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Diastereoselective Diels−Alder Reactions with an Allenyl-Containing Spiro-Amido Chiral Auxiliary

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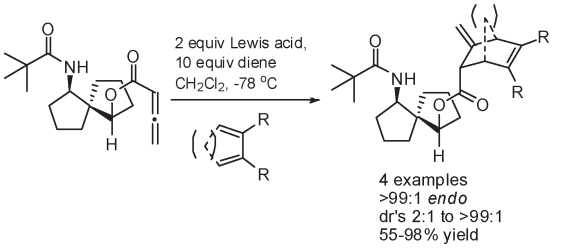
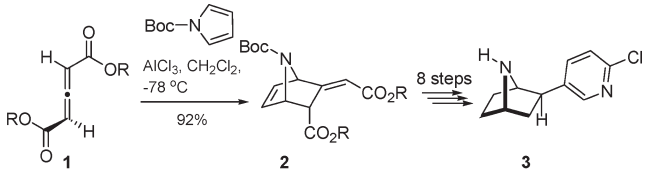


A novel allenyl-containing 1,3-spiro-amido alcohol auxiliary has been prepared and used in a variety of diastereoselective Diels−Alder reactions providing exclusively *endo* adducts with diastereomeric ratios ranging from 2:1 to >99:1.

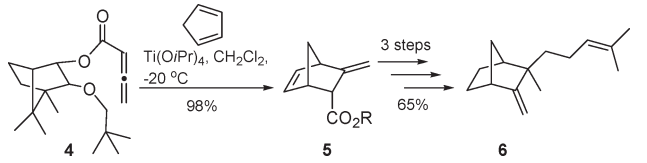
Allenes are a well-known group of compounds that contain cumulative carbon−carbon double bonds. The synthesis and numerous applications of allenes have attracted the attention of many research groups.[1] One interesting area of research is the use of allene-containing compounds as dienophiles in the Diels−Alder reaction. This application provides a potentially powerful method for the installation and control of several stereocenters in addition to the newly formed ring containing an exocyclic double bond. Although the use of allene-containing dienophiles activated by one[2] and two[3] electron-withdrawing groups have been reported, their use with chiral auxiliaries have been limited. Diastereoselective Diels−Alder reactions with allene-1,3-dicarboxylate have generally involved the use of two chiral alcohols such as menthol,[3b,c] borneol,[3d−f] or isoborneol.[3d−f] For example, Node et al. have reported the use of allene-1,3-dicarboxylate dienophile **1** with an isoborneol auxiliary to prepare intermediate **2** in the formal asymmetric synthesis of (−)-epibatidine (**3**) (Scheme 1).[3d]

SCHEME 1



To our knowledge, only two examples of diastereoselective Diels−Alder reactions between a monoester-activated allene-containing dienophile and the highly reactive diene cyclopentadiene have been reported. Oppolzer et al. reported the diastereoselective Diels−Alder reaction of camphor-derived allenic ester **4** with cyclopentadiene to afford adduct **5** in 99% de that was subsequently converted to (−)-*β*-santalene (**6**) (Scheme 2).[4] Similarly, Bertrand et al. demonstrated the same Diels−Alder reaction with cyclopentadiene using three additional chiral alcohols.[5] Given the paucity of diastereoselective Diels−Alder reactions with monoester-activated allenic dienophiles, we decided to expand the scope of these types of Diels−Alder reactions with less reactive dienes.

SCHEME 2



Since 2003, we have reported the synthesis of both enantiomers of (1*R*,5*R*,6*R*)-6-(2,2-dimethylpropanamido)-spiro[4.4]-nonan-1-ol (**8**) from *δ*-valerolactone (**7**) (Scheme 3).[6−8] 1,3-Spiro-amido dienophiles **9a**−**c**, derived from **8**, were shown to

(1) For general allene information, see: (a) Taylor, D. R. *Chem. Rev.* **1967**, *67*, 317. (b) Coppola, G. M.; Schuster, H. F. *Allenes in Organic Synthesis*; Wiley: New York, 1984 (c) *Modern Allene Chemistry*; Krause, N., Hashmi, A. S. K., Eds.; Wiley-VCH: Weinheim, 2004.

