induction to α-oxyaldehyde and α-oxyketone followed by regio- and diastereoselective Pd-catalyzed allylic substitution reaction. We found that trifluoroacetate is a suitable leaving group for the allylic substitution reaction. Various nucleophiles containing carbon, nitrogen, and sulfur can be applied to the method. Both 1,4-*syn*- and 1,4-*anti*-adducts were synthesized with high stereoselectivity by using stereodivergent reduction of the propargyl alcohols followed by allylic substitution reaction.

1. Introduction

A combination of asymmetric alkenylation of α-oxyaldehydes and 1,3-chirality transfer reaction affords an attractive methodology to synthesize olefins flanked by two stereogenic centers, which are synthetically useful chiral building blocks.[1] To make this strategy practical, both high diastereoselectivity in the first step and efficient regio- and diastereoselectivity in the following step are essential. Pd-catalyzed allylic alkylation is known to proceed stereospecifically with various nucleophiles, thereby being a promising candidate for the 1,3-chirality transfer reaction, if the regioselectivity is completely controlled.[2] We have recently reported a novel method to synthesize 1,4-bifunctional compounds via diastereoselective alkenylation of α-hydroxy aldehydes followed by Pd-catalyzed allylic substitution (Scheme 1).[3] We also succeeded in a stereodivergent synthesis of the diastereoisomers of the 1,4-bifunctional compounds by modification of this strategy.[4] In these reactions, the stereogenic center at the protected chiral secondary alcohol not only works as a stereocontroller in the first step but also controls the regiochemistry in the diastereoselective allylic substitution reaction.[5]

In this paper, we reported full details of this methodology including generality of this method by applying it to various substrates and nucleophiles. Extension of the method to α-oxyketone is also described.



Scheme 1.

2. Results and discussion

2.1. Pd-catalyzed 1,3-chirality transfer reaction

Three kinds of allylic esters *anti*-**3a–c** were prepared by alkenylation[6] of aldehyde **1**[7] followed by acylation of the resulting alcohol (Scheme 2). We investigated efficiency of Pd-catalyzed 1,3-chirality transfer reaction using these substrates and also compared the reaction of the *anti*- and *syn*-allylic trifluoroacetates **3c** (Table 1).

In the reaction, the choice of the acyl group was crucial.[8] With increase of the inductive effect of the acyl group, the yield was remarkably increased. Although no reaction proceeded in the allylic acetate *anti*-**3a** even under refluxing conditions (entry 1), more reactive allylic trichloroacetate *anti*-**3b** afforded product *anti*-**4** in 32% yield accompanied

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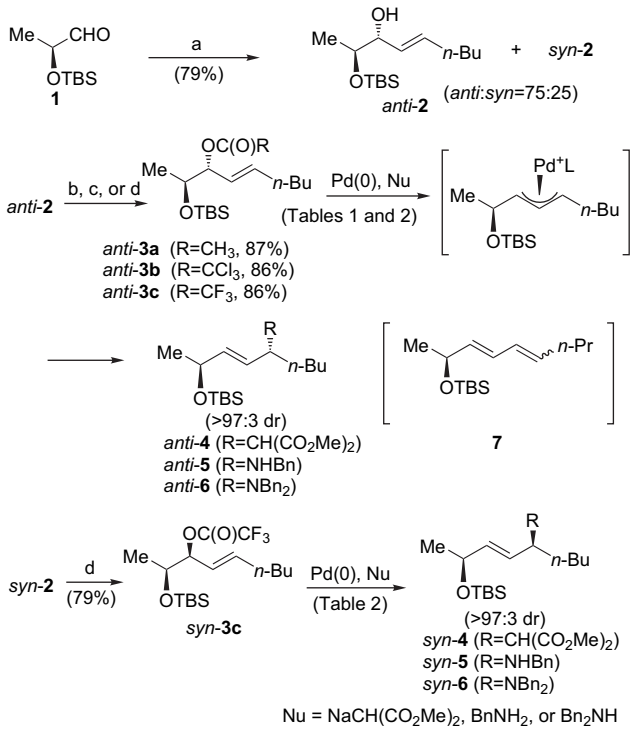


Scheme 2. Reagents and conditions: (a) *t*-BuLi, (*E*)-1-bromo-1-hexene, Et_2O, −65 °C; (b) Ac_2O, DMAP, pyridine, rt; (c) trichloroacetyl chloride, pyridine, rt; (d) $(CF_3CO)_2O$, pyridine, 0 °C.

Table 1. Pd-catalyzed allylic substitution reaction of *anti*-**3a–c** with dimethyl sodiomalonate (Nu=$NaCH(CO_2Me)_2$)[a]

Entry	Substrate	Nu (equiv)	Conditions	Yield (%)[b]	
				anti-**4**	*anti*-**2**
1	*anti*-**3a**	3	Reflux, 5 h	0	0
2	*anti*-**3b**	3	Reflux, 2 h	32	5
3	*anti*-**3c**	3	rt, 0.5 h	74	23
4	*anti*-**3c**	2	rt, 0.5 h	93	tr
5	*anti*-**3c**	1.5	rt, 5 h	72	14
6[c]	*anti*-**3c**	3	rt to reflux, 6 h	0	78

[a] The reactions were carried out using $Pd(PPh_3)_4$ (10 mol %) in THF under Ar.
[b] Isolated yield.
[c] Without Pd catalyst.

by 5% of allylic alcohol *anti*-**2** produced by nucleophilic attack to the ester moiety (entry 2). Trifluoroacetate[9] *anti*-**3c** was the best ester of all to give *anti*-**4** in 74% even at rt, but *anti*-**2** was increased to 23% yield (entry 3). Production of *anti*-**2** was restricted by using 2 equiv of dimethyl sodiomalonate (entry 4). However, when the nucleophile was reduced to 1.5 equiv, the reaction time was prolonged and the yield of *anti*-**4** was decreased (entry 5). The allylic substitution did not occur in the absence of Pd catalyst; instead, nucleophilic attack took place at the ester moiety (entry 6). This means that the reaction is not non-catalytic S_N2' displacement. In all cases, nucleophilic attack took place exclusively at the distal position to the TBSO group with retention of the stereochemistry via double stereoinversion, giving the 1,4-*anti*-adduct as the sole product. Thus, we have found that trifluoroacetate is effective for the allylic substitution under mild conditions.

Next, 1,3-chirality transfer of *anti*- and *syn*-**3c** was investigated using the optimized conditions (Scheme 2, Table 2).

Table 2. Pd-catalyzed allylic substitution reaction of *anti*-**3a–c** with dimethyl sodiomalonate and amines[a]

Entry	Substrate	Product	Conditions	Yield (%)[b]
1	*anti*-**3c**	*anti*-**4**	rt, 30 min	93 (tr)[c]
2	*anti*-**3c**	*anti*-**5**	rt, 30 min	83 (10)[c]
3	*anti*-**3c**	*anti*-**6**	reflux, 23 h	34 (45)[d]
4	*syn*-**3c**	*syn*-**4**	rt, 30 min	98 (tr)[e]
5	*syn*-**3c**	*syn*-**5**	rt, 30 min	84 (15)[e]
6	*syn*-**3c**	*syn*-**6**	rt to reflux, 3 h	46 (23)[d]

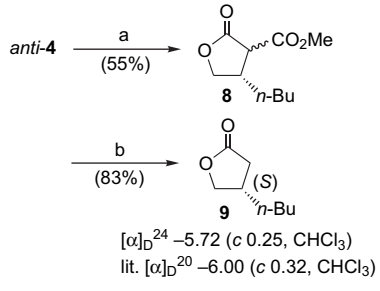
[a] The reactions were carried out using *anti*- or *syn*-**3c** (1 equiv), nucleophile (2 equiv), and $Pd(PPh_3)_4$ (10 mol %) in THF under Ar.
[b] Isolated yield.
[c] Yield in parentheses is the yield of *anti*-**2**.
[d] Yield in parentheses is the yield of **7**.
[e] Yield in parentheses is the yield of *syn*-**2**.

Benzylamine also exclusively attacked distal to the TBSO group at rt, giving the 1,4-*anti*-isomer *anti*-**5** (entry 2).

The reaction was stereospecific and no 1,4-*syn*-isomer was produced from *anti*-**2**. In the case of bulky dibenzylamine, the reaction became sluggish and no product arising from the allylic substitution reaction was formed at rt. When the reaction mixture was refluxed, the starting material disappeared to give the adduct *anti*-**6** in 34% yield along with 45% of diene **7** (ca. 2.7:1 *E*/*Z* mixture) probably formed by β-hydride elimination (entry 3). Although other Pd catalysts were examined, the yields were not better than that of $Pd(PPh_3)_4$ [$Pd_2(dba)_3\cdot CHCl_3$, dppe, 18 h (*anti*-**4**: 9%, **7**: 64%); (η^3-$C_3H_5PdCl)_2$, dppe, 44 h (*anti*-**4**: 0%, **7**: 34%); $Pd_2(dba)_3\cdot CHCl_3$, dppf, 3 h (*anti*-**4**: 29%, **7**: 41%); $Pd(PPh_3)_2Cl_2$, 48 h (*anti*-**4**: 37%, **7**: 14%)].[10]

The reaction of the *syn*-adduct *syn*-**3c** with dimethyl sodiomalonate and benzylamine afforded the corresponding 1,4-*syn*-compounds *syn*-**4** and *syn*-**5**, respectively, in good yields with high regio- and diastereoselectivity (entries 4 and 5). The reaction of *syn*-**3c** with dibenzylamine was sluggish, but the product *syn*-**6** was obtained stereospecifically in 46% yield (entry 6). Thus, two kinds of chiral 1,4-bifunctional compounds *anti*- and *syn*-**4–6** were synthesized stereodivergently.

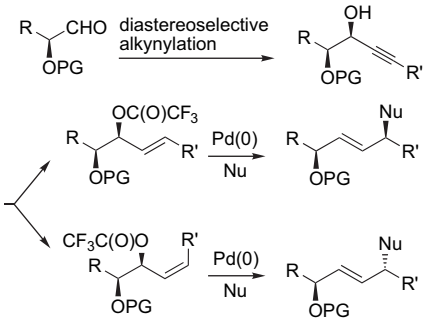
To confirm the absolute configuration, *anti*-**4** was converted to a known compound as shown in Scheme 3. Ozonolysis of the double bond followed by $NaBH_4$ reduction led to *anti*-**4** into γ-lactone **8**. Subsequent demethoxycarboxylation afforded the known γ-lactone **9**.[11] By comparison with the specific rotation, the absolute configuration was determined to be *S*, thereby being consistent with our speculation.[12]



Scheme 3. Reagents and conditions: (a) O_3, CH_2Cl_2, −78 °C then $NaBH_4$, EtOH–H_2O, rt; (b) NaCl, aq DMSO, 130–150 °C.

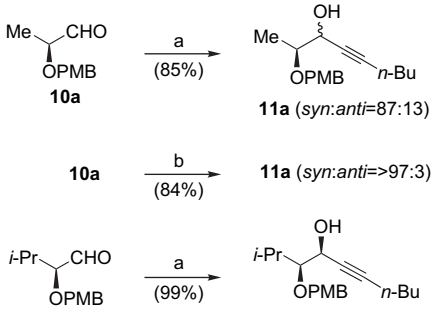
2.2. Stereodivergent synthesis of 1,4-asymmetric compounds

Diastereoselective alkylation affords a new strategy for the stereodivergent synthesis of 1,4-asymmetric compounds. Since propargylic alcohol can be converted to (*E*)- and (*Z*)-allylic alcohols selectively, two diastereoisomers of chiral 1,4-bifunctional compounds could be synthesized by the regio- and diastereoselective allylic substitution reaction (Scheme 4).



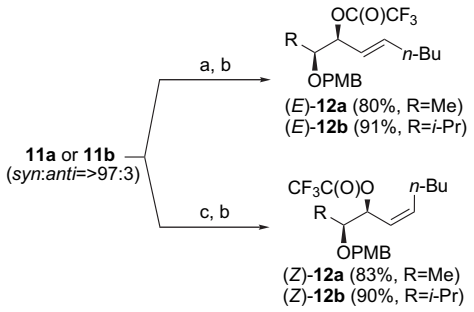
Scheme 4.

Chelation-controlled alkynylation of α-oxyaldehyde **10a**[13] was performed with 1-hexynyllithium under Mead's conditions (Scheme 5).[14] As expected, the *syn*-adduct was obtained mainly (87:13 dr), but the selectivity was unsatisfactory probably due to the small difference in size between Me and H. To improve the diastereoselectivity, we employed Carreira's asymmetric alkynylation using (1*S*,2*R*)-(+)-*N*-methylephedrin (NME) as a chiral ligand.[15] The reaction proceeded in 84% yield and **11a** was obtained with very high diastereoselectivity (>97:3 dr). In the case of α-oxyaldehyde **10b**[16] bearing an isopropyl group, the chiral reagent was not required and alkynylation proceeded under Mead's conditions almost quantitatively with high diastereoselectivity (>97:3 dr).



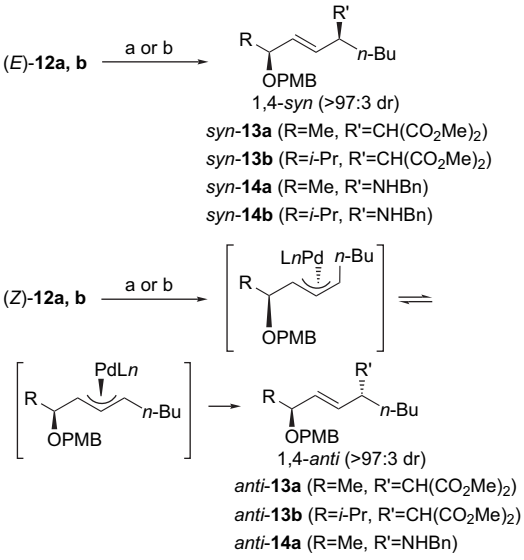
Scheme 5. Reagents and conditions: (a) *n*-BuLi, 1-hexyne, $ZnBr_2$, ether, −78 to 0 °C; (b) 1-hexyne, $Zn(OTf)_2$, (1*R*,2*S*)-(+)-NME, Et_3N, toluene, rt.

The propargylic alcohols **11a** and **11b** were reduced with $LiAlH_4$ in THF and the resulting (*E*)-allylic alcohols were converted to trifluoroacetate (*E*)-**12a** (80%) and (*E*)-**12b** (91%), respectively. On the other hand, the corresponding (*Z*)-isomers were synthesized by hydrogenation on the Lindlar catalyst in MeOH followed by trifluoroacetylation, giving (*Z*)-**12a** and (*Z*)-**12b** in 83% and 90% yield, respectively (Scheme 6).



Scheme 6. Reagents and conditions: (a) $LiAlH_4$, THF, reflux; (b) $(CF_3CO)_2O$, pyridine, Et_2O, rt; (c) H_2, Lindlar catalyst, MeOH, rt.

The results of allylic substitution reactions of trifluoroacetates (*E*)- and (*Z*)-**12a**,**b** are summarized in Scheme 7 and Table 3.



Scheme 7. Reagents and conditions: (a) $Pd(PPh_3)_4$ (10 mol %), $NaCH(CO_2Me)_2$, THF, rt; (b) $Pd(PPh_3)_4$ (10 mol %), $BnNH_2$, THF, rt.

Upon treatment with dimethyl sodiomalonate and benzylamine in the presence of 10 mol % of $Pd(PPh_3)_4$, the nucleophilic substitution proceeded absolutely distal to the *p*-methoxybenzyloxy group in (*E*)-**12a**,**b**, giving 1,4-*syn* isomers *syn*-**13a**,**b** and *syn*-**14a**,**b** in 80–98% yields with high diastereoselectivity by the double inversion via the π-allylpalladium complex (entries 1–4). Bulkiness of the

Table 3. Nucleophilic substitution of allylic trifluoroacetates (*E*)-**12a**,**b** and (*Z*)-**12a**,**b**[a]

Entry	Product	R	R′	Yield (%)[b]	dr[c]
1	*syn*-**13a**	Me	$CH(CO_2Me)_2$	96	>97:3
2	*syn*-**14a**	Me	NHBn	84	>97:3
3	*syn*-**13b**	*i*-Pr	$CH(CO_2Me)_2$	98	>97:3
4	*syn*-**14b**	*i*-Pr	NHBn	80	>97:3
5	*anti*-**13a**	Me	$CH(CO_2Me)_2$	93	>97:3
6	*anti*-**14a**	Me	NHBn	85	>97:3
7	*anti*-**13b**	*i*-Pr	$CH(CO_2Me)_2$	97	>97:3

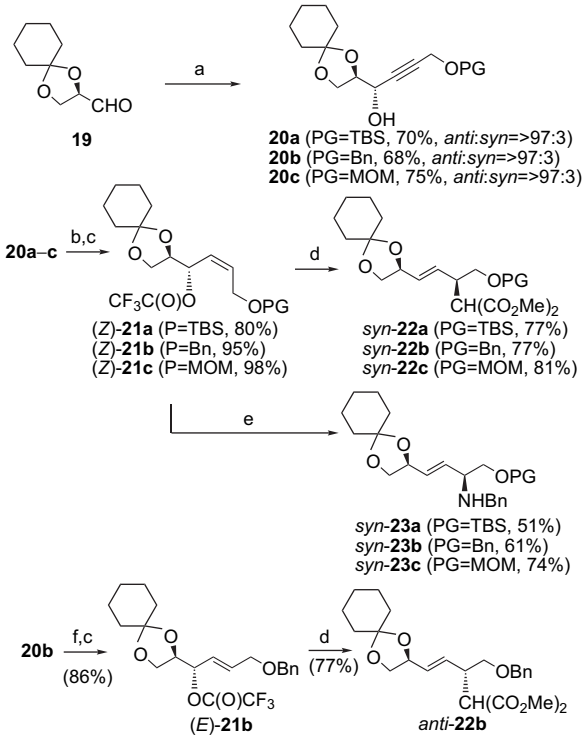
[a] The reactions were carried out using (*E*)- or (*Z*)-**12a**,**b** (1 equiv), nucleophile (2 equiv), and $Pd(PPh_3)_4$ (10 mol %) in THF under Ar.
[b] Isolated yield.
[c] Determined by ^1H NMR spectral data.

substituent R and geometry of the double bond did not influence the reactivity of the allylic substitution reaction. The reaction of the (*Z*)-**12a**,**b** also proceeded regio- and diastereoselectively to give 1,4-*anti* isomers, *anti*-**13a**,**b** and *anti*-**14a** having *trans*-olefin, via π–σ–π isomerization[17] to a thermodynamically more stable π-allyl complex (entries 5–7). The yields ranged from 85% to 97%, wherein the regio- and diastereoselectivity were very high to give the almost sole product. Thus, starting from the common propargylic alcohols, 1,4-*syn* and 1,4-*anti* isomers were synthesized stereodivergently.

Next, the reactions of (*E*)-**12b** with other nucleophiles were examined. The results are summarized in Table 4.

