Asymmetric Diels-Alder cy-cloaddition reactions of chiral a,b-unsaturated-N-acyloxazolidinones

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Several recrystallizations afforded a pure enantiomer of **6c**: $[\alpha]^{25}_D$ -18.7° (*c* 0.076, $CHCl_3$); mp 158-160 °C. This enantiomer gave one doublet for the olefinic proton in the presence of 0.2 equiv of chiral shift reagent tris[3-[(heptafluoropropyl)hydroxymethylene]-*d*-camphorato-[europium(III) [Eu(hfc)] at 270 MHz. This spectrum indicated an ee >99%. In contrast, a similar solution of racemic mixture of **6c**, as resulting from the first recrystallization of reaction product, gave two doublets ($\Delta\nu$ = 2.14 Hz) for the olefinic proton. On the other hand, the filtrate of that recrystallization was evaporated and recrystallized to afford an antipode, $[\alpha]^{24}_D$ +14.9° (*c* 0.388, $CHCl_3$).

(1*RS*,5*RS*,6*RS*,11*SR*)-5-Phenyl-6-(methoxycarbonyl)-3,3-dimethyl-10-oxatricyclo[5.3.1.0^{5,11}]undec-7(8)-en-9-one (6d). In the same manner, the thermal treatment of **5d** (502.6 mg, 1.54 mmol) afforded the [2 + 2] cycloadduct **6d** (205.5 mg, 0.63 mmol) as colorless needles in 40.9% yield. ^{13}C NMR ($CDCl_3$): δ 23.4, 32.4, 32.8, 38.0, 39.7, 45.0, 50.0, 52.3, 60.4, 75.0, 111.9, 126.1, 126.8, 128.6, 147.0, 152.7, 162.6, 168.3. Anal. Calcd for $C_{20}H_{22}O_4$: C, 73.60; H, 6.79. Found: C, 73.64; H, 6.80.

X-ray Crystallography. Crystal Data. $C_{15}H_{18}O_4$ (**6c**), M_r 262.31: monoclinic; $P2_1$; a = 12.583 (1), b = 7.620 (1), c = 7.318 (1) Å; V = 679.2 Å^3; D(calcd) = 1.282 g cm^{-3}; Z = 2; λ(Cu Kα) = 1.5418 Å; μ = 7.2 cm^{-1}; F(000) = 280. Colorless prisms of **6c** grew from diisopropyl ether by slow evaporation at room temperature. The crystal, with dimensions of 0.10 × 0.20 × 0.20 mm, was employed for the experiments on Enraf-Nonius CAD4 diffractometer with graphite monochromator. Lattice parameters were determined on 25 2θ values (22° <2θ < 64°) by the least-squares procedure. Intensity data were collected by θ-2θ scans to a limit of 2θ = 150°, with scan rate 1.65-4.12° min^{-1} in θ and with scan width (0.45 + 0.14 tan θ)°. Range of indices inclusive are $-15 \le h \le 15$, $0 \le k \le 9$, $0 \le l \le 9$. Three standard reflections were monitored after every measurement of 200 reflections for the check of orientation and at the interval of 2 h for the check of intensity. The variation of standards was less than 0.6% of the 1511 independent reflections; 1420 were treated as observed ($|F_o| > 2\sigma|F_o|$). Systematic absences were 0*k*0, *k* odd. The intensities were corrected for Lorentz and polarization effects, but no correction was applied for absorption. $C_{20}H_{22}O_4$ (**6d**), M_r 326.40: monoclinic; $P2_1/a$; a = 16.311 (1), b = 9.959 (1), c = 10.605 (1) Å; β = 95.15 (1)°; V = 1715.9 Å^3; D(calcd) = 1.263 g cm^{-3}; Z = 4; λ(Cu Kα) = 1.5418 Å; μ = 6.7 cm^{-1}; F(000) = 696. Colorless prisms of **6d** grew from diisopropyl ether: crystal size 0.18 × 0.43 × 0.43 mm; Enraf-Nonius CAD4 diffractometer; θ-2θ scan; 1.27-4.12° min^{-1} in θ; scan width (0.45 + 0.14 tan θ)°; range of indices $-20 \le h \le 20$, $0 \le k \le 12$, $0 \le l \le 13$ (2θ < 150°). Lattice parameters were determined on the basis of 25 2θ values (46° < 2θ < 140°). Variation of standard was <0.3%; 3760 reflections were measured; 3060 reflections were observed with $|F_o| > 2\sigma(|F_o|)$. Systematic absences *h*0*l*, *h* odd, 0*k*0, *k* odd. No corrections for absorption were made.

Structure Determination. Crystal structure was solved by direct methods with the program MULTAN/82[13] and refined by full-matrix least-squares method. All hydrogen atoms were refined by full-matrix least-squares method. All hydrogen atoms were located by stereochemical calculation. Non-hydrogen atoms were refined with anisotropic thermal parameters, and hydrogen atoms, with isotropic thermal parameters (B = 5.0, fixed). $\sum w(|F_o| - |F_c|)^2$ was minimized. The weighting scheme for **6c** was as follows: w = 1.0 for F_o < 721.7, $w = (721.7/F_o)^2$ for $F_o \ge 721.7$. Final R index was 0.033, and R_w was 0.030. Secondary extinction factor (g) was refined: 1.18 (2) × 10^{-5} [$|F_o| = |F_c|/(1 + glc)$]. Δ/σ was less than 1.2, and the largest peak in the final difference Fourier map was +0.14 e Å^{-3}. The absolute configuration of the molecule (6*R*,13*R*,17*R*,18*S*) was determined by the Bijvoet method, taking into account the anomalous dispersion effect of oxygen atom for Cu Kα radiation. The same procedure was applied for **6d**. Weighting scheme: w = 1.0 for F_o < 1484.3, $w = (1484.3/F_o)^2$ for $F_o \ge 1484.3$. Final R = 0.048, and R_w = 0.044. Secondary extinction factor (g) was 4.27 (4) × 10^{-6}. Δ/σ < 1.1, and the largest peak in the final ΔF map was +0.20 e Å^{-3}. Atomic scattering factors were taken from ref 16. All the calculations were performed on a DEC VAX 11/730 computer with the programs of Enraf-Nonius SDP[14] and ORTEP II.[15]

Method of Molecular Orbital (MO) and Empirical Force-Field Calculations. QCPE Program MMP2[9] was used for molecular mechanics calculations. Calculations were carried out at the Computing Centers of Hokkaido University and the Institute for Molecular Science.

Supplementary Material Available: Tables of thermal parameters and torsional angles for **6c** and **6d** (5 pages); tables of observed and calculated structure factors (23 pages). Ordering information is given on any current masthead page.

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Asymmetric Diels-Alder Cycloaddition Reactions with Chiral α,β-Unsaturated *N*-Acyloxazolidinones

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Abstract: Chiral α,β-unsaturated *N*-acyloxazolidinones are highly reactive and highly diastereoselective dienophiles in Diels-Alder reactions promoted by dialkylaluminum chlorides. A cationic Lewis acid-dienophile complex is proposed to account for the observed exceptional reactivity and endo/exo selectivities. Acrylate and (*E*)-crotonate carboximides bearing phenylalaninol-derived oxazolidinones undergo rapid and selective cycloadditions with the relatively unreactive dienes isoprene and piperylene at temperatures as low as -100 °C. Intramolecular cycloadditions of (*E*,*E*)-2,7,9-decatrienimides and (*E*,*E*)-2,8,10-undecatrienimides proceed with high diastereoface selectivity and virtually complete endo/exo selectivity. In all cases, high yields of diastereomerically homogeneous products may be obtained by simple recrystallization or silica gel chromatography. Nondestructive chiral auxiliary removal is facile with even the most sterically hindered Diels-Alder adducts. The enhanced diastereoselectivities observed in Diels-Alder reactions of phenylalaninol-derived dienophiles are shown not to be steric in origin but a result of electronic interactions involving the phenyl ring. The technique employed to expose this electronic effect, comparison of diastereoselectivities in analogous alkylation and Diels-Alder reactions, directly provides transition-state structural information.

The venerable Diels-Alder reaction has provided fertile ground for asymmetric reaction engineering. Several recent reviews describe impressive progress in this area, which has included the design of chiral dienophiles, dienes, and Lewis acid catalysts.[1]

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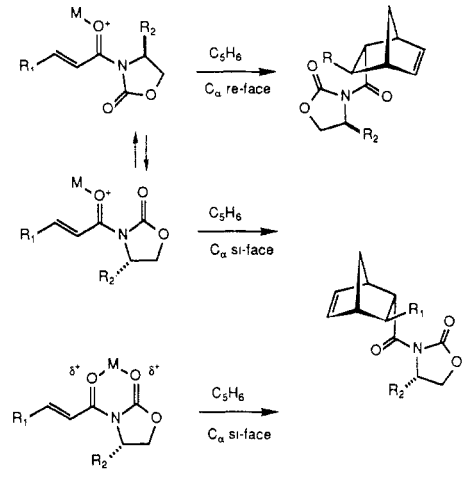
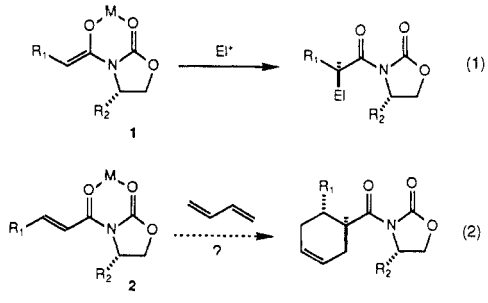
Scheme I



Indeed, near-perfect diastereo- or enantioselectivities have been achieved in each of these areas. In this paper, we describe in detail our own contributions to this exciting field.[2] As a natural outgrowth of the development of chiral enolate-based bond constructions (eq 1),[3] we were stimulated to evaluate other reactions wherein similar design concepts might be utilized. In this respect, the Diels–Alder reaction appeared to be ideal (eq 2). Considerable



structural homology exists between enolates such as **1** and potential chiral dienophiles, such as **2**. In enolate **1**, a well-defined spatial relationship is achieved between chiral and prochiral centers as a consequence of the interplay of nonbonding interactions, which effectively control enolate geometry, and metal ion chelation, which controls the rotational degrees of freedom in the substrate. These same two stereochemical control elements, if they could be implemented, should also be relevant to the design of an effective chiral dienophile **2**.

The establishment of a well-defined diastereofacial bias in such unsaturated *N*-acyloxazolidinones depends critically upon one's ability to control the various rotational degrees of freedom interconnecting chiral and prochiral centers as illustrated in Scheme I. At the outset we assumed that the uncomplexed α,β-unsaturated carbonyl moiety would exist exclusively in the s-cis conformation avoiding the severe nonbonding interactions present between the olefin and chiral auxiliary in its s-trans conformation.

Table I. Synthesis of Dienophiles **6–8** (Eq 3 and 4)

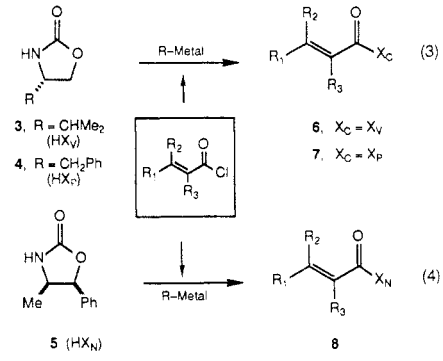
oxazolidinone	R_1	R_2	R_3	product	yield, %	mp, °C
HX_V	CH_3	H	H	**6a**	93	56.0–56.5
HX_V	H	H	H	**6b**	66[a]	44.0–45.0
HX_V	H	H	CH_3	**6c**	92	66.0–67.0
HX_V	CH_3	CH_3	H	**6d**	97	oil
HX_V	Ph	H	H	**6e**	97	oil
HX_P	CH_3	H	H	**7a**	86	85.0–86.0
HX_P	H	H	H	**7b**	53	73.5–74.5
HX_N	CH_3	H	H	**8a**	93	66.0–66.5
HX_N	H	H	H	**8b**	56	oil
HX_N	H	H	CH_3	**8c**	88	80.0–80.5

[a] Acylation with 3-bromopropionyl chloride followed by treatment with triethylamine.

Support for this assumption follows from conformational studies on α,β-unsaturated amides which conclude that the s-cis conformer is strongly favored.[4] A more speculative issue appeared to be one of controlling the topographical relationship between the chiral center of the oxazolidinone and the prochiral s-cis dienophile. It was anticipated that poor diastereofacial differentiation would result unless bidentate chelation could be achieved between the Lewis acid promoter and *both* substrate carbonyl groups. As is illustrated below, the intervention of more than one metal-complexed dienophile in the cycloaddition process could lead to diminished levels of asymmetric induction. This study documents the successful development of chiral dienophiles fulfilling these design criteria.

Results and Discussion

Primary Studies. The unsaturated carboximides **6–8** evaluated during the course of this study were synthesized as illustrated in eq 3 and 4. The yields and selected physical properties of these



dienophiles are summarized in Table I. Previously reported chiral 2-oxazolidinones **3–5**[5] were treated successively with *n*-butyllithium and the requisite acid chlorides to afford the desired dienophiles in 85–100% isolated yields. The acryloyl imides **6b**, **7b**, and **8b** were found not to be amenable to this general set of experimental conditions due to their propensity toward polymerization under these conditions; however, these substrates may be prepared by one of two methods. In the first method, the appropriate 2-oxazolidinone is treated with methylmagnesium bromide in anhydrous ether and subsequently acylated with acryloyl chloride under carefully defined conditions. Alternatively, the oxazolidinone bromomagnesium salt is acylated with 3-bromopropionyl chloride and the resultant 3-bromopropionyl imide dehydrohalogenated with triethylamine. Using these procedures, one may routinely obtain *N*-acryloyl-2-oxazolidinones **6b**, **7b**, and **8b** in 50–70% yield. It is noteworthy that most of these unsaturated carboximides are nicely crystalline compounds which have excellent shelf lives after they have been obtained in a pure state.[6]

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Scheme II

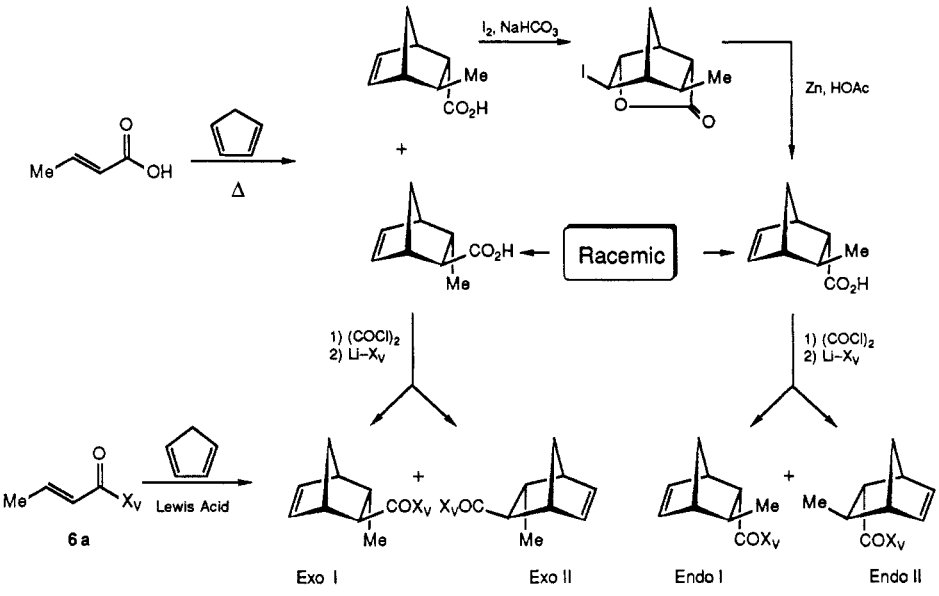


Table II. Lewis Acid Promoted Cycloadditions (Scheme II)

Lewis acid (equiv)	temp, °C	time, h	conv %	Σendo/ Σexo[a]	endo I/ endo II[a]
$SnCl_4$ (1.5)	25	2	100	8.7	2.5
$SnCl_4$ (1.1)	−78	3	70	14.9	3.1
$TiCl_4$ (0.9)	25	3	100	7.1	2.3
$TiCl_4$ (1.1)	−78	3	100	9.9	2.7
$ZrCl_4$ (1.4)	−78	3	100	99	7.2
$AlCl_3$ (1.0)	−78	3	60	4.2	1.5
$EtAlCl_2$ (1.1)	−78	3	50	11	1.7
Et_2AlCl (0.3)	0	6	30	3.1	1.3
Et_2AlCl (0.8)	0	6	100	15	6.5
Et_2AlCl (1.4)	0	0.5	100	42	7.6
Et_2AlCl (1.4)	−78	2.5	100	50	17.0

[a] Ratios determined by capillary gas chromatography.

In the preliminary study we chose to assay cycloaddition diastereoselectivity as a function of Lewis acid addend using the Diels–Alder reaction of crotonyl imide **6a**, bearing the (*S*)-valinol-derived oxazolidinone (X_V), with cyclopentadiene. Authentic samples of each of the products of this cycloaddition reaction were obtained as indicated in Scheme II.[7] Crotonic acid was condensed with cyclopentadiene thermally, and the resultant endo and exo bicyclic acids were separated by iodolactonization. The diastereomerically pure acids were then individually treated successively with oxalyl chloride and 3-lithio-2-oxazolidinone (LiX_V), to afford authentic endo and exo diastereomeric Diels–Alder adducts. These four isomers were readily separable by capillary vapor-phase chromatography, as are the vast majority of diastereomeric mixtures reported in this paper.

After an extensive survey of Lewis acid addends, some of which appear in Table II, we were disappointed to discover that none of the catalysts which we felt likely to maintain bidentate chelation led to acceptable levels of reaction stereoselectivity. Surprisingly, diethylaluminum chloride (DEAC) promoted by far the most diastereoselective Diels–Alder reaction observed in this study. The cycloaddition of crotonyl imide **6a** with cyclopentadiene employing DEAC (1.4 equiv) in dichloromethane at −78 °C afforded both high levels of endo diastereoselection (17:1) and the highest combined endo–exo ratios (50:1) of all the Lewis acids screened. Subsequent studies revealed that dimethylaluminum chloride (DMAC) afforded similar levels of reaction stereoselectivity as well as fewer byproducts. Accordingly, a careful examination of

(6) The oily acrylate **8b**, bearing the (4*R*,5*S*)-norephedrine-derived oxazolidinone, does require refrigeration for extended storage.

(7) Though not explicitly stated, authentic samples were prepared in an analogous fashion for the vast majority of asymmetric cycloadditions reported in this paper.

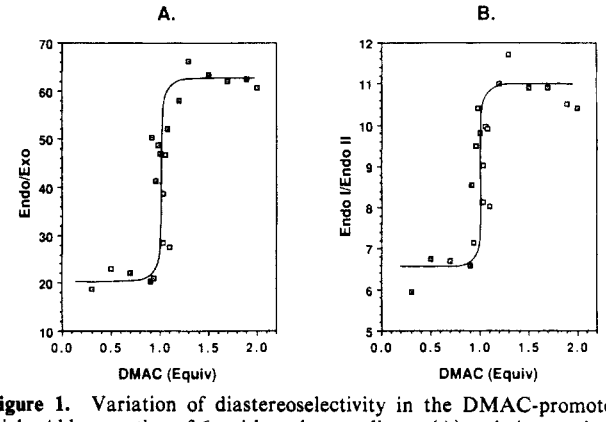
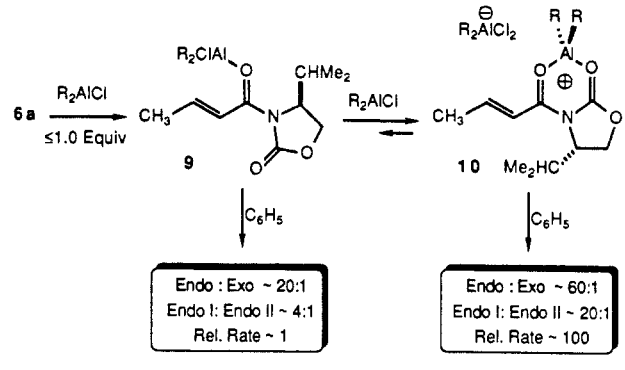


Figure 1. Variation of diastereoselectivity in the DMAC-promoted Diels–Alder reaction of **6a** with cyclopentadiene: (A) endo/exo ratio as a function of DMAC stoichiometry; (B) endo diastereoface selectivity as a function of DMAC stoichiometry.

Scheme III



reaction stereoselectivity as a function of DMAC stoichiometry was undertaken.

A standard solution of dimethylaluminum chloride (DMAC)[8] in dichloromethane was prepared and added in regularly varying amounts to constant solutions of crotonyl imide **6a** and cyclopentadiene in dichloromethane at −78 °C. The reactions were quenched after 5 min and analyzed by capillary vapor-phase chromatography. Endo/exo ratios (Figure 1A) and endo diastereoface selectivities (Figure 1B) were plotted as functions of equivalents of added DMAC. The results were surprising. Both

(8) Diethylaluminum chloride and dimethylaluminum chloride behave similarly in these reactions.

Table III. Diethylaluminum Chloride Promoted Diels–Alder Reactions of Dienophiles **6–8** with Cyclopentadiene (Scheme IV)[a]

entry	dienophile	∑endo:∑exo[b]	endo ds[b]	purified ratio	yield,[c] % (prod)	mp, °C
A	**6b**, R_1 = H	>100:1	93:7	>99:1	81 (**11b**)	77.0–78.0
B	**7b**, R_1 = H	>100:1	95:5	97:3	78 (**13b**)	120–121
C	**8b**, R_1 = H	100:1	5:95	<1:99	82 (**14b**)	91.0–92.0
D	**6a**, R_1 = CH_3	48:1	95:5	>99:1	82 (**11a**)	96.0–98.0
E	**7a**, R_1 = CH_3	55:1	97:3	99:1	83 (**13a**)	oil
F	**8a**, R_1 = CH_3	60:1	2:98	<1:99	8 (**14a**)	oil
G	**6e**, R_1 = Ph[d]	*e*	93:7[f]	>99:1[f]	83 (**11e**)	125–127

[a] Reactions run at −100 °C for 2–5 min using 1.4 equiv of Et_2AlCl. [b] Ratios determined by capillary gas chromatography. [c] Yield of isolated material with the indicated diastereomeric purity. [d] Reaction run at −20 °C, 2.5 h. [e] Exo products not observed by 500-MHz NMR. [f] Ratio determined by 500-MHz NMR.

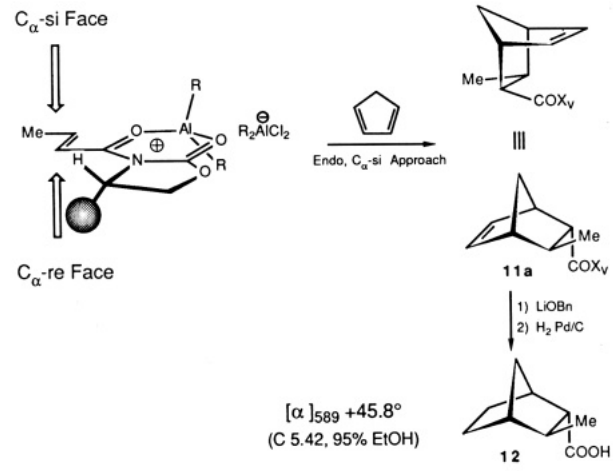


Figure 2. Diastereoface selection in the cycloaddition process.

ordinates increase dramatically in the region of 1 equiv of added DMAC. Furthermore, based on qualitative comprisons of percent conversion in these reactions, a rate acceleration of nearly 100-fold was observed at this point. Our interpretation of these data is summarized in Scheme III.

With less than 1 equiv of added dialkylaluminum chloride, it is presumed that a slow reaction occurs from one of several possible conformations of 1:1 complex **9**, leading to a mixture of diastereomeric products. On the other hand, in the presence of an excess of dialkylaluminum chloride (≥1.0 equiv), both dienophile reactivity and reaction diastereoselectivity dramatically increase as a consequence of chloride ionization from the 1:1 complex **9**. The resulting ionic dienophile **10** might be expected to be both exceptionally reactive and highly organized. Although this type of Lewis acid behavior is not commonly recognized, or documented, substantive precedent for its occurrence has been provided by Lehmkuhl and Kobs.[9] In accord with this model, cycloaddition should occur selectively from the C_α-*si* face of crotonyl imide **6a**, leading to cycloadduct **11a** (Figure 2). The sense of asymmetric induction in the Diels–Alder reaction of **6a** with cyclopentadiene was established by the illustrated stereochemical correlation. Conversion of major cycloadduct **11a** to its corresponding benzyl ester followed by hydrogenation afforded the saturated bicyclic acid **12**, whose enantiomer has known absolute configuration $[\alpha]_{589}$ −40.5° (*c* 10.8, 95% EtOH).[10a] All further stereochemical data that will be presented in this study are fully consistent with the sense of asymmetric induction illustrated in Figure 2.

