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Chiral Lewis Acid Catalyzed Asymmetric Cycloadditions of Carbonyl Ylides Generated from Diazoimide Derivatives and Their Synthetic Applications to Indolizidine Alkaloids

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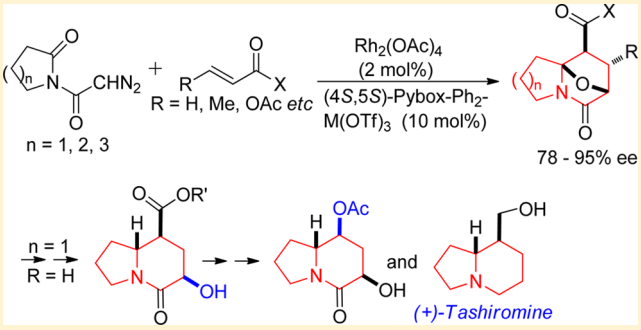
Supporting Information

ABSTRACT: Highly enantioselective 1,3-dipolar cycloaddition reactions, catalyzed by chiral Lewis acids, between several 3-(2-alkenoyl)-2-oxazolidinones and carbonyl ylides that were generated from *N*-diazoacetyl lactams are described. Reactions of *N*-diazoacetyl lactams that possess 5-, 6-, and 7-membered rings were transformed to the corresponding epoxy-bridged indolizidines, quinolizidines, and 1-azabicyclo[5.4.0]undecanes with good to high enantioselectivities. Regio- and stereoselective ring-opening of the epoxy-bridged indolizidine cycloadduct gave the corresponding alcohol as a single diastereomer. The sequence of asymmetric cycloaddition followed by ring-opening was applied to the syntheses of several chiral indolizidine derivatives, including (+)-tashiromine.



INTRODUCTION

Tandem intramolecular carbenoid−carbonyl cyclizations of diazocarbonyl compounds followed by carbonyl ylide cycloaddition sequences have been widely utilized for stereoselective syntheses of a variety of oxygen-functionalized polycyclic compounds.[1] Recently, we have developed a dual-activation methodology containing a chiral Lewis acid catalyzed asymmetric 1,3-dipolar cycloaddition for the tandem carbonyl ylide formation−cycloaddition sequences that have exhibited high levels of asymmetric induction.[2,3] Our methodology can be applied not only to normal electron-demand,[2a−c] but also to inverse electron-demand cycloadditions;[2d,e] surprisingly, catalytically generated carbonyl ylides in situ could be activated by chiral Lewis acids. The range of the diazocarbonyl compounds as the cyclic carbonyl ylide precursors was expanded to include simple 1-diazo-2,5-pentanedione derivatives for the inverse electron-demand cycloadditions.[2d,e] Consequently, we reasoned that the reaction between olefinic dipolarophile and carbonyl ylide (isomünchnone) derived from lactams possessing a diazoimide could serve as a novel asymmetric synthetic scheme of various optically active *N*-fused polycyclic heterocycles including indolizidines, such as (+)-castanospermine, (−)-swainsonine, and (+)-tashiromine, and quinolizidine alkaloids, such as (+)-epilupinine (Scheme 1). Although the construction of epoxy-bridged indolizidine and quinolizidine frameworks in racemic form by the cycloaddition of isomünchnones derived from diazolactams and the transfomation to their derivatives such as alkaloids have been reported, it is important to note that crucial stereochemical outcome obtained by the concerted cycloaddition was not reflected in their syntheses.[4] In this communication, we describe the asymmetric cycloadditions between alkenoic acid derivatives and carbonyl ylides derived from *N*-diazoacetyl lactams, and the subsequent regio- and stereoselective ring-opening of the epoxy-bridge for the construction of chiral indolizidine derivatives including (+)-tashiromine.