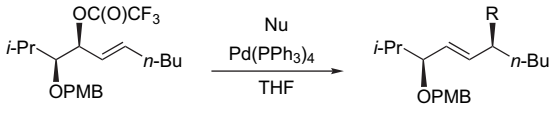
The allylic substitution reaction with malononitrile took place with high regio- and diastereoselectivity to give **15** in 95% yield (entry 1), but the yield of the adduct **16** with Meldrum's acid was low (24%) (entry 2). Morpholine was a good nucleophile even though a secondary amine, giving **17** in 90% yield (entry 3). Sulfur nucleophile, sodium *p*-toluenesulfinate, also afforded the sulfone **18** in 94% yield (entry 4).

Cyclohexylidene acetal-protected aldehyde **19**[18] afforded a route to synthesize highly functionalized compounds (Scheme 8). In this case, diastereoselectivity of chelation-controlled alkynylation was insufficient.[19] However, use of Carreira's conditions furnished *anti*-adducts **20a**–**c** with high diastereoselectivity (>97:3 dr). After conversion to trifluoroacetate (*Z*)-**21a**–**c**, the nucleophilic substitution was carried out under the regular conditions. The reaction of (*Z*)-**21a**–**c** with dimethyl sodiomalonate proceeded in 77–81% yield without being influenced by the protecting group (PG). On the other hand, yield of the reactions with benzylamine varied from 51% to 74% depending on the size of the protecting group. The yield is decreased when the protecting group becomes bulky. Presumably, benzylamine is a weak nucleophile and was affected by the steric hindrance around the reaction site.

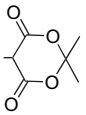
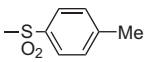


Scheme 8. Reagents and conditions: (a) *O*-protected propargyl alcohol, $Zn(OTf)_2$, (1*S*,2*R*)-(+)-NME, Et_3N, toluene, rt; (b) H_2, Lindlar catalyst, MeOH, rt; (c) $(CF_3CO)_2O$, pyridine, Et_2O, rt; (d) $Pd(PPh_3)_4$ (10 mol %), $NaCH(CO_2Me)_2$, THF, rt; (e) $Pd(PPh_3)_4$ (10 mol %), $BnNH_2$, THF, rt; (f) Red-Al®, ether, rt.

Table 4. Nucleophilic substitution of (*E*)-**12b** with various nucleophiles[a]



(*E*)-**12b** **15–18**

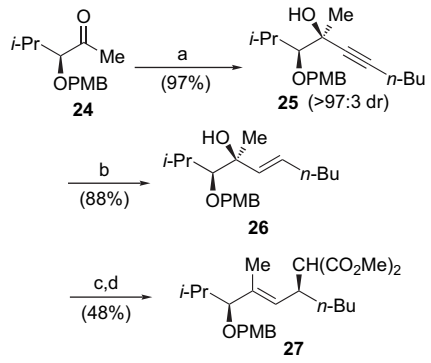
Entry	Product	R	Conditions	Yield (%)[b]	dr[c]
1	**15**	–CH(CN)$_2$	$CH_2(CN)_2$, NaH, rt, 40 min	95	>97:3
2	**16**		Meldrum's acid, NaH, rt, 33.5 h	24	>97:3
3	**17**		Morpholine, rt, 45 min	90	>97:3
4	**18**		TolS(O)ONa, MeOH, rt, 10 min	94	>97:3

[a] The reactions were carried out using (*E*)-**12b** (1 equiv), nucleophile (2 equiv), and $Pd(PPh_3)_4$ (10 mol %) in THF under Ar.
[b] Isolated yield.
[c] Determined by ^1H NMR spectral data.

Stereodivergent conversion was demonstrated using the benzyl ether **20b**. After *E*-selective reduction of **20b** with Red-Al® and subsequent trifluoroacetylation, the resulting (*E*)-**21b** underwent Pd-catalyzed allylic alkylation to furnish 1,4-*anti*-compound *anti*-**22b** in good overall yield. Even in the highly oxygenated and sterically congested substrates, stereodivergent synthesis was accomplished. In all the cases, nucleophiles were introduced with high regio- and diastereoselectivity.

Finally, we examined alkynylation of α-hydroxyketone followed by 1,3-chirality transfer (Scheme 9). Methylketone **24** was alkynylated with magnesium acetylide generated from 1-hexyne with EtMgBr, giving *syn*-adduct **25** as the sole product. *E*-Selective reduction of the triple bond with $LiAlH_4$ led **25** to the allylic alcohol **26**. Trifluoroacetate of **26** was subjected to the Pd-catalyzed 1,3-chirality transfer reaction, but the reaction required refluxing conditions. The adduct **27** with dimethyl sodiomalonate was produced in 48% yield in two steps with high *E*- and diastereoselectivity.

In conclusion, we have developed a strategy to synthesize 1,4-asymmetric compounds by a combination of 1,2-asymmetric addition to α-oxyaldehydes and ketones followed by Pd-catalyzed 1,3-asymmetric transfer. The strategy could be applied to other α-substituted aldehydes and ketones and become a useful tool for synthesis of natural products.



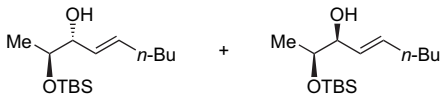
Scheme 9. Reagents and conditions: (a) 1-hexyne, EtMgBr, THF, −40 °C; (b) $LiAlH_4$, THF, reflux; (c) $(CF_3CO)_2O$, pyridine, rt; (d) $Pd(PPh_3)_4$, $NaCH(CO_2Me)_2$, reflux.

3. Experimental

3.1. General

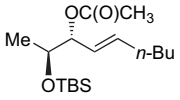
Melting points are uncorrected. NMR spectra were recorded in $CDCl_3$ solution at 500 MHz (^1H) and 75 or 67.8 MHz (^{13}C). IR absorption spectra (FT: diffuse reflectance spectroscopy) were recorded with KBr powder, and only noteworthy absorptions (cm^{-1}) are listed. Column chromatography was carried out using Merck silica gel 60 (70–230 mesh) or Kanto Chemical silica gel 60N (63–210 μm). All air- or moisture-sensitive reactions were carried out in flame-dried glassware under an atmosphere of N_2 or Ar. All solvents were dried and distilled according to standard procedures. All organic extracts were dried over anhydrous $MgSO_4$, filtered, and concentrated with a rotary evaporator under reduced pressure. Experimental procedure of *syn*-**13a** and *syn*-**14a**, and ^1H and ^{13}C NMR spectra of *anti*-**4**–**6**, **13a**, **14a** and *syn*-**4**–**6**, **13a**, **14a** were reported in the Supporting Information of Ref. 4.

3.1.1. (*E*,2*S*,3*R*)- and (*E*,2*S*,3*S*)-2-(*tert*-Butyldimethylsilyloxy)-4-nonen-3-ol (*anti*-2 and *syn*-2).



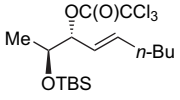
t-BuLi (1.47 M in *n*-pentane, 2.72 mL, 4.00 mmol) was added to a solution of (*E*)-1-bromo-1-hexene (420 mg, 2.00 mmol) in Et_2O (10 mL) with stirring at −78 °C under Ar and the stirring was continued at −65 °C for 10 min. A solution of **1** (376 mg, 2.00 mmol) in Et_2O (1 mL) was added to the mixture with stirring at −78 °C and the whole was stirred at this temperature for 30 min. The reaction was quenched with saturated NH_4Cl, water, and brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (20:1) to give *anti*-**2** and *syn*-**2** (431 mg, 79%, *anti*:*syn*=75:25). *anti*-**2**: Colorless oil. $[\alpha]_D^{19}$ +8.61 (*c* 1.13, $CHCl_3$). ^1H NMR δ: 0.08 (s, 6H, $Si(CH_3)_2$), 0.89 (t, *J*=7.0 Hz, 3H, CH_2CH_3), 0.90 (s, 9H, $C(CH_3)_3$), 1.07 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.28–1.40 (m, 4H, $CH_2\times2$), 2.05 (q, *J*=6.7 Hz, 2H, CH=CHCH_2), 2.22 (d, *J*=3.7 Hz, 1H, OH), 3.81 (qd, *J*=6.1, 3.7 Hz, 1H, TBSOC*H*), 3.97 (dt, *J*=7.3, 3.7 Hz, 1H, C*H*OH), 5.41 (dd, *J*=15.3, 7.3 Hz, 1H, C*H*=CHCH$_2$), 5.69 (dt, *J*=15.3, 6.7 Hz, 1H, CH=C*H*CH$_2$). ^{13}C NMR δ: −4.9, −4.5, 13.9, 17.6, 18.0, 22.2, 25.8 (3C), 31.3, 32.1, 71.6, 76.5, 128.1, 133.8. IR: 3458 (OH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 294 (MNa^+). HRMS (FAB) calcd for $C_{15}H_{32}NaO_2Si$ (MNa^+): 295.2069; found: 295.2062. *syn*-**2**: Colorless oil. $[\alpha]_D^{25}$ +23.2 (*c* 1.03, $CHCl_3$). ^1H NMR δ: 0.07 (s, 6H, $Si(CH_3)_2$), 0.87 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 0.89 (s, 9H, $C(CH_3)_3$), 1.11 (d, *J*=6.7 Hz, 3H, TBSOCHCH_3), 1.26–1.39 (m, 4H, $CH_2\times2$), 2.03 (qd, *J*=6.7, 1.8 Hz, 2H, CH=CHCH_2), 2.57 (d, *J*=3.4 Hz, 1H, OH), 3.62 (quint, *J*=6.7 Hz, 1H, TBSOC*H*), 3.72 (td, *J*=6.7, 3.4 Hz, 1H, C*H*OH), 5.37 (ddt, *J*=15.6, 6.7, 1.8 Hz, 1H, C*H*=CHCH$_2$), 5.71 (dt, *J*=15.6, 6.7 Hz, 1H, CH=C*H*CH$_2$). ^{13}C NMR δ: −4.9, −4.3, 13.9, 18.0, 19.9, 22.2, 25.8 (3C), 31.2, 32.0, 72.2, 77.3, 129.1, 134.1. IR: 3438 (OH), 2956 (CH), 2929 (CH), 2958 (CH). Anal. Calcd for $C_{15}H_{32}O_2Si$: C, 66.11; H, 11.84. Found: C, 66.24; H, 11.67.

3.1.2. (*E*,2*S*,3*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-nonen-3-yl acetate (*anti*-3a).



Acetic anhydride (0.14 mL, 1.50 mmol) was added to a mixture of *anti*-**2** (136 mg, 0.500 mmol) and DMAP (61.1 mg, 0.500 mmol) in pyridine (1 mL) with stirring at 0 °C and the stirring was continued at rt for 30 min. The reaction was quenched with saturated NH_4Cl at 0 °C and the mixture was extracted with Et_2O. The extract was washed with saturated NH_4Cl, water, and brine prior to drying and solvent evaporation. The residue was purified by flash chromatography on silica gel with hexane–EtOAc (50:1) to give *anti*-**3a** (137 mg, 87%) as a colorless oil. $[\alpha]_D^{22}$ −31.9 (*c* 1.08, $CHCl_3$). ^1H NMR δ: 0.04 (s, 3H, $SiCH_3$), 0.05 (s, 3H, $SiCH_3$), 0.89 (t, *J*=7.0 Hz, 3H, CH_2CH_3), 0.89 (s, 9H, $C(CH_3)_3$), 1.07 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.25–1.39 (m, 4H, $CH_2\times2$), 2.05 (s, 3H, $COCH_3$), 2.05 (dq, *J*=6.7, 1.8 Hz, 2H, CH=CHCH_2), 3.90 (qd, *J*=6.1, 3.7 Hz, 1H, TBSOC*H*), 5.03 (dd, *J*=7.9, 3.7 Hz, 1H, C*H*OAc), 5.48 (ddt, *J*=15.6, 7.9, 1.8 Hz, 1H, C*H*=CHCH$_2$), 5.71 (dt, *J*=15.6, 6.7 Hz, 1H, CH=C*H*CH$_2$). ^{13}C NMR δ: −4.7, −4.5, 14.0, 18.1, 19.9, 21.5, 22.3, 25.8 (3C), 31.1, 32.1, 69.6, 79.0, 124.1, 136.5, 170.0. IR: 2958 (CH), 2929 (CH), 2858 (CH), 1740 (C=O). MS (FAB) *m*/*z* 337 (MNa^+). HRMS (FAB) calcd for $C_{17}H_{34}NaO_3Si$ (MNa^+): 337.2175; found: 337.2183.

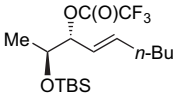
3.1.3. (*E*,2*S*,3*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-nonen-3-yl trichloroacetate (*anti*-3b).



Trichloroacetyl chloride (45 μL, 0.400 mmol) was added to a mixture of *anti*-**2** (54.5 mg, 0.200 mmol) in pyridine (0.4 mL) with stirring at 0 °C and the stirring was continued at rt for 15 min. The reaction was quenched with saturated

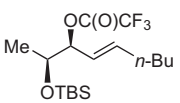
NH_4Cl at 0 °C and the mixture was extracted with Et_2O. The extract was washed with saturated NH_4Cl, water, and brine prior to drying and solvent evaporation. The residue was purified by flash chromatography on silica gel with hexane–EtOAc (50:1) to give *anti*-**3b** (71.5 mg, 86%) as a colorless oil. $[\alpha]_D^{23}$ −8.95 (*c* 0.90, $CHCl_3$). ^1H NMR δ: 0.07 (s, 3H, $SiCH_3$), 0.08 (s, 3H, $SiCH_3$), 0.88 (s, 9H, $C(CH_3)_3$), 0.89 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.16 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.26–1.40 (m, 4H, $CH_2\times2$), 2.08 (dq, *J*=6.7, 1.8 Hz, 2H, CH=CHCH_2), 3.99 (qd, *J*=6.1, 4.3 Hz, 1H, TBSOC*H*), 5.15 (dd, *J*=7.9, 4.3 Hz, 1H, C*H*OC(O)CCl_3), 5.50 (ddt, *J*=15.6, 7.9, 1.8 Hz, 1H, C*H*=CHCH_2), 5.88 (dt, *J*=15.9, 6.7 Hz, 1H, CH=C*H*CH_2). ^{13}C NMR δ: −4.8, −4.4, 14.0, 18.0, 19.4, 22.2, 25.8 (3C), 30.9, 32.1, 69.4, 84.5, 90.4, 122.5, 138.6, 160.9. IR: 2956 (CH), 2929 (CH), 2858 (CH), 1765 (C=O). MS (FAB) *m*/*z* 439 (MNa^+). HRMS calcd for $C_{17}H_{31}NaO_3Si$ (MNa^+): 439.1006; found: 439.0985.

3.1.4. (*E*,2*S*,3*R*)-2-(*tert*-Butyldimethylsilyloxy)-4-nonen-3-yl trifluoroacetate (*anti*-3c).



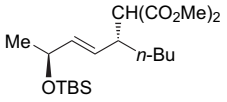
Trifluoroacetic anhydride (0.45 mL, 3.20 mmol) was added to a mixture of *anti*-**2** (437 mg, 1.60 mmol) in pyridine (3.2 mL) with stirring at 0 °C and the stirring was continued at this temperature for 5 min. The reaction was quenched with saturated NH_4Cl at 0 °C and the mixture was extracted with Et_2O. The extract was washed with saturated NH_4Cl, water, and brine prior to drying and solvent evaporation. The residue was purified by flash chromatography on silica gel with hexane–EtOAc (50:1) to give *anti*-**3c** (508 mg, 86%) as a colorless oil. $[\alpha]_D^{24}$ −30.0 (*c* 0.95, $CHCl_3$). ^1H NMR δ: 0.05 (s, 6H, $Si(CH_3)_2$), 0.88 (s, 9H, $C(CH_3)_3$), 0.89 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.11 (d, *J*=6.7 Hz, 3H, TBSOCHCH_3), 1.27–1.40 (m, 4H, $CH_2\times2$), 2.08 (d, *J*=6.7 Hz, 2H, CH=CHCH_2), 3.98 (qd, *J*=6.7, 3.1 Hz, 1H, TBSOC*H*), 5.20 (dd, *J*=7.9, 3.1 Hz, 1H, C*H*OC(O)CF_3), 5.51 (dd, *J*=15.9, 7.9 Hz, 1H, C*H*=CHCH_2), 5.85 (dt, *J*=15.9, 6.7 Hz, 1H, CH=C*H*CH_2). ^{13}C NMR δ: −5.0, −4.6, 14.0, 18.0, 19.4, 22.2, 25.7 (3C), 30.9, 32.1, 69.4, 83.5, 114.5 (q, J_{C-F}=285.1 Hz), 122.1, 139.3, 156.6 (q, J_{C-F}=41.9 Hz). IR: 2958 (CH), 2931 (CH), 2898 (CH), 1786 (C=O). Anal. Calcd for $C_{17}H_{31}F_3O_3Si$: C, 55.41; H, 8.48. Found: C, 55.58; H, 8.47.

3.1.5. (*E*,2*S*,3*S*)-2-(*tert*-Butyldimethylsilyloxy)-4-nonen-3-yl trifluoroacetate (*syn*-3c).



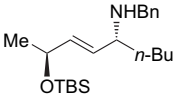
Compound *syn*-**3c** was obtained as a colorless oil (175 mg, 79%) from *syn*-**2** (164 mg, 0.600 mmol) as described for *anti*-**3c**. $[\alpha]_D^{25}$ +33.3 (*c* 1.01, $CHCl_3$). ^1H NMR δ: 0.05 (s, 3H, $SiCH_3$), 0.07 (s, 3H, $SiCH_3$), 0.87 (s, 9H, $C(CH_3)_3$), 0.89 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.12 (d, *J*=6.7 Hz, 3H, TBSOCHCH_3), 1.26–1.39 (m, 4H, $CH_2\times2$), 2.06 (qd, *J*=7.3, 1.8 Hz, 2H, CH=CHCH_2), 3.91 (quint, *J*=6.7 Hz, 1H, TBSOC*H*), 5.17 (t, *J*=6.7 Hz, 1H, C*H*OC(O)CF_3), 5.38 (ddt, *J*=15.3, 6.7, 1.8 Hz, 1H, C*H*=CHCH_2), 5.87 (dt, *J*=15.3, 7.3 Hz, 1H, CH=C*H*CH_2). ^{13}C NMR δ: −5.2, −4.7, 13.8, 17.9, 19.8, 22.1, 25.6 (3C), 30.8, 32.0, 68.9, 83.8, 114.6 (q, J_{C-F}=286.5 Hz), 123.0, 139.3, 156.8 (q, J_{C-F}=41.7 Hz). IR: 2958 (CH), 2931 (CH), 2860 (CH), 1784 (C=O). MS (EI) *m*/*z* (%): 311 ($M^+-C_4H_9$, 50.8). HRMS (EI) calcd for $C_{13}H_{22}F_3O_3Si$ ($M^+-C_4H_9$): 311.1290; found: 311.1300.

3.1.6. General procedure for Pd-catalyzed allylic substitution reaction with dimethyl sodiomalonate: dimethyl 2-[(*E*,2*S*,5*R*)-2-(*tert*-butyldimethylsilyloxy)-3-nonen-5-yl]malonate (*anti*-4).