Scope. Having established an operational protocol for organization of these chiral dienophiles, we set out to define the scope of these cycloadditions. Our initial investigations with cyclopentadiene are summarized in Scheme IV and Table III. The optimum conditions found for the cycloaddition of crotonyl and acryloyl imides employed 1.4 mol equiv of dialkylaluminum chloride and excess cyclopentadiene in dichloromethane at −100 °C for 2–5 min. In all cases endo/exo ratios are extremely high and endo diastereoselectivities good. More significantly, high yields of diastereomerically homogeneous cycloadducts are easily obtained either by recrystallization or by silica gel chromatography. As we have observed in other studies, the high incidence of crystallinity associated with this family of chiral auxiliaries is of great practical advantage.[3] The extremely high reactivity exhibited by these dienophile–aluminum halide complexes is noteworthy. A set of experiments which provide a calibration for this statement follow. Treatment of unsubstituted crotonyl oxazolidinone **15** with excess cyclopentadiene and 1.4 equiv of diethylaluminum chloride in dichloromethane at −100 °C leads within seconds to a single cycloadduct in quantitative yield (eq 5). By comparison, methyl crotonate, when treated under similar conditions (−78 °C, 3 h), is recovered unchanged (eq 6). These comparative experiments highlight one of the attributes of this class of dienophiles. As a consequence of their high levels of reactivity, β-substitution within the dienophile may be tolerated. As a case in point, the "relatively unreactive" chiral cinnamate dienophile (Table III, entry G) affords an excellent yield of the diastereomerically pure cyclo-

Scheme IV

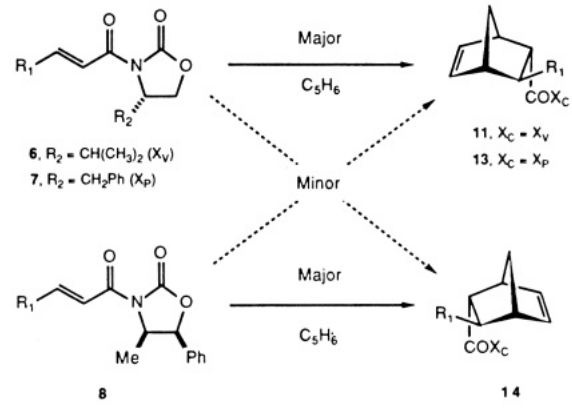
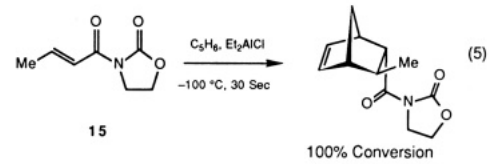
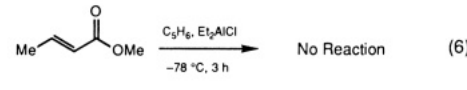


Table IV. Transesterification of Diels–Alder Adducts **11**, **13**, and **14** with Lithium Benzyl Oxide (Eq 7)

imide (X_C)	R	yield, %	product	$[\alpha]_{589}$, deg
11b (X_V)	H	95	**16b**	+130 (*c* 1.37, $CHCl_3$)
13b (X_P, 94% de)	H	86	**16b**	+125 (*c* 1.56, $CHCl_3$)
14b (X_N)	H	91	**17b**	−129 (*c* 1.39, $CHCl_3$)
11a (X_V)	CH_3	94	**16a**	+130 (*c* 2.08, $CHCl_3$)
13a (X_P)	CH_3	86	**16a**	+130 (*c* 1.37, $CHCl_3$)
14a (X_N)	CH_3	88	**17a**	−130 (*c* 2.14, $CHCl_3$)
11e (X_V)	Ph	76	**16e**	+121 (*c* 1.33, $CHCl_3$)

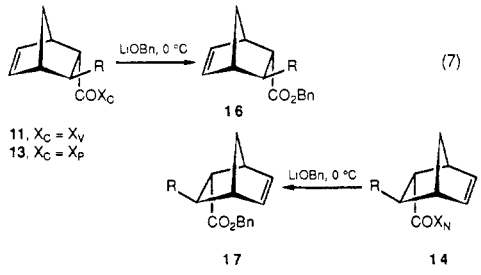




(9) Lehmkuhl, H.; Kobs, H.-D. *Liebigs Ann. Chem.* **1968**, *719*, 11.
(10) (a) Berson, J. A.; Hammons, J. H.; McRowe, A. W.; Bergman, R. G.; Remanick, A.; Houston, D. J. *J. Am. Chem. Soc.* **1967**, *89*, 2590–2600. (b) Berson, J. A.; Walia, J. S.; Remanick, A.; Suzuki, S.; Reynolds-Warnhoff, P.; Willner, D. *J. Am. Chem. Soc.* **1961**, *83*, 3986.

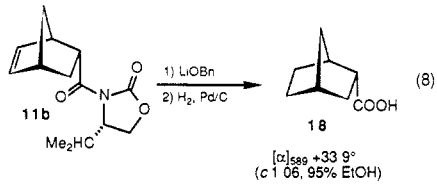
pentadiene cycloadduct. In contrast, those chiral ester dienophiles reported to date do not appear to embody sufficient intrinsic reactivity to tolerate β-substitution.[1a]

Chiral auxiliary removal from these cycloadducts may be accomplished in good yields as shown in eq 7 and Table IV.



(7)

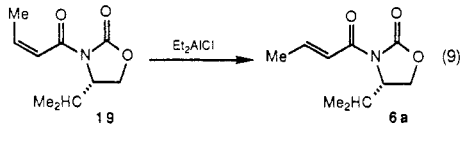
Treatment of the purified Diels–Alder adducts with lithium benzyl oxide in tetrahydrofuran (0 °C, 3 h) afforded 75–95% yields of the corresponding benzyl esters from the crotonate, acrylate, and cinnamate cycloadducts. This protocol for the transesterification of hindered carboximides, which was developed in conjunction with our previously reported enolate alkylation studies,[5b] has proven to afford high yields of the desired esters. Consistent with the results of our previous studies,[3] no epimerization occurs during the course of these transesterifications. As expected, the benzyl esters obtained from cycloadducts bearing the (4*R*,5*S*)-norephedrine-derived oxazolidinone (X_N) have specific rotations equal in magnitude and opposite in sign to those obtained from cycloadducts bearing either the (4*S*)-valinol (X_V) or (4S)-phenylalaninol (X_P) derived auxiliaries. The stereochemical identity of the acrylate Diels–Alder products was confirmed, as before, by conversion of the acrylate cycloadduct **11b** to the corresponding saturated acid of known absolute configuration by the illustrated two-step procedure in eq 8. The literature value for the rotation



(8)

of the enantiomer of **18** ($[\alpha]_{589}$ −30.6°)[10b] confirms the stereochemical assignment. The sense of asymmetric induction in this reaction is fully consistent with the observed stereochemical course of the related crotonate dienophile **6a**. On the basis of these two analogies, the absolute configuration of the cinnamoyloxazolidinone-derived Diels–Alder adduct **11e** was similarly assigned.

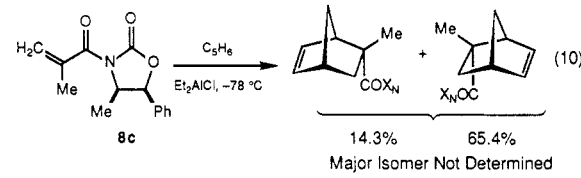
Those unsaturated imides which proved to be less useful are summarized below (eq 9-12). Treatment of a dichloromethane solution of (*Z*)-crotonyloxazolidinone **19** with diethylaluminum chloride (1.4 equiv) and cyclopentadiene (7.5 equiv, −78 °C, 2.5 h) led to an unexpected olefin isomerization (eq 9). Products



(9)

were obtained that proved to be identical in all respects with those observed in the corresponding cycloaddition of the (*E*)-crotonyl imide **6a**. Apparently in this instance, the cycloaddition process does not effectively compete with *Z*–*E* isomerization. We confirmed this fact by treating (*Z*)-crotonyl imide **19** with diethylaluminum chloride (1.4 equiv, −78 °C, 5 min) in the absence of cyclopentadiene. Fully 20% of the crotonyl imide recovered from this reaction was present as the *E* isomer.[11] The C_α–C_β double-bond character must be greatly attenuated in the dienophile–Lewis acid complex to allow such facile Z–E isomerization. Once again, cationic complex **10** is strongly implicated. These observations imply that the general applicability of cycloadditions involving *Z* unsaturated imide dienophiles is limited.

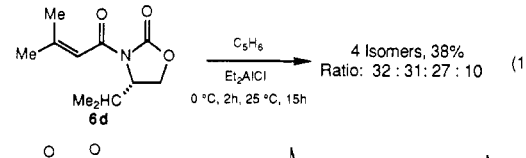
We next investigated the reaction of methacryloyl imide **8c** with cyclopentadiene (eq 10). Due to the well-documented proclivity



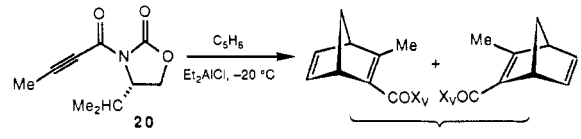
(10)

of methacrylate dienophiles to undergo exo cycloaddition,[12] we were not surprised to discover a poor endo/exo selectivity (4:1) in this reaction. Furthermore, the presence of the α-methyl group significantly destabilizes the s-cis unsaturated carbonyl conformation and the result is poor diastereofacial selectivity (5:1). The identity of the major product of this reaction was not determined.

Two final dienophile/cyclopentadiene cycloadditions were examined (eq 11 and 12). Not surprisingly, the β,β-dimethylacryloyl imide **6d** failed to react with cyclopentadiene at low temperature



(11)



(12)

3 : 1 Ratio
Major Isomer Not Determined

and, after 2 h at 0 °C and 15 h at ambient temperature, a 38% yield of a mixture of cycloadducts was obtained (eq 11). No attempt was made to determine the identity of the individual products. In a more interesting, albeit unoptimized experiment, a dilute dichloromethane solution of acetylenic imide **20** was treated with cyclopentadiene at −20 °C for 3 h (eq 12). Under these conditions, there was obtained an 82% yield[13] of a 3:1 mixture of diastereomeric Diels–Alder adducts, which were not further characterized. The level of reaction diastereoselection, while modest, is unprecedented. This dienophile, as a consequence of its two orthogonal π-systems, may undergo cycloaddition via either (both?) of these sets of p-orbitals.

Having defined that acrylate and (*E*)-β-substituted acrylates showed promise as generally useful dienophiles, we examined the reactions of these imides with the much less reactive acyclic dienes isoprene and piperylene (Scheme V, Table V). In the presence of 1.4 mol equiv of diethylaluminum chloride, the acrylate dienophile **7b** reacts rapidly at −100 °C with both isoprene (20 min, entry B) and piperylene (15 min, entry C); the less reactive crotonyl imides **6a** and **7a** must be warmed to higher temperatures (−30 °C) with both isoprene (10 h) and piperylene (6 h). We observe consistently high levels of asymmetric induction in these cycloadditions and, as before, we obtain high yields of diastereomerically homogeneous products by simple recrystallization or silica gel chromatography. Entries A and B of Table V illustrate a phenomenon that we have found to be general for dienes less reactive than cyclopentadiene. *Unsaturated imides bearing the (S)-phenylalaninol-derived oxazolidinone (X_P) uniformly provide significantly higher diastereoselectivities than their counterparts bearing other oxazolidinones (X_V, X_N).* As we shall demonstrate

(11) The observed side reaction in the isomerization experiment, 1,4 addition of an ethyl group across the unsaturated carbonyl moiety, is rapid in the absence of a suitable diene.

(12) See for example: Onishchenko, A. S. *Diene Synthesis* (translated by L. Mandel and S. Monsen); Israel Program for Scientific Translations, Jerusalem, 1964; p 289.

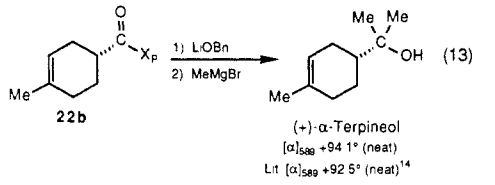
(13) Based on recovered starting material at 50% conversion.

Table V. Et_2AlCl-Promoted Diels–Alder Reactions of Dienophiles **6** and **7** with Acyclic Dienes (Scheme V)

entry	dienophile[a]	diene	diastereoselection[b]	purified ratio	isolated yield,[c] %	mp, °C
A	**6b**, R_1 = H	isoprene	83:17	>99:1	36 (**21b**)	76.2–77.5
B	**7b**, R_1 = H	isoprene	95:5	>99:1	85 (**22b**)	85.7–86.6
C	**7b**, R_1 = H	piperylene	>100:1	>99:1	84 (**23b**)	165–167
D	**7a**, R_1 = CH_3	isoprene	94:6	>99:1	83 (**22a**)	58.8–60.0
E	**7a**, R_1 = CH_3	piperylene	95:1:2:2[Δ]	>99:1	77 (**23a**)	66.0–67.3

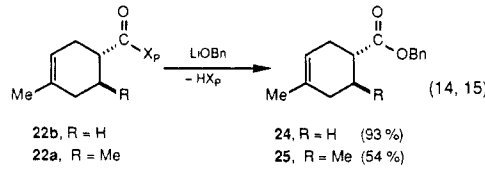
[a] Entries A–C were carried our at −100 °C (1.4 equiv of Et_2AlCl); entries D and E were carried out at −30 °C (1.4 equiv of Et_2AlCl). [b] Ratios were determined by capillary gas chromatography. [c] Yield of isolated, purified cycloadduction with the indicated diastereomeric purity. [d] No attempt was made to assign minor diastereomers.

(vide infra), this effect is only partly steric in origin. To verify the sense of asymmetric induction in these reactions, we converted the isoprene cycloadduct **22b** to (+)-α-terpineol as shown in eq 13. Treatment of **22b** with lithium benzyl oxide in tetrahydrofuran (0 °C, 3 h) followed by excess methylmagnesium bromide afforded synthetic (+)-α-terpineol whose specific rotation agrees well with that reported for the natural product.[14] Again, the sense of asymmetric induction exhibited by these dienophiles with isoprene conforms to the model provided in Figure 2. On the basis of the preceding analogies, we have inferred the sense of asymmetric induction for the reactions with **6** and **7** with piperylene.

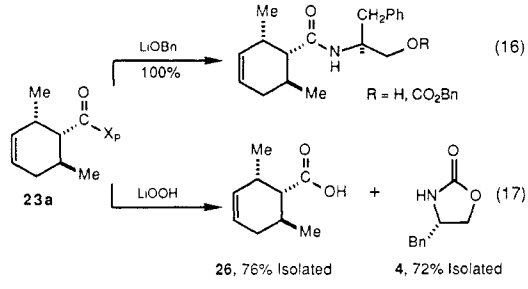


(13)

We have, in the past, experienced difficulty in removing the 2-oxazolidinone chiral auxiliary from substrates which provide extreme steric shielding of the exocyclic carbonyl group. Traditionally, lithium benzyl oxide has been our reagent of choice for such transesterifications and, on occasion, this has been the *only* reagent that has proven successful.[3b] While cyclopentadiene adducts do not present any difficulties in auxiliary removal (vide supra), we have found that some of the more hindered acyclic diene adducts have presented exceptionally challenging problems in the efficient hydrolytic removal of the oxazolidinone auxiliary. For example, while transesterification of acryloyl imide/isoprene Diels–Alder adduct **22b** with lithium benzyl oxide afforded a 93% yield of the corresponding benzyl ester (eq 14), transesterification of the more hindered crotonyl imide/isoprene adduct **22a** gave only a 54% yield of the benzyl ester (eq 15). In the extreme



(14, 15)



(16) (17)

example, the crotonyl imide/piperylene adduct **23a** afforded only undesired ring-opened transesterification products (eq 16). Cycloadduct **23a**, which possesses methyl groups shielding both faces of the exocyclic carbonyl, represents the only substrate to date in which we have observed no detectable transesterification at the exocyclic carbonyl center. In response to this and related problems, we have recently discovered a new protocol employing basic hydrogen peroxide for the nondestructive removal of 2-oxazolidinones from extremely hindered imides.[15] For example, treatment of the Diels–Alder product **23a** with lithium hydroxide and a fourfold excess of 30% hydrogen peroxide in aqueous tetrahydrofuran for 15 h at ambient temperature afforded a 76% isolated yield of the corresponding carboxylic acid **26** and a 72% yield of recovered oxazolidinone **4** (eq 17).[16] Thus, even with the most hindered *N*-acyloxazolidinone that we have yet encountered, we can isolate good yields of both chiral auxiliary and hydrolyzed cycloadduct.

Scheme V

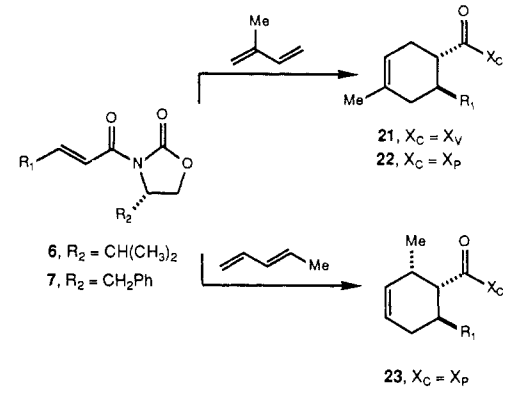
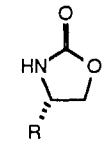
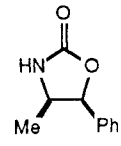
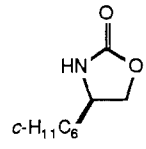


Table VI. Trienimide Synthesis (Eq 18)

Oxazolidinone		n	Product	Yield, %
	R = $CH(CH_3)_2$ (HX_V) **3**	1	**29a**	66
		2	**30a**	84
	R = CH_2Ph (HX_P) **4**	1	**29b**	91
		2	**30b**	83
	HX_N **5**	1	**29c**	65
		2	**30c**	85
	HX_{PPG} **31**	1	**29d**	54
		2	**30d**	52

Intramolecular Cycloaddition Reactions. In view of the general utility of intramolecular Diels–Alder reactions,[17] we felt that it

(14) Specific rotation: Cologne; Crabalona *Bull. Chim. Soc. Fr.* **1960**, 102. Absolute configuration: Henbest, H. B.; McElhinney, R. S. *J. Chem. Soc.* **1959**, 1834.

(15) Evans, D. A.; Ellman, J. A.; Britton, T. C. *Tetrahedron Lett.* **1987**, *28*, 6141, 6144.

(16) We thank T. C. Britton for performing this experiment.

(17) For recent review, see: (a) Brieger, G.; Bennet, J. N. *Chem. Rev.* **1980**, *80*, 63. (b) Oppolzer, W. *Angew. Chem., Int. Ed. Engl.* **1977**, *16*, 10. (c) Oppolzer, W. *Synthesis* **1978**, 793. (d) Funk, R. L.; Vollhardt, K. P. C. *Chem. Soc. Rev.* **1980**, *9*, 41. (e) Fallis, A. G. *Can. J. Chem.* **1984**, *62*, 183–235.

Table VII. Me_2AlCl-Promoted Intramolecular Diels–Alder Reactions of Trienimides **29–30** (Eq 19 and 20)[a]

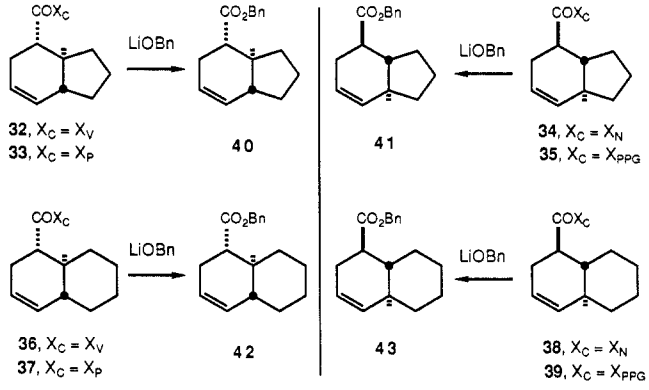
imide (X_C)	endo I: endo II[b]	∑endo: ∑exo[b]	purified ratio	yield,[c] % (prod)	mp, °C
29a (X_V)	83:17	>99:1	>99:1	60 (**32**)	79.5–81.5
29b (X_P)	95:5	>99:1	>99:1	73 (**33**)	oil
29c (X_N)	15:85	>99:1	>99:1	70 (**34**)	119–120
29d (X_{PPG})	3:97	>99:1	>99:1	65 (**35**)	138–139
30a (X_V)	92:8	>30:1	>99:1	65 (**36**)	80.0–81.0
30b (X_P)	97:3	>50:1	>99:1	88 (**37**)	86.5–88.0
30c (X_N)	9:91	>50:1	>99:1	70 (**38**)	oil
30d (X_{PPG})	6:94	>30:1	>99:1	70 (**39**)	140–141

[a] All reactions were carried out with 1.4 equiv of Me_2AlCl in CH_2Cl_2 at −30 °C for 5 h. [b] Ratios were determined by capillary gas chromatography. [c] Yield of purified product having the indicated diastereomeric purity.

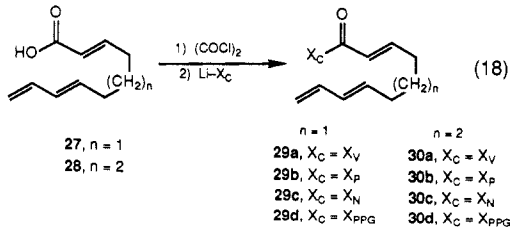
Table VIII. Transesterification of Intramolecular Diels–Alder Adducts **32–39** with Lithium Benzyl Oxide (Scheme VI)

imide (X_C)	product	yield, %	$[\alpha]_{589}$, deg
32 (X_V)	**40**	75	+28.8 (*c* 0.323, CH_2Cl_2)
33 (X_P)	**40**	94	+28.6 (*c* 0.322, CH_2Cl_2)
34 (X_N)	**41**	87	−28.6 (*c* 0.369, CH_2Cl_2)
35 (X_{PPG})	**41**	90	−28.7 (*c* 0.362, CH_2Cl_2)
36 (X_V)	**42**	65	+5.5 (*c* 0.77, $CHCl_3$)
37 (X_P)	**42**	70	+5.56 (*c* 0.809, CH_2Cl_2)
38 (X_N)	**43**	61	−5.58 (*c* 0.242, CH_2Cl_2)
39 (X_{PPG})	**43**	67	−5.57 (*c* 0.323, CH_2Cl_2)

Scheme VI

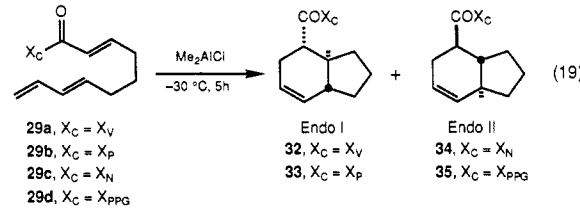


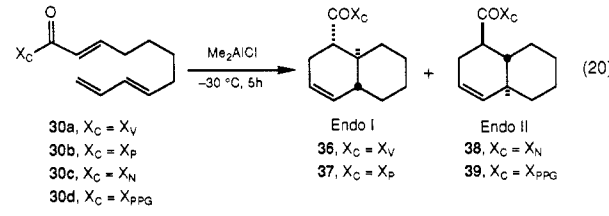
would be worthwhile to apply our design concepts to the asymmetric cycloaddition of suitable triene *N*-acyloxazolidinones.[18] The excellent studies of Roush describing the cycloaddition of 2,7,9-decatrienoic and 2,8,10-undecatrienoic acid esters[19] provided suitable background for our selection of imides **29–30** as substrates for this study. The synthesis of the requisite trienimides is illustrated in eq 18 and Table VI. The known trienoic acids[19b]



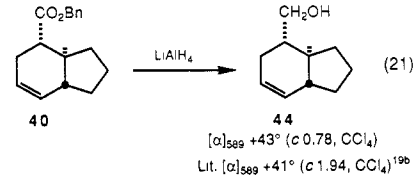
(18)

were treated with oxalyl chloride, and the resultant acid chlorides were used to acylate 3-lithio-2-oxazolidinones in good to excellent overall yields. The cyclohexyl-substituted chiral auxiliary **31** (X_{PPG}) was prepared by hydrogenation (Rh/Al_2O_3) of the corresponding (4*R*)-4-phenyl-2-oxazolidinone[20] derived from (4*R*)-phenylglycinol. Intramolecular Diels–Alder reaction of trienimides **29–30** (eq 19 and 20, Table VII) proceeded in an





analogous fashion to the reactions detailed above. Treatment of a dilute dichloromethane solution of these imides with dimethylaluminum chloride (DMAC)[21] at −30 °C for 5 h provided the illustrated bicyclic cycloadducts in excellent yields. We were pleased to note consistently good endo diastereoface selectivities and excellent endo/exo ratios in these reactions. As before, good yields of diastereomerically homogeneous products were readily obtained either by simple recrystallization or by silica gel chromatography. Chiral auxiliary removal from these intramolecular cycloadducts was easily effected by using lithium benzyl oxide (Scheme VI, Table VIII). Assignment of the absolute configuration of the bicyclo[4.3.0]nonenecarboxylic acid benzyl esters was provided by reduction of ester **40** to the primary carbinol **44**, whose absolute configuration has been established elsewhere (eq 21).[19b] The observed rotation, $[\alpha]_{589}$ +43° (*c* 0.78, CCl_4) for the synthetic material, agrees well with the reported value: $[\alpha]_{589}$ +41° (*c* 1.94, CCl_4).