(2) For examples of activation of allenes by an ester, see: (a) Ismail, Z. M.; Hoffmann, H. M. R. *J. Org. Chem.* **1981**, *46*, 3549. (b) Jung, M. E.; Murakami, M. *Org. Lett.* **2007**, *9*, 461. (c) De Schrijver, J.; De Clercq, P. J. *Tetrahedron Lett.* **1993**, *34*, 4369. Lactone: (d) Jung, M. E.; Zimmerman, C. N.; Lowen, G. T.; Khan, S. I. *Tetrahedron Lett.* **1993**, *34*, 4453. (e) Fotiadu, F.; Archaulis, A.; Buono, G. *Tetrahedron Lett.* **1990**, *31*, 4859. Ketones: (f) Gleiter, R.; Sigwart, C. *J. Org. Chem.* **1994**, *59*, 1027. (g) Gras, J.-L.; Guerin, A. *Tetrahedron Lett.* **1985**, *26*, 1781. Cyano: (h) Danheiser, R. L.; Casebier, D. S.; Huboux, A. H. *J. Org. Chem.* **1994**, *59*, 4844. Sulfoxides: (i) Padwa, A.; Bullock, W. H.; Norman, B. H.; Perumattam, J. *J. Org. Chem.* **1991**, *56*, 4252. Sulfones: (j) Hayakawa, K.; Nishiyama, H.; Kanematsu, K. *J. Org. Chem.* **1985**, *50*, 512. (k) Braverman, S.; Lior, Z. *Tetrahedron Lett.* **1994**, *35*, 6727. (l) Block, E.; Putman, D. *J. Am .Chem. Soc.* **1990**, *112*, 4072.

(3) For examples, see:, (a) Tamura, Y.; Akai, S.; Sasho, M.; Kita, Y. *Tetrahedron Lett.* **1984**, *25*, 1167. (b) Aso, M.; Ikeda, I.; Kawabe, T.; Shiro, M.; Kanematsu, K. *Tetrahedron Lett.* **1992**, *33*, 5787. (c) Ikeda, I.; Honda, K.; Osawa, E.; Shiro, M.; Aso, M.; Kanematsu, K. *J. Org. Chem.* **1996**, *61*, 2031. (d) Node, M.; Nishide, K.; Fujiwara, T.; Ichihashi, S. *Chem. Commun.* **1998**, 2363. (e) Kimura, H.; Fujiwara, T.; Katoh, T.; Nishide, K.; Kajimoto, T.; Node, M. *Chem. Pharm. Bull.* **2006**, *54*, 399. (f) Katoh, T.; Noguchi, C.; Kimura, H.; Fujiwara, T.; Ichihashi, S.; Nishide, K.; Kajimoto, T.; Node, M. *Tetrahedron: Asymmetry* **2006**, *17*, 2943. (g) Clive, D. L. J.; Yeh, V. S. C. *Tetrahedron Lett.* **1998**, *39*, 4789.

(4) Oppolzer, W.; Chapuis, C. *Tetrahedron Lett.* **1983**, *24*, 4665.

(5) Bertrand, M.; Zahra, J. P. *Tetrahedron Lett.* **1989**, *30*, 4117.

(6) (a) Lait, S. M.; Parvez, M.; Keay, B. A. *Tetrahedron: Asymmetry* **2003**, *14*, 749. (b) Lait, S. M.; Parvez, M.; Keay, B. A. *Tetrahedron Asymmetry* **2004**, *15*, 155.

(7) Henderson, J. R.; Parvez, M.; Keay, B. A. *Org. Lett.* **2007**, *9*, 5167.

(8) Lait, S. M.; Rankic, D. A.; Keay, B. A. *Chem. Rev.* **2007**, *107*, 767.