NaH (60% in oil, 12.0 mg, 0.300 mmol) was washed with *n*-hexane under N_2 and suspended in THF (2 mL). Dimethyl malonate (38 μL, 0.33 mmol) was added dropwise to the suspension with stirring at 0 °C and the stirring was continued for 10 min at rt. The solution of dimethyl sodiomalonate in THF was added to a mixture of *anti*-**3c** (55.3 mg, 0.15 mmol) and $Pd(PPh_3)_4$ (17.3 mg, 0.015 mmol) in THF (2 mL), and the whole was stirred at rt for 30 min. The reaction was quenched with water and THF was evaporated. The residue was extracted with EtOAc. The extract was washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (50:1) to give *anti*-**4** (53.9 mg, 93%) as a colorless oil. $[\alpha]_D^{24}$ −1.14 (*c* 0.54, $CHCl_3$). ^1H NMR δ: 0.04 (s, 6H, $Si(CH_3)_2$), 0.86 (t, *J*=7.0 Hz, 3H, CH_2CH_3), 0.88 (s, 9H, $C(CH_3)_3$), 1.16 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.18–1.32 (m, 5H, $CH_2\times3$), 1.39–1.45 (m, 1H, C$H_2CH_2CH_2CH_3$), 2.72 (qd, *J*=9.2, 3.7 Hz, 1H, C*H*$CH(CO_2CH_3)_2$), 3.34 (d, *J*=9.2 Hz, 1H, C*H*$(CO_2CH_3)_2$), 3.67 (s, 3H, CO_2CH_3), 3.72 (s, 3H, CO_2CH_3), 4.23 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.34 (dd, *J*=15.3, 9.2 Hz, 1H, TBSOCHCH=C*H*), 5.53 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCH*CH*=CH). ^{13}C NMR δ: −4.8, −4.6, 14.0, 18.4, 22.5, 24.9, 26.0 (3C), 29.3, 32.4, 42.8, 52.2, 52.4, 57.3, 69.2, 127.9, 138.0, 168.4, 168.6. IR: 2956 (CH), 2929 (CH), 2858 (CH), 1761 (C=O), 1741 (C=O). Anal. Calcd for $C_{20}H_{38}O_5Si$: C, 62.14; H, 9.91. Found: C, 62.18; H, 9.76.

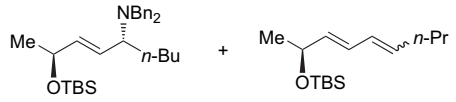
3.1.7. General procedure for Pd-catalyzed allylic substitution reaction with benzylamine: (*E*,2*S*,5*R*)-5-benzylamino-2-(*tert*-butyldimethylsilyloxy)-3-nonene (*anti*-5).



Benzylamine (33 μL, 0.30 mmol) was added to a mixture of *anti*-**3** (221 mg, 0.600 mmol) and $Pd(PPh_3)_4$ (69.3 mg, 60 μmol) in THF (12 mL) and the whole was stirred at rt for 30 min. The reaction was quenched with saturated

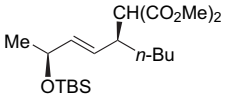
NH_4Cl. After water was added to the mixture at rt, the mixture was extracted with Et_2O. The extract was washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (5:1) to give *syn*-**5** (192 mg, 83%) as a yellow oil along with *anti*-**2** (16.9 mg, 10%). $[\alpha]_D^{23}$ +10.8 (*c* 0.76, $CHCl_3$). ^1H NMR δ: 0.070 (s, 3H, $SiCH_3$), 0.073 (s, 3H, $SiCH_3$), 0.87 (t, *J*=6.1 Hz, 3H, CH_2CH_3), 0.90 (s, 9H, $C(CH_3)_3$), 1.24 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.24–1.31 (m, 5H, $CH_2\times3$), 1.37–1.44 (m, 1H, $CH_2CH_2CH_2CH_3$), 1.50 (br, 1H, NH), 2.99 (td, *J*=7.9, 5.5 Hz, 1H, C*H*NHBn), 3.61 (d, *J*=12.8 Hz, 1H, CH_2Ph), 3.79 (d, *J*=12.8 Hz, 1H, CH_2Ph), 4.33 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.36 (dd, *J*=15.3, 7.9 Hz, 1H, TBSOCHCH=C*H*), 5.56 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCHC*H*=CH), 7.22–7.33 (m, 5H, ArH). ^{13}C NMR δ: −4.8, −4.6, 14.0, 18.3, 22.7, 24.9, 25.9 (3C), 28.2, 35.8, 51.2, 59.8, 69.1, 126.8, 128.2 (2C), 128.3 (2C), 131.4, 136.9, 140.8. IR: 2956 (CH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 362 (MH^+). HRMS (FAB) calcd for $C_{22}H_{40}NOSi$ (MH^+): 362.2879; found: 362.2877.

3.1.8. General procedure for Pd-catalyzed allylic substitution reaction with dibenzylamine: (*E*,2*S*,5*R*)-2-(*tert*-butyldimethylsilyloxy)-5-dibenzylamino-3-nonene (*anti*-6) and (3*E*,5*EZ*,2*S*)-2-(*tert*-butyldimethylsilyloxy)-3,5-nonadiene (7).



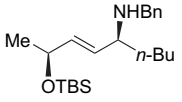
Dibenzylamine (58 μL, 0.300 mmol) was added to a mixture of *anti*-**3** (55.3 mg, 0.150 mmol) and $Pd(PPh_3)_4$ (17.3 mg, 15 μmol) in THF (3 mL) and the whole was refluxed for 23 h. The reaction was quenched with water and THF was evaporated. The residue was extracted with EtOAc. The extract was washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (50:1) to give *anti*-**6** (22.9 mg, 34%) along with **7** (17.3 mg, 45%, major:minor=73:27) each as a colorless oil. *anti*-**6**: $[\alpha]_D^{25}$ +21.2 (*c* 0.34, $CHCl_3$). ^1H NMR δ: 0.087 (s, 3H, $SiCH_3$), 0.093 (s, 3H, $SiCH_3$), 0.84 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 0.92 (s, 9H, $C(CH_3)_3$), 1.17–1.43 (m, 5H, $CH_2\times3$), 1.27 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.64–1.71 (m, 1H, $CH_2CH_2CH_2CH_3$), 2.97 (q, *J*=7.9 Hz, 1H, C*H*NBn_2), 3.31 (d, *J*=13.7 Hz, 2H, CH_2Ph), 3.78 (d, *J*=13.7 Hz, 2H, CH_2Ph), 4.37 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.47 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCHC*H*=CH), 5.55 (dd, *J*=15.3, 7.9 Hz, 1H, TBSOCHCH=C*H*), 7.20 (t, *J*=7.3 Hz, 2H, ArH), 7.28 (t, *J*=7.3 Hz, 4H, ArH), 7.36 (d, *J*=7.3 Hz, 4H, ArH). ^{13}C NMR δ: −4.6, −4.4, 14.2, 18.5, 22.7, 25.2, 26.0 (3C), 28.8, 32.4, 53.7 (2C), 59.5, 69.2, 126.2, 126.5 (2C), 128.0 (4C), 128.6 (4C), 138.3, 140.5 (2C). IR: 2956 (CH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 474 (MNa^+). HRMS (FAB) calcd for $C_{29}H_{45}NNaOSi$ (MNa^+): 474.3168; found: 474.3180. Compound **7**: ^1H NMR δ: 0.038 (s, 0.81H, $SiCH_3$), 0.042 (s, 0.81H, $SiCH_3$), 0.050 (s, 2.19H, $SiCH_3$), 0.058 (s, 2.19H, $SiCH_3$), 0.88–0.92 (m, 11.19H, $C(CH_3)_3$ and 9-H), 1.00 (t, *J*=7.3 Hz, 0.81H, 9-H), 1.12 (d, *J*=6.1 Hz, 0.81H, 1-H), 1.21 (d, *J*=6.7 Hz, 2.19H, 1-H), 1.41 (sext, *J*=7.3 Hz, 1.46H, 8-H), 2.03–2.24 (m, 2.54H, 7-H and 8-H), 3.80 (quint, *J*=6.1 Hz, 0.27H, 2-H), 4.32 (quint, *J*=6.1 Hz, 0.73H, 2-H), 5.51–5.67 (m, 2H, 3-H and 6-H), 5.96–6.12 (m, 2H, 4-H and 5-H). ^{13}C NMR (major) δ: −4.61, −4.42, 13.9, 18.4, 22.6, 24.6, 26.0 (3C), 34.8, 69.0, 128.4, 129.7, 134.1, 135.5; (minor) δ: −4.56, −4.51, 13.8, 18.4, 23.6, 25.7, 26.0 (3C), 43.1, 68.8, 128.4, 129.2, 132.4, 134.3. IR: 2958 (CH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 253 (M^+-H). HRMS (FAB) calcd for $C_{15}H_{29}OSi$ (M^+-H): 253.1988; found: 253.2004.

3.1.9. Dimethyl 2-[(*E*,2*S*,5*S*)-2-(*tert*-butyldimethylsilyloxy)-3-nonen-5-yl]malonate (*syn*-4).



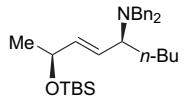
Compound *syn*-**4** was obtained as a colorless oil (56.6 mg, 98%) from *syn*-**3c** (55.3 mg, 0.150 mmol) as described for *anti*-**4**. $[\alpha]_D^{23}$ −8.02 (*c* 1.03, $CHCl_3$). ^1H NMR δ: 0.03 (s, 3H, $SiCH_3$), 0.04 (s, 3H, $SiCH_3$), 0.86 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.88 (s, 9H, $C(CH_3)_3$), 1.16 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.18–1.32 (m, 5H, $CH_2\times3$), 1.39–1.45 (m, 1H, $CH_2CH_2CH_2CH_3$), 2.74 (qd, *J*=9.2, 3.7 Hz, 1H, C*H*$CH(CO_2CH_3)_2$), 3.36 (d, *J*=9.2 Hz, 1H, C*H*$(CO_2Me)_2$), 3.68 (s, 3H, CO_2CH_3), 3.72 (s, 3H, CO_2CH_3), 4.24 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.39 (dd, *J*=15.3, 9.2 Hz, 1H, TBSOCHCH=C*H*), 5.55 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCHC*H*=CH). ^{13}C NMR δ: −4.8, −4.6, 14.0, 18.4, 22.4, 24.8, 25.9 (3C), 29.2, 32.3, 42.4, 52.2, 52.4, 57.1, 68.6, 127.6, 137.7, 168.4, 168.7. IR: 2958 (CH), 2929 (CH), 2860 (CH), 1761 (C=O), 1741 (C=O). Anal. Calcd for $C_{20}H_{38}O_5Si$: C, 62.14; H, 9.91. Found: C, 62.23; H, 9.79.

3.1.10. (*E*,2*S*,5*S*)-5-Benzylamino-2-(*tert*-butyldimethylsilyloxy)-3-nonene (*syn*-5).



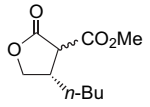
Compound *syn*-**5** was obtained as a yellow oil (45.6 mg, 84%) along with *syn*-**2** (6.3 mg, 15%) from *syn*-**3c** (55.3 mg, 0.150 mmol) as described for *anti*-**5**. $[\alpha]_D^{22}$ −28.1 (*c* 0.45, $CHCl_3$). ^1H NMR δ: 0.08 (s, 6H, $Si(CH_3)_2$), 0.86 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 0.91 (s, 9H, $C(CH_3)_3$), 1.23 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.23–1.31 (m, 5H, $CH_2\times3$), 1.37–1.42 (m, 1H, $CH_2CH_2CH_2CH_3$), 1.51 (br, 1H, NH), 2.99 (td, *J*=8.2, 5.5 Hz, 1H, C*H*NHBn), 3.64 (d, *J*=13.1 Hz, 1H, CH_2Ph), 3.83 (d, *J*=13.1 Hz, 1H, CH_2Ph), 4.32 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.36 (dd, *J*=15.3, 8.2 Hz, 1H, TBSOCHCH=C*H*), 5.57 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCHC*H*=CH), 7.22–7.33 (m, 5H, ArH). ^{13}C NMR δ: −4.6, −4.4, 14.2, 18.5, 22.8, 25.0, 26.0 (3C), 28.3, 35.8, 51.3, 59.8, 69.2, 126.7, 128.1 (2C), 128.3 (2C), 131.3, 136.9, 140.7. IR: 2956 (CH), 2927 (CH), 2858 (CH). MS (FAB) *m*/*z* 377 (MH^+). HRMS (FAB) calcd for $C_{22}H_{40}NOSi$ (MH^+): 362.2879; found: 362.2872.

3.1.11. (*E*,2*S*,5*S*)-2-(*tert*-Butyldimethylsilyloxy)-5-dibenzylamino-3-nonene (*syn*-6).



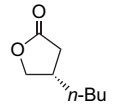
Compound *syn*-**6** was obtained as a colorless oil (31.4 mg, 46%) along with **7** (9.1 mg, 23%) from *syn*-**3c** (55.3 mg, 0.150 mmol) as described for *anti*-**6**. $[\alpha]_D^{25}$ −42.6 (*c* 0.68, $CHCl_3$). ^1H NMR δ: 0.11 (s, 3H, $SiCH_3$), 0.12 (s, 3H, $SiCH_3$), 0.84 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 0.95 (s, 9H, $C(CH_3)_3$), 1.17–1.43 (m, 5H, $CH_2\times3$), 1.25 (d, *J*=6.1 Hz, 3H, TBSOCHCH_3), 1.63–1.69 (m, 1H, $CH_2CH_2CH_2CH_3$), 2.98 (q, *J*=7.9 Hz, 1H, C*H*NBn_2), 3.37 (d, *J*=13.7 Hz, 2H, CH_2Ph), 3.77 (d, *J*=13.7 Hz, 2H, CH_2Ph), 4.33 (quint, *J*=6.1 Hz, 1H, TBSOC*H*), 5.48 (dd, *J*=15.3, 6.1 Hz, 1H, TBSOCHC*H*=CH), 5.56 (dd, *J*=15.3, 7.9 Hz, 1H, TBSOCHCH=C*H*), 7.20 (t, *J*=7.3 Hz, 2H, ArH), 7.28 (t, *J*=7.3 Hz, 4H, ArH), 7.36 (d, *J*=7.3 Hz, 4H, ArH). ^{13}C NMR δ: −4.5, −4.4, 14.2, 18.5, 22.7, 25.1, 26.0 (3C), 28.8, 32.3, 53.6 (2C), 59.3, 69.4, 126.3, 126.5 (2C), 128.0 (4C), 128.6 (4C), 138.3, 140.5 (2C). IR: 2956 (CH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 452 (MH^+). HRMS (FAB) calcd for $C_{29}H_{46}NOSi$ (MH^+): 452.3349; found: 452.3354.

3.1.12. Methyl (3*RS*,4*S*)-4-butyl-2-oxotetrahydrofuran-3-carboxylate (8).



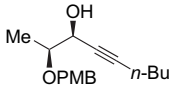
A stream of ozone was bubbled through a solution of *anti*-**4** (77.3 mg, 0.200 mmol) in CH_2Cl_2 (5 mL) at −78 °C for 40 min. Nitrogen was allowed to bubble through the solution to remove excess ozone at this temperature. Then, a solution of $NaBH_4$ (56.7 mg, 1.50 mmol) in aqueous EtOH (1:1 mixture) (1 mL) was added dropwise and the whole was stirred at rt for 12 h. The reaction was quenched with water, and the mixture was extracted with EtOAc. The extract was washed with water and brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (4:1) to give **8** (22.0 mg, 55%, major:minor=89:11) as a colorless oil. ^1H NMR δ: 0.90 (t, *J*=7.3 Hz, 3H, 4′-H), 1.23–1.37 (m, 4H, 2′-H and 3′-H), 1.46–1.58 (m, 2H, 1′-H), 2.75–2.83 (m, 0.11H, 4-H), 2.97 (sext, *J*=7.9 Hz, 0.89H, 4-H), 3.24 (d, *J*=7.9 Hz, 0.89H, 3-H), 3.54 (d, *J*=8.5 Hz, 0.11H, 3-H), 3.77 (s, 0.33H, CO_2CH_3), 3.81 (s, 2.67H, CO_2CH_3), 3.91 (t, *J*=7.9 Hz, 0.89H, 5-H), 4.15 (dd, *J*=10.4, 8.5 Hz, 0.11H, 5-H), 4.43 (t, *J*=8.5 Hz, 0.11H, 5-H), 4.51 (t, *J*=7.9 Hz, 0.89H, 5-H). ^{13}C NMR (major) δ: 13.9, 22.6, 29.1, 32.1, 40.2, 52.5, 53.1, 72.1, 168.1, 171.9. IR: 2958 (CH), 2933 (CH), 2862 (CH), 1778 (C=O), 1739 (C=O). MS (FAB) *m*/*z* 201 (MH^+). HRMS (FAB) calcd for $C_{10}H_{17}O_4$ (MH^+): 201.1127; found: 201.1127.

3.1.13. (*S*)-3-Butyl-γ-butyrolactone (9).



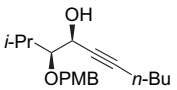
NaCl (5.8 mg, 0.100 mmol) and five drops of water were added to a solution of **8** (13.0 mg, 0.0650 mmol) in DMSO (1 mL). The mixture was heated at 130 °C for 2 h and then 150 °C for 4 h. After cooling, brine was added to the mixture and the whole was extracted with Et_2O. The extract was washed with water and brine and dried. The solvent was evaporated to give **9** (7.7 mg, 83%) as a yellow oil. $[\alpha]_D^{24}$ −5.72 (*c* 0.25, $CHCl_3$).

3.1.14. (2*S*,3*S*)-2-(4-Methoxybenzyloxy)-4-nonyn-3-ol (11a).



A flask was charged with $Zn(OTf)_2$ (800 mg, 2.20 mmol). Vacuum (7 mmHg) was applied and heated to 120 °C for 10 h. After the flask was cooled to rt, the vacuum was released. (1*S*,2*R*)-(+)-*N*-Methylephedrine (NME) (430 mg, 2.40 mmol), toluene (2.2 mL), and Et_3N (0.33 mL, 2.40 mmol) were added to the flask with stirring at rt. After 3.5 h, a solution of 1-hexyne (0.23 mL, 2.00 mmol) was added to the mixture with stirring at rt. After 15 min, a solution of **10a** (194 mg, 1.00 mmol) in toluene (0.5 mL) was added to the mixture with stirring at rt. The reaction mixture was stirred for 20 h. The reaction was quenched with saturated NH_4Cl and the mixture was extracted with EtOAc and the extract was washed with saturated NH_4Cl, water, and brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (4:1) to give **11a** (232 mg, 84%, >97:3 dr) as a pale yellow oil. $[\alpha]_D^{22}$ +49.5 (*c* 0.66, $CHCl_3$). ^1H NMR δ: 0.90 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.26 (d, *J*=6.4 Hz, 3H, PMBOCHCH_3), 1.37–1.53 (m, 4H, $CH_2\times2$), 2.22 (td, *J*=6.7, 1.8 Hz, 2H, C≡CCH_2), 2.66 (d, *J*=3.1 Hz, 1H, OH), 3.56 (quint, *J*=6.4 Hz, 1H, PMBOC*H*), 3.81 (s, 3H, OCH_3), 4.18–4.21 (m, 1H, C*H*OH), 4.48 (d, *J*=11.3 Hz, 1H, CH_2Ar), 4.62 (d, *J*=11.3 Hz, 1H, CH_2Ar), 6.88 (d, *J*=8.5 Hz, 2H, ArH), 7.27 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.5, 15.9, 18.4, 21.9, 30.5, 55.2, 66.6, 71.2, 78.1, 78.2, 86.6, 113.8 (2C), 129.4 (2C), 130.1, 159.3. IR: 3431 (OH), 2958 (CH), 2933 (CH), 2873 (CH). MS (FAB) *m*/*z* 299 (MNa^+). HRMS (FAB) calcd for $C_{17}H_{24}NaO_3$ (MNa^+): 299.1623; found: 299.1646.