In order to obtain further calibration on the reactivity differences between esters and imides in Diels–Alder reactions, methyl (*E,E*)-2,7,9-decatrienoate and (*E,E*)-decatrienimide **29a** (eq 19) were cyclized at varying temperatures under otherwise identical conditions. While complete conversion to imide cycloadduct **32** occurred within 5 h at −30 °C, the corresponding ester required 42 h at 25 °C to achieve 84% conversion. This differential reactivity is important to successful asymmetric cyclization of 2,7,9-decatrienoic acid derivatives and is absolutely crucial to the high-yield asymmetric cycloaddition of 2,8,10-undecatrienoic acid derivatives. Roush observed that, while a variety of potent Lewis acids (e.g., $SnCl_4$, $TiCl_4$, BF_3, R_nAlCl_{3-n}) efficiently promote the cyclization of methyl (*E,E*)-2,7,9-decatrienoate, the much more hindered chiral ester derived from 8-phenylmenthol **45** can only be cyclized, in the face of competing polymerization, by employing mild Lewis acids ($ROAlCl_2$, eq 22).[19b] More significantly, intramolecular Diels–Alder reaction of 2,8,10-undecatrienoic acid esters **46** has not been successfully promoted using *any* Lewis acid. Since the thermal cyclization of these esters is a stereorandom process (eq 23),[19b] the importance of the enhanced reactivity

(18) After our initial communication of this work (ref 2b), a similar study was reported; Oppolzer, W.; Dupuis, D. *Tetrahedron Lett.* **1985**, *26*(44), 5437–5440.

(19) (a) Roush, W. R.; Gillis, H. R. *J. Org. Chem.* **1980**, *45*(21), 4264–4268. (b) Roush, W. R.; Gillis, H. R.; Ko, A. I. *J. Am. Chem. Soc.* **1982**, *104*, 2269–2283. (c) Roush, W. R.; Gillis, H. R. *J. Org. Chem.* **1982**, *47*(25), 4825–4829. (d) Roush, W. R.; Hall, S. E. *J. Am. Chem. Soc.* **1981**, *103*, 5200–5211.

(20) Mathre, D. J. Ph.D. Dissertation, California Institute of Technology, Pasadena, CA, 1984.

(21) We have found DMAC to be slightly more reactive and less prone to 1,4-alkyl addition than DEAC.

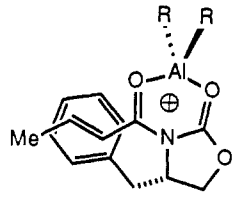
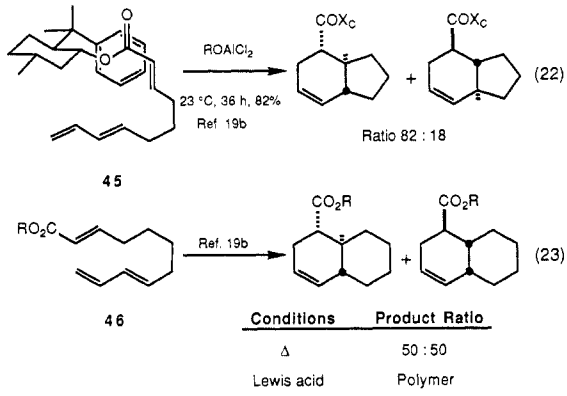
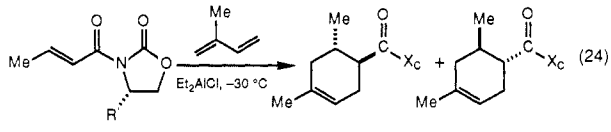


Figure 3. Model for π-stacking interaction.

inherent to the *N*-acyloxazolidinone dienophiles should not be underestimated.



New Auxiliaries. During the initial phases of this study, we surveyed mainly the (4*S*)-valinol- and (4*R*,5*S*)-norephedrine-derived oxazolidinones for reaction diastereoselection. Although these auxiliaries proved to be quite adequate for reactive dienes such as cyclopentadiene (Table III) and in intramolecular cycloadditions (Table VII), they proved to be inadequate in those reactions of crotonyl- and acryloyloxazolidinones with less reactive dienes such as isoprene and piperylene (Table V). For example, the cycloaddition of imide **6a** with isoprene resulted in poor stereoselectivity (4.9:1) even at −30 °C (eq 24). These observations



Substrate	Ratio
6a, R = $CHMe_2$	5.3 : 1
7a, R = CH_2Ph	20.7 : 1
47, R = CH_2Cyclohexyl	9.7 : 1

led us to a redesign of the oxazolidinone auxiliary. In this regard, the observations of Corey[22] with respect to the importance of the phenyl ring in his 8-phenylmenthol chiral auxiliary prompted us to examine oxazolidinone auxiliary **4**, bearing a benzyl group at the 4-position. It was felt, somewhat naively, that the phenyl ring might participate in a charge-transfer interaction with the extremely electron-deficient dienophilic moiety, thereby enhancing the π-facial stereoselectivity of the ensuing cycloaddition (Figure 3). In support of this supposition, *N*-crotonyl-2-oxazolidinone **7a** does undergo cycloaddition with isoprene at −30 °C to afford an improved 20:1 ratio of the expected Diels–Alder adducts (eq 24). As a control experiment, we also carried out the analogous cycloaddition of the reduced cyclohexylmethyl-substituted dienophile **47**. We were pleased to note a significant decrease in the diastereoselectivity of this cycloaddition relative to that of **7a** despite the increased steric bulk of the appended side chain. Thus, the aromatic ring is clearly important to the observed diastereofacial bias.

Electronic Substituent Effects. The implication from the above data is that there is some stereochemical control element that is operating to improve the cycloaddition diastereoselectivity of dienophile **7a** over that of its closely related congener **6a**. Since the steric bulk of an isopropyl group is normally considered to be greater than that of a benzyl substituent, the origin of the enhanced reaction diastereoselectivity of **7a** could be electronic in nature as in the charge-transfer interaction between benzyl and dienophilic moieties illustrated in Figure 3. In view of the potential importance of such interactions to asymmetric synthesis design, a detailed understanding of such noncovalent interactions is essential. In this regard, the literature provides a number of instances where related phenomena may be operating to influence the stereochemical outcome of a given reaction. Subsequent to the elegant work of Corey on the diastereoselective reduction of C-15 prostanoid ketones,[23] numerous cases of prochiral carbon shielding by aromatic ring π-solvation can be cited. Aromatic rings have been suggested to selectively shield diastereofaces in Diels–Alder reactions,[24] ene reactions,[25] photochemical [2 + 2] cycloadditions,[26] Michael reactions,[27] nickel-promoted [3 + 2] cycloadditions,[28] Claisen rearrangements,[29] and nucleophilic carbonyl additions.[30] In the most comprehensive study of its kind to date, Whitesell convincingly established the requirement of a proximal phenyl ring for highly diastereoselective glyoxylate ene reactions.[25a-e] As was concluded in the study, however, these results do not demand the presence of an electronic effect, but imply that some property of the phenyl ring, be it size, shape, or electronic character, is absolutely required. In conjunction with the present Diels–Alder study, we have attempted to provide a set of experiments that might unambiguously reveal the source of the "benzyl" substituent effects documented above (eq 24).

It seemed reasonable to expect that a charge-transfer interaction between the aromatic ring and the dienophilic moiety of **7a** *should manifest itself not only in increased diastereoselectivity but also in decreased reactivity.* Accordingly, a relative rate comparison between **7a** and **47** in the cycloaddition with isoprene was carried out. The reaction was quenched after 5 min at −78 °C (10% conversion). Contrary to expectation, it was found that the phenyl-substituted dienophile **7a** actually reacts slightly faster (1.3 times) than does its fully saturated counterpart **47**. Although the interpretation of this experiment is complicated by our lack of knowledge concerning the effects of steric bulk on reaction rates, we nonetheless conclude that little, if any, electronic reorganization

(22) Corey, E. J.; Ensley, H. E. *J. Am. Chem. Soc.* **1975**, *97*(23), 6908–6909.

(23) Corey, E. J.; Becker, K. B.; Varma, R. K. *J. Am. Chem. Soc.* **1972**, *94*(24), 8616–8618.

(24) (a) Ensley, H. E. Ph.D. Thesis, Harvard University, 1976. (b) Reference 22. (c) Ensley, H. E.; Parnell, C. A.; Corey, E. J. *J. Org. Chem.* **1978**, *43*(8), 1610–1612. (d) Trost, B. M.; O'Krongly, D.; Belletire, J. L. *J. Am. Chem. Soc.* **1980**, *102*(25), 7595–7596. Rebuttals: Masamune, S.; Choy, W.; Petersen, J. S.; Sita, L. R. *Angew. Chem., Int. Ed. Engl.* **1985**, *24*(1), 1–76; see footnote, p 12. Charleton, J. L. *Tetrahedron Lett.* **1985**, *26*, 3413. (e) Trost, B. M. *Chem. Br.* **1984**, *20*, 315. (f) De Jesus, K. Ph.D. Thesis, University of Wisconsin, Madison, 1986. (g) Dauben, W. G.; Bunce, R. A. *Tetrahedron Lett.* **1982**, *23*(47), 4875–4878. (h) Smith, A. B.; Liverton, N. J.; Hrib, N. J.; Sivaramakrishnan, H.; Winzenberg, K. *J. Am. Chem. Soc.* **1986**, *108*(11), 3040–3048. (i) Ito, Y.; Amino, Y.; Nakatsuka, M.; Saegusa, T. *J. Am. Chem. Soc.* **1983**, *105*(6), 1586–1590. Rebuttal: Charleton, J. L. *Can. J. Chem.* **1986**, *64*, 720–725. (j) See for example: Oppolzer, W.; Kurth, M.; Reichlin, D.; Chapuis, C.; Monhaupt, M.; Moffat, F. *Helv. Chim. Acta* **1981**, *64*, 2802–2807. (k) Oppolzer, W.; Chapuis, C.; Dao, G. M.; Reichlin, D.; Godel, T. *Tetrahedron Lett.* **1982**, 4781.

(25) (a) Whitesell, J. K.; Battacharya, A.; Aguilar, D. A.; Henke, K. *J. Chem. Soc., Chem. Commun.* **1982**, 989–990. (b) Whitesell, J. K.; Deyo, D.; Battacharya, A. *J. Chem. Soc., Chem. Commun.* **1983**, 802. (c) Whitesell, J. K.; Younathan, J. N.; Hurst, J. R.; Fox, M. A. *J. Org. Chem.* **1985**, *50*, 5499–5503. (d) Whitesell, J. K. *Acc. Chem. Res.* **1985**, *18*, 280–284. (e) Whitesell, J. K.; Lawrence, R. M.; Chen, H. H. *J. Org. Chem.* **1986**, *51*(25), 4779–4784. (f) Oppolzer, W.; Robbiani, C.; Battig, K. *Helv. Chim. Acta* **1980**, *63*(7), 2015–2018. (g) Oppolzer, W. *Pure Appl. Chem.* **1981**, *53*, 1181–1201.

(26) (a) Lange, G. L.; Lee, M. *Tetrahedron Lett.* **1985**, *26*(50), 6163–6166. (b) Herzog, H.; Koch, H.; Scharf, H.-D.; Runsink, J. *Tetrahedron* **1986**, *42*(13), 3547–3558.

(27) d'Angelo, J.; Maddaluno, J. *J. Am. Chem. Soc.* **1986**, *108*, 8112–8114.

(28) Binger, P.; Brinkmann, A.; Richter, J. *Tetrahedron Lett.* **1983**, *24*(34), 3599–3602.

(29) Kallmerton, J.; Gould, T. J. *J. Org. Chem.* **1986**, *51*, 1152–1155.

(30) (a) Whitesell, J. K.; Bhattacharya, A.; Henke, K. *J. Chem. Soc., Chem. Commun.* **1982**, 988–989. (b) Yamamoto, Y.; Yatagai, H.; Ishihara, Y.; Maeda, N.; Maruyama, K. *Tetrahedron* **1984**, *40*(12), 2239–2246. (c) Grossen, P.; Herold, P.; Mohr, P.; Tamm, C. *Helv. Chim. Acta* **1984**, *67*, 1625–1629.

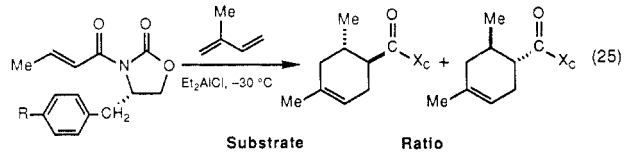
Table IX. Variation of Diastereoface Shielding in Oxazolidinone Crotonate/Isoprene Diels–Alder Cycloadditions and Oxazolidinone Butyrate/Methyl Iodide Alkylations (Eq 26 and 27)

entry	R	ratio D_1/D_2[a]	ratio A_1/A_2[a]
A	Ph (a)	2.06	4.24
B	Me (b)	3.83	6.95
C	Et (c)	5.50	9.21
D	i-C_3H_7 (d)	5.34	9.85
E	$CH_2(c$-$C_6H_{11})$ (e)	9.68	17.4
F	$tert$-C_4H_9 (f)[b]	>100[c]	67.7
G	CH_2Ph (g)	20.7	16.7
H	$CH_2(p$-MeOPh) (h)	23.3	16.9
I	$CH_2(p$-ClPh) (i)	22.8	15.8
J	$CH_2(p$-CF_3Ph) (j)[d]	21.0	16.8

[a] Ratios determined by capillary vapor phase chromatography. [b] Reference 34. [c] Diastereoselectivity beyond the limits of detection. [d] Reference 35.

accompanies the alleged charge-transfer or "π-stacking" interaction in the cycloaddition of **7a**.

Although there is no apparent electronic deactivation of the dienophile due to the presence of the aromatic ring, we hoped to provide evidence for π-complexation by perturbing the donor ability of the phenyl ring and observing the incumbent changes in reaction diastereoselectivity. In particular, it was anticipated that an increase in the donor ability of the phenyl ring should lead to an increase in the π–π interaction and therefore to higher reaction diastereoselection. With this in mind, analogues of **7a** substituted in the para position of the phenyl ring with methoxy (**48**), chloro (**49**), and trifluoromethyl (**50**) groups were synthesized from their respective amino acids. Surprisingly, the reactions of these analogues with isoprene afforded adducts with diastereoselectivities insignificantly different from that of the parent crotonate **7a** (eq 25). It is thus concluded that if there is a contribution to Diels–Alder diastereoselectivity due to electronic π-solvation, that contribution is not significantly perturbed by the presence of methoxy, chloro, or trifluoromethyl groups.



Substrate	Ratio
7a, R = H	20.7 : 1
48, R = OMe	23.3 : 1
49, R = Cl	22.8 : 1
50, R = CF_3	21.0 : 1

The analysis of substituent effects of the type under discussion would be greatly aided if the steric and electronic components of a given substituent could be separated and independently evaluated for a given set of reactions. For the Diels–Alder reaction under discussion, we hoped to dissect the steric component of diastereoface shielding from the associated electronic component by a direct comparison of the diastereomeric Diels–Alder transition states to the corresponding transition states of a structurally analogous but unrelated reaction. For example, there is considerable structural homology between *N*-acyloxazolidinone enolates[31] and dienophiles (eq 1 and 2). It occurred to us that direct comparison of the diastereoselectivities in analogous alkylation and Diels–Alder reactions employing imides with varying oxazolidinone substituents should reveal the presence of any stereochemical control element not common to both sets of transition states. Although the lithium enolate complex **1** (M = Li) is topographically similar to the metal-complexed dienophile **2** (M = AlR_2), the presumed reactive species in these Diels–Alder reactions, the electron-rich nature of the enolate π-system would be presumed to disfavor π-solvation by the aromatic ring. It follows that those substituents which define reaction diastereoselectivity

(31) The diastereoselectivity of the cycloaddition of crotonate **51f** bearing the 4-*tert*-butyl substituent was beyond the limits of our capillary VPC detection and could not be used for these comparisons.

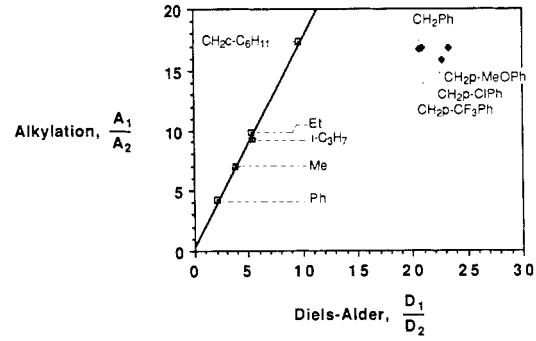
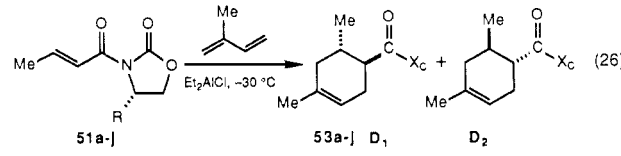
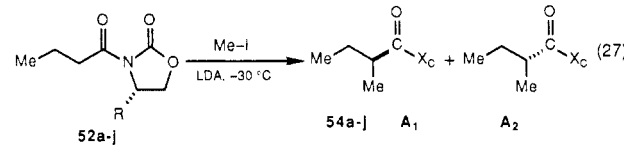


Figure 4. Plot of crotonate oxazolidinone/isoprene Diels–Alder diastereomer ratio versus corresponding butyrate oxazolidinone/methyl iodide alkylation diastereomer ratio. (See Table IX.)

exclusively through steric effects (Me, Et, i-C_3H_7, etc.) should show a strong correlation for the two reactions; however, those substituents which operate through *more* than one stereochemical control element for a given reaction (benzyl?) should not. Accordingly, a series of 4-substituted 2-oxazolidinones were prepared and acylated with both butanoyl chloride and (*E*)-crotonyl chloride. The methyl iodide alkylation of butanoyloxazolidinone lithium enolates[5b] (eq 27) and isoprene Diels–Alder reactions of (*E*)-crotonyl-2-oxazolidinones (eq 26) were selected for comparison





at common reaction temperatures (−30 °C). Product diastereomer ratios for these reactions are shown in Table IX and are plotted against each other in Figure 4.[31] Oxazolidinone substituents that cannot π-solvate the Diels–Alder transition state (Ph, Me, Et, i-C_3H_7, CH_2-c-C_6H_{11}) lie on a line representing the purely steric contribution to diastereoface differentiation in both reactions. The observed excellent linear correlation (r = 0.997) validates this direct comparison of Diels–Alder and alkylation diastereoselectivities. On the other hand, aryl-substituted methyl substituents lie well off this line in the direction of *higher* Diels–Alder diastereoselectivity. As would be expected on purely steric grounds, the cyclohexylmethyl-substituted oxazolidinone and the arylmethyl-substituted oxazolidinones give similar diastereoselectivities in their butyrate alkyation reactions. They differ dramatically, however, in their corresponding crotonate Diels–Alder diastereoselectivities. This direct alkylation/Diels–Alder comparison provides compelling evidence that π-facial differentiation, which is basically controlled by steric effects, is enhanced by the electronic contributions documented in these Diels–Alder transition states. Alteration of the π-donor ability of the phenyl group has little effect on the Diels–Alder reaction diastereoselection and, as would be expected, has essentially no effect on the corresponding alkylation process (Table IX, entries G–J). Furthermore, we observed no rate retardation in the direct competition between **7a** and **47** (vide infra). In view of these observations, we believe the "enhanced steric effect", promoted by electronic contributions, observed in these reactions results largely from dipole–dipole and van der Waals attractions and not from charge-transfer interactions. Indeed, it has been suggested that the binding forces stabilizing many π–π molecular complexes may be explained without recourse to charge transfer.[32]

(32) (a) Dewar, M. J. S.; Thompson, C. C. *Tetrahedron Suppl.* **1966**, *7*, 97. (b) Bently, M. D.; Dewar, M. J. S. *Tetrahedron Lett.* **1967**, *50*, 5043.

The method of analysis used herein to reveal electronic contributions to reaction diastereoselectivity exhibits a remarkable level of internal consistency and provides compelling circumstantial evidence that such dissimilar reactions can be legitimately compared. This protocol for dissecting the contributing aggregated stereochemical control elements for substituents could well be extended to other reactions.

The exceptional selectivity observed in the Diels–Alder reaction of crotonyloxazolidinone **51f**, bearing the *tert*-butyl substituent, is worthy of special note (Table IX, entry F). The isoprene Diels–Alder diastereoselectivity was beyond the limit of our capillary VPC detection and thus could not be used in our direct comparisons. We very conservatively set the lower limits of the asymmetric induction in this reaction at >100:1. With the excellent, recently published procedure for the synthesis and resolution of *tert*-leucine,[33] 4-(*tert*-C_4H_9)-2-oxazolidinone is now a viable auxiliary for asymmetric cycloadditions of particularly poor inherent diastereoselectivity.[34,35]

Conclusions

Unsaturated *N*-acyloxazolidinones are useful diastereoselective dienophiles with well-defined limitations. Their advantages include exceptional reactivity, high diastereofacial differentiation, enhanced secondary orbital interaction, easy product separation, effective and nondestructive chiral auxiliary removal, and high incidence of crystallinity. Thus far, successful diastereoselective Diels–Alder reaction has been limited to monosubstituted and *E*-disubstituted imide dienophiles. Nevertheless, the inexpensive commercial availability of both optical antipodes of phenylalanine together with the aforementioned advantages make unsaturated *N*-acyloxazolidinones attractive choices for many asymmetric Diels–Alder applications.

Experimental Section

Melting points are uncorrected. Dialkylaluminum chlorides were obtained from Texas Alkyls Inc. Tetrahydrofuran, diethyl ether, triethylamine, benzene, and toluene were distilled from sodium/benzophenone ketyl. Dichloromethane, diisopropylamine, and acetonitrile were distilled from calcium hydride. Methanol was distilled from magnesium methoxide. Unless otherwise noted, all nonaqueous reactions were carried out under a dry nitrogen atmosphere with flame-dried glassware.

General Protocol for the Acylation of 2-Oxazolidinones. To a solution of the appropriate oxazolidinone in anhydrous THF (~0.3 M) at −78 °C is added 1.0 equiv of *n*-butyllithium. After 15 min, 1.1 equiv of freshly distilled acid chloride is added. The mixture is stirred at −78 °C for 30 min and at 0 °C for 15 min. The reaction is quenched with excess saturated aqueous ammonium chloride, and the resultant slurry is concentrated in vacuo. The residue is diluted with ether and washed successively with saturated aqueous sodium bicarbonate and then saturated aqueous sodium chloride. The organic layer is dried over magnesium sulfate, filtered, and concentrated in vacuo. The product is purified by flash chromatography on silica gel to afford the desired *N*-acyloxazolidinone.