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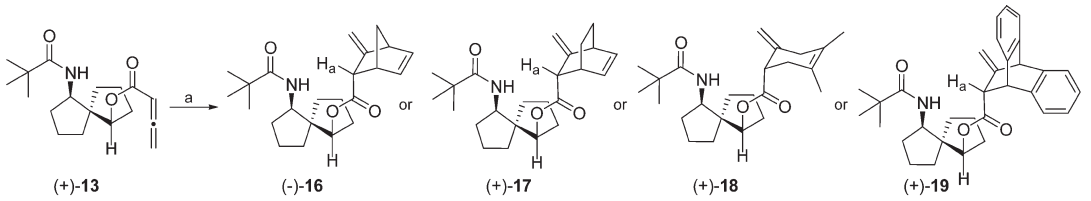
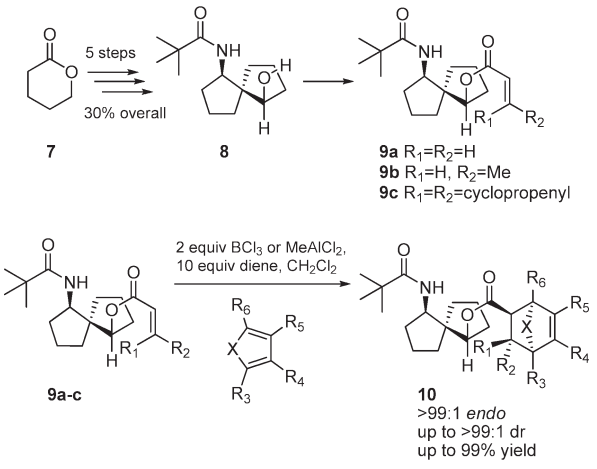
TABLE 1. Diels–Alder Reactions between Allene (+)-13 and Various Dienes



entry	Lewis acid	temp (°C)	time (h)	diene	product	*endo*:*exo*[a]	% yield[b]	dr[a]	config at H_a[c]
1	BCl_3	−78	8	cyclopentadiene	(−)-**16**	>99:1	75	>99:1	*S*
2	BCl_3	−78	18	1,3-cyclohexadiene	(+)-**17**	>99:1	58	>99:1	*S*
3	BCl_3	−78	18	2,3-dimethyl-1,3-butadiene	(+)-**18**		4	>99:1	
4	BCl_3	>-40	18	2,3-dimethyl-1,3-butadiene	(+)-**18**		cm[d]		
5	$MeAlCl_2$	−23	18	1,3-cyclohexadiene	(+)-**17**	>99:1	62	2:1	
6	$MeAlCl_2$	−23	18	2,3-dimethyl-1,3-butadiene	(+)-**18**	>99:1	67	2.5:1	
7	$MeAlCl_2$	−23	18	anthracene		nr			
8	$MeAlCl_2$	0	22	anthracene	(+)-**19**	>99:1	55	>99:1	*S*

[a]Diastereomeric ratios determined by integration of 300 MHz NMR spectra and/or by GC analysis. [b]Isolated yields. [c]Absolute configuration determined by X-ray crystallography. [d]Complex mixture of unreacted starting material, Diels–Alder adducts, and byproducts **14** and **15**.

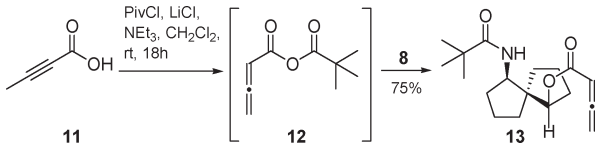
SCHEME 3



undergo diastereoselective Diels–Alder reactions by Lewis acid activation (2 equiv of BCl_3 or $MeAlCl_2$) with a variety of symmetrical and unsymmetrical dienes to give adducts **10**. To expand the scope on the use of **8**, we decided to append to it an allene via an ester linkage.

The proposed 1,3-spiro-amido allenyl dienophile **13** was predicted to be accessible by an *in situ* base-catalyzed alkyne to allene rearrangement. Previous reports have shown that 3-butynoic acid or similar esters can undergo facile allene rearrangements using K_2CO_3.[9] Rearranging 2-butynoic acid (**11**), on the other hand, typically requires more strongly basic conditions ($NaNH_2$[10] or LDA[11]) or organometallic reagents.[12] Surprisingly, treatment of 2-butynoic acid (**11**) with pivaloyl chloride in the presence of triethylamine formed mixed anhydride **12** that, upon treatment with

SCHEME 4



1,3-spiro-amido alcohol **8**, smoothly afforded the desired allene product **13** in 75% yield (Scheme 4).