RESULTS AND DISCUSSION

The cycloaddition reaction was initially carried out by adding *N*-diazoacetyl-2-pyrrolidinone (**1**) to a solution of 3-acryloyl-2-oxazolidinone (**2a**) in CH_2Cl_2 at rt over a period of 1 h in the presence of $Rh_2(OAc)_4$ (2 mol %) and (4*S*,5*S*)-Pybox-Ph$_2$-Yb(OTf)$_3$ complex (10 mol %) (Scheme 2). The corresponding cycloadducts were obtained in a combined yield of 82% with an *exo*/*endo* ratio of 78:22, which is slightly higher than that for the reaction in the absence of any Lewis acids (89% yield, *exo*/*endo* = 52:48). The enantioselectivity of the *exo*-cycloadduct, after conversion to the corresponding *p*-bromobenzyl ester, was determined to be 77% ee using chiral HPLC analysis (Daicel Chiralpak AD-H). To improve the *exo*- and enantioselectivities, and to establish the reproducibility of the reaction, we investigated the effects of the Pybox ligands and lanthanide triflates, and optimized the reaction conditions,

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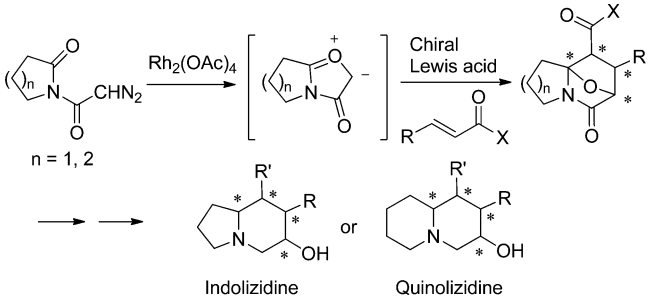
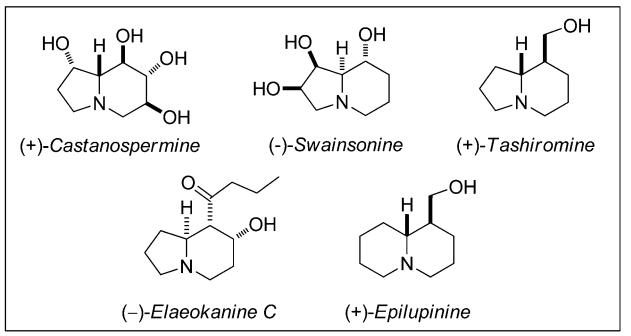
Scheme 1. Novel Route to Afford Chiral Indolizidines and Quinolizidines through Asymmetric Cycloadditions of Carbonyl Ylides Derived from *N*-Diazoacetyl Lactams





Indolizidine and quinolizidine alkaloids

including choice of solvent, addition time, reaction temperature, and type of alcohol additives for the preparation of the catalyst. As a result, the reaction products were obtained in a quantitative yield with high enantio- (87% ee) and *exo*-selectivities (92:8) (Table 1, entry 1); optimal reaction conditions involved the addition of diazo substrate **1** over a period of 6 h at 10 °C in CH_2Cl_2 using (4*S*,5*S*)-Pybox-Ph_2-$Sm(OTf)_3$ complex (10 mol %) that was prepared in THF by stirring at rt for 2 h in the presence of *i*-PrOH (10 mol %) as a catalyst. As a note, under the same reaction conditions, the use of $Eu(OTf)_3$, $Tb(OTf)_3$, or $Ho(OTf)_3$ instead of $Sm(OTf)_3$ also gave good results in terms of yield (95% to quant), and *exo*- (90:10 to 92:8) and enantioselectivities (84–85% ee, *exo*) (see Supporting Information for other lanthanide triflates).

For the reaction of 2-acryloyl-1-benzyl-5,5-dimethyl-3-pyrazolidinone (**3a**) as the dipolarophile, the use of (*R*)-BINIM-2QN-$Ni(ClO_4)_2$-$6H_2O$ complex (10 mol %) in $CHCl_3$ at 50 °C gave good *exo*- (80:20) and enantioselectivities (81% ee, *exo*) for **5a** (Scheme 2). Interestingly, the configuration on an indolizidine ring of the *exo*-cycloadduct *exo*-**5a** (the opposite configuration was drawn in Scheme 2) was found to be the opposite to that obtained from the reaction catalyzed by (4*S*,5*S*)-Pybox-Ph_2-$Sm(OTf)_3$ for *exo*-**4a**, as determined by HPLC analysis of the corresponding *p*-bromobenzyl ester of the products.