(4*S*)-3-((*E*)-2-Butenoyl)-4-(1-methylethyl)-2-oxazolidinone (6a). Oxazolidinone **3**[20] (3.00 g, 23.2 mmol) was acylated with (*E*)-crotonyl chloride according to the general protocol detailed above to afford **6a** (4.25 g, 93%, >99% pure by VPC): VPC (30 m SE-54, 135 °C, 15 psi, t_r 4.05 min); R_f 0.14 (30% ether/hexane); IR ($CHCl_3$) 3020, 2970, 1775, 1685, 1638, 1385, 1365, 1340 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.20 (m, 2 H, C*H*=C*H*), 4.10–4.60 (m, 3 H, C*H*N, CH_2O), 2.50 (m, 1 H, C*H*(CH_3)$_2$), 1.95 (d, 3 H, J = 5 Hz, CH_3CH=CH), 0.90 (2 d, 6 H, CH(CH_3)$_2$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 165.07, 154.15, 146.74, 121.98, 63.43, 58.62, 28.59, 18.59, 18.13, 14.82; $[\alpha]_{589}$ +105° (*c* 1.97, $CHCl_3$). An analytical sample was prepared by recrystallization from hexane to afford colorless needles, mp 56.0–56.5 °C.

Anal. Calcd for $C_{10}H_{15}NO_3$: C, 60.89; H, 7.66. Found: C, 60.87; H, 7.72.

(4*S*)-3-(2-Propenoyl)-4-(1-methylethyl)-2-oxazolidinone (6b). Method A. To a solution of 1.0 g (7.7 mmol) of oxazolidinone **3** in 50 mL of anhydrous THF at 0 °C was added 2.6 mL (3.0 M in ether, 7.7 mmol, 1.0 equiv) of methylmagnesium bromide. After 10 min the mixture was cooled to −78 °C and 0.80 mL (890 mg, 9.9 mmol, 1.3 equiv) of freshly distilled acryloyl chloride was added. The mixture was stirred at −78 °C for 10 min and at 0 °C for 20 min. The reaction was quenched with 10 mL of saturated aqueous ammonium chloride, the resultant slurry diluted with 150 mL of ether (peroxide free!), and the ethereal solution washed with saturated aqueous ammonium chloride. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 1.3 g (92% mass balance) of a cloudy, pale yellow oil. The product was purified by flash chromatography on silica gel (30 × 180 mm column, 50% ether (peroxide free!)/hexane, 20-mL fractions) to afford 673 mg (47%, >99% pure by VPC) of the title compound as a clear, colorless oil, which crystallized on standing: VPC (30 m SE-54, 125 °C, 15 psi, t_r 2.74 min); R_f 0.11 (30% ether/hexane); IR ($CHCl_3$) 3030, 2980, 1770, 1690, 1620, 1410, 1388, 1320, 1250 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.50 (dd, 1 H, J = 10.5, 17.0 Hz, C*H*=CH_2), 6.50 (dd, 1 H, J = 2.0, 17.0 Hz, (*Z*)-C*H*H=CH), 5.85 (dd, 1 H, J = 2.0, 10.5 Hz, (*E*)-C*H*H=CH), 4.10–4.60 (m, 3 H, C*H*N, CH_2O), 2.40 (m, 1 H, C*H*(CH_3)$_2$), 0.90 (2 d, 6 H, J = 7 Hz, CH(CH_3)$_2$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 164.74, 153.96, 131.34, 127.57, 63.56, 58.55, 28.46, 17.94, 14.69; $[\alpha]_{589}$ +110° (*c* 1.00, $CHCl_3$). An analytical sample was prepared by recrystallization from hexane to afford colorless needles: mp 44.0–45.0 °C.

Anal. Calcd for $C_9H_{13}NO_3$: C, 59.00; H, 7.15. Found: C, 59.21; H, 7.31.

Method B. To a solution of 505 mg (3.9 mmol) of oxazolidinone **3** in 30 mL of anhydrous THF at 0 °C was added 1.33 mL (2.9 M in ether, 3.9 mmol, 1.0 equiv) of methylmagnesium bromide. The mixture was stirred at 0 °C for 10 min and 0.45 mL (765 mg, 4.5 mmol, 1.2 equiv) of 3-bromopropionyl chloride was added. The mixture was stirred for 10 min, diluted with 100 mL of ether (peroxide free!), and washed with saturated aqueous ammonium chloride. The ether layer was dried over magnesium sulfate and filtered. Triethylamine (4 mL) was added and a colorless precipitate formed immediately. The slurry was stirred at ambient temperature for 3 h and then washed with 50 mL of a 1:1 mixture of saturated aqueous ammonium chloride and 1 N aqueous hydrochloric acid. The aqueous layer was extracted with ether (peroxide free!), and the combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 677 mg (95% mass balance) of a cloudy, pale yellow oil. The product was purified by flash chromatography on silica gel (30 × 180 mm column, 50% ether (peroxide free!)/hexane, 20-mL fractions) to afford 459 mg (66%, >99% pure by VPC) of the title compound as a clear, colorless oil.

(4*S*)-3-(2-Methyl-2-propenoyl)-4-(1-methylethyl)-2-oxazolidinone (6c). Oxazolidinone **3** (1.0 g, 7.7 mmol) was acylated with methacryloyl chloride according to the general protocol detailed above to afford **6c** (1.4 g, 92%, >99% pure by VPC): VPC (30 m SE-54, 135 °C, 15 psi, t_r 2.52 min); R_f 0.14 (30% ether/hexane); IR ($CHCl_3$) 3020, 2980, 1790, 1688, 1388, 1365, 1325, 1300, 1200 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.45 (br s, 2 H, CH_2=C), 4.10–4.70 (m, 3 H, C*H*N, CH_2O), 2.45 (m, 1 H, C*H*(CH_3)$_2$), 2.05 (d, 3 H, J = 1 Hz, CH_3C=CH_2), 0.90 (2 d, 6 H, CH(CH_3)$_2$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 170.85, 153.24, 139.66, 120.10, 63.43, 58.03, 28.14, 18.98, 17.68, 14.75; $[\alpha]_{589}$ +98.7° (*c* 1.69, $CHCl_3$). An analytical sample was prepapred by recrystallization from hexane to afford colorless needles, mp 66.0–67.0 °C.

Anal. Calcd for $C_{10}H_{15}NO_3$: C, 60.90; H, 7.67. Found: C, 60.71; H, 7.49.

(4*S*)-3-(3-Methyl-2-butenoyl)-4-(1-methylethyl)-2-oxazolidinone (6d). Oxazolidinone **3** (3.00 g, 23.2 mmol) was acylated with 3-methylbutenoyl chloride according to the general protocol detailed above to afford **6d** (4.75 g, 97%, >99% pure by VPC): VPC (30 m SE-54, 125 °C, 15 psi, t_r 5.13 min); R_f 0.19 (30% ether/hexane); IR ($CHCl_3$) 2970, 2880, 1780, 1680, 1635, 1450, 1390, 1365, 1260, 1212, 1190 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 6.95 (m, 1 H, C*H*=C), 4.10–4.60 (m, 3 H, C*H*N, CH_2O), 2.40 (m, 1 H, C*H*(CH_3)$_2$), 2.18 (d, 3 H, J = 1 Hz, CH_3C=CH), 2.00 (d, 3 H, J = 1 Hz, CH_3C=CH), 0.90 (2 d, 6 H, J = 7 Hz, CH(CH_3)$_2$).

(4*S*)-3-((*E*)-3′-Phenyl-2′-propenoyl)-4-(1-methylethyl)-2-oxazolidinone (6e). Oxazolidinone **3** (1.30 g, 10.0 mmol) was acylated with cinnamoyl chloride according to the general protocol detailed above to afford **6e** (2.52 g, 97%, >99% pure by VPC): VPC (30 m SE-54, 180 °C, 15 psi, t_r 6.64 min); R_f 0.25 (50% ether/hexane); IR ($CHCl_3$) 3025, 2975, 1778, 1687, 1620, 1388, 1368, 1344, 1205 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.90 (d, 2 H, J = 2 Hz, C*H*=C*H*), 7.55 (m, 2 H, aromatic H's), 7.30 (m, 3 H, aromatic H's), 4.10–4.60 (m, 3 H, C*H*N, CH_2O), 2.40 (m, 1 H, C*H*(CH_3)$_2$), 0.90 (2 d, 6 H, J = 7 Hz, CH(CH_3)$_2$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 165.13, 154.15, 146.09, 134.59, 130.50, 128.87, 128.55, 117.17, 63.43, 58.68, 28.53, 18.00, 14.75; $[\alpha]_{589}$ +94.6° (*c* 1.65, $CHCl_3$).

Anal. Calcd for $C_{15}H_{17}NO_3$: C, 69.48; H, 6.61. Found: C, 69.22; H, 6.69.

(4*S*)-3-((*E*)-2-Butenoyl)-4-(phenylmethyl)-2-oxazolidinone (7a). Oxazolidinone **4**[5c] (50.0 g, 282 mmol) was acylated with (*E*)-crotonyl chloride according to the general protocol detailed above to afford **7a**

(33) Viret, J.; Patzelt, H.; Collet, A. *Tetrahedron Lett.* **1986**, *27*(48), 5865.
(34) We thank D. T. Hung for performing these experiments. See ref 2c.
(35) We thank A. Kawaguchi for performing these experiments. See ref 2c.

(59.5 g, 86%, >99% pure by VPC): mp 85.0–86.0 °C; VPC (30 m SE-54, 170 °C, 15 psi, t_r 5.12 min); R_f 0.14 (30% ether/hexane); IR ($CHCl_3$) 3020, 1780, 1685, 1632, 1446, 1384, 1354, 1270, 1220 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.16–7.34 (m, 7 H, aromatic H's, C*H*=C*H*), 4.71 (ddt, 1 H, J = 3.2, 7.6, 9.5 Hz, C*H*N), 4.19 (ddd, 1 H, J = 0.5, 9.1, 7.7 Hz, C*H*HO), 4.15 (dd, 1 H, J = 3.0, 9.1 Hz, CH*H*O), 3.31 (dd, 1 H, J = 3.3, 13.4 Hz, C*H*HPh), 2.78 (dd, 1 H, J = 9.6, 13.4 Hz, CH*H*Ph), 1.97 (dd, 3 H, J = 1.0, 6.3 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.72, 153.26, 146.69, 135.28, 129.30, 128.76, 127.10, 121.76, 65.96, 55.12, 37.71, 18.40; $[\alpha]_{589}$ +77.9° (*c* 2.00, $CHCl_3$).

Anal. Calcd for $C_{14}H_{15}NO_3$: C, 68.56; H, 6.16. Found: C, 68.77; H, 6.27.

(4*S*)-3-(2-Propenoyl)-4-(phenylmethyl)-2-oxazolidinone (7b). To a solution of 210 mg (1.2 mmol) of oxazolidinone **4** in 10 mL of anhydrous THF at −20 °C was added 0.4 mL (3.0 M in ether, 1.2 mmol, 1.0 equiv) of methylmagnesium bromide. After 10 min, 0.10 mL (111 mg, 1.2 mmol, 1.0 equiv) of freshly distilled acryloyl chloride was added. The mixture was stirred at −20 °C for 15 min, and the reaction was quenched with 1 mL of saturated aqueous ammonium chloride. The resultant slurry was diluted with 50 mL of ether (peroxide free!) and washed with saturated aqueous ammonium chloride. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 266 mg (96% mass balance) of a clear, colorless oil. The product was purified by flash chromatography on silica gel (20 × 180 mm column, 50% ether (peroxide free!)/hexane, 10-mL fractions) to afford 146 mg (55%, >99% pure by VPC) of the title compound as a colorless, crystalline solid: VPC (30 m SE-54, 150 °C, 15 psi, t_r 6.36 min); R_f 0.14 (30% ether/hexane); IR ($CHCl_3$) 3020, 1785, 1686, 1410, 1385, 1365, 1225 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.55 (dd, 1 H, J = 10.5, 17.3 Hz, C*H*=CH_2), 7.30 (m, 5 H, aromatic H's), 6.58 (dd, 1 H, J = 2.0, 17.3 Hz, (*Z*)-C*H*HC=CH), 5.90 (dd, 1 H, J = 2.0, 10.5 Hz, (*E*)-CH*H*=CH), 4.75 (m, 1 H, C*H*N), 4.20 (m, 2 H, CH_2O), 3.40 (dd, 1 H, J = 3.5, 13.5 Hz, C*H*HPh), 2.80 (dd, 1 H, J = 9.0, 13.5 Hz, CH*H*Ph); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 164.81, 153.24, 135.24, 131.80, 129.39, 128.94, 127.38, 66.29, 55.24, 37.76; $[\alpha]_{589}$ +71.9° (*c* 2.41, $CHCl_3$). An analytical sample was prepared by recrystallization from 1:8 ethyl acetate/hexane to afford colorless needles, mp 73.5–74.5 °C.

Anal. Calcd for $C_{13}H_{13}NO_3$: C, 67.53; H, 5.67. Found: C, 67.65; H, 5.70.

(4*R*,5*S*)-3-((*E*)-2-Butenoyl)-4-methyl-5-phenyl-2-oxazolidinone (8a). Oxazolidinone **5**[20] (2.00 g, 11.3 mmol) was acylated with (*E*)-crotonyl chloride according to the general protocol detailed above to afford **8a** (2.57 g, 93%, >99% pure by VPC): VPC (30 m SE-54, 180 °C, 15 psi, t_r 5.28 min); R_f 0.40 (33% ether/hexane); IR ($CHCl_3$) 3020, 1780, 1688, 1640, 1350, 1220, 1200, 1048 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.15–7.50 (m, 7 H, aromatic H's, C*H*=C*H*), 5.68 (d, 1 H, J = 7 Hz, C*H*O), 4.80 (q, 1 H, J = 7 Hz, C*H*N), 1.95 (d, 3 H, J = 5 Hz, CH_3CH=CH), 0.90 (d, 3 H, J = 7 Hz, CH_3CHN); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 164.48, 152.79, 146.42, 133.29, 128.48, 125.49, 121.92, 78.77, 54.65, 18.33, 14.43; $[\alpha]_{589}$ +52.5° (*c* 1.35, $CHCl_3$). An analytical sample was prepared by recrystallization from 1:30 ethyl acetate/hexane to afford colorless needles, mp 66.0–66.5 °C.

Anal. Calcd for $C_{14}H_{15}NO_3$: C, 68.56; H, 6.16. Found: C, 68.61; H, 6.17.

(4*R*,5*S*)-3-(2-Propenoyl)-4-methyl-5-phenyl-2-oxazolidinone (8b). To a solution of 690 mg (3.9 mmol) of oxazolidinone **5** and 5 mg of hydroquinone in 25 mL of anhydrous THF at 0 °C was added 1.3 mL (2.9 M in ether, 3.8 mmol, 1.0 equiv) of methylmagnesium bromide. After 10 min, 0.32 mL (356 mg, 3.9 mmol, 1.0 equiv) of freshly distilled acryloyl chloride was added. The mixtur was stirred for 5 min, diluted with 50 mL of ether (peroxide free!), and finally washed with first saturated aqueous ammonium chloride and then saturated aqueous sodium bicarbonate. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 850 mg (94% mass balance) of a pale yellow oil. The product was purified by flash chromatography on silica gel (20 × 200 mm column, 33% ether (peroxide free!)/hexane, 10-mL fractions) to afford 494 mg (56%, >99% pure by VPC) of the title compound as a clear, colorless oil: VPC (30 m SE-54, 150 °C, 15 psi, t_r 5.51 min); R_f 0.19 (30% ether/hexane); IR ($CHCl_3$) 3040, 2930, 1780, 1690, 1620, 1410, 1350, 1250, 1198, 1150, 1124 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.50 (dd, 1 H, J = 10.5, 17.3 Hz, C*H*=CH_2), 7.35 (m, 5 H, aromatic H's), 6.50 (dd, 1 H, J = 2.3, 17.3 Hz, (*Z*)-C*H*H=C), 5.85 (dd, 1 H, J = 2.3, 10.5 Hz, (*E*)-C*H*H=C), 5.70 (d, 1 H, C*H*O), 4.80 (q, 1 H, J = 7 Hz, C*H*N), 0.93 (d, 3 H, J = 7 Hz, CH_3); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 164.61, 152.92, 133.22, 131.67, 128.74, 127.51, 125.62, 79.09, 54.91, 14.56; $[\alpha]_{589}$ +29.0° (*c* 2.61, $CHCl_3$).

Anal. Calcd for $C_{13}H_{13}NO_3$: C, 67.53; H, 5.67. Found: C, 67.79; H, 5.85.

(4*R*,5*S*)-3-(2-Methyl-2-propenoyl)-4-methyl-5-phenyl-2-oxazolidinone (8c). Oxazolidinone **5** (710 mg, 4.00 mmol) was acylated with methacryloyl chloride according to the general protocol detailed above to afford **8c** (859 mg, 88%, >99% pure by VPC): VPC (30 m SE-54, 170 °C, 15 psi, t_r 3.20 min); R_f 0.14 (30% ether/hexane); IR ($CHCl_3$) 3030, 1790, 1690, 1350, 1220, 1145, 1120 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (m, 5 H, aromatic H's), 5.70 (d, 1 H, J = 7 Hz, C*H*O), 5.45 (br s, 2 H, CH_2=C), 4.75 (q, 1 H, J = 7 Hz, C*H*N), 2.05 (d, 3 H, J = 1 Hz, CH_3C=CH_2), 0.95 (d, 3 H, J = 7 Hz, CH_3CHN); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 170.79, 152.46, 139.79, 133.49, 128.74, 125.75, 120.16, 79.22, 55.11, 19.11, 14.43; $[\alpha]_{589}$ +36.8° (*c* 1.27, $CHCl_3$). An analytical sample was prepared by recrystallization from ether/hexane to afford colorless needles, mp 80.0–80.5 °C.

Anal. Calcd for $C_{14}H_{15}NO_3$: C, 68.56; H, 6.16. Found: C, 68.32; H, 6.20.

General Protocol for Preparation of Diels–Alder Authentic Mixtures. Thermal Diels–Alder cycloadditions of the requisite diene with the requisite unsaturated carboxylic acid were performed according to the appropriate literature procedure.[36] The carboxylic acid cycloadducts were converted to their corresponding acid chlorides by using oxalyl chloride.[37] The authentic mixtures were prepared as follows: To a solution of 0.1 mmol of the appropriate oxazolidinone in 1.0 mL of anhydrous THF at −78 °C is added 0.11 mmol of *n*-butyllithium. The mixture is stirred for 5 min and 100 μL of racemic acid chloride is added. The mixture is allowed to warm to ambient temperature over 30 min and 1.0 mL of saturated aqueous sodium bicarbonate is added. The slurry is diluted with 10 mL of water and extracted with 10 mL of dichloromethane. The organic layer is dried over magnesium sulfate, filtered, and concentrated in vacuo. The product is then passed through a 5 × 60 mm column (pipet) of silica gel using 50% ethyl acetate/hexane as eluent, diluted to the appropriate volume (~1 mg/mL), and analyzed by VPC.

(4*S*)-3-((3′*R*,4′*R*,5′*S*,6′*S*)-5′-Methylbicyclo[2.2.1]heptene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (11a). To a stirred solution of 1.07 g (5.44 mmol) of crotonate imide **6a** and 11.2 mL (136 mmol, 25.0 equiv) of cyclopentadiene in 11 mL of anhydrous dichloromethane at −100 °C was added 4.10 mL (1.80 M in toluene, 7.61 mmol, 1.40 equiv) of diethylaluminum chloride. The initially formed bright yellow color faded completely within 2 min and the solution was poured into 50 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 20 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 100 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 40 × 80 mm column of silica gel and washed with 300 mL of hexane (discarded). The column was then eluted with 800 mL of 20% ethyl acetate/hexane, and the eluent way concentrated in vacuo to give 1.43 g (100% mass balance) of a colorless, crystalline solid. Analysis by VPC (30 m DB-5, 150 °C, 15 psi, t_r major endo 10.44 min, t_r minor endo 9.07 min, t_r minor exo 9.61 min, t_r minor exo 10.05 min) revealed the presence of four isomers in the ratio of 95:5:1:1. The mixture was recrystallized from ether/hexane to give 1.17 g (82%, >99% pure by VPC) of the title compound is a colorless, crystalline solid: mp 96.0–98.0 °C; IR ($CHCl_3$) 3040, 2980, 2890, 1780, 1700, 1490, 1465, 1390, 1380, 1220, 1030 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.36 (dd, 1 H, J = 3.0, 6.0 Hz, C*H*=CH), 5.74 (dd, 1 H, J = 2.8, 6.0 Hz, CH=C*H*), 4.60–4.10 (m, 3 H, C*H*N, CH_2O), 3.55 (dd, 1 H, J = 3.5, 4.5 Hz, C*H*C=O), 3.37 (br s, 1 H, bridgehead H), 2.53 (br s, 1 H, bridgehead H), 2.20–1.10 (m, 4 H, CH_2CHC*H*CH$_3$, C*H*(CH$_3$)$_2$), 1.10 (d, 3 H, J = 7 Hz, CH_3), 0.88 (d, 6 H, J = 7 Hz, CH(CH_3)$_2$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 173.84, 153.83, 139.92, 130.63, 63.04, 58.29, 51.93, 49.59, 47.83, 47.12, 35.55, 28.27, 20.41, 17.87, 14.49; $[\alpha]_{589}$ +261° (*c* 1.78, $CHCl_3$).

Anal. Calcd for $C_{15}H_{21}NO_3$: C, 68.42; H, 8.04. Found: C, 68.46; H, 8.03.

(*S*)-3-((3′*R*,4′*R*,6′*R*)-Bicyclo[2.2.1]heptene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (11b). To a stirred solution of 75 mg (0.41 mmol) of acrylate imide **6b** in 10 mL of anhydrous dichloromethane at −100 °C was added 0.25 mL (1.8 M in toluene, 0.45 mmol, 1.4 equiv) of diethylaluminum chloride. To the bright yellow solution was added 2.0 mL (24 mmol, 83 equiv) of precooled cyclopentadiene via cannula. After 5 min, the yellow color had completely faded and the solution was

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(37) Adams, R.; Ulich, L. H. *J. Am. Chem. Soc.* **1920**, *42*, 599.

poured into 30 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 10 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 30 × 70 mm column of silica gel and washed with 250 mL of hexane (discarded). The column was then eluted with 300 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 99 mg (96% mass balance) of a colorless oil. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 20 min, 15 psi, t_r major 9.34 min, t_r minor endo 8.33 min, t_r minor exo 8.55) revealed the presence of three isomers in the ratio of 93:7:0.9. Isolation of the major diastereomer by MPLC (two Merck Lobar B columns, 5% ether/toluene, 8 mL/min, 8-mL fractions) afforded 83 mg (81%, >99% pure by VPC) of the title compound as a colorless, crystalline solid: mp 77.0–78.0 °C; IR ($CHCl_3$) 3030, 2980, 1780, 1700, 1386, 1375, 1225 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 6.20 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.78 (dd, 1 H, J = 3, 6 Hz), 3.85–4.50 (m, 4 H, C*H*N, CH_2O, C*H*O=O), 3.35 (br s, 1 H, bridgehead C*H*), 2.94 (br s, 1 H, birdgehead C*H*), 2.25–1.40 (m, 5 H, CH_2CHCH_2, $CH(CH_3)_2$), 0.85 (2 d, 6 H, J = 7 Hz, $CH(CH_3)_2$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 174.17, 153.89, 138.36, 130.95, 63.10, 58.36, 50.37, 46.92, 43.35, 43.09, 28.72, 28.33, 17.94, 14.56; $[\alpha]_{589}$ +242° (c 1.33, $CHCl_3$).

Anal. Calcd for $C_{14}H_{19}NO_3$: C, 67.45; H, 7.68. Found: C, 67.66; H, 7.73.

(4*S*)-3-((3′*R*,4′*S*,5′*S*,6′*R*)-5′-Phenylbicyclo[2.2.1]heptene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (11e). To a stirred solution of 325 mg (1.3 mmol) of cinnamate imide **6e** in 20 mL of anhydrous dichloromethane at −78 °C was added 0.90 mL (1.8 M in toluene, 1.65 mmol, 1.4 equiv) of diethylaluminum chloride. To the bright yellow solution was added 0.5 mL (400 mg, 6.1 mmol, 4.7 equiv) of precooled cyclopentadiene via cannula. The solution was warmed to −20 °C and stirred for 2.5 h, during which time the color faded completely, and 75 mL of dichloromethane was added. The mixture was washed with 1 N aqueous hydrochloric acid, and the organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 538 mg (132% mass balance) of a pale yellow oil. The major product was isolated by flash chromatography on silica gel (20 × 200 mm column, 33% ether/hexane, 10-mL fractions) to afford 337 mg (83%) of the title compound as a colorless oil, which solidified on standing. The product was shown to consist of a single diastereomer by 500-MHz NMR: R_f 0.24 (30% ether/hexane); IR ($CHCl_3$) 3020, 2975, 1775, 1692, 1384, 1332, 1300, 1210 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.20 (m, 5 H, aromatic H's), 6.51 (dd, 1 H, J = 3.0, 5.8 Hz, C*H*=CH), 5.88 (dd, 1 H, J = 3.0, 5.8 Hz, CH=C*H*), 4.43 (dt, 1 H, J = 3.5, 8.8 Hz, C*H*N), 4.21 (m, 2 H, C*H*HO, C*H*C=O), 4.14 (dd, 1 H, J = 3.3, 9.0 Hz, CH*H*O), 3.52 (br s, 1 H, bridgehead H), 3.36 (dd, 1 H, J = 2.0, 5.0 Hz, C*H*Ph), 2.99 (q, 1 H, J = 1 Hz, bridgehead H), 2.24 (d of heptets, 1 H, J = 3.5, 7.0 Hz, $CH(CH_3)_2$), 1.96 (br d, 1 H, J = 8.6 Hz, C*H*H), 1.58 (dq, 1 H, J = 1.0, 8.6 Hz, CH*H*), 0.90 (2 d, 6 H, J = 7.0 Hz, CH_3); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 173.45, 153.83, 143.82, 140.31, 131.93, 128.48, 127.64, 126.08, 63.17, 58.29, 50.95, 49.72, 48.09, 47.77, 46.14, 28.40, 17.87, 14.62; $[\alpha]_{589}$ +215° (c 2.50, $CHCl_3$). An analytical sample was prepared by recrystallization from isopropyl ether to afford colorless needles, mp 125.0–126.5 °C.