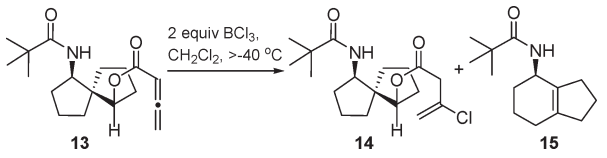
With allene dienophile **13** in hand, its use in several Diels–Alder reactions was investigated. As with the previously reported spiro-amido systems **9a–c**,[6,7] it was found that 2 equiv of Lewis acid were necessary to activate the dienophile in **13**.[13] Treatment of allene (+)-**13** with 2.0 equiv of BCl_3 and 10 equiv of cyclopentadiene at −78 °C exclusively afforded *endo*-(−)-**16** in >99:1 dr and 98% yield (Table 1, entry 1). Similarly, treatment of allene (+)-**13** with 2.0 equiv of BCl_3 and 10 equiv of 1,3-cyclohexadiene at −78 °C afforded *endo*-(+)-**17** in >99:1 dr and 58% yield (Table 1, entry 2). Complications arose when using acylic diene 2,3-dimethyl-1,3-butadiene where, at −78 °C, use of 2.0 equiv BCl_3 only afforded 4% yield of adduct (+)-**18** albeit in >99:1 dr (Table 1, entry 3). In an effort to increase the yield, it was found that increasing the reaction temperature to >−40 °C led to an inseparable complex mixture of Diels–Alder adducts (Table 1, entry 4) and two byproducts, **14** and **15** (Scheme 5).

As with the previous cyclopropenyl dienophile **9c**,[7] treatment of allene **13** with 2.0 equiv BCl_3 at higher temperatures (>−40 °C) led to large amounts of Michael addition byproduct **14** and rearranged chiral auxiliary **15**[14] (Scheme 5).[15] Both byproducts are formed in the presence of HCl impurities[16]

(9) Eglinton, G.; Jones, E. R. H.; Mansfield, G. H.; Whiting, M. C. *J. Chem. Soc.* **1954**, 3197.
(10) Craig, J. C.; Moyle, M. *J. Chem. Soc.* **1963**, 4402.
(11) Doye, S.; Hotopp, T.; Wartchow, R.; Winterfeldt, E. *Chem.—Eur. J.* **1998**, *4*, 1480.
(12) Franck-Neumann, M.; Brion, F. *Angew. Chem., Int. Ed. Engl.* **1979**, *18*, 688.

(13) ^1H NMR binding studies indicated the first equivalent of Lewis acid binds to the pivalamide in **13** (and **9a–c**) while the second equivalent of Lewis acid binds to the ester, thereby activating the dienophile. For more details, see: Henderson, J. R. Ph.D. Thesis, University of Calgary, **2009**.
(14) Byproduct **15** resulted from a series of carbocation rearrangements followed by the loss of H^+ to form the double bond.
(15) The structure of byproduct **15** had been incorrectly assigned in past publications (refs 2 and 3), and the correct structure was verified by X-ray crystallography. See Supporting Information.
(16) We have shown that byproduct **14** can be formed when **13** is treated with 1.0 M HCl in Et_2O at rt.

SCHEME 5



within the BCl_3 and may be minimized by using newly purchased BCl_3 at lower reaction temperatures. Compound **14** was not unexpected, as allenes are known to be good Michael acceptors.[17]

As previously reported,[7] the use of the weaker aluminum-based Lewis acids does not lead to the formation of byproducts **14** and **15**, and the use of 2 equiv of $MeAlCl_2$ in the Diels–Alder reaction with **13** afforded more synthetically useful results. The Diels–Alder reaction between allene (+)-**13** and 1,3-cyclohexadiene in the presence of 2.0 equiv of $MeAlCl_2$ did not proceed at −78 °C but at −23 °C only to afford *endo*-(+)-**17** in 62% yield and 2:1 dr after 18 h (Table 1, entry 5). Reaction between allene (+)-**13** and acyclic 2,3-dimethyl-1,3-butadiene in the presence of $MeAlCl_2$ afforded adduct (+)-**18** with an improved 67% yield but a lower dr of 2.5:1 (Table 1, entry 6). Allene (+)-**13** did not undergo a Diels–Alder reaction with anthracene with $MeAlCl_2$ at −23 °C (Table 1, entry 7), but after warming of the reaction to 0 °C, adduct (+)-**19** was obtained in 55% yield and >99:1 dr (Table 1, entry 8). Regardless of the Lewis acid used or the temperature reported in Table 1, the *endo*/*exo* selectivities were always >99:1.

The *endo*/*exo* stereochemistry of adducts (−)-**16**, (+)-**17**, and (+)-**19** were assigned by ^{1}H NMR spectroscopy, while the absolute configurations of adducts (−)-**16**, (+)-**17**, and (+)-**19** were determined by examination of their X-ray crystal structures.[18] X-ray crystal analysis also confirmed that the major stereoisomer from the Diels–Alder reactions was *endo*. Unfortunately, X-ray quality crystals could not be grown for adduct (+)-**18**.