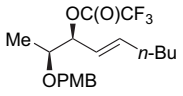
3.1.15. (3*S*,4*S*)-3-(4-Methoxybenzyloxy)-2-methyl-5-decyn-4-ol (11b).



n-BuLi (1.15 M in hexane, 33.6 mL, 38.6 mmol) was added to a solution of 1-hexyne (4.44 mL, 38.6 mmol) in Et_2O

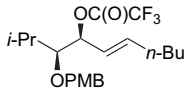
(77 mL) at 0 °C. After 30 min, $ZnBr_2$ (9.62 g, 42.7 mmol, dried at 120 °C for 4 h under 5 mmHg) was added to the mixture and the whole was stirred at 0 °C for 20 min. A solution of aldehyde **10b** (4.30 g, 19.3 mmol) in Et_2O (23 mL) was added to the mixture and the stirring was continued at −78 °C for 30 min. Then, the mixture was warmed to 0 °C over 1 h and stirred for 3 h. The reaction was quenched with saturated aqueous NH_4Cl solution and the mixture was extracted with Et_2O. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (10:1) to give **11b** (5.81 g, 99%, >97:3 dr) as a colorless oil. $[\alpha]_D^{27}$ +35.4 (*c* 1.17, $CHCl_3$). ^1H NMR δ: 0.90 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.97 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 0.99 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 1.41 (qt, *J*=6.7, 6.7 Hz, 2H, CH_2CH_3), 1.51 (tt, *J*=6.7, 6.7 Hz, 2H, C=CCH_2CH_2), 2.02 (m, 1H, $CH(CH_3)_2$), 2.23 (td, *J*=6.7, 1.8 Hz, 2H, C=CCH_2), 2.49 (br, 1H, OH), 3.26 (dd, *J*=5.5, 5.5 Hz, 1H, CHOPMB), 3.81 (s, 3H, $ArOCH_3$), 4.37 (m, 1H, CHOH), 4.64 (d, *J*=11.0 Hz, 1H, CH_2Ar), 4.79 (d, *J*=11.0 Hz, 1H, CH_2Ar), 6.89 (d, *J*=8.5 Hz, 2H, ArH), 7.31 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.6, 17.8, 18.5, 19.8, 22.0, 30.1, 30.6, 55.3, 63.1, 75.0, 79.8, 86.1, 87.4, 113.8 (2C), 129.6 (2C), 130.6, 159.3. IR: 3428 (OH), 2956 (CH), 2871 (CH). MS (FAB) *m/z* 327 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{28}NaO_3$ (MNa^+): 327.1936; found: 327.1921.

3.1.16. (*E*,2*S*,3*S*)-2-(4-Methoxybenzyloxy)-4-nonen-3-yl trifluoroacetate [(*E*)-12a].



$LiAlH_4$ (15.2 mg, 0.400 mmol) was added to a stirred solution of **11a** (55.3 mg, 0.200 mmol) in THF (2 mL) at 0 °C. The mixture was heated at reflux for 2.5 h. Saturated Rochelle salt was gradually added to the stirred mixture. The mixture was extracted with Et_2O, and the extract was washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel hexane–EtOAc (4:1) to give the allylic alcohol (52.3 mg, 94%) as a colorless oil. $[\alpha]_D^{24}$ +50.8 (*c* 0.82, $CHCl_3$). ^1H NMR δ: 0.89 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.15 (d, *J*=6.7 Hz, 3H, PMBOCHCH_3), 1.25–1.40 (m, 4H, $CH_2\times2$), 2.05 (q, *J*=6.7 Hz, 2H, CH=$CHCH_2$), 2.79 (s, 1H, OH), 3.37 (quint, *J*=6.7 Hz, 1H, PMBOCH), 3.81 (s, 3H, OCH_3), 3.86 (t, *J*=6.7 Hz, 1H, CHOH), 4.39 (d, *J*=11.0 Hz, 1H, CH_2Ar), 4.61 (d, *J*=11.0 Hz, 1H, CH_2Ar), 5.39 (dd, *J*=15.3, 6.7 Hz, 1H, CH=$CHCH_2$), 5.76 (dt, *J*=15.3, 6.7 Hz, 1H, CH=$CHCH_2$), 6.89 (d, *J*=8.5 Hz, 2H, ArH), 7.27 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 14.0, 15.6, 22.3, 31.2, 32.1, 55.3, 70.8, 76.6, 78.3, 113.8 (2C), 128.2, 129.3 (2C), 130.2, 134.9, 159.1. IR: 3462 (OH), 2958 (CH), 2929 (CH), 2875 (CH). MS (FAB) *m/z* 301 (MNa^+). HRMS (FAB) calcd for $C_{17}H_{26}NaO_3$ (MNa^+): 301.1780; found: 301.1778. Trifluoroacetic anhydride (0.14 mL, 1.00 mmol) was added to a solution of the allylic alcohol (139 mg, 0.500 mmol) in pyridine (1 mL) with stirring at rt. After 5 min, the reaction was quenched with saturated NH_4Cl at 0 °C and the mixture was extracted with Et_2O. The extract was washed with water and brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel hexane–Et_2O (10:1) to give (*E*)-**12a** (159 mg, 85%) as a colorless oil. $[\alpha]_D^{24}$ +23.8 (*c* 0.82, $CHCl_3$). ^1H NMR δ: 0.89 (t, *J*=7.3 Hz, 3H, CH_2CH_3), 1.14 (d, *J*=6.7 Hz, 3H, PMBOCHCH_3), 1.26–1.39 (m, 4H, $CH_2\times2$), 2.06 (qd, *J*=7.3, 1.5 Hz, 2H, CH=$CHCH_2$), 3.65 (quint, *J*=6.7 Hz, 1H, PMBOCH), 3.80 (s, 3H, OCH_3), 4.47 (d, *J*=11.3 Hz, 1H, CH_2Ar), 4.55 (d, *J*=11.3 Hz, 1H, CH_2Ar), 5.33 (dd, *J*=8.2, 6.7 Hz, 1H, CHOC(O)CF_3), 5.41 (ddt, *J*=15.3, 8.2, 1.5 Hz, 1H, CH=$CHCH_2$), 5.89 (dt, *J*=15.3, 7.3 Hz, 1H, CH=$CHCH_2$), 6.87 (d, *J*=8.5 Hz, 2H, ArH), 7.23 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.9, 16.1, 22.2, 30.8, 32.0, 55.3, 71.3, 74.7, 82.4, 113.7 (2C), 114.5 (q, J_{C-F}=285.6 Hz), 122.6, 129.2 (2C), 130.0, 139.4, 156.5 (q, J_{C-F}=41.9 Hz), 159.1. IR: 2960 (CH), 2931 (CH), 2862 (CH), 1782 (C=O). MS (FAB) *m/z* 397 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{25}F_3NaO_4$ (MNa^+): 397.1603; found: 397.1595.

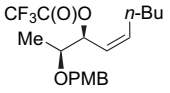
3.1.17. (*E*,3*S*,4*S*)-3-(4-Methoxybenzyloxy)-2-methyl-5-decen-4-yl trifluoroacetate [(*E*)-12b].



Compound **11b** (153 mg, 0.50 mmol) was converted into allylic alcohol (142 mg, 92%) in a similar procedure (reaction time 1 h) as described for (*E*)-**12a**. Colorless oil. $[\alpha]_D^{26}$ +24.7 (*c* 1.15, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.90 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.95 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 1.01 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 1.28–1.41 (m, 4H, $CH_2\times2$), 1.92 (septd, *J*=6.7, 5.5 Hz, 1H, $CH(CH_3)_2$), 2.05 (dt, *J*=6.7, 6.7 Hz, 2H, C=$CHCH_2$), 2.35 (br, 1H, OH), 3.09 (dd, *J*=5.5, 5.5 Hz, 1H, CHOPMB), 3.81 (s, 3H, $ArOCH_3$), 4.07 (dd, *J*=6.7, 6.7 Hz, 1H, CHOH), 4.54 (d, *J*=11.0 Hz, 1H, CH_2Ar), 4.61 (d, *J*=11.0 Hz, 1H, CH_2Ar), 5.46 (dd, *J*=15.6, 6.7 Hz, 1H, CH(OH)CH=C), 5.74 (dt, *J*=15.6, 6.7 Hz, 1H, C=$CHCH_2$), 6.88 (d, *J*=8.5 Hz, 2H, ArH), 7.28 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.8, 17.4, 20.1, 22.2, 29.8, 31.1, 32.0, 55.1, 73.0, 74.8, 87.5, 113.7 (2C), 129.3 (2C), 130.1, 130.6, 133.2, 159.2. IR: 3464 (OH), 2958 (CH), 2871 (CH). MS (FAB) *m/z* 329 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{30}NaO_3$ (MNa^+): 329.2093; found: 329.2078. Trifluoroacetic anhydrous (0.47 mL, 3.4 mmol) was added to a solution of the allylic alcohol (515 mg, 1.7 mmol) and pyridine (0.30 mL, 3.7 mmol) in ether (3.3 mL) with stirring at 0 °C. The stirring was continued at rt for 30 min. The reaction was quenched with saturated NH_4Cl and the mixture was extracted with ether. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (3:1) to give (*E*)-**12b** (670 mg, 99%) as a colorless oil. $[\alpha]_D^{26}$ +10.4 (*c* 1.00, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.81 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.82 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 0.90 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 1.16–1.33 (m, 4H, $CH_2\times2$), 1.75 (qnd, *J*=6.7, 3.6 Hz, 1H, $CH(CH_3)_2$), 1.98 (dt, *J*=6.7, 6.7 Hz, 2H, C=$CHCH_2$), 3.30 (dd, *J*=6.7, 3.6 Hz, 1H, CHOPMB), 3.70 (s, 3H, $ArOCH_3$), 4.40 (d, *J*=11.0 Hz, 1H, CH_2Ar), 4.56 (d, *J*=11.0 Hz, 1H, CH_2Ar), 5.33 (dd, *J*=14.6, 8.5 Hz, 1H, CH(OC(O)CF_3)CH=C),

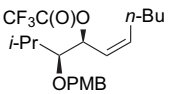
5.38 (dd, J=8.5, 8.5 Hz, 1H, CHOC(O)CF_3), 5.86 (dt, J=14.6, 6.7 Hz, 1H, C=C*H*CH_2), 6.78 (d, J=8.5 Hz, 2H, ArH), 7.15 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.8, 15.9, 20.0, 22.1, 29.5, 30.7, 32.0, 55.2, 74.9, 82.2, 83.9, 113.7 (2C), 114.6 (q, J_{C-F}=286.5 Hz), 123.1, 129.4 (2C), 130.4, 139.5, 156.6 (q, J_{C-F}=41.7 Hz), 159.2. IR: 2960 (CH), 2877 (CH), 1782 (C=O). MS (FAB) m/z 425 (MNa^+). HRMS (FAB) calcd for $C_{21}H_{29}F_3NaO_4$ (MNa^+): 425.1916; found: 425.1941.

3.1.18. (*Z*,2*S*,3*S*)-2-(4-Methoxybenzyloxy)-4-nonen-3-yl trifluoroacetate [(*Z*)-12a].



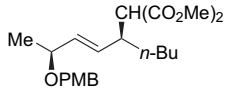
A solution of **11a** (55.3 mg, 0.200 mmol) in MeOH (2 mL) was hydrogenated on Lindlar catalyst (2.8 mg, 5% w/w) with stirring at rt for 21 h. Lindlar catalyst (2.8 mg, 5% w/w) was added to the mixture and the stirring was continued for 9 h, and then filtered off through Celite. The filtrate was concentrated under reduced pressure and the residue was chromatographed on silica gel with hexane–EtOAc (4:1) to give the allylic alcohol (54.5 mg, 98%) as a colorless oil. $[\alpha]_D^{24}$ +45.1 (c 1.33, $CHCl_3$). ^{1}H NMR δ: 0.89 (t, J=7.3 Hz, 3H, CH_2CH_3), 1.14 (d, J=6.1 Hz, 3H, PMBOCHCH_3), 1.28–1.40 (m, 4H, CH_2×2), 2.05–2.20 (m, 2H, CH=CHCH_2), 2.77 (s, 1H, OH), 3.39 (dq, J=8.5, 6.1 Hz, 1H, PMBOC*H*), 3.81 (s, 3H, OCH_3), 4.25 (t, J=8.5 Hz, 1H, C*H*OH), 4.40 (d, J=11.0 Hz, 1H, CH_2Ar), 4.62 (d, J=11.0 Hz, 1H, CH_2Ar), 5.32 (dd, J=11.0, 8.5 Hz, 1H, C*H*=CHCH_2), 5.63 (dt, J=11.0, 7.3 Hz, 1H, CH=C*H*CH_2), 6.89 (d, J=8.5 Hz, 2H, ArH), 7.27 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 14.0, 15.5, 22.4, 27.8, 31.7, 55.2, 70.8, 71.2, 78.5, 113.7 (2C), 127.8, 129.3 (2C), 130.2, 135.0, 159.1. IR: 3458 (OH), 2958 (CH), 2931 (CH), 2871 (CH). MS (FAB) m/z 301 (MNa^+). HRMS (FAB) calcd for $C_{17}H_{26}NaO_3$ (MNa^+): 301.1780; found: 301.1786. Compound (*Z*)-**12a** was obtained as a colorless oil (160 mg, 85%) from **11a** (139 mg, 0.500 mmol) as described for (*E*)-**12a**. $[\alpha]_D^{25}$ −18.4 (c 1.07, $CHCl_3$). ^{1}H NMR δ: 0.89 (t, J=7.0 Hz, 3H, CH_2CH_3), 1.15 (d, J=6.4 Hz, 3H, PMBOCHCH_3), 1.26–1.39 (m, 4H, CH_2×2), 2.12–2.26 (m, 2H, CH=CHCH_2), 3.67 (dq, J=7.6, 6.4 Hz, 1H, PMBOC*H*), 3.80 (s, 3H, OCH_3), 4.47 (d, J=11.6 Hz, 1H, CH_2Ar), 4.55 (d, J=11.6 Hz, 1H, CH_2Ar), 5.33 (ddt, J=11.0, 9.8, 1.8 Hz, 1H, C*H*=CHCH_2), 5.69 (dd, J=9.8, 7.6 Hz, 1H, C*H*OC(O)CF_3), 5.77 (dt, J=11.0, 7.9 Hz, 1H, CH=C*H*CH_2), 6.87 (d, J=8.5 Hz, 2H, ArH), 7.23 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 14.0, 15.9, 22.4, 27.9, 31.4, 55.3, 71.4, 75.0, 77.5, 113.7 (2C), 114.6 (q, J_{C-F}=285.6 Hz), 122.0, 129.2 (2C), 129.9, 138.9, 156.5 (q, J_{C-F}=41.9 Hz), 159.1. IR: 2958 (CH), 2935 (CH), 2870 (CH), 1782 (C=O). MS (FAB) m/z 397 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{25}F_3NaO_4$ (MNa^+): 397.1603; found: 397.1603.

3.1.19. (*Z*,3*S*,4*S*)-3-(4-Methoxybenzyloxy)-2-methyl-5-decen-4-yl trifluoroacetate [(*Z*)-12b].



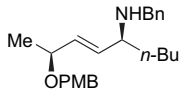
Compound **11b** (208 mg, 0.68 mmol) was converted into allylic alcohol (208 mg, quant.) in a similar procedure (reaction time 22 h) as described for (*Z*)-**12a**. $[\alpha]_D^{25}$ +25.1 (c 2.19, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.90 (t, J=6.7 Hz, 3H, CH_2CH_3), 0.96 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.03 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.25–1.45 (m, 4H, CH_2×2), 1.90 (septd, J=6.7, 4.9 Hz, 1H, C*H*(CH_3)$_2$), 2.01 (m, 2H, C=CHCH_2), 2.45 (br, 1H, OH), 3.11 (dd, J=6.7, 4.9 Hz, 1H, C*H*OPMB), 3.81 (s, 3H, ArOCH_3), 4.42 (dd, J=8.5, 6.7 Hz, 1H, C*H*OH), 4.56 (d, J=11.0 Hz, 1H, CH_2Ar), 4.64 (d, J=11.0 Hz, 1H, CH_2Ar), 5.42 (dd, J=11.0, 8.5 Hz, 1H, CH(OH)C*H*=C), 5.55 (dt, J=11.0, 6.7 Hz, 1H, C=C*H*CH_2), 6.89 (d, J=8.5 Hz, 2H, ArH), 7.29 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.9, 17.4, 20.3, 22.3, 27.6, 29.8, 31.6, 55.2, 68.0, 75.0, 88.0, 113.8 (2C), 129.4 (2C), 129.7, 130.6, 133.6, 159.2. IR: 3473 (OH), 2958 (CH), 2871 (CH). MS (FAB) m/z 329 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{30}NaO_3$ (MNa^+): 329.2093; found: 329.2123. The allylic alcohol (61 mg, 0.20 mmol) was converted into (*Z*)-**12b** (73 mg, 90%) in a similar procedure as described for (*E*)-**12b**. $[\alpha]_D^{26}$ −22.9 (c 0.32, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.90 (t, J=6.7 Hz, 3H, CH_2CH_3), 0.90 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 0.98 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.20–1.75 (m, 4H, CH_2×2), 1.83 (qnd, J=6.7, 3.1 Hz, 1H, C*H*(CH_3)$_2$), 2.10–2.35 (m, 2H, C=CHCH_2), 3.41 (dd, J=8.5, 3.1 Hz, 1H, C*H*OPMB), 3.80 (s, 3H, ArOCH_3), 4.49 (d, J=11.0 Hz, 1H, CH_2Ar), 4.65 (d, J=11.0 Hz, 1H, CH_2Ar), 5.35 (dd, J=11.0, 11.0 Hz, 1H, CH(OC(O)CF_3)C*H*=C), 5.74 (dt, J=11.0, 6.7 Hz, 1H, C=C*H*CH_2), 5.80 (dd, J=11.0, 8.5 Hz, 1H, CHOC(O)CF_3), 6.86 (d, J=8.5 Hz, 2H, ArH), 7.23 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.9, 16.1, 20.3, 22.4, 28.0, 29.6, 31.4, 55.3, 75.1, 84.1 (2C), 113.7 (2C), 114.6 (q, J_{C-F}=285.8 Hz), 122.4, 129.4 (2C), 130.4, 138.1, 156.6 (q, J_{C-F}=42.2 Hz), 159.2. IR: 2962 (CH), 2875 (CH), 1784 (C=O). MS (FAB) m/z 425 (MNa^+). HRMS (FAB) calcd for $C_{21}H_{29}F_3NaO_4$ (MNa^+): 425.1916; found: 425.1937.