Anal. Calcd for $C_{20}H_{23}NO_3$: C, 73.82; H, 7.12. Found: C, 73.70; H, 7.15.

(4*S*)-3-((3′*R*,4′*R*,5′*S*,6′*S*)-5-Methylbicyclo[2.2.1]heptene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (13a). To a stirred solution of 72 mg (0.29 mmol) of crotonate imide **7a** and 0.60 mL (7.3 mmol, 25 equiv) of cyclopentadiene in 0.60 mL of anhydrous dichloromethane at −100 °C was added 0.22 mL (1.8 M in toluene, 0.41 mmol, 1.4 equiv) of diethylaluminum chloride. The initially formed bright yellow color faded completely within 2 min and the solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 4 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 10 × 50 mm column of silica gel and washed with 25 mL of hexane (discarded). The column was then eluted with 50 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 90 mg (99% mass balance) of a colorless oil. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 20 min, 15 psi, t_r major 13.47 min, t_r minor endo 12.67 min, t_r minor exo 12.93 min) revealed the presence of three isomers in the ratio of 97:3:2. Isolation by MPLC (two Merck Lobar B columns, 2% ether/toluene, 8 mL/min, 8-mL fractions) afforded 75 mg (82%, >99% pure by VPC) of the title compound as a colorless oil: IR ($CHCl_3$) 3030, 2980, 1780, 1695, 1372, 1350, 1290, 1220, 1118 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.20 (m, 5 H, aromatic H's), 6.33 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.78 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 4.62 (m, 1 H, C*H*N), 4.13 (m, 2 H, CH_2O), 3.50 (dd, 1 H, J = 3, 4 Hz, C*H*C=O), 3.35 (br s, 1 H, bridgehead H), 3.20 (dd, 1 H, J = 3, 13.5 Hz, C*H*HPh), 2.60 (dd, 1 H, J = 9.5, 13.5 Hz, CH*H*Ph), 2.55 (br d, 1 H, bridgehead H), 2.2–1.4 (m, 3 H, $CH_2CHCHCH_3$), 1.18 (d, 3 H, J = 7 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 174.17, 153.37, 139.92, 135.37, 130.76, 129.33, 128.94, 127.31, 66.09, 55.37, 51.80, 49.72, 47.64, 47.18, 38.15, 36.39, 20.47; $[\alpha]_{589}$ +187° (c 2.30, $CHCl_3$).

Anal. Calcd for $C_{19}H_{21}NO_3$: C, 73.29; H, 6.80. Found: C, 73.03; H, 6.79.

(4*S*)-3-((3′*R*,4′*R*,6′*R*)-Bicyclo[2.2.1]heptene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (13b). To a stirred solution of 666 mg (2.88 mmol) of acrylate imide **7b** in 500 mL of anhydrous dichloromethane at −100 °C was added 1.76 mL (1.80 M in toluene, 3.17 mmol, 1.40 equiv) of diethylaluminum chloride. To the bright yellow solution was added 10.0 mL (121 mmol, 42 equiv) of precooled cyclopentadiene via cannula. After 30 min, the yellow color had completely faded and the solution was poured into 200 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 100 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 40 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 40 × 70 mm column of silica gel and washed with 300 mL of hexane (discarded). The column was then eluted with 600 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 819 mg (91% mass balance) of a colorless, crystalline solid. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 20 min, 15 psi, t_r major 12.71 min, t_r minor endo 12.16 min, t_r minor exo 12.33 min) revealed the presence of three isomers in the ratio of 95:5:0.7. The mixture was recrystallized from hexane to afford 667 mg (78%, 97:3 ratio by VPC) of the title compound as a colorless, crystalline solid: mp 120.0–120.5 °C; IR ($CHCl_3$) 3030, 1780, 1700, 1385, 1225 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (m, 5 H, aromatic H's), 6.28 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.90 (dd, 1 H, J = 3, 6 Hz, CH=C*H*), 4.60 (m, 1 H, C*H*N), 4.30–3.85 (m, 3 H, CH_2O, C*H*C=O), 3.40 (br s, 1 H, bridgehead H), 3.30 (dd, 1 H, J = 3, 13.5 Hz, C*H*HPh), 2.98 (br s, 1 H, bridgehead H), 2.69 (dd, 1 H, J = 9.5, 13.5 Hz, CH*H*Ph), 2.0–1.4 (m, 4 H, CH_2CHCH_2); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 174.43, 153.24, 138.23, 135.43, 131.34, 129.33, 128.87, 127.25, 66.09, 55.37, 50.24, 46.53, 43.54, 43.02, 38.08, 29.44; $[\alpha]_{589}$ +175° (c 1.57, $CHCl_3$).

Anal. Calcd for $C_{18}H_{19}NO_3$: C, 72.71; H, 6.44; Found: C, 72.55; H, 6.55.

(4*R*,5*S*)-3-((3′*S*,4′*S*,5′*R*,6′*R*)-5-Methylbicyclo[2.2.1]heptene-4′-carbonyl)-4-methyl-5-phenyl-2-oxazolidinone (14a). To a stirred solution of 77 mg (0.31 mmol) of crotonate imide **8a** and 0.65 mL (7.8 mmol, 25 equiv) of cyclopentadiene in 0.70 mL of anhydrous dichloromethane at −100 °C was added 0.24 mL (1.8 M in toluene, 0.44 mmol, 1.4 equiv) of diethylaluminum chloride. The initially formed bright yellow color faded completely within 5 min and the solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 4 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 10 × 50 mm column of silica gel and washed with 25 mL of hexane (discarded). The column was then eluted with 50 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 98 mg (100% mass balance) of a colorless oil. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 20 min, 15 psi, t_r major 12.74 min, t_r minor endo 12.01 min, t_r minor exo 12.32 min) revealed the presence of three isomers in the ratio of 98:2:1. Isolation by MPLC (two Merck Lobar B columns, 30% ether/hexane, 8 mL/min, 8-mL fractions) afforded 86 mg (88%, >99% pure by VPC) of the title compound as a colorless oil: IR ($CHCl_3$) 3030, 2980, 1780, 1700, 1466, 1372, 1345, 1230, 1200, 1125, 1038 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.30 (m, 5 H, aromatic H's), 6.30 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.68 (dd, 1 H, J = 3, 6 Hz, CH=C*H*), 5.60 (d, 1 H, J = 7.5 Hz, C*H*O), 5.70 (q, 1 H, J = 7 Hz, C*H*N), 3.48 (dd, 1 H, J = 3, 4 Hz, C*H*C=O), 3.35 (br s, 1 H, bridgehead H), 2.50 (br s, 1 H, bridgehead H), 2.1–1.4 (m, 3 H, $CH_2CHCHCH_3$), 1.16 (d, 3 H, J = 7 Hz, CH_3), 0.80 (d, 3 H, J = 7 Hz, $CHOCH_3$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 173.84, 152.92, 139.72, 133.61, 130.69, 128.68, 125.69, 78.77, 54.72, 51.93, 49.72, 47.51, 47.05, 36.33, 20.47, 14.69; $[\alpha]_{589}$ −142° (c 1.57, $CHCl_3$).

Anal. Calcd for $C_{19}H_{21}NO_3$: C, 73.29; H, 6.80. Found: C, 73.10; H, 6.72.

(4*R*,5*S*)-3-((3′*S*,4′*S*,6′*S*)-Bicyclo[2.2.1]heptene-4′-carbonyl)-4-methyl-5-phenyl-2-oxazolidinone (14b). To a stirred solution of 78 mg (0.34 mmol) of acrylate imide **8b** in 10.0 mL of anhydrous dichloromethane at −100 °C was added 0.21 mL (1.8 M in toluene, 0.37 mmol, 1.4 equiv) of diethylaluminum chloride. To the bright yellow solution

was added 1.0 mL (12 mmol, 35 equiv) of precooled cyclopentadiene via cannula. After 5 min, the yellow color had completely faded and the solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 10 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 30 × 60 mm column of silica gel and washed with 250 mL of hexane (discarded). The column was then eluted with 250 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 97 mg (97% mass balance) of a colorless, crystalline solid. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 20 min, 15 psi, t_r major 12.10 min, t_r minor endo 11.55 min, t_r minor exo 11.72 min) revealed the presence of three isomers in the ratio of 95:5:1. Isolation of the major isomer by MPLC (two Merck Lobar B columns, 3% ether/toluene, 8 mL/min, 8-mL fractions) afforded 82 mg (82%, >99% pure by VPC) of the title compound as a colorless, crystalline solid: mp 91–92 °C; IR ($CHCl_3$) 3020, 2980, 1780, 1700, 1365, 1340 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.35 (m, 5 H, aromatic H's), 6.23 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.83 (dd, 1 H, J = 3, 6 Hz, CH=C*H*), 5.63 (d, 1 H, J = 7 Hz, C*H*O), 4.72 (q, 1 H, J = 7 Hz, C*H*N), 3.95 (m, 1 H, C*H*O), 3.40 (br s, 1 H, bridgehead H), 2.95 (br s, 1 H, bridgehead H), 2.0–1.3 (m, 4 H, CH_2CHCH_2), 0.83 (d, 3 H, J = 7 Hz, CH_3); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 174.10, 152.79, 138.03, 133.61, 131.47, 128.68, 125.69, 78.83, 54.78, 50.11, 46.40, 43.80, 43.02, 29.50, 14.56; $[\alpha]_{589}$ −98° (*c* 0.73, $CHCl_3$).

Anal. Calcd for $C_{18}H_{19}NO_3$: C, 72.71; H, 6.44. Found: C, 72.88; H, 6.57.

General Protocol for the Conversion of Carboximide Diels–Alder Adducts to Their Corresponding Benzyl Esters. To a stirred solution of 2.0 equiv of benzyl alcohol in anhydrous THF (~0.2 M) at −78 °C is added 1.5 equiv of *n*-butyllithium. A solution of carboximide Diels–Alder adduct in anhydrous THF (~1 M) is added via cannula and the mixture warmed to 0 °C. The solution is stirred at that temperature for 3 h and the reaction quenched with excess saturated aqueous ammonium chloride. The mixture is concentrated in vacuo, diluted with water, and extracted with dichloromethane. The combined organic layers are dried over magnesium sulfate, filtered, and concentrated in vacuo. The resultant oily product is purified by flash chromatography on silica gel to provide the desired benzyl ester.

Phenylmethyl (3*R*,4*R*,5*S*,6*S*)-5-Methylbicyclo[2.2.1]heptene-4-carboxylate (16a) from 11a. Imide **11a** (560 mg, 2.1 mmol) was converted to its corresponding benzyl ester (485 mg, 94%) as described in the general protocol: IR ($CHCl_3$) 3030, 2980, 1730, 1270, 1220 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (br s, 5 H, aromatic H's), 6.25 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.92 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.02 (s, 2 H, CH_2Ph), 3.10 (br s, 1 H, bridgehead H), 2.45 (m, 2 H, C*H*C=O, bridgehead H), 1.9–1.4 (m, 3 H, $CH_2CHCHCH_3$), 1.18 (d, 3 H, J = 7 Hz, CH_3); $[\alpha]_{589}$ +124° (neat), $[\alpha]_{589}$ +130° (*c* 2.08, $CHCl_3$ (UV grade)), $[\alpha]_{589}$ +132° (*c* 2.03, $CHCl_3$ (filtered through alumina)).

Anal. Calcd for $C_{16}H_{18}O_2$: C, 79.30; H, 7.49. Found: C, 79.16; H, 7.52.

Phenylmethyl (3*R*,4*R*,5*S*,6*S*)-5-Methylbicyclo[2.2.1]heptene-4-carboxylate (16a) from 13a. Imide **13a** (1.04 g, 3.33 mmol) was converted to its corresponding benzyl ester (740 mg, 92%, >99% pure by VPC) as described in the general protocol: $[\alpha]_{589}$ +130° (*c* 1.37, $CHCl_3$).

(3*R*,4*R*,5*S*,6*S*)-5-Methylbicyclo[2.2.1]heptane-4-carboxylic Acid (12) from 16a. To a solution of 490 mg (2.0 mmol) of phenylmethyl (3*R*,4*R*,5*S*,6*S*)-5-methylbicyclo[2.2.1]heptene-4-carboxylate (**16a**) in 30 mL of degassed ethanol was added 100 mg of Pd on charcoal. The mixture was stirred vigorously under 1 atm of hydrogen for 24 h. The mixture was filtered through Celite and concentrated in vacuo to give 490 mg (100%) of the known carboxylic acid[10a] as a colorless, crystalline solid: $[\alpha]_{589}$ +45.9° (*c* 5.42, 95% ethanol).

Phenylmethyl (3*R*,4*R*,6*R*)-Bicyclo[2.2.1]heptene-4-carboxylate (16b) from 11b. Imide **11b** (470 mg, 1.9 mmol) was converted to its corresponding benzyl ester (406 mg, 95%, >99% pure by VPC) as described in the general protocol: VPC (30 m SE-54, 140 °C, 15 psi, t_r 5.47 min); R_f 0.22 (10% ether/hexane); IR ($CHCl_3$) 3030, 2980, 1730, 1335, 1272, 1110 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (m, 5 H, aromatic H's), 6.18 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 5.89 (dd, 1 H, J = 3, 6 Hz, CH=C*H*), 5.03 (s, 2 H, CH_2Ph), 3.20 (br s, 1 H, bridgehead H), 2.90 (m, 2 H, C*H*O=O, birdgehead H), 1.9–1.4 (m, 4 H, CH_2CHCH_2); $[\alpha]_{589}$ +127° (neat), $[\alpha]_{589}$ +130° (*c* 1.42, $CHCl_3$ (UV grade)), $[\alpha]_{589}$ +134° (*c* 1.37, $CHCl_3$ (filtered through alumina)).

Anal. Calcd for $C_{15}H_{16}O_2$: C, 78.92; H, 7.06. Found: C, 78.64; H, 7.18.

Phenylmethyl (3*R*,4*R*,6*R*)-Bicyclo[2.2.1]heptene-4-carboxylate (16b) from 13b. Imide **13b** (130 mg, 0.43 mmol, 94% de) was converted to its corresponding benzyl ester (85 mg, 86%, >99% pure by VPC) as described in the general protocol: $[\alpha]_{589}$ +125°, $[\alpha]_{365}$ +432° (*c* 1.56, $CHCl_3$).

Phenylmethyl (3*R*,4*R*,5*S*,6*S*)-5-Phenylbicyclo[2.2.1]heptene-4-carboxylate (16e) from 11e. Imide **11e** (120 mg, 0.37 mmol) was converted to its corresponding benzyl ester (86 mg, 76%) as described in the general protocol: IR ($CHCl_3$) 3020, 1728, 1330, 1260, 1200, 1112 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (m, 10 H, aromatic H's), 6.40 (dd, 1 H, J = 3, 6 Hz, C*H*=CH), 6.03 (dd, 1 H, J = 3, 6 Hz, CH=C*H*), 5.10 (s, 2 H, CH_2Ph), 3.30 (br s, 1 H, bridgehead H), 3.05 (m, 3 H, bridgehead H, C*H*Ph, C*H*C=O), 1.78 (br d, 1 H, J = 9 Hz, C*H*H), 1.50 (dm, 1 H, J = 9 Hz, CH*H*); $[\alpha]_{589}$ +121° (*c* 1.33, $CHCl_3$).

Phenylmethyl (3*S*,4*S*,5*R*,6*R*)-5-Methylbicyclo[2.2.1]heptene-4-carboxylate (17a) from 14a. Imide **14a** (320 mg, 1.0 mmol) was converted to its corresponding benzyl ester (214 mg, 87%) as described in the general protocol: $[\alpha]_{589}$ −122° (neat), $[\alpha]_{589}$ −130° (*c* 2.14, $CHCl_3$ (UV grade)), $[\alpha]_{589}$ −132° (*c* 3.13, $CHCl_3$ (filtered through alumina)).

Phenylmethyl (3*S*,4*S*,6*S*)-Bicyclo[2.2.1]heptene-4-carboxylate (17b) from 14b. Imide **14b** (107 mg, 0.36 mmol) was converted to its corresponding benzyl ester (75 mg, 91%, >99% pure by VPC) as described in the general protocol: $[\alpha]_{589}$ −129°, $[\alpha]_{365}$ −455° (*c* 1.39, $CHCl_3$).

(3*R*,4*R*,6*R*)-Bicyclo[2.2.1]heptane-4-carboxylic Acid (18) from 16b. To a solution of 420 mg (2.0 mmol) of phenylmethyl (3*R*,4*R*,6*R*)-Bicyclo[2.2.1]heptene-4-carboxylate (**16b**) in 30 mL of degassed ethanol was added 100 mg of 5% Pd on charcoal. The mixture was stirred vigorously under 1 atm of hydrogen for 24 h. The mixture was filtered through Celite and concentrated in vacuo to give 419 mg (100%) of the known carboxylic acid as a colorless, crystalline solid: $[\alpha]_{589}$ +33.9° (*c* 1.06, 95% ethanol).

(4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (22a). To a solution of 1.15 g (4.68 mmol) of crotonate oxazolidinone **7a** in 4.0 mL of dichloromethane and 10.0 mL (6.81 g, 100 mmol, 21 equiv) of freshly distilled isoprene at −90 °C (CO_2/ether) was added 3.64 mL (1.8 M in toluene, 6.55 mmol, 1.4 equiv) of diethylaluminum chloride. The bright yellow solution was stirred at −40 °C for 10 h and at 0 °C for 30 min, after which time the color had completely faded. The reaction mixture was added via cannula to excess 10% aqueous hydrochloric acid. The resultant slurry was diluted with dichloromethane, and the layers were separated. The aqueous layer was extracted twice with dichloromethane, and the combined organic layers were dried over magnesium sulfate and concentrated in vacuo to give 1.55 g (105% mass balance) of a colorless oil. The product was dissolved in dichloromethane, 5 g of silica gel was added, and the slurry was concentrated in vacuo. The free-flowing white powder was placed atop a 6 × 1 cm column of silica gel and washed with 250 mL of hexane (discarded). The column was then eluted with 500 mL of 20% ethyl acetate/hexane, and the eluent was concentrated in vacuo to give 1.43 g (97%) of a colorless, crystalline solid. Analysis by VPC indicated a 94:6 ratio of diastereomers (30 m DB-1, 175 °C, 15 psi t_r major 16.01 min, t_r minor 17.35 min). The mixture was recrystallized from pentane to give 1.07 g of colorless prisms, mp 58.8–60.0 °C. The mother liquors were further purified by MPLC (Merck Lobar B column, 10% ether/hexane) to afford 146 mg of a colorless, crystalline solid. The combined yield of product was 1.22 g (83%, >99% purity by VPC): R_f 0.20 (10% ether/cyclohexane); IR (CCl_4) 1790, 1695, 1380, 1345, 1240, 1206, 1193 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.2–7.4 (m, 5 H, aromatic H's), 5.40 (br s, 1 H, C*H*=C(CH_3)), 4.72 (m, 1 H, C*H*N), 4.23 (m, 2 H, CH_2O), 3.61 (ddd, 1 H, C*H*C=O), 3.25 (dd, 1 H, C*H*HPh), 2.80 (dd, 1 H, CH*H*Ph), 2.37 (m, 1 H, C*H*HCH=C(CH_3)), 2.20 (m, 1 H, CH*H*CH=C(CH_3)), 2.10 (m, 1 H, C*H*CH_3), 2.05 (m, 1 H, C*H*HC-(CH_3)=CH), 1.75 (m, 1 H, CH*H*C(CH_3)=CH), 1.65 (br s, 3 H, CH_3C=CH), 0.95 (d, 3 H, CH_3CH); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 176.6, 153.1, 135.3, 133.5, 129.5, 128.9, 127.3, 118.7, 66.0, 55.3, 44.3, 38.1, 38.0, 30.8, 29.5, 23.3, 19.6; $[\alpha]_{589}$ +179° (*c* 2.91, CH_2Cl_2).

Anal. Calcd for $C_{19}H_{23}NO_3$: C, 72.82; H, 7.40. Found: C, 72.80; H, 7.40.

(4*S*)-3-((4′*S*)-1′-Methylcyclohexene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (22b). To a solution of 100 mg (0.43 mmol) of acrylate imide **7b** in 1.0 mL of anhydrous dichloromethane and 1.0 mL (10 mmol) of isoprene at −100 °C was added 0.34 mL (1.8 M in toluene, 0.61 mmol, 1.4 equiv) of diethylaluminum chloride which had been precooled to −100 °C. The solution was stirred for 20 min at that temperature and then poured into 20 mL of 1 N aqueous hydrochloric acid. The mixture was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered onto 10 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a short column of silica gel and the column washed with 100 mL of hexane (discarded). The Diels–Alder adducts were eluted with 200 mL of 20% ethyl acetate/hexane, and the eluent was concentrated to give 116 mg (98% mass balance) of a colorless, crystalline solid. Analysis by VPC (30 m DB-1, 175 °C, 5 psi, t_r major 46.82 min, t_r minor 47.16 min)

revealed the presence of two diastereomers in a ratio of 95:5. Isolation of the major diastereomer by MPLC (two Merck Lobar B columns, 12% ethyl acetate/hexane, 8 mL/min, 8-mL fractions) afforded 101 mg (85%, >99% pure by VPC) of the title compound as a colorless, crystalline solid: mp 85.7–86.6 °C; IR (CCl_4) 1790, 1700, 1380, 1348, 1239, 1205, 1195 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 7.26 (m, 5 H, aromatic H's), 5.43 (br s, 1 H, C*H*=C), 4.70 (m, 1 H, C*H*N), 4.20 (m, 2 H, CH_2O), 3.70 (m, 1 H, C*H*C=O), 3.28 (dd, 1 H, CH*H*Ph), 2.77 (dd, 1 H, CH*H*Ph), 2.35–1.5 (m, 6 H, CH_2CH_2, CH_2C=C), 1.65 (br s, 3 H, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 176.4, 153.0, 135.3, 133.7, 129.4, 128.8, 127.2, 119.1, 66.0, 55.2, 38.4, 37.9, 29.4, 27.7, 25.7, 23.4; $[\alpha]_{589}$ +113° (*c* 1.63, CH_2Cl_2).

Anal. Calcd for $C_{18}H_{21}NO_3$: C, 72.22; H, 7.07. Found: C, 72.30; H, 7.10.