Although the chiral auxiliary was not removed from adducts **16**–**19**, we have shown that it can be removed (NaOH, MeOH, 80 °C, 20 h) without loss of the stereochemistry α to the ester.[6a]

In summary, a novel spiro-amido allenyl dienophile **13** was efficiently synthesized from 2-butynoic acid and was shown to undergo facile Lewis acid activated Diels–Alder reactions with several symmetrical dienes to provide exclusively *endo* products with up to >99:1 dr depending on the structure of the diene.

Experimental Section

(1*R*,5*R*,6*R*)-Buta-2,3-dienoic Acid 6-(2,2-Dimethyl-propionylamino)-spiro[4.4]non-1-yl Ester ((+)-13). Anhydrous LiCl (240 mg, 5.70 mmol) was suspended in anhydrous THF (10 mL), and NEt_3 (1.50 mL, 10.8 mmol) was added followed by trimethylacetyl chloride (0.62 mL, 5.03 mmol). After mixing for 10 min at room temperature, the mixture was cooled to 0 °C, and 2-butynoic acid (200 mg, 2.38 mmol) in THF (6 mL) added dropwise. After mixing at 0 °C for 1 h, spiro-amido-dienophile (+)-**8**[6] (500 mg, 2.09 mmol) was added as a solid. The mixture was warmed to room temperature and mixed for 18 h. The reaction was subsequently quenched with 10% $HCl_{(aq)}$ (10 mL) and extracted with ether (3 × 20 mL). The combined organic layers were dried over anhydrous $MgSO_4$, filtered, and concentrated to a tan colored oil that was purified *via* flash column chromatography (5:1 hexanes/EtOAc) to give desired allene (+)-**13** as a white solid (460 mg, 1.51 mmol, 72%): mp 90–94 °C; $[\alpha]^{20}_D$ +51.4 (*c* 0.585, $CHCl_3$); IR (film) ν_{max} 3325, 2963, 2860, 1718, 1632, 1535, 1459, 1167, 871 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 5.93 (d, 1H, *J* = 7.63 Hz), 5.54 (t, 1H, *J* = 6.71 Hz), 5.16 (ddd, 2H, *J* = 20.71, 6.76 Hz), 4.99 (m, 1H), 4.15 (q, 1H, *J* = 5.51 Hz), 2.08–1.40 (m, 12H), 1.08 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 215.8, 177.2, 164.8, 88.0, 82.1, 79.3, 56.6, 55.5, 38.5, 35.3, 35.2, 32.1, 31.9, 27.4, 20.8, 20.4; MS *m*/*z* 305 [M$^+$] 220, 204, 179, 164, 153, 128, 120, 102, 93, 85, 79, 67; HRMS calcd for $C_{18}H_{27}NO_3$ 305.1991, found 305.1978. Anal. Calcd for $C_{18}H_{27}NO_3$: C, 70.79; H, 8.91; N, 4.59. Found: C, 70.72; H, 8.57; N, 4.54.

General Procedure for Diels–Alder Reactions. A flask containing 4 Å molecular sieves (100 mg per 100 mmol auxiliary) was flame-dried under vacuum and back-purged with argon. Solid dienophile (0.216 mmol) was added, and the flask flushed with dry nitrogen for 5 min. Freshly distilled dichloromethane (5.2 mL) was added, and the solution was cooled to −78 °C before the addition of boron trichloride (1.0 M in dichloromethane, 2 equiv). The Lewis acid mixture was allowed to mix for 30 min, and freshly distilled diene (10–16 equiv, see Supporting Information for exact amounts) was added dropwise down the side of the flask. After the reaction was complete (see times in Table 1), the mixture was filtered through a plug of silica (prewetted with dichloromethane) and flushed with ether. Concentration followed by purification by column chromatography (hexanes/ethyl acetate) resulted in pure Diels–Alder adduct.