3.1.20. Dimethyl 2-[(*E*,2*S*,5*S*)-2-(4-methoxybenzyloxy)-3-nonen-5-yl]malonate (*syn*-13a).



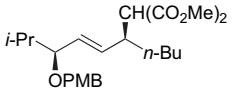
The procedure was described in the communication.[4] $[\alpha]_D^{23}$ −46.9 (c 0.76, $CHCl_3$). ^{1}H NMR δ: 0.87 (t, J=6.7 Hz, 3H, CH_2CH_3), 1.20–1.35 (m, 5H, CH_2×3), 1.23 (d, J=6.7 Hz, 3H, PMBOCHCH_3), 1.42–1.49 (m, 1H, C$H_2CH_2CH_2CH_3$), 2.81 (qd, J=8.9, 3.7 Hz, 1H, C*H*CH(CO_2CH_3)$_2$), 3.42 (d, J=8.9 Hz, 1H, C*H*(CO_2CH_3)$_2$), 3.69 (s, 3H, CO_2CH_3), 3.74 (s, 3H, CO_2CH_3), 3.80 (s, 3H, ArOCH_3), 3.82–3.87 (m, 1H, PMBOC*H*), 4.22 (d, J=11.3 Hz, 1H, CH_2Ar), 4.44 (d, J=11.3 Hz, 1H, CH_2Ar), 5.43–5.50 (m, 2H, C*H*=C*H*), 6.87 (d, J=8.5 Hz, 2H, ArH), 7.26 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.9, 21.9, 22.3, 29.1, 32.0, 42.7, 52.3, 52.4, 55.2, 57.0, 69.1, 74.7, 113.6 (2C), 129.3 (2C), 130.7, 131.9, 135.3, 158.9, 168.5, 168.7. IR: 2952 (CH), 2929 (CH), 2861 (CH), 1753 (C=O), 1738 (C=O). MS (FAB) m/z 415 (MNa^+). HRMS (FAB) calcd for $C_{22}H_{32}NaO_6$ (MNa^+): 415.2097; found: 415.2093.

3.1.21. (*E*,2*S*,5*S*)-5-Benzylamino-2-(4-methoxybenzyloxy)-3-nonene (*syn*-14a).



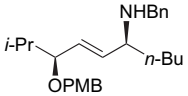
The procedure was described in the communication.[4] $[\alpha]_D^{23}$ −67.1 (*c* 0.57, $CHCl_3$). ^1H NMR δ: 0.88 (t, *J*=7.0 Hz, 3H, CH_2CH_3), 1.25–1.56 (m, 6H, $CH_2\times3$), 1.29 (d, *J*=6.7 Hz, 3H, PMBOCHCH_3), 1.76 (br, 1H, NH), 3.06 (td, *J*=7.9, 5.5 Hz, 1H, C*H*NHBn), 3.69 (d, *J*=13.4 Hz, 1H, NHCH_2Ph), 3.79 (s, 3H, OCH_3), 3.88 (d, *J*=13.4 Hz, 1H, NHCH_2Ph), 3.94 (quint, *J*=6.7 Hz, 1H, PMBOC*H*), 4.35 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.55 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.43 (dd, *J*=15.3, 7.9 Hz, 1H, PMBOCHCH=C*H*), 5.51 (dd, *J*=15.3, 6.7 Hz, 1H, PMBOCHC*H*=CH), 6.87 (d, *J*=8.5 Hz, 2H, ArH), 7.24–7.34 (m, 7H, ArH). ^{13}C NMR δ: 14.0, 21.9, 22.6, 28.1, 35.5, 51.4, 55.2, 59.9, 69.5, 75.2, 113.7 (2C), 126.8, 128.1 (2C), 128.4 (2C), 129.2 (2C), 130.7, 134.1, 135.3, 140.3, 158.9. IR: 2954 (CH), 2929 (CH), 2860 (CH). MS (FAB) *m*/*z* 368 (MH^+). HRMS (FAB) calcd for $C_{24}H_{34}NO_2$ (MH^+): 368.2590; found: 368.2584.

3.1.22. Dimethyl 2-[(*E*,3*S*,6*S*)-3-(4-methoxybenzyloxy)-2-methyl-4-dec-6-yl]malonate (*syn*-13b).



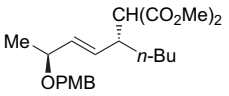
Compound *syn*-**13b** was obtained as a yellow oil (61.7 mg, 98%) from (*E*)-**12b** (60.4 mg, 0.150 mmol) as described for *anti*-**4**. $[\alpha]_D^{25}$ −36.9 (*c* 2.07, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.83 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 0.87 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.91 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 1.22–1.50 (m, 6H, $CH_2\times3$), 1.73 (septd, *J*=6.7, 6.7 Hz, 1H, C*H*(CH_3)$_2$), 2.86 (m, 1H, C*H*CH(CO_2CH_3)$_2$), 3.31 (dd, *J*=6.7, 6.7 Hz, 1H, C*H*OPMB), 3.43 (d, *J*=8.5 Hz, 1H, C*H*(CO_2CH_3)$_2$), 3.69 (s, 3H, CO_2CH_3), 3.74 (s, 3H, CO_2CH_3), 3.80 (s, 3H, ArOCH_3), 4.18 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.46 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.43 (m, 2H, CH=CH), 6.86 (d, *J*=8.5 Hz, 2H, ArH), 7.25 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.9, 18.4, 18.9, 22.2, 29.3, 32.1, 32.8, 42.9, 52.3, 52.4, 55.2, 57.2, 69.2, 84.5, 113.6 (2C), 129.2 (2C), 131.0, 132.6, 134.0, 158.9, 168.5, 168.8. IR: 2954 (CH), 2871 (CH), 1759 (C=O), 1738 (C=O). MS (FAB) *m*/*z* 443 (MNa^+). HRMS (FAB) calcd for $C_{24}H_{36}NaO_6$ (MNa^+): 443.2410; found: 443.2427.

3.1.23. (*E*,3*S*,6*S*)-6-Benzylamino-3-(4-methoxybenzyloxy)-2-methyl-4-decene (*syn*-14b).



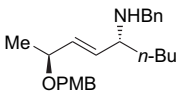
Compound *syn*-**14b** was obtained as a yellow oil (47.6 mg, 80%) from (*E*)-**12b** (60.4 mg, 0.15 mmol) as described for *anti*-**5**. $[\alpha]_D^{24}$ −39.9 (*c* 2.28, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.87 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 0.88 (m, 3H, CH_2CH_3), 0.96 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 1.25–1.60 (m, 6H, $CH_2\times3$), 1.78 (septd, *J*=6.7, 6.7 Hz, 1H, C*H*(CH_3)$_2$), 3.09 (dt, *J*=6.7, 6.7 Hz, 1H, C*H*NHBn), 3.42 (dd, *J*=6.7, 6.7 Hz, 1H, C*H*OPMB), 3.69 (d, *J*=13.4 Hz, 1H, NCH_2Ph), 3.79 (s, 3H, OCH_3), 3.90 (d, *J*=13.4 Hz, 1H, NCH_2Ph), 4.31 (d, *J*=11.6 Hz, 1H, OCH_2Ar), 4.58 (d, *J*=11.6 Hz, 1H, OCH_2Ar), 5.40 (dd, *J*=15.3, 6.7 Hz, 1H, C=C*H*CHNHBn), 5.45 (dd, *J*=15.3, 6.7 Hz, 1H, C=C*H*CHOPMB), 6.86 (d, *J*=8.5 Hz, 2H, ArH), 7.25 (d, *J*=8.5 Hz, 2H, ArH), 7.30–7.40 (m, 5H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.0, 18.5, 19.0, 22.6, 28.2, 32.8, 35.7, 51.4, 55.2, 60.2, 69.7, 84.9, 113.7 (2C), 126.9, 128.1 (2C), 128.4 (2C), 129.2 (2C), 131.0, 131.4, 137.4, 140.5, 158.9. IR: 2956 (CH), 2869 (CH). MS (FAB) *m*/*z* 396 (MH^+). HRMS (FAB) calcd for $C_{26}H_{38}NO_2$ (MH^+): 396.2903; found: 396.2898.

3.1.24. Dimethyl 2-[(*E*,2*S*,5*R*)-2-(4-methoxybenzyloxy)-3-nonen-5-yl]malonate (*anti*-13a).



Compound *anti*-**13a** was obtained as a colorless oil (54.9 mg, 93%) from (*Z*)-**12a** (56.2 mg, 0.150 mmol) as described for *anti*-**4a**. $[\alpha]_D^{24}$ −31.2 (*c* 1.23, $CHCl_3$). ^1H NMR δ: 0.88 (t, *J*=6.1 Hz, 3H, CH_2CH_3), 1.21 (d, *J*=6.1 Hz, 3H, PMBOCHCH_3), 1.24–1.37 (m, 5H, $CH_2\times3$), 1.45–1.50 (m, 1H, C$H_2CH_2CH_2CH_3$), 2.80 (qd, *J*=9.2, 3.7 Hz, 1H, C*H*CH(CO_2CH_3)$_2$), 3.38 (d, *J*=9.2 Hz, 1H, C*H*(CO_2CH_3)$_2$), 3.68 (s, 3H, CO_2CH_3), 3.73 (s, 3H, CO_2CH_3), 3.80 (s, 3H, ArOCH_3), 3.83–3.87 (m, 1H, PMBOC*H*), 4.26 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.47 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.42–5.50 (m, 2H, CH=CH), 6.87 (d, *J*=8.5 Hz, 2H, ArH), 7.24 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 14.0, 21.9, 22.3, 29.4, 32.1, 42.8, 52.2, 52.4, 55.2, 57.0, 69.5, 75.1, 113.8 (2C), 129.2 (2C), 130.8, 131.8, 135.4, 159.0, 168.5, 168.7. IR: 2952 (CH), 2929 (CH), 2860 (CH), 1757 (C=O), 1739 (C=O). MS (FAB) *m*/*z* 415 (MNa^+). HRMS (FAB) calcd for $C_{22}H_{32}NaO_6$ (MNa^+): 415.2097; found: 415.2094.

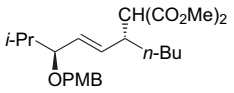
3.1.25. (*E*,2*S*,5*R*)-5-Benzylamino-2-(4-methoxybenzyloxy)-3-nonene (*anti*-14a).



Compound *anti*-**14a** was obtained as a yellow oil (46.7 mg, 85%) from (*Z*)-**12a** (56.2 mg, 0.150 mmol) as described for *anti*-**4**. $[\alpha]_D^{23}$ −25.6 (*c* 0.71, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.89 (t, *J*=7.0 Hz, 3H, CH_2CH_3), 1.26–1.58 (m, 6H, $CH_2\times3$), 1.30 (d, *J*=6.7 Hz, 3H, PMBOCHCH_3), 1.65 (br, 1H, NH), 3.06 (td, *J*=8.2, 5.5 Hz, 1H, C*H*NHBn), 3.65 (d, *J*=12.8 Hz, 1H, NHCH_2Ph), 3.80 (s, 3H, OCH_3), 3.81 (d, *J*=12.8 Hz, 1H, NHCH_2Ph), 3.94 (quint, *J*=6.7 Hz, 1H, PMBOC*H*), 4.31 (d, *J*=11.3 Hz, 1H, CH_2Ar), 4.50 (d, *J*=11.3 Hz, 1H, CH_2Ar), 5.43 (dd, *J*=15.3, 8.2 Hz, 1H, PMBOCHCH=C*H*), 5.50 (dd, *J*=15.3, 6.7 Hz, 1H,

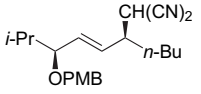
PMBOCHC*H*═CH), 6.87 (d, *J*=9.2 Hz, 2H, ArH), 7.23–7.33 (m, 7H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.2, 22.1, 22.7, 28.4, 35.7, 51.3, 55.3, 59.9, 69.5, 75.1, 113.7 (2C), 126.8, 128.1 (2C), 128.3 (2C), 129.1 (2C), 130.7, 134.1, 135.1, 140.4, 158.9. IR: 2958 (CH), 2929 (CH), 2858 (CH). MS (FAB) *m*/*z* 368 (MH^+). HRMS (FAB) calcd for $C_{24}H_{34}NO_2$ (MH^+): 368.2590; found: 368.2575.

3.1.26. Dimethyl 2-[(*E*,3*S*,6*R*)-3-(4-methoxybenzyloxy)-2-methyl-4-decen-6-yl]malonate (*anti*-13b).



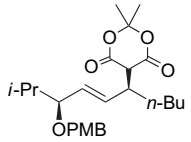
Compound *anti*-**13b** was obtained as a yellow oil (61.0 mg, 97%) from (*Z*)-**12b** (60.4 mg, 0.150 mmol) as described for *anti*-**4**. $[\alpha]_D^{25}$ −29.7 (*c* 2.38, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.82 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 0.88 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.91 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 1.20–1.50 (m, 6H, CH_2×3), 1.73 (septd, *J*=6.7, 6.7 Hz, 1H, C*H*(CH$_3$)$_2$), 2.85 (m, 1H, C*H*CH(CO$_2$CH$_3$)$_2$), 3.34 (dd, *J*=6.7, 6.7 Hz, 1H, C*H*OPMB), 3.40 (d, *J*=8.5 Hz, 1H, C*H*(CO$_2$CH$_3$)$_2$), 3.68 (s, 3H, CO_2CH_3), 3.73 (s, 3H, CO_2CH_3), 3.80 (s, 3H, ArOCH_3), 4.22 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.49 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.38–5.48 (m, 2H, CH═CH), 6.86 (d, *J*=8.5 Hz, 2H, ArH), 7.23 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.0, 18.3, 18.7, 22.3, 29.4, 32.2, 32.8, 42.9, 52.3, 52.4, 55.2, 57.0, 69.6, 84.6, 113.6 (2C), 129.1 (2C), 131.0, 132.6, 133.5, 158.9, 168.4, 168.7. IR: 2954 (CH), 2871 (CH), 1759 (C═O), 1739 (C═O). MS (FAB) *m*/*z* 443 (MNa^+). HRMS (FAB) calcd for $C_{24}H_{36}NaO_6$ (MNa^+): 443.2410; found: 443.2441.

3.1.27. 2-[(*E*,3*S*,6*S*)-3-(4-Methoxybenzyloxy)-2-methyl-4-decen-6-yl]malononitrile (15).



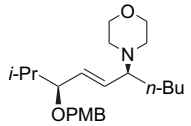
$Pd(PPh_3)_4$ (17.3 mg, 0.015 mmol) was added to a solution of (*E*)-**12b** (60.4 mg, 0.150 mmol) in THF (2 mL) with stirring at rt. After 15 min, a solution of sodiomalononitrile generated from NaH (60% in oil, 12 mg, 0.30 mmol) and $CH_2(CN)_2$ (0.019 mL, 0.30 mmol) in THF (2 mL) was added to the mixture. After 30 min, the reaction was quenched with water. Almost of the solvent was evaporated and the residue was extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica with gel with hexane–EtOAc (5:1) to give **15** (50.7 mg, 95%) as a yellow oil. $[\alpha]_D^{25}$ −8.7 (*c* 2.04, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.87 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 0.91 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.96 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 1.25–1.70 (m, 6H, CH_2×3), 1.81 (septd, *J*=6.7, 6.7 Hz, 1H, C*H*(CH$_3$)$_2$), 2.71 (ddt, *J*=9.8, 9.8, 4.9 Hz, 1H, C*H*CH(CN)$_2$), 3.45 (dd, *J*=6.7, 6.7 Hz, 1H, C*H*OPMB), 3.68 (d, *J*=4.9 Hz, 1H, CH(CN)$_2$), 3.80 (s, 3H, ArOCH_3), 4.32 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.56 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.45 (dd, *J*=15.3, 8.5 Hz, 1H, C═C*H*CH(CN)$_2$), 5.70 (dd, *J*=15.3, 8.5 Hz, 1H, C═C*H*CHOPMB), 6.87 (d, *J*=8.5 Hz, 2H, ArH), 7.26 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 13.8, 18.6, 18.7, 22.1, 28.9 (2C), 31.7, 32.7, 44.2, 55.2, 70.1, 84.0, 111.6, 112.1, 113.7 (2C), 129.2, 129.3 (2C), 130.6, 136.9, 159.0. IR: 2958 (CH), 2873 (CH), 2254 (CN). MS (FAB) *m*/*z* 377 (MNa^+). HRMS (FAB) calcd for $C_{22}H_{30}N_2NaO_2$ (MNa^+): 377.2205; found: 377.2206.

3.1.28. 5-[(*E*,3*S*,6*S*)-3-(4-Methoxybenzyloxy)-2-methyl-4-decen-6-yl]-2,2-dimethyl-1,3-dioxane-4,6-dione (16).



$Pd(PPh_3)_4$ (17.3 mg, 0.015 mmol) was added to a solution of (*E*)-**12b** (60.4 mg, 0.150 mmol) and in THF (2 mL) at rt. After stirring for 15 min, a solution of sodium salt of Meldrum's acid generated from NaH (60% in oil, 12 mg, 0.30 mmol) and meldrum's acid (43 μL, 0.30 mmol) in THF (2 mL) was added. After 30 min, the reaction was quenched with water. Almost of the solvent was evaporated and the residue was extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (4:1) to give **16** (15.7 mg, 24%) as a yellow oil. $[\alpha]_D^{25}$ −18.2 (*c* 0.51, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.83 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 0.89 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 0.91 (d, *J*=6.7 Hz, 3H, CH(CH_3)$_2$), 1.20–1.60 (m, 6H, CH_2×3), 1.71 (s, 3H, O$_2$C(CH$_3$)$_2$), 1.75 (s, 3H, O$_2$C(CH$_3$)$_2$), 1.81 (m, 1H, C*H*(CH$_3$)$_2$), 3.19 (m, 1H, C*H*n-Bu), 3.34 (dd, *J*=6.7, 6.7 Hz, 1H, C*H*OPMB), 3.50 (d, *J*=3.0 Hz, 1H, C*H*(CO$_2$R)$_2$), 3.79 (s, 3H, ArOCH_3), 4.19 (d, *J*=11.6 Hz, 1H, CH_2Ar), 4.44 (d, *J*=11.6 Hz, 1H, CH_2Ar), 5.50 (dd, *J*=15.6, 8.5 Hz, 1H, C═C*H*CHn-Bu), 5.67 (dd, *J*=15.6, 8.5 Hz, 1H, C═C*H*CHOPMB), 6.85 (d, *J*=8.5 Hz, 2H, ArH), 7.22 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.0, 18.3, 18.9, 22.3, 27.6, 28.2, 30.0, 31.7, 32.6, 42.7, 51.1, 55.2, 69.6, 84.6, 104.8, 113.7 (2C), 129.3 (2C), 130.9, 133.3, 133.4, 158.9, 164.7, 165.1. IR: 2962 (CH), 2873 (CH), 1784 (C═O), 1749 (C═O). MS (FAB) *m*/*z* 455 (MNa^+). HRMS (FAB) calcd for $C_{25}H_{36}NaO_6$ (MNa^+): 455.2410; found: 455.2427.