(4*S*)-3-((3′*S*,4′*R*,5′*S*)-3′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (23a). To a solution of 960 mg (3.91 mmol) of crotonate imide **7a** in 12.0 mL of anhydrous dichloromethane and 12.0 mL (8.29 g, 120 mmol, 30.7 equiv) of (*E*)-piperylene at −78 °C was added 3.00 mL (5.48 mmol, 1.40 equiv) of diethylaluminum chloride. The bright yellow solution was warmed to −30 °C and stirred for 6 h, after which time the color had almost completely faded. The mixture was poured into 100 mL of 1 N aqueous hydrochloric acid and the layers were separated. The aqueous layer was extracted with dichloromethane (2 × 20 mL) and the combined organic layers were dried over magnesium sulfate, filtered onto 50 g of silica gel, and concentrated in vacuo. The free-flowing white solid was placed atop a short column of silica gel and washed with 400 mL of hexane (discarded). The Diels–Alder adducts were eluted with 800 mL of 20% ethyl acetate/hexane, and the eluent was concentrated to give 1.23 g (100% mass balance) of a colorless oil, which crystallized on standing. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 5 min, 15 psi, t_r major 13.25 min, t_r minor 12.15 min) revealed the presence of four diastereomers in the ratio of 95:1:2:2. The mixture was recrystallized from pentane to afford 943 mg (77%, >99% pure by VPC) of the title compound as colorless prisms: mp 66.0–67.3 °C; IR (CCl_4) 1790, 1700, 1382, 1348, 1240, 1190 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.30 (m, 5 H, aromatic H's), 5.65 (m, 2 H, C*H*=C*H*), 4.74 (dq, 1 H, *J* = 3.4, 7.0 Hz, C*H*N), 4.16 (m, 2 H, CH_2O), 3.70 (dd, 1 H, *J* = 5.4, 10.5 Hz, C*H*C=O), 3.41 (dd, 1 H, *J* = 3.4, 13.0 Hz, CH*H*Ph), 2.78 (m, 1 H, C*H*CH=CH), 2.65 (dd, 1 H, *J* = 10.2, 13.2 Hz, CH*H*Ph), 2.18 (m, 2 H, CH_2CHCH_3), 1.75 (m, 1 H, CH_2CHCH_3), 0.98 (2 d, 6 H, CH_3, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 173.91, 153.05, 135.50, 131.34, 129.33, 128.94, 127.31, 124.97, 66.03, 55.24, 48.81, 38.28, 33.40, 30.54, 24.76, 20.08, 17.29; $[\alpha]_{589}$ +243° (*c* 3.17, CH_2Cl_2).

Anal. Calcd for $C_{19}H_{23}NO_3$: C, 72.82; H, 7.39. Found: C, 72.90; H, 7.39.

(3*S*,4*R*,5*S*)-3,5-Dimethylcyclohexene-4-carboxylic Acid (26).[15,16] A solution of 157 mg (0.500 mmol) of **23a** in 7.5 mL of THF (stabilized with 0.025% BHT) and 2.1 mL of H_2O, stirred at 0 °C under N_2, was treated with 0.40 mL (4.0 mmol; 8.0 equiv) of 31% H_2O_2 followed by 24 mg (1.0 mmol; 2.0 equiv) of LiOH. He resulting mixture was stirred at 22 °C for 15 h, cooled to 0 °C, and treated with a solution of 0.56 g (4.4 mmol; 8.9 equiv) of Na_2SO_3 in 3.0 mL of H_2O followed by 5 mL of 0.5 N $NaHCO_3$. The THF was evaporated in vacuo. The aqueous residue was diluted to 50 mL with H_2O and extracted with four 60-mL portions of CH_2Cl_2. The CH_2Cl_2 extracts were combined, dried (Na_2SO_4), and evaporated in vacuo to yield 86.9 mg of a white solid, found by 300-MHz ^1H NMR to be a mixture of X_PH and the ring-opened product in the respective molar ratio of 82:18. Recovery of X_PH: 64.1 mg (72%). The aqueous phase was acidified to pH 1–2 with 5 N HCl and extracted with four 75-mL portions of EtOAc. The EtOAc extracts were combined, dried (Na_2SO_4), and evaporated in vacuo. The white solid residue (64.8 mg) was chromatographed on 6 g of Mallinckrodt Silicar CC4, eluting with hexane/EtOAc (9:1) to afford 58.4 mg (76%) of **26** as a white solid: mp 74–75.5 °C; IR ($CHCl_3$) 3510, 3400–2400 (br CO_2H), 1705, 1660, 1420, 1305, 1204 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.68–5.58 (sym m, 2 H, C*H*=C*H*), 2.64–2.54 (m, 1 H, CH=CHC*H*-(CH_3)), 2.47 (dd, 1 H, *J* = 5.5, 11.0 Hz, C*H*C=O) 2.22–2.13 (m, 1 H, CH=CHC$H_{eq}H_{ax}$), 2.08–1.93 (sym m, 1 H, CH=CHCH$_2$C*H*(CH_3)), 1.74–1.63 (m, 1 H, CH=CHCH$_{eq}H_{ax}$), 1.04 (d, 3 H, *J* = 6.2 Hz, eq CH_3), 1.00 (d, 3 H, *J* = 7.1 Hz, ax CH_3; ^{13}C NMR (75.5 MHz; $CDCl_3$) δ 180.8, 131.1, 125.0, 50.6, 33.3, 31.6, 24.7, 20.0, 17.2; $[\alpha]^{25}_D$ +288° (*c* 1.53, 95% EtOH).

Anal. Calcd for $C_9H_{14}O_2$: C, 70.10; H, 9.15. Found: C, 70.19; H, 9.18.

(4*S*)-3-((3′*S*,4′*R*)-3′-Methylcyclohexene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (23b). To a solution of 230 mg (1.0 mmol) of acrylate imide **7b** in 2.0 mL of anhdyrous dichloromethane and 2.0 mL (20 mmol) of (*E*)-piperylene at −100 °C was added 0.77 mL (1.8 M in toluene, 1.4 mmol, 1.4 equiv) of diethylaluminum chloride. After 15 min the initially formed bright yellow color had faded to a very pale yellow, and the solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were separated, and the aqueous layer was extracted with 10 mL of dichloromethane. The combined organic layers were dried over magnesium sulfate, filtered onto 20 g of silica gel, and concentrated in vacuo. The free-flowing white powder was placed atop a 40 × 60 mm column of silica gel, which was then washed with 200 mL of hexane (discarded). The Diels–Alder adducts were eluted with 250 mL of 20% ethyl acetate/hexane, and the resultant solution was concentrated in vacuo to give 249 mg (84%) of a colorless, crystalline solid. Analysis by VPC (30 m DB-5, temperature program: 180 °C 5 min, 4 °C/min, 200 °C 5 min, 15 psi, t_r 13.41 min, >99% pure) indicated the presence of essentially a single product. A small portion was recrystallized from hexane for analysis: mp 165–167 °C; IR (CCl_4) 1790, 1700, 1380, 1350, 1198 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.27 (m, 5 H, aromatic H's), 5.7 (m, 2 H, C*H*=C*H*), 4.7 (m, 1 H, C*H*N), 4.20 (m, 2 H, CH_2O), 3.8 (m, 1 H, C*H*C=O), 3.4 (dd, 1 H, CH*H*Ph), 2.9 (m, 1 H, C*H*CH=CH), 2.6 (dd, 1 H, CH*H*Ph), 2.2–1.7 (m, 4 H, CH_2CH_2), 0.95 (d, 3 H, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.08, 153.05, 135.43, 131.60, 129.26, 128.87, 127.18, 125.62, 66.16, 55.17, 42.63, 38.34, 30.15, 24.63, 19.43, 16.50; $[\alpha]_{589}$ +222° (*c* 2.19, CH_2Cl_2).

Anal. Calcd for $C_{18}H_{21}NO_3$: C, 72.22; H, 7.07. Found: C, 71.99; H, 6.99.

Phenylmethyl (4*R*)-1-Methylcyclohexene-4-carboxylate (24) from 22b. Imide **22b** (623 mg, 2.3 mmol) was converted to its corresponding benzyl ester (487 mg, 93%, >99% pure by VPC) as described in the general protocol: IR (neat) 1735, 1453, 1168, 1157 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.30 (s, 5 H, aromatic H's), 5.35 (br m, 1 H, C=C*H*), 5.10 (s, 2 H, CH_2Ph), 2.7–1.5 (m, 7 H, C*H*C=O, CH_2CH_2, CH_2C=C), 1.60 (br s, 3 H, CH_3); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 175.53, 136.34, 133.61, 128.48, 128.03, 127.90, 119.25, 65.96, 39.25, 29.24, 27.68, 25.48, 23.40; $[\alpha]_{589}$ +62.9° (*c* 2.10, CH_2Cl_2), $[\alpha]_{589}$ +65.1° (neat).

Anal. Calcd for $C_{15}H_{18}O_2$: C, 78.23; H, 7.88. Found: C, 78.30; H, 7.82.

(*R*)-(+)-Terpineol. To a solution of 35 mL (2.9 M in ether, 100 mmol, 43 equiv) of methylmagnesium bromide in 250 mL of anhydrous ether at 0 °C was added a solution of 535 mg (2.32 mmol) of benzyl ester **24** in 10.0 mL of anhydrous ether. The mixture was stirred for 3 h and poured into 500 mL of 1 N aqueous Na_4EDTA. The layers were separated, and the aqueous layer was extracted with ether (2 × 100 mL). The combined organic layers were dried over sodium sulfate, filtered, and concentrated in vacuo at 0 °C. The oil was redissolved in 100 mL of 1:1 ether/pentane, dried over sodium sulfate, filtered, and concentrated in vacuo at 0 °C. The pale yellow oil was purified by flash chromatography on silica gel (60 × 180 mm column, 30% ether/pentane, 50-mL fractions) to give, after concentration of fractions 8–9 at 0 °C, a colorless, low-melting, crystalline solid: IR (neat) 3400 br, 2980, 2940, 1380, 1370, 1160, 1135, 923, 915 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.38 (br m, 1 H, C*H*=C), 2.20–1.20 (m, 6 H, CH_2CH_2, CH_2C=C), 1.70 (br s, 3 H, CH_3C=C), 1.22 (s, 6 H, $CH(CH_3)_2$); $[\alpha]_{589}$ +94.1° (neat).

Phenylmethyl (4*S*,5*S*)-1,5-Dimethylcyclohexene-4-carboxylate (25) from 22a. Imide **22a** (53 mg, 0.17 mmol) was converted to its corresponding benzyl ester (22 mg, 54%, >99% pure by VPC) as described in the general protocol: IR (neat) 1737, 1152, 693 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.28 (s, 5 H, aromatic H's), 5.28 (br s, 1 H, C*H*=C), 5.1 (s, 2 H, CH_2Ph), 2.3–1.1 (m, 6 H, CH_2C=CCH_2CHCH_3), 1.56 (br s, 3 H, CH_3C=C), 0.90 (d, 3 H, CH_3CH); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 176.10, 136.16, 133.36, 128.50, 128.32, 128.10, 118.67, 65.96, 46.97, 38.08, 31.07, 28.85, 23.28, 19.73; $[\alpha]_{589}$ +54° (*c* 0.055, CH_2Cl_2).

Anal. Calcd for $C_{16}H_{20}O_2$: C, 78.65; H, 8.25. Found: C, 78.44; H, 8.36.

(*E*,*E*)-2,7,9-Decatrienoyl Chloride. To a solution of 1.57 g (8.72 mmol) of methyl (*E*,*E*)-2,7,9-decatrienoate[19b] in 35 mL of THF was added 25 mL of aqueous 1.5 N sodium hydroxide. The mixture was heated at 70 °C for 8 h, cooled to ambient temperature, diluted with 30 mL of saturated aqueous sodium bicarbonate, and washed with 60 mL of ether. The aqueous layer was cooled to 0 °C and acidified to pH 1 with aqueous 6 N hydrochloric acid. The mixture was extracted with 50 mL of dichloromethane, and the organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 1.30 g (90%) of a colorless oil: ^1H NMR (90 MHz, $CDCl_3$) δ 11.52 (br s, 1 H, CO_2H), 7.05 (dt, 1 H, *J* = 7, 15 Hz), 5.40–6.50 (m, 4 H), 5.10 (m, 2 H), 2.20 (m, 4 H), 1.60 (m, 2 H).

To a solution of 650 mg (3.9 mmol) of the above acid in 15 mL of toluene at ambient temperature was added 0.70 mL (1.0 g, 8.0 mmol, 2.0 equiv) of oxalyl chloride. The mixture was stirred at room temperature for 20 h and then concentrated in vacuo to leave the acid chloride as a clear, yellow oil, which was used without purification.

General Protocol for the Acylation of 2-Oxazolidinones with (*E*,*E*)-2,7,9-Decatrienoyl Chloride and (*E*,*E*)-2,8,10-Undecatrienoyl Chloride. To a solution of 1.0 equiv of the appropriate oxazolidinone in anhydrous THF (~0.2 M) at −78 °C is added 0.95 equiv of *n*-butyllithium. The mixture is stirred for 10 min, and a solution of 1.0 equiv of (*E*,*E*)-2,7,9-decatrienoyl chloride or (*E*,*E*)-2,8,10-undecatrienoyl chloride in anhydrous THF (~0.6 M) is added via cannula. The reaction mixture is allowed to warm slowly to ambient temperature and then quenched by addition of excess saturated aqueous ammonium chloride. The colorless slurry is concentrated in vacuo and extracted with dichloromethane. The combined organic layers are dried over magnesium sulfate, filtered, and concentrated in vacuo. The resultant pale yellow oil is purified by flash chromatography on silica gel to afford the desired trienimide.

(4*S*)-3-((*E*,*E*)-2′,7′,9′-Decatrienoyl)-4-(1-methylethyl)-2-oxazolidinone (29a). Oxazolidinone **3** in (800 mg, 6.20 mmol) was acylated with (*E*,*E*)-2,7,9-decatrienoyl chloride according to the general protocol detailed above to afford **29a** (711 mg, 66%) as a colorless, air-sensitive oil: R_f 0.17 (30% ether/hexane); IR ($CHCl_3$) 3030, 2980, 2950, 1780, 1685, 1638, 1487, 1388, 1368, 1300, 1210 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.28 (dt, 1 H, J = 1.3, 15.3 Hz, CH=C*H*C=O), 7.13 (dt, 1 H, J = 6.8, 15.3 Hz, C*H*=CHC=O), 6.30 (dt, 1 H, J = 16.9, 10.2 Hz, CH_2=C*H*), 6.07 (dd, 1 H, J = 15.1, 10.4 Hz, CH_2=CHC*H*=CH), 5.67 (dt, 1 H, J = 15.1, 6.9 Hz, CH_2=CHCH=C*H*), 5.10 (d, 1 H, J = 15.9 Hz, (*Z*)-CH*H*=CH), 4.97 (d, 1 H, J = 10.0 Hz, (*E*)-C*H*H=CH), 4.45 (m, 1 H, C*H*N), 4.26 (m, 2 H, C*H*$_2$O), 2.29 (m, 2 H, C*H*$_2$CH=CHC=O), 2.14 (m, 2 H, CH_2=CHCH=CHC*H*$_2$), 2.02 (m, 1 H, C*H*CHN), 1.60 (m, 2 H, $CH_2CH_2CH_2CH$=CHC=O), 0.90 (2 d, 6 H, J = 7.0 Hz, C*H*$_3$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 165.00, 154.02, 150.84, 137.06, 134.13, 131.73, 120.75, 115.16, 63.36, 58.55, 31.91, 28.53, 27.55, 18.00, 14.75; $[\alpha]_{589}$ +76.7° (*c* 2.02, $CHCl_3$).

(4*S*)-3-((*E*,*E*)-2′,7′,9′-Decatrienoyl)-4-(phenylmethyl)-2-oxazolidinone (29b). Oxazolidinone **4** (200 mg, 1.08 mmol) was acylated with (*E*,*E*)-2,7,9-decatrienoyl chloride according to the general protocol detailed above to afford **29b** (273 mg, 91%) as a colorless, air-sensitive oil: R_f 0.24 (20% ethyl acetate/hexane); IR (neat) 1782, 1685, 1638, 1387, 1354, 1212, 1007 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.4–7.1 (m, 7 H, C*H*=C*H*C=O, aromatic H's), 6.30 (dt, 1 H, J = 17.0, 10.3 Hz, CH_2=C*H*), 6.07 (dd, 1 H, J = 15.1, 10.3 Hz, CH_2=CHC*H*=CH), 5.67 (dt, 1 H, J = 15.1, 6.9 Hz, CH=C*H*CH$_2$), 5.10 (dd, 1 H, J = 17.0, 1.0 Hz, (*Z*)-CH*H*=CH), 4.97 (dd, 1 H, J = 10.1, 1.0 Hz, (*E*)-C*H*H=CH), 4.70 (m, 1 H, C*H*N), 4.16 (m, 2 H, C*H*$_2$O), 3.31 (dd, 1 H, J = 13.5, 3.2 Hz, CH*H*Ph), 2.79 (dd, 1 H, J = 13.5, 9.6 Hz, C*H*HPh), 2.30 (m, 2 H, C*H*$_2$CH=CHC=O), 2.14 (q, 2 H, J = 7.2 Hz, CH_2=CHCH=CHC*H*$_2$), 1.61 (m, 2 H, $CH_2CH_2CH_2$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.78, 153.22, 151.00, 136.85, 135.25, 134.10, 131.86, 129.28, 128.73, 127.09, 120.49, 115.08, 65.90, 55.45, 37.68, 31.88, 27.34; $[\alpha]_{589}$ +74.7° (*c* 0.174, CH_2Cl_2).

HRMS Calcd for $C_{20}H_{23}NO_3$: 325.16778. Found: 325.16774.

(4*R*,5*S*)-3-((*E*,*E*)-2′,7′,9′-Decatrienoyl)-4-methyl-5-phenyl-2-oxazolidinone (29c). Oxazolidinone **5** (240 mg, 1.4 mmol) was acylated with (*E*,*E*)-2,7,9-decatrienoyl chloride according to the general protocol detailed above to afford **29c** (189 mg, 65%) as a colorless, air-sensitive oil: IR ($CHCl_3$) 3010, 2930, 1775, 1675, 1630, 1345, 1190 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.10–7.60 (m, 7 H, aromatic H's, CH=C*H*C=O, C*H*=CHC=O), 5.50–6.60 (m, 4 H, C*H*N, CH_2=C*H*, CH_2=CHC*H*=CH, CH_2=CHCH=C*H*), 4.60–5.20 (m, 3 H, C*H*O, C*H*$_2$=CH), 2.20 (m, 4 H, C*H*$_2$CH=CHC=O, CH_2=CHCH=CHC*H*$_2$), 1.65 (m, 2 H, $CH_2CH_2CH_2CH$=CHC=O), 0.95 (d, 3 H, J = 7 Hz, C*H*$_3$); $[\alpha]_{589}$ +33.0° (*c* 1.60, $CHCl_3$).

(4*R*)-Cyclohexyl-2-oxazolidinone (31). To a stirred suspension of 0.3 g of 5% rhodium on alumina in 20 mL of freshly distilled methanol was added 0.4 g (2.4 mmol) of (4*R*)-4-phenyl-2-oxazolidinone.[20] The mixture was stirred vigorously under 1 atm of hydrogen for 15 h. The mixture was filtered through Celite and concentrated in vacuo to give 393 mg (98%) of the title compound as a colorless, crystalline solid: IR (CCl_4) 3260, 3160, 2940, 2870, 1760, 1482, 1451, 1406, 1247 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 6.07 (br s, 1 H, N*H*), 4.48 (m, 1 H, C*H*HO), 4.16 (m, 1 H, CH*H*O), 3.62 (m, 1 H, C*H*N), 1.90–0.90 (m, 11 H, c-C_6H_{11}); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 160.52, 68.62, 57.54, 42.35, 28.43, 28.18, 26.05, 25.54, 25.49; $[\alpha]_{589}$ +2.30° (*c* 1.26, CH_2Cl_2). A small portion was recrystallized from ethyl acetate/hexane for analysis: mp 119.5–121.2 °C.

Anal. Calcd for $C_9H_{15}NO_2$: C, 63.88; H, 8.93. Found: C, 64.05; H, 8.94.

(4*R*)-3-((*E*,*E*)-2′,7′,9′-Decatrienoyl)-4-cyclohexyl-2-oxazolidinone (29d). Oxazolidinone **31** (118 mg, 0.70 mmol) was acylated with (*E*,*E*)-2,7,9-decatrienoyl chloride according to the general protocol detailed above to afford **29d** (139 mg, 54%) as a colorless, air-sensitive oil: IR (neat) 1782, 1690, 1641, 1207 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.28 (dt, 1 H, J = 1.3, 15.3 Hz, CH=C*H*C=O), 7.13 (dt, 1 H, J = 6.8, 15.3 Hz, C*H*=CHC=O), 6.30 (dt, 1 H, J = 16.9, 10.2 Hz, CH_2=C*H*), 6.07 (dd, 1 H, J = 15.1, 10.4 Hz, CH_2=CHC*H*=CH), 5.67 (dt, 1 H, J = 15.1, 6.9 Hz, CH=C*H*CH$_2$), 5.10 (d, 1 H, J = 15.9 Hz, (*Z*)-CH*H*=CH), 4.97 (d, 1 H, J = 10.0 Hz, (*E*)-C*H*H=CH), 4.45 (m, 1 H, C*H*N), 4.26 (m, 2 H, C*H*$_2$O), 2.29 (m, 2 H, C*H*$_2$CH=CHC=O), 2.14 (m, 2 H, CH_2=CHCH=CHC*H*$_2$), 2.02 (m, 1 H, C*H*CHN), 1.8–0.9 (m, 12 H, ring C*H*$_2$, $CH_2CH_2CH_2CH$=CHC=O); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.88, 153.83, 150.30, 136.97, 133.81, 131.67, 120.85, 114.82, 64.23, 58.20, 38.94, 31.84, 31.71, 28.43, 27.50, 26.12, 25.86, 25.62, 25.49; $[\alpha]_{589}$ −87.4° (*c* 1.39, CH_2Cl_2).

HRMS Calcd for $C_{19}H_{27}NO_3$: 317.19908. Found: 317.19936.

(*E*,*E*)-2,8,10-Undecatrienoyl Chloride. To a solution of 630 mg (3.25 mmol) of methyl (*E*,*E*)-2,8,10-undecatrienoate[19b] in 20 mL of THF was added 15 mL of aqueous 1.5 N sodium hydroxide. The mixture was heated at 70 °C for 8 h, cooled to ambient temperature, diluted with 30 mL of saturated aqueous sodium bicarbonate, and washed with 60 mL of ether. The aqueous layer was cooled to 0 °C and acidified to pH 1 with aqueous 6 N hydrochloric acid. The mixture was extracted with 50 mL of dichloromethane, and the organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 505 mg (87%) of a colorless oil: ^1H NMR (90 MHz, $CDCl_3$) δ 11.35 (br s, 1 H, CO_2H), 7.10 (dt, 1 H, J = 7, 15 Hz), 5.40–6.50 (m, 4 H), 5.00 (m, 2 H), 2.10 (m, 4 H), 1.40 (m, 4 H).

To a solution of 305 mg (1.7 mmol) of the above acid in 15 mL of toluene at ambient temperature was added 0.20 mL (1.0 g, 2.3 mmol, 1.3 equiv) of oxalyl chloride. The mixture was stirred at room temperature for 16 h and then concentrated in vacuo to leave the acid chloride as a clear, yellow oil, which was used without purification.

(4*S*)-3-((*E*,*E*)-2′,8′,10′-Undecatrienoyl)-4-(1-methylethyl)-2-oxazolidinone (30a). Oxazolidinone **3** (435 mg, 3.37 mmol) was acylated with (*E*,*E*)-2,8,10-undecatrienoyl chloride according to the general protocol detailed above to afford **30a** (825 mg, 84%) as a colorless, air-sensitive oil: IR ($CHCl_3$) 3020, 2970, 2940, 1778, 1682, 1635, 1365, 1300, 1200 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.27 (dt, 1 H, J = 15.3, 1.2 Hz, CH=C*H*C=O), 7.13 (dt, 1 H, J = 6.7, 15.3 Hz, C*H*=CHC=O), 6.30 (dt, 1 H, J = 16.9, 10.2 Hz, CH_2=C*H*), 6.05 (ddt, 1 H, J = 0.6, 15.0, 10.3 Hz, CH_2=CHC*H*=CH), 5.68 (dt, 1 H, J = 15.2, 6.9 Hz, CH=C*H*CH$_2$), 5.09 (br d, 1 H, J = 16.9 Hz, (*Z*)-CH*H*=CH), 4.95 (br d, 1 H, J = 10.3 Hz, (*E*)-C*H*H=CH), 4.49 (m, 1 H, C*H*N), 4.28 (t, 2 H, J = 9.0 Hz, CH*H*O), 4.21 (dd, 1 H, J = 3.3, 9.1 Hz, C*H*HO), 2.28 (br q, 2 H, J = 6.6 Hz, C*H*$_2$CH=CHC=O), 2.10 (br q, 2 H, J = 6.7 Hz, CH_2=CHCH=CHC*H*$_2$), 1.58–1.38 (m, 4 H, $CH_2CH_2CH_2CH_2$), 0.93 (d, 3 H, J = 7.0 Hz, C*H*$_3$), 0.88 (d, 3 H, J = 6.9 Hz, C*H*$_3$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.98, 153.95, 150.99, 137.11, 134.64, 131.20, 120.52, 114.72, 63.28, 58.45, 32.37, 32.12, 28.60, 28.46, 27.52, 17.89, 14.65; $[\alpha]_{589}$ +75.0° (*c* 1.76, $CHCl_3$).