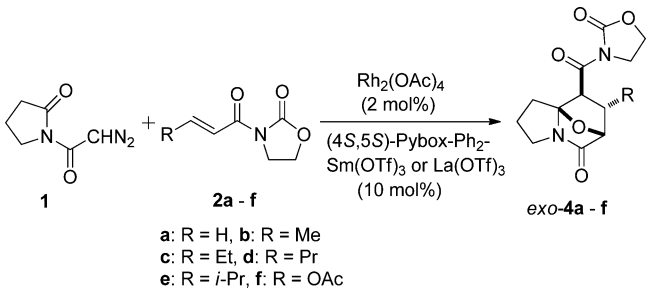
To determine the range of the olefinic dipolarophiles, reactions were carried out using 3-crotonoyl-2-oxazolidinone (**2b**) (Scheme 3, R = Me). The cycloaddition of the carbonyl

Table 1. Reactions of Diazo Compound 1 with 3-(2-Alkenoyl)-2-oxazolidinones 2a–f Catalyzed by (4*S*,5*S*)-Pybox-Ph_2-$La(OTf)_3$[a]

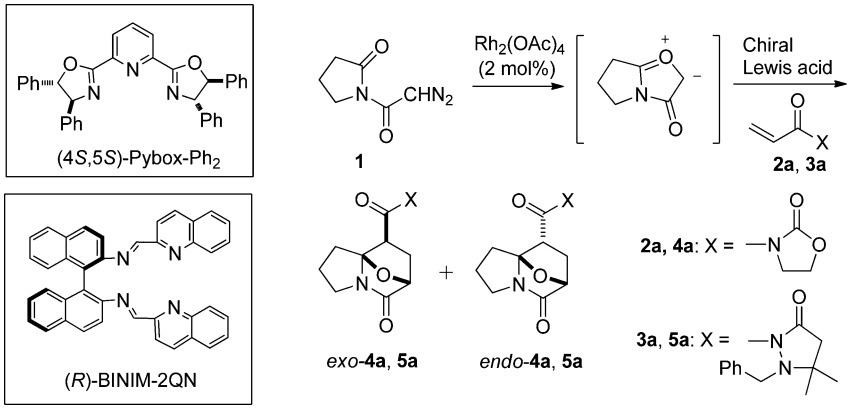
entry	R	temp (°C)	product	yield (%)	*exo*: *endo*	% ee[b]
1[c]	H	10	**4a**	quant	92:8	87
2[c]	Me	−20[d]	**4b**	84	93:7	57
3	Me	−20[d]	**4b**	quant	75:25	95
4	Et	0	**4c**	84	64:36	92
5	Pr	0	**4d**	65	77:23	92
6	*i*-Pr	0	**4e**	44	95:5	93
7	OAc	−10	**4f**	60	99:1	81[e]

[a]The reactions were carried out by adding a solution of **1** in CH_2Cl_2 to a suspension of **2a–f**, $Rh_2(OAc)_4$ (2 mol %), MS 4 Å, and (4*S*,5*S*)-Pybox-Ph_2-$La(OTf)_3$ complex (10 mol %) in CH_2Cl_2 over a period of 6 h. [b]Enantiomeric excess of the *exo*-adduct was determined using chiral HPLC after conversion to the corresponding *p*-bromobenzyl ester. [c]$Sm(OTf)_3$ was used for the preparation of the catalyst. [d]Stirring was continued at −20 °C for additional 12 h. [e]Enantiomeric excess of *exo*-adduct **4f** was determined using chiral HPLC.

Scheme 3. (4*S*,5*S*)-Pybox-Ph_2-$Sm(OTf)_3$ or $La(OTf)_3$ Catalyzed Reactions of Diazo Compound 1 with Oxazolidinones 2a–f



Scheme 2. Chiral Lewis Acid Catalyzed Reactions of Diazo Compound 1 with Acrylic Acid Derivatives 2a or 3a



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ylide generated from diazo substrate **1**, in the presence of (4*S*,5*S*)-Pybox-Ph_2-Sm$(OTf)_3$ complex (10 mol %), proceeded smoothly, even at −20 °C, to afford the cycloadducts **4b** in 84% yield with high *exo*-selectivity (*exo*/*endo* = 93:7). However, the enantioselectivity of cycloadduct *exo*-**4b** was merely 57% ee (Table 1, entry 2). Among the several lanthanide triflates (see Supporting Information for other lanthanide triflates), the use of La$(OTf)_3$ provided the corresponding cycloadducts **4b** in a high yield with the highest enantioselectivity (95% ee, *exo*), albeit with a slightly lower diastereoselectivity (*exo*/*endo* = 75:25) (entry 3).