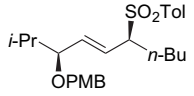
3.1.29. (*E*,3*S*,6*S*)-3-(4-Methoxybenzyloxy)-2-methyl-6-morpholino-4-decene (17).



$Pd(PPh_3)_4$ (17.3 mg, 0.015 mmol) was added to a solution of (*E*)-**12b** (60.4 mg, 0.15 mmol) and in THF (4 mL) with stirring at rt. After 15 min, morpholine (26 μL, 0.30 mmol) was added to the mixture. After 45 min, the reaction was quenched with water. Almost of solvent was evaporated and the residue was extracted with EtOAc. The combined

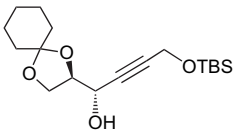
organic layers were washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (1:1) to give **17** (50.6 mg, 90%) as a yellow oil. $[\alpha]_D^{24}$ −19.4 (*c* 2.55, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.84–0.98 (m, 9H, $CH(CH_3)_2$ and CH_2CH_3), 1.20–1.65 (m, 6H, $CH_2\times3$), 1.78 (m, 1H, $CH(CH_3)_2$), 2.50 (m, 2H, NCH_2), 2.63 (m, 2H, NCH_2), 2.79 (m, 1H, NCH), 3.41 (m, 1H, CHOPMB), 3.73 (br, 4H, $O(CH_2)_2$), 3.81 (s, 3H, $ArOCH_3$), 4.29 (dd, *J*=11.6, 3.0 Hz, 1H, CH_2Ar), 4.54 (dd, *J*=11.6, 3.0 Hz, 1H, CH_2Ar), 5.45 (m, 2H, CH=CH), 6.87 (dd, *J*=8.5, 3.0 Hz, 2H, ArH), 7.25 (dd, *J*=8.5, 3.0 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.0, 18.5, 18.9, 22.6, 28.5, 31.6, 32.8, 50.3 (2C), 55.2, 67.3, 67.7 (2C), 69.8, 84.9, 113.6 (2C), 129.1 (2C), 130.9, 133.0, 133.2, 158.9. IR: 2956 (CH), 2856 (CH). MS (FAB) *m/z* 376 (MH^+). HRMS (FAB) calcd for $C_{23}H_{38}NO_3$ (MH^+): 376.2852; found: 376.2852.

3.1.30. (*E*,3*S*,6*S*)-3-(4-Methoxybenzyloxy)-2-methyl-6-(*p*-tolylsulfonyl)-4-decene (18).



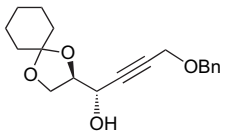
$Pd(PPh_3)_4$ (17.3 mg, 0.015 mmol) was added to a solution of (*E*)-**12b** (60.4 mg, 0.15 mmol) in THF (2 mL) at rt. After 10 min, a solution of sodium sulfinate (0.054 mL, 0.30 mmol) in THF–MeOH (1:1, 2 mL) was added. After 10 min, the reaction was quenched with water. Almost of the solvent was evaporated and the mixture was extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was chromatographed on silica gel with hexane–EtOAc (3:1) to give **18** (62.6 mg, 94%) as a yellow oil. $[\alpha]_D^{24}$ −18.8 (*c* 2.87, $CHCl_3$). ^1H NMR (500 MHz, $CDCl_3$) δ: 0.76 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 0.87 (d, *J*=6.7 Hz, 3H, $CH(CH_3)_2$), 0.88 (t, *J*=6.7 Hz, 3H, CH_2CH_3), 1.15–1.50 (m, 4H, $CH_2\times2$), 1.57–1.77 (m, 2H, $CH_2CH_2CH_2CH_3$), 2.14 (m, 1H, $CH(CH_3)_2$), 2.33 (s, 3H, $ArCH_3$), 3.34 (ddd, *J*=5.8, 5.8, 1.8 Hz, 1H, CHOPMB), 3.60 (m, 1H, $CHSO_2Ar$), 3.81 (s, 3H, $ArOCH_3$), 4.00 (d, *J*=11.0 Hz, 1H, CH_2Ar), 4.12 (d, *J*=11.0 Hz, 1H, CH_2Ar), 5.38–5.46 (m, 2H, CH=CH), 6.86 (d, *J*=8.5 Hz, 2H, ArH), 7.15 (d, *J*=8.5 Hz, 2H, ArH), 7.27 (d, *J*=8.5 Hz, 2H, ArH), 7.74 (d, *J*=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 14.3, 18.9, 19.3, 22.1, 22.6, 27.1, 29.3, 33.3, 55.8, 69.4, 70.4, 84.7, 114.2 (2C), 126.3, 129.3 (2C), 129.8 (2C), 130.2 (2C), 131.1, 135.5, 139.6, 145.1, 159.6. IR: 2956 (CH), 2871 (CH), 1143 (SO_2), 1298 (SO_2). MS (FAB) *m/z* 467 (MNa^+). HRMS (FAB) calcd for $C_{26}H_{36}NaO_4S$ (MNa^+): 467.2232; found: 467.2235.

3.1.31. (2*R*,3*S*)-6-(*tert*-Butyldimethylsilyloxy)-1,2-cyclohexylidenedioxy-4-hexyn-3-ol (20a).



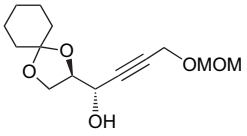
Compound **20a** was obtained as a colorless oil (306 mg, 70%, >97:3 dr) from **19** (560 mg, 3.28 mmol) as described for **11a**. $[\alpha]_D^{26}$ +18.3 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 0.11 (s, 6H, $SiCH_3$), 0.90 (s, 9H, $C(CH_3)_3$), 1.30–1.70 (m, 10H, $CH_2\times5$), 2.23 (d, *J*=4.8 Hz, 1H, OH), 4.05 (dd, *J*=17.3, 8.5 Hz, 1H, H-1), 4.06 (dd, *J*=17.3, 8.5 Hz, 1H, H-1), 4.23 (m, 1H, H-2 or H-3), 4.34 (d, *J*=1.2 Hz, 2H, H-6), 4.52–4.55 (m, 1H, H-2 or H-3). ^{13}C NMR δ: −5.3 (2C), 18.1, 23.6, 23.8, 25.0, 25.6 (3C), 34.5, 35.8, 51.5, 62.4, 64.8, 77.5, 82.1, 84.5, 110.5. IR: 3438 (OH), 2929 (CH), 2860 (CH). MS (FAB) *m/z* 341 (MH^+). HRMS (FAB) calcd for $C_{18}H_{33}O_4Si$ (MH^+): 341.2148; found: 341.2150.

3.1.32. (2*R*,3*S*)-6-Benzyloxy-1,2-cyclohexylidenedioxy-4-hexyn-3-ol (20b).



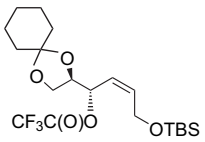
Compound **20b** was obtained as a colorless oil (643 mg, 68%, >97:3 dr) from **19** (538 mg, 3.16 mmol) as described for **11a**. $[\alpha]_D^{26}$ +18.6 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 1.30–1.70 (m, 10H, $CH_2\times5$), 2.25 (d, *J*=4.3 Hz, 1H, OH), 4.05 (dd, *J*=8.5, 6.4 Hz, 1H, H-1), 4.09 (dd, *J*=8.5, 6.4 Hz, 1H, H-1), 4.22 (d, *J*=1.2 Hz, 2H, H-6), 4.23–4.28 (m, 1H, H-2 or H-3), 4.53–4.57 (m, 1H, H-2 or H-3), 4.59 (s, 2H, CH_2Ph), 7.28–7.38 (m, 5H, ArH). ^{13}C NMR δ: 23.6, 23.9, 25.0, 34.5, 35.9, 57.2, 62.6, 64.9, 71.5, 77.4, 82.0, 83.9, 110.6, 127.8, 128.0 (2C), 128.3 (2C), 137.2. IR: 3415 (OH), 2937 (CH), 2857 (CH), 1626 (Ph). MS (FAB) *m/z* 317 (MH^+). HRMS (FAB) calcd for $C_{19}H_{25}O_4Si$ (MH^+): 317.1753; found: 317.1747.

3.1.33. (2*R*,3*S*)-1,2-Cyclohexylidenedioxy-6-methoxymethoxy-4-hexyn-3-ol (20c).



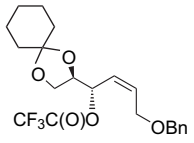
Compound **20c** was obtained as a yellow oil (608 mg, 75%, >97:3 dr) from **19** (556 mg, 3.26 mmol) as described for **11a**. $[\alpha]_D^{25}$ +16.9 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 1.30–1.75 (m, 10H, $CH_2\times5$), 2.41 (br, 1H, OH), 3.38 (s, 3H, OCH_3), 4.05 (m, 2H, H-1), 4.24 (m, 1H, H-2), 4.26 (s, 2H, H-6), 4.53 (dd, *J*=4.0, 1.2 Hz, 1H, H-3), 4.70 (s, 2H, OCH_2O). ^{13}C NMR δ: 23.6, 23.8, 25.0, 34.5, 35.9, 54.2, 55.5, 62.5, 64.9, 77.4, 81.6, 83.6, 94.6, 110.6. IR: 3452 (OH), 2936 (CH), 2864 (CH). MS (FAB) *m/z* 271 (MH^+). HRMS (FAB) calcd for $C_{14}H_{23}O_5$ (MH^+): 271.1546; found: 271.1540.

3.1.34. (*Z*,2*R*,3*S*)-6-(*tert*-Butyldimethylsilyloxy)-1,2-cyclohexylidenedioxy-4-hexen-3-yl trifluoroacetate [(*Z*)-21a].



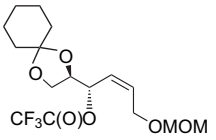
Compound **20a** (682 mg, 2.00 mmol) was converted into the (*Z*)-allylic alcohol (610 mg, 90%) by the procedure that described for compound (*Z*)-**12a**. Yellow oil. $[\alpha]_D^{25}$ +26.9 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 0.08 (s, 6H, $Si(CH_3)_2$), 0.91 (s, 9H, $C(CH_3)_3$), 1.30–1.75 (m, 10H, $CH_2\times5$), 2.58 (br, 1H, OH), 3.92 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.00 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.07 (m, 1H, H-3), 4.13 (dd, *J*=12.8, 5.5 Hz, 1H, H-6), 4.26 (dd, *J*=12.8, 8.5 Hz, 1H, H-6), 4.55 (m, 1H, H-2), 5.48 (ddd, *J*=11.6, 8.5, 1.2 Hz, 1H, H-4), 5.74 (m, 1H, H-5). ^{13}C NMR δ: −5.44, −5.40, 18.1, 23.6, 23.8, 25.0, 25.7 (3C), 34.5, 36.0, 59.7, 64.9, 67.8, 77.7, 109.6, 128.9, 132.9. IR: 3457 (OH), 2937 (CH), 2894 (CH). MS (FAB) *m/z* 343 (MH^+). HRMS (FAB) calcd for $C_{18}H_{35}O_4Si$ (MH^+): 343.2305; found: 343.2310. Compound (*Z*)-**21a** was obtained as a yellow oil (210 mg, 89%) from the (*Z*)-allylic alcohol (186 mg, 054 mmol) as described for (*E*)-**12a**. $[\alpha]_D^{25}$ +4.5 (*c* 1.07, $CHCl_3$). ^1H NMR δ: 0.11 (s, 6H, $Si(CH_3)_2$), 0.92 (s, 9H, $C(CH_3)_3$), 1.35–1.70 (m, 10H, $CH_2\times5$), 3.88 (dd, *J*=7.6, 7.6 Hz, 1H, H-1), 4.07 (dd, *J*=7.6, 7.6 Hz, 1H, H-1), 4.26 (m, 1H, H-2), 4.37 (m, 2H, H-6), 5.37 (m, 1H, H-4), 5.89 (dt, *J*=11.6, 5.5 Hz, 1H, H-5), 5.94 (m, 1H, H-3). ^{13}C NMR δ: −5.5, −5.4, 18.2, 23.7, 23.8, 25.0, 25.8 (3C), 34.8, 35.7, 60.0, 64.5, 73.5, 75.7, 110.7, 114.5 (q, J_{C-F}=285.9 Hz), 121.8, 137.4, 156.5 (q, J_{C-F}=42.4 Hz). IR: 2942 (CH), 2890 (CH), 1786 (C═O). MS (FAB) *m/z* 461 (MNa^+). HRMS (FAB) calcd for $C_{20}H_{33}F_3NaO_5Si$ (MNa^+): 461.1947; found: 461.1927.

3.1.35. (*Z*,2*R*,3*S*)-6-Benzyloxy-1,2-cyclohexylidenedioxy-4-hexen-3-yl trifluoroacetate [(*Z*)-21b].



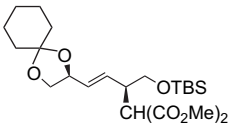
Compound **20b** (682 mg, 2.16 mmol) was converted into the (*Z*)-allylic alcohol (655 mg, 95%) by the procedure that described for compound (*Z*)-**12a**. Yellow oil. $[\alpha]_D^{25}$ +22.3 (*c* 0.87, $CHCl_3$). ^1H NMR δ: 1.36–1.65 (m, 10H, $CH_2\times5$), 2.48 (br, 1H, OH), 3.89 (dd, *J*=8.1, 6.7 Hz, 1H, H-1), 3.98 (dd, *J*=8.1, 6.7 Hz, 1H, H-1), 4.04 (m, 1H, H-2), 4.09 (ddd, *J*=12.8, 6.7, 1.2 Hz, 1H, H-6), 4.16 (ddd, *J*=12.8, 6.7, 1.2 Hz, 1H, H-6), 4.49 (m, 1H, H-3), 4.52 (q, *J*=16.5, 11.6 Hz, 2H, CH_2Ph), 5.57 (dd, *J*=11.6, 7.9 Hz, 1H, H-4), 5.82 (dt, *J*=11.6, 6.7 Hz, 1H, H-5), 7.25–7.37 (m, 5H, ArH). ^{13}C NMR δ: 23.7, 23.9, 25.1, 34.6, 36.1, 64.7, 66.1, 67.9, 72.6, 77.2, 77.7, 109.9, 127.8 (2C), 128.4 (2C), 130.4, 131.0, 137.8. IR: 3446 (OH), 2937 (CH), 2858 (CH). MS (FAB) *m/z* 319 (MH^+). HRMS (FAB) calcd for $C_{19}H_{27}O_4$ (MH^+): 319.1909; found: 319.1919. Compound (*Z*)-**21b** was obtained as a yellow oil (868 mg, quant.) from the (*Z*)-allylic alcohol (637 mg, 2.0 mmol) as described for (*E*)-**12a**. $[\alpha]_D^{25}$ +9.1 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 1.25–1.75 (m, 10H, $CH_2\times5$), 3.85 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.04 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.21 (m, 2H, H-6), 4.22 (m, 1H, H-2), 4.54 (dd, *J*=14.3, 11.6 Hz, 2H, CH_2Ph), 5.48 (dd, *J*=11.6, 8.5 Hz, 1H, H-4), 5.80 (dd, *J*=8.5, 5.5 Hz, 1H, H-3), 5.98 (dt, *J*=11.6, 5.5 Hz, 1H, H-5), 7.20–7.40 (m, 5H, ArH). ^{13}C NMR δ: 23.7, 23.8, 24.9, 34.7, 35.6, 64.6, 66.1, 72.8, 73.6, 75.5, 110.7, 114.4 (q, J_{C-F}=285.9 Hz), 123.9, 127.8 (3C), 128.4 (2C), 134.8, 137.7, 156.5 (q, J_{C-F}=42.4 Hz). IR: 2937 (CH), 2894 (CH), 1786 (C═O). MS (FAB) *m/z* 415 (MH^+). HRMS (FAB) calcd for $C_{21}H_{26}F_3O_5$ (MH^+): 415.1732; found: 415.1729.

3.1.36. (*Z*,2*R*,3*S*)-1,2-Cyclohexylidenedioxy-6-methoxymethoxy-4-hexen-3-yl trifluoroacetate [(*Z*)-21c].



Compound **20c** (500 mg, 1.85 mmol) was converted into the (*Z*)-allylic alcohol (495 mg, 98%) by the procedure that described for compound (*Z*)-**12a**. Yellow oil. $[\alpha]_D^{25}$ +26.9 (*c* 1.00, $CHCl_3$). ^1H NMR δ: 1.30–1.70 (m, 10H, $CH_2\times5$), 3.38 (s, 3H, OCH_3), 3.92 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.00 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.08 (dd, *J*=11.6, 6.7 Hz, 1H, H-3), 4.13 (ddd, *J*=12.8, 5.5, 1.2 Hz, 1H, H-6), 4.26 (ddd, *J*=12.8, 7.9, 1.2 Hz, 1H, H-6), 4.55 (m, 1H, H-2), 4.63 (d, *J*=6.7 Hz, 1H, OCH_2O), 4.67 (d, *J*=6.7 Hz, 1H, OCH_2O), 5.61 (m, 1H, H-4 or H-5), 5.78 (m, 1H, H-4 or H-5). ^{13}C NMR δ: 23.5, 23.7, 24.9, 34.4, 35.8, 55.0, 62.8, 64.9, 67.6, 77.5, 95.2, 109.6, 129.3, 131.5. IR: 3467 (OH), 2937 (CH), 2894 (CH). MS (FAB) *m/z* 273 (MH^+). HRMS (FAB) calcd for $C_{14}H_{25}O_5$ (MH^+): 273.1702; found: 273.1705. Compound (*Z*)-**21c** was obtained as a yellow oil (421 mg, quant.) from the (*Z*)-allylic alcohol (300 mg, 1.1 mmol) as described for (*E*)-**12a**. $[\alpha]_D^{26}$ +0.65 (*c* 1.30, $CHCl_3$). ^1H NMR δ: 1.25–1.60 (m, 10H, $CH_2\times5$), 3.31 (s, 3H, OCH_3), 3.80 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.01 (dd, *J*=8.5, 6.7 Hz, 1H, H-1), 4.14 (ddd, *J*=13.3, 6.7, 1.2 Hz, 1H, H-6), 4.18 (dd, *J*=11.6, 6.7 Hz, 1H, H-2), 4.23 (ddd, *J*=13.3, 6.7, 1.2 Hz, 1H, H-6), 4.58 (s, 2H, OCH_2O), 5.42 (dddd, *J*=11.6, 9.7, 1.2, 1.2 Hz, 1H, H-4), 5.74 (dd, *J*=9.7, 6.7 Hz, 1H, H-3), 5.88 (dt, *J*=11.6, 6.7 Hz, 1H, H-5). ^{13}C NMR δ: 23.7, 23.8, 24.9, 34.7, 35.6, 55.3, 63.1, 64.7, 73.4, 75.5, 95.9, 110.8, 114.4 (q, J_{C-F}=285.9 Hz), 124.0, 134.3, 156.4 (q, J_{C-F}=42.4 Hz). IR: 2942 (CH), 2890 (CH), 1786 (C═O). MS (FAB) *m/z* 369 (MH^+). HRMS (FAB) calcd for $C_{16}H_{24}F_3O_6$ (MH^+): 369.1525; found: 369.1532.