(1*S*)-3-Methylene-bicyclo[2.2.1]hept-5-ene-2-carboxylic Acid (1*R*,5*R*,6*R*)-6-(2,2-Dimethyl-propionylamino)-spiro[4.4]non-1-yl Ester ((−)-16). Compound (−)-**16** was prepared according the above general procedure (60 mg, 0.162 mmol, 75%): mp 118–120 °C; $[\alpha]^{20}_D$ −62.6 (*c* 0.415, $CHCl_3$); IR (film) ν_{max} 3355, 2967, 2860, 1731, 1625, 1529, 1309, 1203, 1173, 884 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.22 (dd, 1H, *J* = 5.3, 3.2 Hz), 6.10 (dd, 1H, *J* = 5.3, 3.2 Hz), 5.86 (d, 1H, *J* = 7.87 Hz), 5.64 (bs, 1H), 5.04 (d, 1H, *J* = 1.93 Hz), 4.98–4.92 (m, 2H), 4.20 (m, 1H), 3.41 (q, 1H, *J* = 2.57 Hz), 3.21–3.13 (m, 2H), 2.02–1.41 (m, 13H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.2, 171.7, 148.7, 135.5, 134.6, 105.5, 80.7, 56.6, 56.4, 51.5, 50.4, 49.2, 45.2, 38.7, 34.8, 34.2, 32.0, 31.8, 27.5, 20.8, 20.2; MS *m*/*z* 371 [M$^+$] 286, 238, 222, 151, 138, 133, 121, 102, 93, 79, 67; HRMS calcd for $C_{23}H_{33}NO_3$ 371.2460, found 371.2464.

(1*S*)-3-Methylene-bicyclo[2.2.2]oct-5-ene-2-carboxylic Acid (1*R*,5*R*,6*R*)-6-(2,2-Dimethyl-propionylamino)-spiro[4.4]non-1-yl Ester ((+)-17). Compound (+)-**17** was prepared according the above general procedure (14.4 mg, 0.037 mmol, 58%): mp 127–130 °C; $[\alpha]^{20}_D$ +17.3 (*c* 0.54, $CHCl_3$); IR (film) ν_{max} 3461, 3380, 2947, 2866, 1728, 1652, 1504, 1195, 1171, 704 cm^{-1}; ^{1}H NMR (300 MHz, $CDCl_3$) δ 6.27 (m, 2H), 5.86 (d, 1H, *J* = 7.8 Hz), 4.97–4.89 (m, 2H), 4.87 (m, 1H), 4.18 (m, 1H), 3.25 (ddd, 1H, *J* = 2.22, 2.17 Hz), 3.05 (m, 1H), 2.91 (m, 1H), 2.00–1.29 (m, 15H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.3, 171.7, 147.5, 132.9, 132.1, 107.0, 80.9, 56.5, 56.4, 50.3, 40.8, 38.6, 34.7, 34.2, 33.9, 31.9, 31.7, 27.5, 25.8, 24.1, 20.7, 20.2; MS *m*/*z* 385 [M$^+$] 300, 238, 222, 165, 146, 121, 102, 91, 79, 77, 57; HRMS calcd for $C_{24}H_{35}NO_3$ 385.2617, found 385.2604.

(1*S*)-3,4-Dimethyl-6-methylene-cyclohex-3-enecarboxylic Acid (1*R*,5*R*,6*R*)-6-(2,2-Dimethyl-propionylamino)-spiro[4.4]non-1-yl Ester ((+)-18). Compound (+)-**18** was prepared as an inseparable mixture of two diastereomers according the above general procedure (170 mg, 0.439 mmol, 67%): mp 85–93 °C;

(17) For examples, see: (a) Padwa, A.; Kline, D. N.; Norman, B. H. *J. Org. Chem.* **1989**, *54*, 810. (b) Kumar, K.; Kapoor, R.; Kapur, A.; Ishar, M. P. S. *Org. Lett.* **2000**, *2*, 2023. (c) El Achqar, A.; Boumzebra, M.; Roumestant, M.-L.; Viallefont, P. *Tetrahedron* **1988**, *44*, 5319.

(18) See Supporting Information for X-ray crystallographic data.

$[\alpha]^{20}_D$ +32.5 (*c* 0.43, $CHCl_3$); IR (film) ν_{max} 3455, 3364, 2962, 2864, 1716, 1658, 1509, 1197, 886 cm^{-1}; ^1H NMR of mixture of diastereomers; only major peaks are indicated (300 MHz, $CDCl_3$) δ 6.00 (d, 1H, J = 8.40 Hz), 5.04 (m, 1H,), 4.89 (bs, 1H), 4.77 (bs, 1H), 4.23 (m, 1H), 3.30 (t, 1H, J = 6.99 Hz), 2.71 (bs, 2H,), 2.58−1.24 (m, 21H), 1.17 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.3, 172.4, 143.5, 124.3, 123.9, 109.0, 81.5, 56.5, 55.5, 47.4, 39.0, 38.5, 35.3, 35.1, 34.8, 32.1, 31.6, 27.4, 20.9, 20.2, 18.6, 18.4; MS CI m/z 388 [M + H^+]; HRMS calcd for $C_{24}H_{38}NO_3$ 388.2852, found 388.2839.