HRMS Calcd for $C_{17}H_{25}NO_3$: 291.18343. Found: 291.18325.

(4*S*)-3-((*E*,*E*)-2′,8′,10′-Undecatrienoyl)-4-(phenylmethyl)-2-oxazolidinone (30b). Oxazolidinone **4** (624 mg, 3.40 mmol) was acylated with (*E*,*E*)-2,8,10-undecatrienoyl chloride according to the general protocol detailed above to afford **30b** (996 mg, 83%) as a colorless, air-sensitive oil: IR (neat) 1785, 1687, 1640, 1390, 1360, 1210, 1007 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.35–7.13 (m, 7 H, C*H*=C*H*C=O, aromatic CH's), 6.30 (dt, 1 H, J = 16.9, 10.2 Hz, CH_2=C*H*), 6.05 (dd, 1 H, J = 14.8, 10.2 Hz, CH_2=CHC*H*=CH), 5.69 (dt, 1 H, J = 15.1, 7.0 Hz, CH=C*H*CH$_2$), 5.09 (dd, 1 H, J = 16.8, 1.0 Hz, (*Z*)-CH*H*=CH), 4.95 (dd, 1 H, J = 10.5, 1.0 Hz, (*E*)-C*H*H=CH), 4.70 (m, 1 H, C*H*N), 4.16 (m, 2 H, C*H*$_2$O), 3.31 (dd, 1 H, J = 13.4, 3.2 Hz, CH*H*Ph), 2.79 (dd, 1 H, J = 13.4, 9.5 Hz, C*H*HPh), 2.30 (q, 2 H, J = 7 Hz, C*H*$_2$CH=CHC=O), 2.10 (q, 2 H, J = 7.2, CH_2=CHCH=CHC*H*$_2$), 1.60–1.38 (m, 4 H, $CH_2CH_2CH_2CH_2$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.88, 153.24, 151.18, 137.07, 135.33, 134.57, 131.16, 129.28, 128.76, 127.11, 120.47, 114.69, 65.95, 55.12, 37.76, 32.33, 32.06, 28.53, 27.45; $[\alpha]_{589}$ +78.2°, $[\alpha]_{577}$ +81.4°, $[\alpha]_{546}$ +94.7°, $[\alpha]_{435}$ +166°, $[\alpha]_{365}$ +277° (*c* 0.188, CH_2Cl_2).

HRMS Calcd for $C_{21}H_{25}NO_3$: 339.18343. Found: 339.18354.

(4*R*,5*S*)-3-((*E*,*E*)-2′,8′,10′-Undecatrienoyl)-4-methyl-5-phenyl-2-oxazolidinone (30c). Oxazolidinone **5** (240 mg, 1.4 mmol) was acylated with (*E*,*E*)-2,8,10-undecatrienoyl chloride according to the general protocol detailed above to afford **30c** (189 mg, 65%) as a colorless, air-sensitive oil: IR ($CHCl_3$) 3010, 2930, 1775, 1675, 1630, 1345, 1190 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 7.10–7.60 (m, 7 H, aromatic H's, CH=C*H*C=O, C*H*=CHC=O), 5.50–6.60 (m, 4 H, C*H*N, CH_2=C*H*, CH_2=CHC*H*=CH, CH_2=CHCH=C*H*), 4.60–5.20 (m, 3 H, C*H*O, C*H*$_2$=CH), 2.20 (m, 4 H, C*H*$_2$CH=CHC=O, CH_2=CHCH=CHC*H*$_2$), 1.65 (m, 2 H, $CH_2CH_2CH_2CH$=CHC=O), 0.95 (d, 3 H, J = 7 Hz, C*H*$_3$); $[\alpha]_{589}$ +33.0° (*c* 1.60, $CHCl_3$).

(4*R*)-3-((*E*,*E*)-2′,8′,10′-Undecatrienoyl)-4-cyclohexyl-2-oxazolidinone (30d). Oxazolidinone **31** (126 mg, 0.74 mmol) was acylated with (*E*,*E*)-2,8,10-undecatrienoyl chloride according to the general protocol de-

tailed above to afford **30d** (127 mg, 52%) as a colorless, air-sensitive oil: R_f 0.35 (20% ethyl acetate/hexane); IR (neat) 1774, 1680, 1630, 1350, 1198 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.27 (br d, 1 H, J = 15.3 Hz, CH=C*H*C=O), 7.13 (dt, 1 H, J = 6.6, 15.3 Hz, C*H*=CHC=O), 6.30 (dt, 1 H, J = 16.9, 10.2 Hz, CH_2=C*H*), 6.05 (dd, 1 H, J = 15.0, 10.3 Hz, CH_2=CHC*H*=CH), 5.68 (dt, 1 H, J = 15.1, 6.9 Hz, CH=C*H*CH_2), 5.08 (br d, 1 H, J = 16.6 Hz, (*Z*)-CH*H*=CH), 4.95 (br d, 1 H, J = 10.5 Hz, (*E*)-C*H*H=CH), 4.45 (m, 1 H, C*H*N), 4.26 (m, 2 H, CH_2O), 2.29 (m, 2 H, CH_2CH=CHC=O), 2.10 (m, 2 H, CH_2=CHCH=CHCH_2), 2.08–0.90 (m, 15 H, C_6H_{11}, $CH_2CH_2CH_2CH_2$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 164.85, 153.85, 150.82, 137.06, 134.54, 131.16, 120.50, 114.64, 64.16, 58.15, 38.77, 32.30, 32.06, 28.55, 28.40, 27.47, 26.10, 25.81, 25.42; $[\alpha]_{589}$ −85.1° (*c* 1.27, CH_2Cl_2).

HRMS Calcd for $C_{20}H_{29}NO_3$: 331.21473. Found: 331.21531.

(4*S*)-3-((4′*S*,5′*S*,6′*R*)-Bicyclo[4.3.0]nonene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (32). To a solution of 91 mg (0.33 mmol) of trienimide **29a** in 20 mL of dichloromethane at −78 °C was added 0.35 mL (1.3 M in toluene, 0.46 mmol, 1.4 equiv) of dimethylaluminum chloride. The mixture was warmed to −30 °C and stirred for 5 h. The solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were separated, and the aqueous layer was extracted with dichloromethane. The combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 92 mg (101% mass balance) of a colorless oil. The mixture was analyzed by VPC (DB-5, 200 °C, 15 psi, t_r major 3.67 min, t_r minor 3.85 min) and found to be an 83:17 mixture of diastereomers. The major isomer was obtained by flash chromatography on silica gel (20 × 200 mm column, 15% ethyl acetate/hexane, 8-mL fractions) to give 59 mg (65%, >99% pure by VPC) of a colorless, crystalline solid: mp 79.5–81.5 °C; IR ($CHCl_3$) 3020, 2965, 1775, 1695, 1382, 1205 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.86 (dd, 1 H, J = 1.5, 9.5 Hz, CH_2CH=C*H*, 5.59 (m, 1 H, CH_2C*H*=CH), 4.48 (m, 1 H, C*H*N), 4.25 (m, 2 H, CH_2O), 3.88 (dt, 1 H, J = 6.0, 10.7 Hz, C*H*C=O), 2.62 (m, 1 H, C*H*HCH=CH), 2.35 (d of heptets, 1 H, J = 4.0, 7.2 Hz, C*H*$(CH_3)_2$), 2.15 (m, 1 H, CH*H*CH=CH), 2.05–1.00 (m, 8 H, C*H*CH_2CH_2CH_2C*H*), 0.92 (d, 3 H, J = 7.2 Hz, CH_3), 0.88 (d, 3 H, J = 7.2 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.64, 153.66, 129.91, 125.23, 63.28, 58.35, 45.14, 43.54, 30.58, 28.89, 28.48, 27.69, 21.84, 17.82, 14.68; $[\alpha]_{589}$ +175° (*c* 2.39, $CHCl_3$).

Anal. Calcd for $C_{16}H_{23}NO_3$: C, 69.29; H, 8.36. Found: C, 69.47; H, 8.50.

(4*S*)-3-((4′*S*,5′*S*,6′*R*)-Bicyclo[4.3.0]nonene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (33). To a solution of 137 mg (0.42 mmol) of trienimide **29b** in 20 mL of dichloromethane at −78 °C was added 0.45 mL (1.3 M in toluene, 0.59 mmol, 1.4 equiv) of dimethylaluminum chloride. The solution was warmed to −30 °C and stirred for 5 h. The mixture was poured into 30 mL of 1 N aqueous hydrochloric acid, and the resultant layers were separated. The aqueous layer was extracted with dichloromethane, and the combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 142 mg (104% mass balance) of a colorless oil. Analysis by VPC (30 m DB-1, 200 °C, 15 psi, t_r major 14.44 min, t_r minor 15.05) revealed the presence of a 95:5 mixture of two diastereomers. Isolation by MPLC (20% ethyl acetate/hexane, two Merck Lobar B columns, 8 mL/min, 8-mL fractions) afforded 100.4 mg of the title compound (73%, >99% pure by VPC) as a colorless oil: R_f 0.28 (20% ethyl acetate/hexane): IR (neat) 1783, 1700, 1390, 1352 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.37–7.18 (m, 5 H, aromatic H's), 5.86 (dd, 1 H, J = 9.4, 2.0 Hz, CH=C*H*CH), 5.60 (m, 1 H, CH_2C*H*=CH), 4.70 (m, 1 H, C*H*N), 4.18 (m, 2 H, CH_2O), 3.86 (dt, 1 H, J = 10.5, 6.2 Hz, C*H*C=O), 3.24 (dd, 1 H, J = 13.4, 3.3 Hz, C*H*HPh), 2.78 (dd, 1 H, J = 13.3, 9.5 Hz, CH*H*Ph), 2.60 (m, 1 H, C*H*HCH=CH), 2.24 (m, 1 H, CH*H*CH=CH), 2.06–1.64 (m, 6 H, CH_2CHCHCH_2), 1.19 (m, 2 H, $CH_2CH_2CH_2$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.69, 153.02, 135.23, 129.79, 129.32, 128.78, 127.21, 125.23, 66.00, 55.14, 45.41, 43.55, 43.33, 37.86, 30.22, 28.84, 27.60, 21.78; $[\alpha]_{589}$ +141° (*c* 0.553, CH_2Cl_2).

HRMS Calcd for $C_{20}H_{23}NO_3$: 325.16778. Found: 325.16805.

(4*R*,5*S*)-3-((4′*R*,5′*R*,6′*S*)-Bicyclo[4.3.0]nonene-4′-carbonyl)-4-methyl-5-phenyl-2-oxazolidinone (34). To a solution of 189 mg (0.58 mmol) of trienimide **29c** in 20 mL of dichloromethane at −78 °C was added 0.62 mL (1.3 M in toluene, 0.81 mmol, 1.4 equiv) of dimethylaluminum chloride. The mixture was warmed to −30 °C and stirred for 5 h. The solution was poured into 20 mL of 1 N aqueous hydrochloric acid. The layers were separated, and the aqueous layer was extracted with dichloromethane. The combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 198 mg (105% mass balance) of a colorless solid. The mixture was analyzed by VPC (DB-5, 200 °C, 15 psi, t_r major 16.40 min, t_r minor 17.25 min) and found to be an 85:15 mixture of diastereomers. The major isomer was isolated by MPLC (20% ethyl acetate/hexane, two Merck Lobar B columns, 8 mL/min, 8-mL fractions) to give 129 mg (70%, >99% pure by VPC) of a colorless, crystalline solid: mp 118.5–120.0 °C; IR ($CHCl_3$) 3030, 2965, 2880, 1780, 1695, 1345, 1195, 1120 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.46–7.28 (m, 5 H, aromatic H's), 5.86 (dd, 1 H, J = 1.7, 9.7 Hz, CH_2CH=C*H*), 5.67 (d, 1 H, J = 7.0 Hz, C*H*O), 5.60 (m, 1 H, CH_2C*H*=CH), 4.80 (quintet, 1 H, J = 7.0 Hz, C*H*N), 3.88 (dt, 1 H, J = 6.2, 10.6 Hz, C*H*C=O), 2.59 (m, 1 H, C*H*HCH=CH), 2.21 (m, 1 H, CH*H*CH=CH), 2.08–1.10 (m, 8 H, C*H*CH_2CH_2CH_2C*H*), 0.89 (d, 3 H, J = 6.5 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.54, 152.73, 133.37, 129.76, 128.65, 128.59, 125.57, 125.33, 78.84, 54.87, 45.61, 43.65, 43.48, 29.98, 28.92, 27.64, 21.83, 14.41; $[\alpha]_{589}$ −38.4° (*c* 3.73, $CHCl_3$).

Anal. Calcd for $C_{20}H_{23}NO_3$: C, 73.82; H, 7.12. Found: C, 73.70; H, 7.23.

(4*R*)-3-((4′*R*,5′*R*,6′*S*)-Bicyclo[4.3.0]nonene-4′-carbonyl)-4-cyclohexyl-2-oxazolidinone (35). To a solution of 120 mg (0.38 mmol) of trienimide **29d** in 10.0 mL of dichloromethane at −78 °C was added 0.40 mL (1.3 M in toluene, 0.53 mmol, 1.4 equiv) of dimethylaluminum chloride. The mixture was stirred for 5 h at −30 °C. The mixture was poured into a 30-mL separatory funnel containing 10 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 20 mL). The combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give a colorless solid. Analysis by HPLC (Waters 5-μm radial pak, 10% *tert*-butyl methyl ether/hexane, 2 mL/min, t_r major 8.07 min, t_r minor 6.52 min) revealed the presence of a 97:3 mixture of diastereomers. The mixture was purified by flash chromatography on silica gel (40 × 200 mm column, 15% ethyl acetate/hexane, 8-mL fractions) to give 72.4 mg (65%, >99% pure by VPC) of a colorless, crystalline solid: R_f 0.42 (20% ethyl acetate/hexane); mp 138.0–139.3 °C; IR (CCl_4) 1790, 1700, 1450, 1394, 1386, 1348, 1219, 1200 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.85 (dd, 1 H, J = 1.5, 9.7 Hz, CH=C*H*CH), 5.58 (m, 1 H, CH_2C*H*=CH), 4.44 (m, 1 H, C*H*N), 4.26 (m, 2 H, CH_2O), 3.86 (dt, 1 H, J = 10.8, 6.3 Hz, C*H*C=O), 2.62 (m, 1 H, CH=CHC*H*H), 2.16 (m, 1 H, CH=CHCH*H*), 2.04–0.90 (m, 19 H, C_6H_{11}, C*H*CH_2CH_2CH_2C*H*); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.66, 153.68, 129.96, 125.33, 64.31, 58.23, 45.48, 43.70, 43.62, 39.17, 30.66, 28.99, 28.45, 27.75, 26.25, 25.93, 25.85, 25.66, 21.93; $[\alpha]_{589}$ −169° (*c* 0.632, CH_2Cl_2).

Anal. Calcd for $C_{19}H_{27}NO_3$: C, 71.89; H, 8.57. Found: C, 71.94; H, 8.68.

Methyl (4*S,5*S**,6*R**)-Bicyclo[4.3.0]nonene-4-carboxylate. (a) Thermal Reaction.** A solution of 45 mg (0.25 mmol) methyl (*E*,*E*)-2,7,9-decatrienoate in 6.0 mL of toluene was heated at reflux for 25 h. The solution was cooled to ambient temperature, diluted with dichloromethane, and analyzed by VPC: (30 m SE-54, 85 °C, 15 psi, t_r 9.64 min (17%) starting material, t_r 6.29 min (53%) endo isomer, t_r 6.79 (24%) exo isomer). Roush[19b] has reported a 3:2 endo:exo ratio for this thermal cycloaddition.

(b) Diethylaluminum Chloride Promoted Reaction. A solution of 150 mg (0.83 mmol) of methyl (*E*,*E*)-2,7,9-decatrienoate in 10 mL of dichloromethane at 0 °C was treated with 0.45 mL (1.8 M in toluene, 0.82 mmol, 1.0 equiv) of diethylaluminum chloride and stirred at ambient temperature for 42 h. The reaction mixture was diluted with 60 mL of dichloromethane and washed with a 1:1 mixture of saturated aqueous ammonium chloride and 1 N aqueous hydrochloric acid. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 114 mg (76% mass balance) of a cloudy oil. Analysis by VPC (30 m SE-54, 85 °C, 15 psi, t_r 9.64 min (17%) starting material, t_r 6.29 min (83%) endo isomer, t_r 6.79 (0.7%) exo isomer) revealed the presence of a 115:1 ratio of the two Diels–Alder cycloaddition products. The major diastereomer was isolated by flash chromatography on silica gel (20 × 180 mm column, 10% ether/hexane, 10-mL fractions) to afford 48 mg (32%, 99% pure by VPC) of the title compound as a colorless oil: IR ($CHCl_3$) 3030, 2960, 2880, 1730, 1438, 1220, 1170 cm^{-1}; ^1H NMR (90 MHz, $CDCl_3$) δ 5.80 (br d, 1 H, J = 10 Hz, CHC*H*=CH), 5.52 (dm, 1 H, J = 10 Hz, CHCH=C*H*), 3.65 (s, 3 H, CH_3), 0.90–2.40 (m, 11 H).

(4*S*)-3-((4′*S*,5′*S*,6′*R*)-Bicyclo[4.4.0]decene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (36). To a solution of 198 mg (0.68 mmol) of trienimide **30a** in 20 mL of dichloromethane at −78 °C was added 0.72 mL (1.3 M in toluene, 0.95 mmol, 1.40 equiv) of dimethylaluminum chloride. The mixture was warmed to −30 °C and stirred for 5 h. The mixture was poured into 25 mL of 1 N aqueous hydrochloric acid, and the layers were shaken and separated. The aqueous layer was extracted with dichloromethane, and the combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give a colorless oil. Analysis by VPC (30 m DB-5, 200 °C, 15 psi, t_r major 4.86 min, t_r minor 5.07 min) revealed the presence of a 92:8 mixture of two diastereomers. Isolation of the major diastereomer by flash chromatography

on silica gel (40 × 150 mm column, 15% ethyl acetate/hexane, 20-mL fractions) afforded 128 mg (65%, >99% pure by VPC) of the title compound as a colorless, crystalline solid: R_f 0.39 (20% ethyl acetate/hexane); mp 80.0–81.0 °C; IR ($CHCl_3$) 3020, 2970, 2940, 2860, 1780, 1690, 1380, 1300, 1200 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.60 (m, 1 H, CH_2CH=CH), 5.45 (br d, 1 H, J = 9.8 Hz, CH_2CH=C*H*), 4.48 (dt, 1 H J = 3.2, 8.0 Hz, C*H*N), 4.27 (t, 1 H, J = 8.0 Hz, CH*H*O), 4.21 (dd, 1 H, J = 3.1, 9.1 Hz, C*H*HO), 3.91 (dt, 1 H, J = 5.7, 8.9 Hz, C*H*C=O), 2.44–2.15 (m, 3 H, CH_2CH=CH, C*H*$(CH_3)_2$), 1.91–0.97 (m, 10 H, C*H*$CH_2CH_2CH_2CH_2CH$), 0.92 (d, 3 H, J = 7.0 Hz, CH_3), 0.87 (d, 3 H, J = 7.0 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 176.05, 153.58, 132.01, 123.83, 63.08, 58.30, 43.01, 42.08, 40.93, 32.89, 30.02, 29.85, 28.41, 26.54, 26.33, 17.74, 14.56; $[\alpha]_{589}$ +110° (c 0.949, $CHCl_3$).

Anal. Calcd for $C_{17}H_{25}NO_3$: C, 70.07; H, 8.65. Found: C, 70.21; H, 8.81.

(4*S*)-3-((4′*S*,5′*S*,6′*R*)-Bicyclo[4.4.0]decene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (37). To a solution of 421 mg (1.24 mmol) of trienimide **30b** in 20 mL of dichloromethane at −78 °C was added 1.32 mL (1.32 M in toluene, 1.73 mmol, 1.40 equiv) of dimethylaluminum chloride. The mixture was warmed to −30 °C and stirred for 5 h. The mixture was poured into 25 mL of 1 N aqueous hydrochloric acid, and the layers were shaken and separated. The aqueous layer was extracted with dichloromethane, and the combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 418 mg (99% mass balance) of a colorless oil. Analysis by VPC (30 m DB-5, 225 °C, 15 psi, t_r major 9.42 min, t_r minor 9.72 min) revealed the presence of a 97:3 mixture of two diastereomers. Isolation of the major diastereomer by flash chromatography on silica gel (40 × 150 mm column, 15% ethyl acetate/hexane, 20-mL fractions) afforded 370 mg (88%, >99% pure by VPC) of the title compound as a colorless glass, which crystallized on standing: R_f 0.35 (20% ethyl acetate/hexane); IR (CCl_4) 1790, 1697, 1391, 1352, 1378, 1204, 1193, 1182, 1095 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.26–7.07 (m, 5 H, aromatic H's), 5.53 (m, 1 H, CH_2CH=CH), 5.36 (br d, 1 H, J = 9.9 Hz, CH_2CH=C*H*), 4.60 (m, 1 H, C*H*N), 4.06 (m, 2 H, CH_2O), 3.79 (dt, 1 H, J = 5.9, 10.7 Hz, C*H*C=O), 3.13 (dd, 1 H, J = 3.2, 13.3 Hz, CH*H*Ph), 2.69 (dd, 1 H, J = 9.3, 13.3 Hz, C*H*HPh), 2.37–2.13 (m, 2 H, CH_2CH=CH), 1.83–0.86 (m, 10 H, C*H*$CH_2CH_2CH_2CH_2CH$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 176.05, 152.91, 135.20, 131.94, 129.25, 128.69, 127.09, 123.86, 65.80, 55.02, 43.03, 29.96, 29.90, 26.43, 26.22; $[\alpha]_{589}$ +111° (c 1.53, CH_2Cl_2). A small portion was recrystallized from hexane for analysis: mp 86.5–88.0 °C.

Anal. Calcd for $C_{21}H_{25}NO_3$: C, 74.31; H, 7.42. Found: C, 74.33; H, 7.50.

(4*R*,5*S*)-3-((4′*R*,5′*R*,6′*S*)-Bicyclo[4.4.0]decene-4′-carbonyl)-4-methyl-5-phenyl-2-oxazolidinone (38). To a solution of 200 mg (0.59 mmol) of trienimide **30c** in 20 mL of dichloromethane at −78 °C was added 0.63 mL (1.3 M in toluene, 0.82 mmol, 1.4 equiv) of dimethylaluminum chloride. The mixture was warmed to −30 °C and stirred for 5 h. The mixture was poured into 25 mL of 1 N aqueous hydrochloric acid, and the layers were shaken and separated. The aqueous layer was extracted with dichloromethane, and the combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give a colorless oil. Analysis by VPC (30 m DB-5, 225 °C, 15 psi, t_r major 8.78 min, t_r minor 9.25 min) revealed the presence of a 91:9 mixture of two diastereomers. The major diastereomer was isolated by flash chromatography on silica gel (40 × 150 mm column, 15% ethyl acetate/hexane, 20-mL fractions) to afford 140 mg (70%, >99% pure by VPC) of the title compound as a clear, colorless oil: R_f 0.47 (20% ethyl acetate/hexane); IR (neat) 1787, 1696, 1343, 1226, 1197 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.36–7.19 (m, 5 H, aromatic H's), 5.57 (d, 1 H, J = 7.2 Hz, C*H*O), 5.52 (m, 1 H, CH_2CH=CH), 5.37 (br d, 1 H, J = 9.9 Hz, CH_2CH=C*H*), 4.71 (quintet, 1 H, J = 6.7 Hz, C*H*N), 3.79 (dt, 1 H, J = 5.7, 10.8 Hz, C*H*O), 2.30 (m, 1 H, CH*H*CH=CH), 2.16 (m, 1 H, C*H*HCH=CH), 1.84–0.90 (m, 10 H, C*H*$CH_2CH_2CH_2CH_2CH$), 0.79 (d, 3 H, J = 6.6 Hz, CH_3); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.91, 152.63, 133.29, 131.92, 128.56, 128.52, 125.52, 123.90, 78.67, 54.77, 43.26, 42.37, 41.05, 32.89, 29.85, 29.51, 26.52, 26.35, 14.31; $[\alpha]_{589}$ −30° (c 0.52, CH_2Cl_2).

Anal. Calcd for $C_{21}H_{25}NO_3$: C, 74.31; H, 7.43. Found: C, 74.33; H, 7.42.