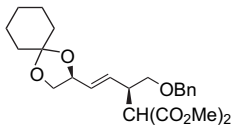
3.1.37. Dimethyl 2-[(*E*,2*S*,5*R*)-6-(*tert*-butyldimethylsilyloxy)-1,2-cyclohexylidenedioxy-3-hexen-5-yl]malonate (*syn*-22a).



Compound *syn*-**22a** was obtained as a yellow oil (70 mg, 77%) from (*Z*)-**21a** (88 mg, 0.20 mmol) as described for *anti*-**4**. $[\alpha]_D^{24}$ +35.9 (*c* 1.12, $CHCl_3$). ^1H NMR δ: 0.10 (s, 6H, $Si(CH_3)_2$), 0.87 (s, 9H, $C(CH_3)_3$), 1.30–1.70 (m, 10H, $CH_2\times5$), 2.99 (m, 1H, H-5′), 3.52 (m, 1H, H-2′), 3.62 (dd, *J*=9.8, 6.7 Hz, 1H, CH_2OTBS), 3.69 (m, 1H, CH_2OTBS), 3.70 (s, 3H, OCH_3), 3.71 (d, *J*=8.5 Hz, 1H, $CH(CO_2CH_3)_2$), 3.72 (s, 3H, OCH_3), 4.05 (dd, *J*=13.7, 8.5 Hz, 1H, H-1′),

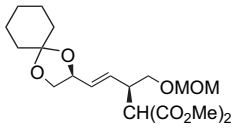
4.44 (dd, J=13.7, 6.7 Hz, 1H, H-1′), 5.56 (dd, J=15.6, 6.7 Hz, 1H, H-4′), 5.81 (dd, J=15.6, 8.5 Hz, 1H, H-3′). ^{13}C NMR δ: −5.4 (2C), 18.5, 24.1, 24.2, 25.4, 26.0 (3C), 35.7, 36.5, 44.9, 52.4, 52.6, 52.6, 63.9, 69.3, 76.4, 110.1, 130.9, 132.0, 169.0, 169.1. IR: 2933 (CH), 2861 (CH), 1755 (C═O), 1739 (C═O). MS (FAB) m/z 479 (MNa^+). HRMS (FAB) calcd for $C_{23}H_{40}NaO_7Si$ (MNa^+): 479.2441; found: 479.2474.

3.1.38. Dimethyl 2-[(*E*,2*S*,5*R*)-6-benzyloxy-1,2-cyclohexylidenedioxy-3-hexen-5-yl]malonate (*syn*-22b).



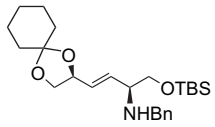
Compound *syn*-**22b** was obtained as a yellow oil (166 mg, 77%) from (*Z*)-**21b** (207 mg, 0.50 mmol) as described for *anti*-**4**. $[\alpha]_D^{25}$ +30.9 (c 1.02, $CHCl_3$). ^{1}H NMR δ: 1.30–1.65 (m, 10H, $CH_2\times5$), 3.16 (dddd, J=8.5, 6.7, 6.7, 5.5 Hz, 1H, H-5′), 3.51 (d, J=8.5 Hz, 1H, CH($CO_2CH_3)_2$), 3.52 (dd, J=8.5, 6.7 Hz, 1H, CH_2OBn), 3.58 (dd, J=8.5, 5.5 Hz, 1H, CH_2OBn), 3.66 (s, 3H, OCH_3), 3.67 (s, 3H, OCH_3), 3.68 (dd, J=15.6, 6.7 Hz, 1H, H-1′), 4.04 (dd, J=8.5, 6.7 Hz, 1H, H-2′), 4.44 (dd, J=15.6, 6.7 Hz, 1H, H-1′), 4.45 (s, 2H, CH_2Ph), 5.57 (dd, J=15.6, 6.7 Hz, 1H, H-4′), 5.80 (dd, J=15.6, 8.5 Hz, 1H, H-3′), 7.20–7.35 (m, 5H, ArH). ^{13}C NMR δ: 23.8, 23.8, 25.0, 35.3, 36.1, 42.4, 52.2, 52.3, 53.0, 68.9, 70.7, 73.0, 76.0, 110.0, 127.5, 127.7 (2C), 128.2 (2C), 130.2, 131.8, 137.9, 168.4, 168.5. IR: 2941 (CH), 2864 (CH), 1755 (C═O), 1736 (C═O). MS (FAB) m/z 455 (MNa^+). HRMS (FAB) calcd for $C_{24}H_{32}NaO_7$ (MNa^+): 455.2046; found: 455.2048.

3.1.39. Dimethyl 2-[(*E*,2*S*,5*R*)-1,2-cyclohexylidenedioxy-6-methoxymethoxy-3-hexen-5-yl]malonate (*syn*-22c).



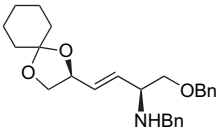
Compound *syn*-**22c** was obtained as a yellow oil (62 mg, 81%) from (*Z*)-**21c** (74 mg, 0.20 mmol) as described for *anti*-**4**. $[\alpha]_D^{25}$ +29.5 (c 2.54, $CHCl_3$). ^{1}H NMR δ: 1.30–1.70 (m, 10H, $CH_2\times5$), 3.12 (ddd, J=9.6, 7.6, 4.8 Hz, 1H, H-5′), 3.33 (s, 3H, CH_2OCH_3), 3.53 (m, 1H, H-2′), 3.57 (dd, J=9.8, 7.6 Hz, 1H, CH_2OMOM), 3.62 (dd, J=9.8, 4.8 Hz, 1H, CH_2OMOM), 3.68 (d, J=7.6 Hz, 1H, CH($CO_2CH_3)_2$), 3.71 (s, 3H, CO_2CH_3), 3.74 (s, 3H, CO_2CH_3), 4.05 (dd, J=14.0, 7.6 Hz, 1H, H-1′), 4.46 (dd, J=14.0, 6.7 Hz, 1H, H-1′), 4.57 (s, 2H, OCH_2O), 5.56 (dd, J=15.6, 7.6 Hz, 1H, H-3′), 5.81 (dd, J=15.6, 9.8 Hz, 1H, H-4′). ^{13}C NMR δ: 23.9, 23.9, 25.1, 35.4, 36.2, 42.4, 52.3, 52.4, 53.0, 55.3, 68.2, 69.0, 76.0, 96.4, 109.9, 130.2, 132.0, 168.4, 168.6. IR: 2937 (CH), 2863 (CH), 1755 (C═O), 1736 (C═O). MS (FAB) m/z 409 (MNa^+). HRMS (FAB) calcd for $C_{19}H_{30}NaO_8$ (MNa^+): 409.1838; found: 409.1833.

3.1.40. (*E*,2*S*,5*S*)-5-Benzylamino-6-(*tert*-butyldimethylsilyloxy)-1,2-cyclohexylidenedioxy-3-hexene (*syn*-23a).



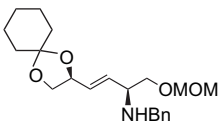
Compound *syn*-**23a** was obtained as a yellow oil (44 mg, 51%) from (*Z*)-**21a** (88 mg, 0.20 mmol) as described for *anti*-**5**. $[\alpha]_D^{24}$ +37.1 (c 2.00, $CHCl_3$). ^{1}H NMR δ: 0.10 (s, 6H, $Si(CH_3)_2$), 0.87 (s, 9H, $C(CH_3)_3$), 1.30–1.70 (m, 10H, $CH_2\times5$), 2.05 (br, 1H, NH), 3.25 (ddd, J=6.7, 6.7, 6.7 Hz, 1H, H-5), 3.51 (dd, J=17.4, 6.7 Hz, 1H, H-6), 3.54 (dd, J=17.4, 6.7 Hz, 1H, H-6), 3.57 (dd, J=6.7, 6.7 Hz, 1H, H-2), 3.67 (d, J=13.4 Hz, 1H, CH_2Ph), 3.87 (d, J=13.4 Hz, 1H, CH_2Ph), 4.07 (dd, J=13.7, 6.7 Hz, 1H, H-1), 4.52 (dd, J=13.7, 6.7 Hz, 1H, H-1), 5.60 (dd, J=15.6, 6.7 Hz, 1H, H-4), 5.68 (dd, J=15.6, 6.7 Hz, 1H, H-3), 7.20–7.40 (m, 5H, ArH). ^{13}C NMR δ: −5.4, −5.4, 18.2, 23.9, 23.9, 25.1, 25.8 (3C), 35.5, 36.2, 51.2, 61.1, 66.1, 69.2, 76.3, 109.9, 126.7, 128.0 (2C), 128.3 (2C), 131.4, 133.3, 140.5. IR: 2933 (CH), 2860 (CH). MS (FAB) m/z 432 (MH^+). HRMS (FAB) calcd for $C_{25}H_{42}NO_3Si$ (MH^+): 432.2934; found: 432.2956.

3.1.41. (*E*,2*S*,5*S*)-5-Benzylamino-6-benzyloxy-1,2-cyclohexylidenedioxy-3-hexene (*syn*-23b).



Compound *syn*-**23b** was obtained as a yellow oil (50 mg, 61%) from (*Z*)-**21b** (83 mg, 0.20 mmol) as described for *anti*-**5**. $[\alpha]_D^{25}$ +28.0 (c 1.61, $CHCl_3$). ^{1}H NMR δ: 1.30–1.70 (m, 10H, $CH_2\times5$), 2.06 (br, 1H, NH), 3.43 (m, 1H, H-5 or H-6), 3.45 (m, 2H, H-5 or H-6), 3.55 (dd, J=6.7, 6.7 Hz, 1H, H-2), 3.66 (d, J=13.4 Hz, 1H, CH_2Ph), 3.85 (d, J=13.4 Hz, 1H, CH_2Ph), 4.07 (dd, J=13.7, 6.7 Hz, 1H, H-1), 4.48 (dd, J=15.6, 12.2 Hz, 2H, CH_2Ph), 4.52 (dd, J=13.7, 6.7 Hz, 1H, H-1), 5.65 (dd, J=15.6, 5.5 Hz, 1H, H-4), 5.70 (dd, J=15.6, 6.7 Hz, 1H, H-3), 7.20–7.40 (m, 10H, ArH). ^{13}C NMR δ: 23.8, 23.9, 25.1, 35.5, 36.2, 51.3, 59.1, 69.1, 73.1, 73.2, 76.2, 110.0, 126.8, 127.7 (4C), 128.1, 128.4 (4C), 131.5, 133.0, 138.0, 140.3. MS (FAB) m/z 408 (MH^+). HRMS (FAB) calcd for $C_{26}H_{34}NO_3$ (MH^+): 408.2539; found: 408.2538.

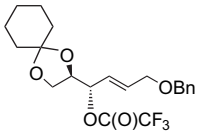
3.1.42. (*E*,2*S*,5*S*)-5-Benzylamino-1,2-cyclohexylidenedioxy-6-methoxymethoxy-3-hexene (*syn*-23c).



Compound *syn*-**23c** was obtained as a yellow oil (53 mg, 74%) from (*Z*)-**21c** (74 mg, 0.20 mmol) as described for *anti*-**5**. $[\alpha]_D^{26}$ +28.8 (c 2.72, $CHCl_3$). ^{1}H NMR δ: 1.30–1.70

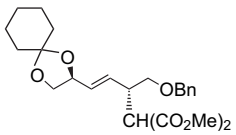
(m, 10H, $CH_2\times5$), 2.05 (br, 1H, NH), 3.33 (s, 3H, OCH_3), 3.40 (m, 1H, H-5), 3.47 (m, 1H, H-6), 3.54 (m, 1H, H-2), 3.56 (m, 1H, H-6), 3.68 (d, J=13.4 Hz, 1H, CH_2Ph), 3.87 (d, J=13.4 Hz, 1H, CH_2Ph), 4.07 (dd, J=13.4, 6.1 Hz, 1H, H-1), 4.53 (dd, J=13.4, 6.1 Hz, 1H, H-1), 4.60 (s, 2H, OCH_2O), 5.66 (dd, J=15.6, 6.1 Hz, 1H, H-4), 5.72 (dd, J=15.6, 6.1 Hz, 1H, H-3), 7.20–7.40 (m, 5H, ArH). ^{13}C NMR δ: 23.8, 23.9, 25.1, 35.4, 36.2, 51.3, 55.3, 59.2, 69.1, 70.7, 76.2, 96.6, 110.0, 126.9, 128.1 (2C), 128.4 (2C), 131.6, 132.9, 140.2. IR: 2933 (CH), 2864 (CH). MS (FAB) m/z 362 (MH^+). HRMS (FAB) calcd for $C_{21}H_{32}NO_4$ (MH^+): 362.2331; found: 362.2325.

3.1.43. (*E*,2*R*,3*S*)-6-Benzyloxy-1,2-cyclohexylidenedioxy-4-hexen-3-yl trifluoroacetate [(*E*)-21b].



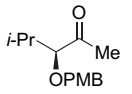
Red-Al® (65% in toluene, 1.20 mL, 4.0 mmol) was added to a solution of **20b** (633 mg, 2.0 mmol) with stirring at 0 °C. The stirring was continued for 1 h at this temperature. The reaction was quenched with saturated aqueous Rochelle salt and extracted with Et_2O. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (3:1) to give (*E*)-allylic alcohol (547 mg, 86%) as a yellow oil. $[\alpha]_D^{21}$ +4.20 (*c* 1.00, $CHCl_3$). ^{1}H NMR δ: 1.25–1.65 (m, 10H, $CH_2\times5$), 2.15 (br, 1H, OH), 3.92 (m, 2H, H-1), 4.05 (dd, J=5.5, 1.2 Hz, 2H, H-6), 4.11 (ddd, J=6.7, 6.7, 4.3 Hz, 1H, H-2), 4.35 (dd, J=5.5, 4.3 Hz, 1H, H-3), 4.52 (s, 2H, CH_2Ph), 5.72 (ddt, J=15.6, 5.5, 1.2 Hz, 1H, H-4), 5.94 (dtd, J=15.6, 5.5, 1.2 Hz, 1H, H-5), 7.20–7.40 (m, 5H, ArH). ^{13}C NMR δ: 23.7, 23.9, 25.1, 34.6, 36.1, 64.3, 69.9, 71.1, 72.2, 77.7, 109.9, 127.6, 127.7 (2C), 128.4 (2C), 129.2, 130.2, 138.1. IR: 3444 (OH), 2931 (CH), 2860 (CH). MS (FAB) m/z 319 (MH^+). HRMS (FAB) calcd for $C_{19}H_{27}O_4$ (MH^+): 319.1909; found: 319.1916. Compound (*E*)-**21b** was obtained as a yellow oil (240 mg, quant.) from the (*E*)-allylic alcohol (191 mg, 0.6 mmol) as described for (*E*)-**12a**. $[\alpha]_D^{25}$ +23.6 (*c* 1.00, $CHCl_3$). ^{1}H NMR δ: 1.25–1.75 (m, 10H, $CH_2\times5$), 3.85 (dd, J=8.5, 6.7 Hz, 1H, H-2), 4.05 (m, 1H, H-1), 4.06 (m, 2H, H-6), 4.26 (dd, J=11.6, 6.7 Hz, 1H, H-1), 4.52 (s, 2H, CH_2Ph), 5.57 (dd, J=8.5, 6.7 Hz, 1H, H-3), 5.74 (dd, J=15.6, 6.7 Hz, 1H, H-4), 5.98 (dt, J=15.6, 5.5 Hz, 1H, H-5), 7.25–7.37 (m, 5H, ArH). ^{13}C NMR δ: 23.8, 23.8, 25.1, 34.8, 35.8, 64.7, 69.2, 72.6, 75.7, 77.1, 110.9, 114.5 (q, J_{C-F}= 285.9 Hz), 123.8, 127.8 (2C), 127.8, 128.5 (2C), 133.9, 137.8, 156.5 (q, J_{C-F}=42.4 Hz). IR: 2937 (CH), 2859 (CH), 1788 (C=O). MS (FAB) m/z 421 (MLi^+). HRMS (FAB) calcd for $C_{21}H_{25}F_3LiO_5$ (MLi^+): 421.1814; found: 421.1818.

3.1.44. Dimethyl 2-[(*E*,2*S*,5*S*)-6-benzyloxy-1,2-cyclohexylidenedioxy-3-hexen-5-yl]malonate (*anti*-22b).



Compound *anti*-**22b** was obtained as a yellow oil (65 mg, 77%) from (*E*)-**24b** (83 mg, 0.20 mmol) as described for *anti*-**4**. $[\alpha]_D^{25}$ −14.4 (*c* 1.69, $CHCl_3$). ^{1}H NMR δ: 1.30–1.70 (m, 10H, $CH_2\times5$), 3.15 (ddd, J=8.5, 6.7, 4.9 Hz, 1H, H-1′), 3.50 (dd, J=8.5, 8.5 Hz, 1H, CH(CO_2CH_3)$_2$), 3.52 (dd, J=8.5, 6.7 Hz, 1H, CH_2OBn), 3.58 (dd, J=8.5, 4.9 Hz, 1H, CH_2OBn), 3.65 (s, 3H, OCH_3), 3.66 (s, 3H, OCH_3), 3.71 (dd, J=14.6, 8.5 Hz, 1H, H-5′), 4.02 (td, J=8.5, 6.7 Hz, 1H, H-4′), 4.44 (dd, J=14.6, 6.7 Hz, 1H, H-5′), 4.45 (s, 2H, CH_2Ph), 5.58 (dd, J=15.6, 8.5 Hz, 1H, H-2′), 5.81 (dd, J=15.6, 8.5 Hz, 1H, H-3′), 7.27–7.35 (m, 5H, ArH). ^{13}C NMR δ: 23.8, 23.9, 25.1, 35.4, 36.2, 42.7, 52.2, 52.3, 53.0, 68.9, 70.6, 73.1, 76.3, 110.0, 127.6, 127.6 (2C), 128.3 (2C), 130.8, 131.9, 137.9, 168.4, 168.6. IR: 2942 (CH), 2937 (CH), 2863 (CH), 1754 (C=O), 1737 (C=O). MS (FAB) m/z 455 (MNa^+). HRMS (FAB) calcd for $C_{24}H_{32}NaO_7$ (MNa^+): 455.2046; found: 455.2045.