***endo*-(+)-19.** Compound (+)-**19** was prepared according the above general procedure (17.7 mg, 0.0366 mmol, 55%): mp 174−181 °C; $[\alpha]^{20}_D$ +23.7 (*c* 0.89, $CHCl_3$); IR (film) ν_{max} 3300, 2965, 2863, 1734, 1655, 1503, 1450 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.32−7.23 (m, 4H), 7.13−7.05 (m, 4H), 5.66 (d, 1H, J = 8.18 Hz), 5.30 (d, 1H, J = 2.38 Hz), 5.05 (d, 1H, J = 1.86 Hz), 4.88 (m, 1H), 4.74 (s, 1H), 4.63 (d, 1H, J = 2.68 Hz), 4.02 (m, 1H), 3.45 (q, 1H, J = 2.16 Hz), 1.90−1.26 (m, 12H), 1.15 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 176.9, 170.9, 143.7, 142.8, 141.9, 141.3, 140.1, 126.4, 126.2, 126.0, 125.8, 125.1, 123.7, 123.1, 111.1, 80.7, 57.0, 56.3, 55.0, 50.1, 48.0, 38.6, 34.3, 33.4, 31.8, 31.5, 27.4, 20.3, 20.2; MS m/z 483 [M^+], 263, 244, 222, 217, 215, 202, 178, 121, 102, 79, 67; HRMS calcd for $C_{32}H_{37}NO_3$ 483.2773, found 483.2764. Anal. Calcd for $C_{32}H_{37}NO_3$: C, 79.47; H, 7.71; N, 2.90. Found: C, 79.19; H, 7.64; N, 2.87.

(1*R*,5*R*,6*R*)-3-Chloro-but-3-enoic Acid 6-(2,2-Dimethyl-propionylamino)-spiro[4.4]non-1-yl Ester (14). Compound **14** was formed as a byproduct when treating allene-dienophile (+)-**13** with 2.0 equiv of BCl_3 at > −40 °C during Diels−Alder reactions: IR (film) ν_{max} 3289, 2963, 2864, 1728, 1638, 1512, 1459, 1383, 1094, 1017 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.82 (bs, 1H), 5.37 (s, 2H), 5.03 (m, 1H), 4.27 (m, 1H), 3.36 (ddd, 2H, J = 20.11,16.13 Hz), 2.04−1.43 (m, 12H), 1.16 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$) δ 177.2, 168.1, 134.4, 116.7, 82.0, 56.8, 56.1, 45.1, 38.7, 34.7, 34.1, 31.9, 27.5, 20.9, 20.4; HRMS calcd for $C_{18}H_{28}NO_3Cl$ 341.1758, found 341.1751.

***N*-(2,3,4,5,6,7-Hexahydro-1*H*-inden-4-yl)-2,2-dimethyl-propionamide (15).** Compound **15** was formed as a byproduct when treating any spiro-auxiliary with 2.0 equiv of BCl_3 at > −40 °C during Diels−Alder reactions: IR (film) ν_{max} 3311, 2951, 2868, 1632, 1631, 1531, 1452, 1200, 748 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$): δ 5.49 (d, 1H, J = 9.0 Hz), 4.49 (br s, 1H), 2.30 (m, 4H), 2.00−1.60 (m, 12H), 1.19 (s, 9H); ^{13}C NMR (75 MHz, $CDCl_3$): δ 180.0, 139.9, 134.3, 45.3, 38.9, 36.5, 33.3, 30.4, 27.9, 25.9, 21.8, 20.4; MS: m/z 221 [M^+], 120, 102, 57; HRMS calcd for $C_{14}H_{23}NO$ 221.17796, found 221.17610.

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Supporting Information Available: Full experimental procedures, spectral data and X-ray crystallographic data for compounds (+)-**13**, **15**, (−)-**16**, (+)-**17** and (+)-**19** is available free of charge via the Internet at http://pubs.acs.org.