(4*R*)-3-((4′*R*,5′*R*,6′*S*)-Bicyclo[4.4.0]decene-4′-carbonyl)-4-cyclohexyl-2-oxazolidinone (39). To a solution of 111 mg (0.34 mmol) of trienimide **30d** in 10.0 mL of dichloromethane at −78 °C was added 0.36 mL (1.3 M in toluene, 0.47 mmol, 1.4 equiv) of dimethylaluminum chloride. The mixture was stirred for 5 h at −30 °C. The mixture was poured into a 30-mL separatory funnel containing 10 mL of 1 N aqueous hydrochloric acid. The layers were shaken and separated, and the aqueous layer was extracted with dichloromethane (2 × 10 mL). The combined organic layers were dried over magnesium sulfate, filtered, and concentrated in vacuo to give 111 mg (100% mass balance) of a colorless solid. Analysis by VPC (DB-5, 225 °C, 15 psi, t_r major 17.83 min, t_r minor 17.46 min) revealed the presence of a 94:6 mixture of diastereomers. The mixture was purified by flash chromatography on silica gel (40 × 180 mm column, 15% ethyl acetate/hexane, 8-mL fractions) to give 77.4 mg (70%, >99% pure by VPC) of a colorless, crystalline solid: R_f 0.44 (20% ethyl acetate/hexane); mp 139.5–140.5 °C; IR (CCl_4) 1790, 1700, 1451, 1383, 1348 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 5.60 (m, 1 H, CH_2CH=CH), 5.45 (br d, 1 H, J = 9.9 Hz, CH_2CH=C*H*), 4.44 (m, 1 H, C*H*N), 4.24 (m, 2 H, CH_2O), 3.90 (dt, 1 H, J = 10.8, 5.8 Hz, C*H*C=O), 2.45–2.16 (m, 2 H, CH=CHC*H*$_2$), 2.05–0.90 (m, 21 H, C_6H_{11}, C*H*$CH_2CH_2CH_2CH_2CH$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 176.18, 153.71, 132.16, 124.00, 64.21, 58.25, 43.25, 42.22, 41.19, 39.16, 33.11, 30.19, 30.02, 28.48, 26.69, 26.52, 26.25, 25.93, 25.83, 25.66; $[\alpha]_{589}$ −122° (c 0.679, CH_2Cl_2).

Anal. Calcd for $C_{20}H_{29}NO_3$: C, 72.47; H, 8.82. Found: C, 72.37; H, 8.92.

Methyl (4*S,5*S**,6*R**)-Bicyclo[4.4.0]decene-4-carboxylate. (a) Thermal Reaction.** A solution of 13 mg (0.07 mmol) methyl (*E*,*E*)-2,8,10-undecatrienoate in 6.0 mL of toluene containing 1 mg of hydroquinone was heated at reflux for 19 h. The solution was cooled to ambient temperature, diluted with dichloromethane, and analyzed by VPC (30 m SE-54, 100 °C, 15 psi, t_r 8.77 min (60%) starting material, t_r 5.75 min (20%) endo isomer, t_r 6.38 (20%) exo isomer).

(b) Diethylaluminum Chloride Promoted Reaction. A solution of 64 mg (0.33 mmol) of methyl (*E*,*E*)-2,8,10-undecatrienoate in 10 mL of dichloromethane at −78 °C was treated with 0.18 mL (1.8 M in toluene, 0.33 mmol, 1.0 equiv) of diethylaluminum chloride and stirred at ambient temperature for 18 h. The reaction mixture was diluted with 60 mL of dichloromethane and washed with a 1:1 mixture of saturated aqueous ammonium chloride and 1 N aqueous hydrochloric acid. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo. Analysis by VPC (30 m SE-54, 85 °C, 15 psi, t_r 8.77 min (61%) starting material, t_r 5.76 min (34%) endo isomer, t_r 6.39 (4%) exo isomer) revealed the presence of an 8.:51 ratio of the two Diels–Alder cycloaddition products.

Phenylmethyl (4*S*,5*S*,6*R*)-Bicyclo[4.3.0]nonene-4-carboxylate (40) from 32. Imide **32** (51 mg, 0.19 mmol) was converted to its corresponding benzyl ester (36 mg, 75%, >99% pure by VPC) as described in the general protocol: R_f 0.59 (15% ethyl acetate/hexane); VPC (30 m DB-5, 175 °C, 15 psi) t_r 5.60 min; IR ($CHCl_3$) 3020, 2980, 2880, 1728, 1170 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.43–7.27 (m, 5 H, aromatic H's), 5.82, (br dd, 1 H, J = 11.4, 9.9 Hz, CH_2CH=C*H*), 5.58 (m, 1 H, CH_2CH=CH), 5.14 (s, 2 H, CH_2Ph), 2.57 (ddd, 1 H, J = 7.6, 9.4, 10.1 Hz, C*H*C=O), 2.38 (m, 2 H, CH_2CH=CH), 1.97–1.09 (m, 8 H, C*H*$CH_2CH_2CH_2CH$); ^{13}C NMR (22.5 MHz, $CDCl_3$) δ 175.40, 136.15, 129.72, 128.48, 128.09, 125.49, 66.09, 45.95, 45.43, 44.26, 29.89, 28.98, 28.07, 21.90; $[\alpha]_{589}$ +28.8° (c 0.323, CH_2Cl_2).

Anal. Calcd for $C_{17}H_{20}O_2$: C, 79.65; H, 7.86. Found: C, 79.72; H, 7.84.

Phenylmethyl (4*S*,5*S*,6*R*)-Bicyclo[4.3.0]nonene-4-carboxylate (40) from 33. Imide **33** (47 mg, 0.14 mmol) was converted to its corresponding benzyl ester (35 mg, 94%, >99% pure by VPC) as described in the general protocol (reaction time 1 h): $[\alpha]_{589}$ +28.6° (c 0.322, CH_2Cl_2).

Phenylmethyl (4*R*,5*R*,6*S*)-Bicyclo[4.3.0]nonene-4-carboxylate (41) from 34. Imide **34** (123 mg, 0.38 mmol) was converted to its corresponding benzyl ester (84 mg, 87%, >99% pure by VPC) as described in the general protocol (reaction time 1.5 h): $[\alpha]_{589}$ −28.6° (c 0.369, CH_2Cl_2).

Phenylmethyl (4*R*,5*R*,6*S*)-Bicyclo[4.3.0]nonene-4-carboxylate (41) from 35. Imide **35** (50 mg, 0.16 mmol) was converted to its corresponding benzyl ester (36 mg, 90%, >99% pure by VPC) as described in the general protocol: $[\alpha]_{589}$ −28.7° (c 0.362, CH_2Cl_2).

Phenylmethyl (4*S*,5*S*,6*R*)-Bicyclo[4.4.0]decene-4-carboxylate (42) from 36. Imide **36** (37 mg, 0.13 mmol) was converted to its corresponding benzyl ester (23 mg, 65%, >99% pure by VPC) as described in the general protocol (reaction time 18 h): R_f 0.58 (15% ethyl acetate/hexane); IR (neat) 3023, 2928, 2855, 1729, 1440, 1303, 1246, 1149 cm^{-1}; ^1H NMR (300 MHz, $CDCl_3$) δ 7.40–7.26 (m, 5 H, aromatic H's), 5.58 (m, 1 H, CH_2CH=CH), 5.42 (m, 1 H, CH_2CH=C*H*), 5.12 (s, 2 H, CH_2Ph), 2.46 (dt, 1 H, J = 10.7, 5.4 Hz, C*H*C=O), 2.43–2.18 (m, 2 H, CH_2CH=CH), 1.81–0.96 (m, 10 H, C*H*$CH_2CH_2CH_2CH_2CH$); ^{13}C NMR (75.5 MHz, $CDCl_3$) δ 175.47, 136.13, 131.99, 128.41, 128.02, 123.98, 65.83, 46.32, 42.49, 41.46, 32.94, 30.32, 29.51, 26.57, 26.35; $[\alpha]_{589}$ +5.5° (c 0.77, $CHCl_3$).

Anal. Calcd for $C_{18}H_{22}O_2$: C, 79.96; H, 8.20. Found: C, 80.13; H, 8.26.

Phenylmethyl (4*S*,5*S*,6*R*)-Bicyclo[4.4.0]decene-4-carboxylate (42) from 37. Imide **37** (150 mg, 0.44 mmol) was converted to its corre-

sponding benzyl ester (82 mg, 70%, >99% pure by VPC) as described in the general protocol (reaction time 18 h): $[\alpha]_{589}$ +5.56° (*c* 0.809, CH_2Cl_2).

Phenylmethyl (4*R*,5*R*,6*S*)-Bicyclo[4.4.0]decene-4-carboxylate (43) from 38. Imide **38** (50 mg, 0.15 mmol) was converted to its corresponding benzyl ester (24 mg, 61%, >99% pure by VPC) as described in the general protocol (reaction time 18 h): $[\alpha]_{589}$ −5.58° (*c* 0.242, CH_2Cl_2).

Phenylmethyl (4*R*,5*R*,6*S*)-Bicyclo[4.4.0]decene-4-carboxylate (43) from 39. Imide **39** (60 mg, 0.18 mmol) was converted to its corresponding benzyl ester (32 mg, 67%, >99% pure by VPC) as described in the general protocol (reaction time 18 h): $[\alpha]_{589}$ −5.57° (*c* 0.323, CH_2Cl_2).

(4*S*,5*S*,6*S*)-4-(Hydroxymethyl)bicyclo[4.3.0]nonene (44) from 40. To a solution of 49 mg (0.19 mmol) of benzyl ester **40** in 5.0 mL of ether at 0 °C was added 0.30 mL (1.0 M in THF, 0.30 mmol, 1.6 equiv) of lithium aluminum hydride. The mixture was stirred at 0 °C for 30 min and then at ambient temperature for 45 min. The reaction was quenched with 5.0 mL of 1 N aqueous hydrochloric acid, diluted with 30 mL of ether, washed with 15 mL of 1 N aqueous hydrochloric acid, and finally washed with 15 mL of saturated aqueous sodium chloride. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give 45 mg of a colorless oil. The inseparable mixture of alcohols was dissolved in 10 mL of dichloromethane and treated with 0.1 mL of acetic anhydride, 0.1 mL of triethylamine, and 1 mg of DMAP. The mixture was stirred for 18 h at ambient temperature and then was washed with 1 N aqueous sodium bisulfate. The organic layer was dried over magnesium sulfate, filtered, and concentrated in vacuo to give a colorless oil. The acetates were separated by flash chromatography on silica gel (20 × 200 mm column, 10% ether/hexane, 10-mL fractions) to give 27 mg of the bicyclic acetate as a colorless oil. A solution of this acetate in 5.0 mL of methanol at ambient temperature was treated with 50 mg of potassium carbonate. The mixture was stirred for 3 h and concentrated in vacuo, and the residue was triturated with ether. The supernatant was filtered through a column of silica gel (15 × 100 mm column, ether, 60 mL) and concentrated in vacuo to give 13 mg (45%) of the title compound as a clear, colorless oil, which crystallized on standing: ^{1}H NMR (90 MHz, $CDCl_3$) δ 5.82 (br d, 1 H, *J* = 10 Hz), 5.60 (dm, 1 H, *J* = 10 Hz), 3.60 (m, 2 H), 0.90–2.50 (br m, 12 H); $[\alpha]_{589}$ +43° (*c* 0.78, CCl_4), in good agreement with the data reported for this compound.[19b]

General Protocol for Crotonate Oxazolidinone/Isoprene Diels–Alder Cycloadditions. To a solution of ca. 0.3 mmol of the appropriate crotonate oxazolidinone imide in 1.0 mL of freshly distilled dichloromethane and 1.0 mL of isoprene (distilled, then filtered through neutral alumina immediately prior to use) at −78 °C is added 1.4 equiv (1.8 M in toluene) of diethylaluminum chloride. The solution is then placed in a constant-temperature bath at −30 ± 0.5 °C and stirred at that temperature for 3 h. The reaction is then quenched with 10 mL of 1 N aqueous hydrochloric acid. The aqueous layer is extracted with dichloromethane (3 × 10 mL), and the combined organic layers are dried over magnesium sulfate, filtered, and concentrated in vacuo. The products are passed through a 5 × 60 mm column (pipet) of silica gel, using 50% ethyl acetate/hexane as eluent. The resultant solution of Diels–Alder adducts is diluted to the appropriate volume (~1 mg/mL) and analyzed by VPC.

Stereoselective Diels–Alder Cycloadditions. (4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-phenyl-2-oxazolidinone (53a). (4*S*)-3-((*E*)-2-Butenoyl)-4-phenyl-2-oxazolidinone (**51a**)[38] (74.3 mg, 0.321 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford an 67.3:32.7 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 2 °C/min, 200 °C 10 min, 15 psi, t_r major 12.02 min, t_r minor 12.38 min).

(4*S)-3-((4′*S**,5′*S**)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-methyl-2-oxazolidinone (53b).** (4*S**)-3-((*E*)-2-Butenoyl)-4-methyl-2-oxazolidinone (**51b**)[38] (40.5 mg, 0.239 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 79.3:20.7 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, 150 °C, 15 psi, t_r major 4.18 min, t_r minor 4.57 min).

(4*S)-3-((4′*S**,5′*S**)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-ethyl-2-oxazolidinone (53c).** (4*S**)-3-((*E*)-2-Butenoyl)-4-ethyl-2-oxazolidinone (**51c**)[38] (53.0 mg, 0.289 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford an 84.6:15.4 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, 150 °C, 15 psi, t_r major 5.99 min, t_r minor 6.53 min).

(4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(1-methylethyl)-2-oxazolidinone (53d). (4*S*)-3-((*E*)-2-Butenoyl)-4-(1-methylethyl)-2-oxazolidinone (**6a, 51d**)[38,39] (71.5 mg, 0.360 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford an 84.2:15.8 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 4 °C/min, 200 °C 10 min, 15 psi, t_r major 3.79 min, t_r minor 4.10 min).

(4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(cyclohexylmethyl)-2-oxazolidinone (53e). (4*S*)-3-((*E*)-2-Butenoyl)-4-(cyclohexylmethyl)-2-oxazolidinone (**47, 51e**)[38,39] (62.7 mg, 0.250 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 90.6:9.4 mixture of the two expeected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 2 °C/min, 200 °C 10 min, 15 psi, t_r major 15.29 min, t_r minor 16.09 min).

(4*S)-3-((4′*S**,5′*S**)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(1,1-dimethylethyl)-2-oxazolidinone (53f).** (4*S**)-3-((*E*)-2-Butenoyl)-4-(1,1-dimethylethyl)-2-oxazolidinone (**51f**)[38] (63 mg, 0.30 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a single Diels–Alder diastereomer: VPC (30 m DB-1, 160 °C, 15 psi, t_r 7.26 min).

(4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-(phenylmethyl)-2-oxazolidinone (53g). (4*S*)-3-((*E*)-2-Butenoyl)-4-(phenylmethyl)-2-oxazolidinone (**7a, 51g**)[39] (72.1 mg, 0.294 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 95.4:4.6 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 2 °C/min, 200 °C 10 min, 15 psi, t_r major 15.56 min, t_r minor 16.39 min).

(4*S*)-3-((4′*S*,5′*S*)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-((4′-methoxyphenyl)methyl)-2-oxazolidinone (53h). (4*S*)-3-((*E*)-2-Butenoyl)-4-((4′-methoxyphenyl)methyl)-2-oxazolidinone (**48, 51h**)[38,39] (53.8 mg, 0.195 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 95.9:4.1 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 4 °C/min, 200 °C 10 min, 15 psi, t_r major 26.95 min, t_r minor 29.21 min).

(4*S)-3-((4′*S**,5′*S**)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-((4′-chlorophenyl)methyl)-2-oxazolidinone (53i).** (4*S**)-3-((*E*)-2-Butenoyl)-4-((4′-chlorophenyl)methyl)-2-oxazolidinone (**49, 51i**)[38,39] (61.6 mg, 0.220 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 95.8:4.2 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, temperature program, 180 °C 5 min, 4 °C/min, 200 °C 10 min, 15 psi, t_r major 23.77 min, t_r minor 25.54 min).

(4*S)-3-((4′*S**,5′*S**)-1′,5′-Dimethylcyclohexene-4′-carbonyl)-4-((4′-(trifluoromethyl)phenyl)methyl)-2-oxazolidinone (53j).** (4*S**)-3-((*E*)-2-Butenoyl)-4-((4′-(trifluoromethyl)phenyl)methyl)-2-oxazolidinone (**50, 51j**)[38,39] (94 mg, 0.30 mmol) and isoprene were allowed to react in the presence of diethylaluminum chloride according to the general protocol detailed above to afford a 95.5:4.5 mixture of the two expected Diels–Alder diastereomers: VPC (30 m DB-5, 200 °C, 15 psi, t_r major 8.20 min, t_r minor 9.08 min).

General Protocol for Butyrate Oxazolidinone Enolate Alkylations. Methyl Iodide Alkylations. A 0.10 M stock solution of lithium diisopropylamide is prepared as follows: A flame-dried 100-mL volumetric flask containing a small magnetic stir bar is charged with 10.0 mL of freshly distilled THF and 1.47 mL (10.5 mmol) of freshly distilled diisopropylamine. The solution is cooled to −78 °C and 10.0 mmol of *n*-butyllithium is added. The mixture is then warmed to 0 °C, stirred for 30 min, and recooled to −78 °C. The solution is carefully diluted to 100 mL with freshly distilled THF and thoroughly stirred. To 2.2 mL (0.22 mmol) of the above solution at −78 °C is added via cannula a solution of 0.20 mmol of the appropriate butyrate oxazolidinone in 1.0 mL of freshly distilled THF. The mixture is stirred at −78 °C for 45 min and 1.0 mmol of methyl iodide (passed through neutral alumina immediately prior to use, 62 μL) is added. The mixture is placed in a constant-temperature bath at −30.0 ± 0.5 °C and stirred at that temperature for 12 h. The reaction is quenched with 0.5 mL of saturated aqueous ammonium chloride and warmed to ambient temperature. The slurry is diluted with 20 mL of 1 N aqueous sodium bisulfate and extracted with dichloromethane (3 × 10 mL). The combined organic layers are then washed with saturated aqueous sodium bicarbonate, dried over magnesium sulfate, filtered, and concentrated in vacuo. The alkylation products

(38) Chapman, K. Ph.D. Dissertation, Harvard University, Cambridge, MA, 1987.

(39) This compound was given two numbers in the text for the sake of clarity.

are diluted to the appropriate volume (~1 mg/mL) and analyzed by VPC.

Protocol for Preparation of Butyrate Oxazolidinone/Methyl Iodide Alkylation Authentic Mixtures. To a solution of 0.1 mmol of the appropriate oxazolidinone in 1.0 mL of anhydrous THF at −78 °C is added 0.11 mmol of *n*-butyllithium. The mixture is stirred for 5 min and 100 μL of *rac*-2-methylbutanoyl chloride is added. The mixture is allowed to warm to ambient temperature over 30 min and 1.0 mL of saturated aqueous sodium bicarbonate is added. The slurry is diluted with 10 mL of water and extracted with 10 mL of dichloromethane. The organic layer is dried over magnesium sulfate, filtered, and concentrated in vacuo. The product is then passed through a 5 × 60 mm column (pipet) of silica gel using 50% ethyl acetate/hexane as eluent, diluted to the appropriate volume (~1 mg/mL), and analyzed by VPC.

Stereoselective Alkylations. (4*S*)-3-(2-Methylbutanoyl)-4-phenyl-2-oxazolidinone (54a). (4*S*)-3-Butanoyl-4-phenyl-2-oxazolidinone (**52a**)[20] (46.6 mg, 0.20 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford an 81:19 mixture of the two expected diastereomers: VPC (25 m Carbowax 20M, 200 °C, 15 psi, t_r major 9.42, t_r minor 9.58). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and(4*R*)-4-phenyl-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (25 m Carbowax 20M, 200 °C, 15 psi, t_r 9.39 min, t_r 9.56 min).

(4*S)-3-(2-Methylbutanoyl)-4-methyl-2-oxazolidinone (54b).** (4*S**)-3-Butanoyl-4-methyl-2-oxazolidinone (**52b**)[20] (38.7 mg, 0.226 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford an 87.4:12.6 mixture of the two expected diastereomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r major 2.78 min, t_r minor 2.93 min). An auuthentic sample was prepared from *rac*-2-methylbutanoyl chloride and 4-methyl-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r 2.78 min, t_r 2.93 min).

(4*S)-3-(2-Methylbutanoyl)-4-ethyl-2-oxazolidinone (54c).** (4*S**)-3-Butanoyl-4-ethyl-2-oxazolidinone (**52c**)[38] (37.8 mg, 0.204 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 90.2:9.8 mixture of the two expected diastereomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r major 4.14 min, t_r minor 4.40 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and 4-ethyl-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r 4.14 min, t_r 4.40 min).

(4*S*)-3-(2-Methylbutanoyl)-4-(1-methylethyl)-2-oxazolidinone (54d). (4*S*)-3-Butanoyl-4-(1-methylethyl)-2-oxazolidinone (**52d**)[20] (40.4 mg, 0.203 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 90.8:9.2 mixture of the two expeected diastreomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r major 5.30 min, t_r minor 5.62 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and (4*S*)-4-(1-methylethyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 120 °C, 15 psi, t_r 5.29 min, t_r 5.63 min).

(4*S*)-3-(2-Methylbutanoyl)-4-(cyclohexylmethyl)-2-oxazolidinone (54e). (4*S*)-3-Butanoyl-4-(cyclohexylmethyl)-2-oxazolidinone (**52e**)[38] (51.2 mg, 0.202 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 94.6:5.4 mixture of the two expected diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r major 6.21 min, t_r minor 6.37 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and (4*S*)-4-(cyclohexymethyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r 6.21 min, t_r 6.39 min).

(4*S*)-3-(2-Methylbutanoyl)-4-(1,1-dimethylethyl)-2-oxazolidinone (54f). (4*S*)-3-Butanoyl-4-(1,1-dimethylethyl)-2-oxazolidinone (**52f**)[38] (43 mg, 0.20 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 67.7:1 mixture of the two expected diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r major 5.61 min, t_r minor 5.95 min). An auuthentic sample was prepared from *rac*-2-methylbutanoyl chloride and (4*S*)-4-(cyclohexymethyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r 5.61 min, t_r 5.95 min).

(4*S*)-3-(2-Methylbutanoyl)-4-(phenylmethyl)-2-oxazolidinone (54g). (4*S*)-3-Butanoyl-4-(phenylmethyl)-2-oxazolidinone (**52g**)[20] (55.6 mg, 0.220 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 94.4:5.6 mixture of the two expected diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r major 6.30 min, t_r minor 6.51 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and oxazolidinone **4** as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r 6.30 min, t_r 6.53 min).

(4*S*)-3-(2′-Methylbutanoyl)-4-((4′-methoxyphenyl)methyl)-2-oxazolidinone (54h). (4*S*)-3-Butanoyl-4-((4′-methoxyphenyl)methyl)-2-oxazolidinone (**52h**)[38] (52.1 mg, 0.188 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 94.4:5.6 mixture of the two expected diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r major 16.58 min, t_r minor 17.15 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and (4*S*)-3-(2′-methylbutanoyl)-4-((4′-methoxyphenyl)methyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 170 °C, psi, t_r 16.51 min, t_r 17.13 min).

(4*S)-3-(2′-Methylbutanoyl)-4-((4′-chlorophenyl)methyl)-2-oxazolidinone (54i).** (4*S**)-3-Butanoyl-4-((4′-chlorophenyl)methyl)-2-oxazolidinone (**52i**)[38] (49.2 mg, 0.174 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 93.9:6.1 mixture of the two expected diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r major 13.79 min, t_r minor 14.21 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and 4-((4′-chlorophenyl)methyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 170 °C, 15 psi, t_r 13.72 min, t_r 14.22 min).

(4*S)-3-(2′-Methylbutanoyl)-4-((4′-(trifluoromethyl)phenyl)-methyl)-2-oxazolidinone (54j).** (4*S**)-3-Butanoyl-4-((4′-(trifluoromethyl)phenyl)methyl)-2-oxazolidinone (**52j**)[38] (63 mg, 0.20 mmol) was alkylated with methyl iodide according to the general protocol detailed above to afford a 94.0:6.0 mixture of the two expected diastereomers: VPC (30 m DB-5, 145 °C, 15 psi, t_r major 16.26 min, t_r minor 16.93 min). An authentic sample was prepared from *rac*-2-methylbutanoyl chloride and 4-((4′-chlorophenyl)methyl)-2-oxazolidinone as detailed above to afford a 1:1 mixture of the two diastereomers: VPC (30 m DB-5, 145 °C, 15 psi, t_r 16.26 min, t_r 16.93 min).

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