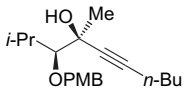
3.1.45. (*S*)-3-(4-Methoxybenzyloxy)-4-methylpentan-2-one (24).



A solution of (*S*)-(+)-2-hydroxy-3-methylbutyric acid (650 mg, 5.50 mmol), *N*,*O*-dimethylhydroxyamine (488 mg, 5.00 mmol), 1-hydroxybenzotriazole (676 mg, 5.00 mmol) and *i*Pr_2NEt (0.86 mL, 5.00 mmol) in CH_2Cl_2 (20 mL) was stirred at rt for 30 min. A solution of 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide (1.05 g, 5.50 mmol) in CH_2Cl_2 (10 mL) was added, and the mixture was stirred at 0 °C for 2 h and then at rt for 3 h. The reaction mixture was extracted with EtOAc and acid after evaporation. The combined organic layers were washed with saturated $NaHCO_3$ and brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (1:1) to give 2-hydroxy-*N*-methoxy-3,*N*-dimethylbutyramide (746 mg, 93%) as a pale oil. $[\alpha]_D^{24}$ −14.8 (*c* 1.19, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.79 (d, J=6.7 Hz, 3H, CCH_3), 1.01 (d, J=6.7 Hz, 3H, CCH_3), 2.01 (br, 1H, CH(CH_3)$_2$), 3.08 (br, 1H, OH), 3.22 (s, 3H, NCH_3), 3.68 (br, 3H, OCH_3), 4.24 (br, 1H, CHOH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 15.1 (2C), 19.3, 31.1, 60.9, 72.5, 174.4. IR: (KBr) cm^{-1}: 3462 (OH), 2966 (CH), 1655 (C=O). MS (FAB) m/z 162 (MH^+). HRMS (FAB) calcd for $C_7H_{16}NO_3$ (MH^+): 162.1130; found: 162.1125. *p*-Methoxybenzyl chloride (0.150 mL, 1.10 mmol) and tetrabutylammonium iodide (19.0 mg, 0.05 mmol) were added to the alkoxide generated from the alcohol (161 mg, 1.00 mmol) and NaH (60% in oil, 44.0 mg, 1.10 mmol) in THF (4 mL) at rt and stirred for 8 h. The reaction mixture was quenched with saturated aqueous NH_4Cl solution and extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (2:1) to give *N*-methoxy-2-(4-methoxybenzyloxy)-3,*N*-dimethylbutyramide (199 mg, 71%) as a brown oil. $[\alpha]_D^{26}$ −51.0 (*c* 1.04, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.91 (d, J=6.7 Hz, 3H, CCH_3), 1.01 (d, J=6.7 Hz, 3H, CCH_3), 2.09 (m, 1H, CH(CH_3)$_2$), 3.22 (s, 3H, NCH_3), 3.59 (s, 3H, $NOCH_3$), 3.80 (s, 3H, ArOCH_3),

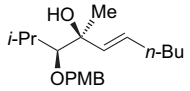
4.01 (br, 1H, CHCO), 4.30 (d, J=11.6 Hz, 1H, CH_2Ar), 4.62 (d, J=11.6 Hz, 1H, CH_2Ar), 6.86 (d, J=8.5 Hz, 2H, ArH), 7.28 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 18.1, 18.9, 30.8, 32.2, 55.1, 61.0, 71.1, 80.0, 113.5 (2C), 129.3 (2C), 130.0, 159.1, 173.2. IR: (KBr) cm^{-1} 2962 (CH), 1670 (C=O). MS (FAB) m/z 282 (MH^+). HRMS (FAB) calcd for $C_{15}H_{24}NO_4$ (MH^+): 282.1705; found: 282.1690. MeMgI (0.84 M in ether, 16.6 mL, 14.0 mmol) was added to a solution of the PMB ether (1.12 g, 4.0 mmol) in ether (20 mL) at 0 °C and stirred for 2 h after warming to rt. The reaction was quenched with saturated aqueous NH_4Cl solution. The reaction mixture was extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (2:1) to give **24** (727 mg, 77%) as a colorless oil. $[\alpha]_D^{26}$ −81.0 (c 1.10, $CHCl_3$). ^{1}H NMR (500 MHz, $CDCl_3$) δ: 0.86 (d, J=6.7 Hz, 3H, CCH_3), 0.94 (d, J=6.7 Hz, 3H, CCH_3), 1.94 (hept, J=6.7 Hz, 1H, CH(CH_3)$_2$), 2.12 (s, 3H, $COCH_3$), 3.37 (d, J=6.7 Hz, 1H, CHOPMB), 3.78 (s, 3H, ArOCH_3), 4.29 (d, J=11.6 Hz, 1H, CH_2Ar), 4.48 (d, J=11.6 Hz, 1H, CH_2Ar), 6.85 (d, J=8.5 Hz, 2H, ArH), 7.23 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR (75 MHz, $CDCl_3$) δ: 18.2, 18.6, 25.8, 30.8, 55.2, 72.5, 90.2, 113.8 (2C), 129.5 (2C), 129.6, 159.3, 211.9. IR: (KBr) cm^{-1} 2964 (CH), 1712 (C=O). MS (FAB) m/z 259 (MNa^+). HRMS (FAB) calcd for $C_{14}H_{20}NaO_3$ (MNa^+): 259.1310; found: 259.1318.

3.1.46. (3*S*,4*S*)-3-(4-Methoxybenzyloxy)-2,4-dimethyl-5-decyn-4-ol (25).



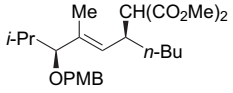
EtMgBr (1 M in THF, 4.5 mL, 4.51 mmol) was added to a solution of 1-hexyne (0.49 mL, 4.27 mmol) in THF (4 mL) at rt and stirred under reflux for 1 h. The magnesium acetylide was added to a solution of **24** (288 mg, 1.22 mmol) in THF (10 mL) at 45 °C and stirred for 2 h at the same temperature. The reaction mixture was quenched with saturated aqueous NH_4Cl solution and extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (9:1) to give **25** (379 mg, 97%, >97:3 dr) as a brown oil. $[\alpha]_D^{21}$ +31.2 (c 1.64, $CHCl_3$). ^{1}H NMR δ: 0.82 (t, J=7.3 Hz, 3H, H-10), 0.92 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 0.97 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.25–1.48 (m, 4H, H-8 and H-9), 1.35 (s, 3H, 4-CH_3), 1.96 (heptd, J=6.7, 3.1 Hz, 1H, H-2), 2.13 (t, J=7.3 Hz, 2H, H-7), 2.68 (br, 1H, OH), 3.27 (d, J=3.1 Hz, 1H, H-3), 3.73 (s, 3H, ArOCH_3), 4.57 (d, J=11.0 Hz, 1H, CH_2Ar), 4.75 (d, J=11.0 Hz, 1H, CH_2Ar), 6.81 (d, J=8.5 Hz, 2H, ArH), 7.24 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.6, 17.3, 18.4, 22.0, 22.6, 25.5, 29.7, 30.7, 55.2, 70.4, 75.7, 83.7, 84.3, 89.0, 113.7 (2C), 129.3 (2C), 130.8, 159.2. IR: 3479 (OH), 2956 (CH). MS (FAB) m/z 341 (MNa^+). HRMS (FAB) calcd for $C_{20}H_{30}NaO_3$ (MNa^+), 341.2093; found: 341.2111.

3.1.47. (*E*,3*S*,4*S*)-3-(4-Methoxybenzyloxy)-2,4-dimethyl-5-decen-4-ol (26).



$LiAlH_4$ (25 mg, 0.65 mmol) was added to a solution of **25** (104 mg, 0.33 mmol) in THF (3 mL) at 0 °C and stirred under reflux for 1 h. The reaction mixture was quenched with saturated aqueous Rochelle salt and extracted with ether. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (9:1) to give **26** (92.1 mg, 88%) as a colorless oil. $[\alpha]_D^{27}$ +31.5 (c 0.90, $CHCl_3$). ^{1}H NMR δ: 0.89 (t, J=6.7 Hz, 3H, H-10), 1.00 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.02 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 1.23 (s, 3H, 4-CH_3), 1.28–1.40 (m, 4H, H-8 and H-9), 1.95 (septd, J=6.7, 3.1 Hz, 1H, H-2), 2.06 (dt, J=6.7, 6.7 Hz, 2H, H-7), 2.33 (br, 1H, OH), 3.12 (d, J=3.1 Hz, 1H, H-3), 3.81 (s, 3H, ArOCH_3), 4.56 (d, J=12.8 Hz, 1H, CH_2Ar), 4.58 (d, J=12.8 Hz, 1H, CH_2Ar), 5.56 (d, J=15.9 Hz, 1H, H-5), 5.70 (dt, J=15.9, 6.7 Hz, 1H, H-6), 6.88 (d, J=8.5 Hz, 2H, ArH), 7.26 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 13.9, 17.3, 22.2, 23.0, 23.7, 29.4, 31.4, 32.0, 55.2, 75.2, 75.5, 89.4, 113.6, 113.7, 128.9, 129.1, 129.3, 130.9, 136.0, 159.1. IR: 3548 (OH), 2958 (CH). MS (FAB) m/z 343 (MNa^+). HRMS (FAB) calcd for $C_{20}H_{32}NaO_3$ (MNa^+), 343.2249; found: 343.2234.

3.1.48. Dimethyl 2-[(*E*,3*S*,6*S*)-3-(4-methoxybenzyloxy)-2,4-dimethyl-4-decen-6-yl]malonate (27).



Trifluoroacetic anhydrate (0.30 mL, 2.2 mmol) was added to a solution of **26** (342 mg, 1.1 mmol) and pyridine (0.19 mL, 2.4 mmol) in ether (5.0 mL) at 0 °C. After the reaction mixture was warmed to rt, stirred for 30 min. The reaction was quenched with saturated aqueous NH_4Cl. The reaction mixture was extracted with ether. The combined organic layers were washed with brine prior to drying and solvent evaporation. The crude was used in next step. $Pd(PPh_3)_4$ (17 mg, 0.015 mmol) was added to a solution of the crude (62 mg) in THF (1.5 mL) at rt and the stirring was continued for 15 min. Dimethyl malonate (0.072 mL, 0.63 mmol) was added to a suspension of NaH (60% in oil, 24 mg, 0.60 mmol) in THF (2 mL) with stirring at 0 °C. After stirring for 30 min, the solution was added to the abovementioned mixture and the whole was refluxed for 3 h. The reaction was quenched with water. The reaction mixture was concentrated before extracted with EtOAc. The combined organic layers were washed with brine prior to drying and solvent evaporation. The residue was purified by column chromatography on silica gel with hexane–EtOAc (9:1) to give **27** (31 mg, 48%) as a pale oil. $[\alpha]_D^{25}$ −23.7 (c 1.56, $CHCl_3$). ^{1}H NMR δ: 0.71 (d, J=6.7 Hz, 3H, CH(CH_3)$_2$), 0.85 (t, J=6.7 Hz, 3H, CH_2CH_3), 0.97 (d, J=6.7 Hz, 3H,

$CH(CH_3)_2$), 1.15–1.50 (m, 6H, $CH_2\times3$), 1.63 (s, 3H, $C{=}CCH_3$), 1.78 (dsept, J=9.1, 6.7 Hz, 1H, $CH(CH_3)_2$), 3.10 (d, J=9.1 Hz, 1H, CHOPMB), 3.20 (dtd, J=10.4, 9.1, 3.0 Hz, 1H, H-6′), 3.40 (d, J=9.1 Hz, 1H, $CH(CO_2CH_3)_2$), 3.68 (s, 3H, CO_2CH_3), 3.74 (s, 3H, $ArOCH_3$), 3.80 (s, 3H, CO_2CH_3), 4.04 (d, J=11.6 Hz, 1H, CH_2Ar), 4.33 (d, J=11.6 Hz, 1H, CH_2Ar), 5.10 (d, J=10.4 Hz, 1H, C=CH), 6.86 (d, J=8.5 Hz, 2H, ArH), 7.24 (d, J=8.5 Hz, 2H, ArH). ^{13}C NMR δ: 11.2, 13.9, 19.2, 19.8, 22.4, 29.2, 30.2, 32.9, 38.2, 52.3, 52.4, 55.2, 57.3, 69.0, 90.8, 113.6 (2C), 129.4 (2C), 130.0, 131.0, 137.3, 158.9, 168.7, 168.9. IR: 2954 (CH), 1759 (C=O), 1736 (C=O). MS (FAB) *m/z* 457 (MNa^+). HRMS (FAB) calcd for $C_{25}H_{38}NaO_6$ (MNa^+): 457.2566: found: 457.2588.

References and notes

1. For application of olefins flanking two stereogenic centers to a sythesis of natural products, see: (a) Block, O.; Klein, G.; Altenbach, H.-J.; Brauer, D. J. *J. Org. Chem.* **2000**, *65*, 716–721; (b) Carretero, J. C.; Arrayas, R. G. *J. Org. Chem.* **1998**, *63*, 2993–3005; (c) Rigby, J. H.; Mateo, M. E. *J. Am. Chem. Soc.* **1997**, *119*, 12655–12656; (d) Hudlicky, T.; Olivo, H. F. *J. Am. Chem. Soc.* **1992**, *114*, 9694–9696; (e) Takeda, K.; Kaji, E.; Konda, Y.; Sato, N.; Nakamura, H.; Miya, N.; Morizane, A.; Yanagisawa, Y.; Akiyama, A.; Zen, S.; Harigaya, Y. *Tetrahedron Lett.* **1992**, *33*, 7145–7148; (f) Bäckvall, J.-E.; Schink, H. E.; Renko, Z. D. *J. Org. Chem.* **1990**, *55*, 826–831.
2. Two methods have been developed so far; Pd-catalyzed allylic substitution reactions of cyclic carbonates and 1,3-diene monoepoxides, see: (a) Pettersson-Fasth, H.; Riesinger, S. W.; Bäckvall, J.-E. *J. Org. Chem.* **1995**, *60*, 6091–6096; (b) Kang, S.-K.; Kim, S.-G.; Lee, J.-S. *Tetrahedron: Asymmetry* **1992**, *3*, 1139–1140; (c) Tsuji, J.; Kataoka, H.; Kobayashi, Y. *Tetrahedron Lett.* **1981**, *22*, 2575–2578; (d) Trost, B. M. *Acc. Chem. Res.* **1980**, *13*, 385–393.
3. For selected recent reviews for Pd-catalyzed allylic substitutions, see: (a) Trost, B. M.; Crawley, M. L. *Chem. Rev.* **2003**, *103*, 2921–2943; (b) Kazmaier, U. *Curr. Org. Chem.* **2003**, *7*, 317–328; (c) Trost, B. M. *Chem. Pharm. Bull.* **2002**, *50*, 1–14; (d) van Leeuwen, P. W. N. M.; Kamer, P. C. J.; Reek, J. N. H.; Dierkes, P. *Chem. Rev.* **2000**, *100*, 2741–2769; (e) Moberg, C.; Bremberg, U.; Hallman, K.; Svensson, M.; Norrby, P.-O.; Hallberg, A.; Larhed, M.; Csöregh, I. *Pure Appl. Chem.* **1999**, *71*, 1477–1483; (f) Poli, G.; Scolastico, C. *Chemtracts* **1999**, *12*, 822–836; (g) Trost, B. M.; van Vranken, D. L. *Chem. Rev.* **1996**, *96*, 395–422; (h) Reiser, O. *Angew. Chem.* **1993**, *105*, 576–578; (i) Sawamura, M.; Ito, Y. *Chem. Rev.* **1992**, *92*, 857–871.
4. Maezaki, N.; Hirose, Y.; Tanaka, T. *Org. Lett.* **2004**, *6*, 2177–2180.
5. Clayden and co-workers reported the Pd-catalyzed rearrangement of allylic esters controlled by a dibenzylamino group. However, the regioselectivity depends on the acyl groups and is not sufficiently high, see: Clayden, J.; McCarthy, C.; Cumming, J. G. *Tetrahedron: Asymmetry* **1998**, *9*, 1427–1440.
6. Related reaction using iodohexene, see: Chen, M.-J.; Narkunan, K.; Liu, R.-S. *J. Org. Chem.* **1999**, *64*, 8311–8318.
7. Massad, S. K.; Hawkins, L. D.; Baker, D. C. *J. Org. Chem.* **1983**, *48*, 5180–5182.
8. Precursors of π-allylpalladium complexes, see: Tsuji, J. *Tetrahedron* **1986**, *42*, 4361–4401.
9. Vitagliano, A.; Åkermark, B.; Hansson, S. *Organometallics* **1991**, *10*, 2592–2599.
10. All reactions were carried out using Pd catalyst (10 mol %), ligand (30 mol %), dibenzylamine (2 equiv) in refluxing THF.
11. Kosugi, H.; Tagami, K.; Takahashi, A.; Kanna, H.; Uda, H. *J. Chem. Soc., Perkin Trans. 1* **1989**, 935–943.
12. Modified Mosher method was applied for determination of the absolute configuration of *anti*-**5** after reductive deprotection with $Pd(OH)_2$–C and conversion to the corresponding MTPA esters. The R-configuration does not contradict the double inversion mechanism. Stereochemistry of other products was assumed by analogy of these results. For Modified Mosher method, see: Ohtani, I.; Kusumi, T.; Kashman, Y.; Kakisawa, H. *J. Am. Chem. Soc.* **1991**, *113*, 4092–4096.
13. Roush, W. R.; Bennett, C. E.; Roberts, S. E. *J. Org. Chem.* **2001**, *66*, 6389–6393.
14. Mead, K. T. *Tetrahedron Lett.* **1987**, *28*, 1019–1022.
15. For the Carreira's asymmetric alkynylation, see: (a) Anand, N. K.; Carreira, E. M. *J. Am. Chem. Soc.* **2001**, *123*, 9687–9688; (b) Frants, D. E.; Fässler, R.; Tomooka, C. S.; Carreira, E. M. *Acc. Chem. Res.* **2000**, *33*, 373–381; (c) Frants, D. E.; Fässler, R.; Carreira, E. M. *J. Am. Chem. Soc.* **2000**, *122*, 1806–1807.
16. Li, W.-R.; Ewing, W. R.; Harris, B. D.; Joullie, M. M. *J. Am. Chem. Soc.* **1990**, *112*, 7659–7672.
17. Hayashi, T.; Yamamoto, A.; Hagihara, T. *J. Org. Chem.* **1986**, *51*, 723–727.
18. (a) Evans, D. A.; Burch, J. D. *Org. Lett.* **2001**, *3*, 503–506; (b) Wroblewski, A. E.; Balcerzak, K. B. *Tetrahedron* **1998**, *54*, 6833–6840; (c) Chattopadhyay, A.; Mamdapur, V. R. *J. Org. Chem.* **1995**, *60*, 585–587.
19. Nucleophilic addition to the acetonide-protected glyceraldehyde regularly affords poor selectivity; see: Mead, K.; Macdonald, T. L. *J. Org. Chem.* **1985**, *50*, 422–424.