Subsequently, reactions were carried in the presence of (4*S*,5*S*)-Pybox-Ph_2-La$(OTf)_3$ complex (10 mol %) using 3-(2-alkenoyl)-2-oxazolidinones **2c−f** (R = Et, Pr, *i*-Pr, OAc) (Scheme 3, Table 1, entries 4−7). Although the yields and diastereoselectivities of the *exo*-adducts varied as a function of the R substituents (Et, Pr, *i*-Pr, OAc), the enantioselectivities were mostly over 90% ee (81−93% ee, entries 4−7).

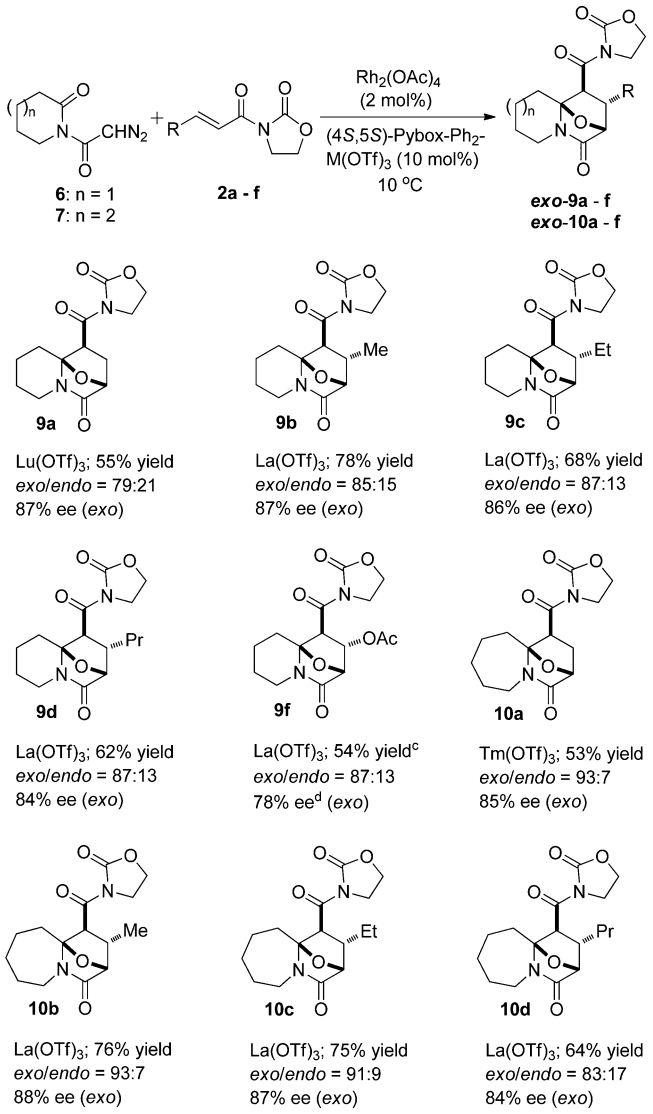
To further investigate the applicability of our methodology, the cycloaddition reactions were carried out using other carbonyl ylides that were derived from their corresponding *N*-diazoacetyl lactams. Although optimal combinations of the lanthanide triflates and (4*S*,5*S*)-Pybox-Ph_2 were dependent on the diazo substrates and 3-(2-alkenoyl)-2-oxazolidinones, the reactions of 6-menbered lactam **6** and 7-membered lactam **7** with several 3-(2-alkenoyl)-2-oxazolidinones selectively afforded the *exo*-cycloadducts, with good to high enantioselectivities (Chart 1).

To extend the utility of this asymmetric cycloaddition, we examined the ring-opening of the epoxy-bridge of the cycloadducts (Scheme 4). Although the separation of *exo*- and *endo*-**4a** proved to be unsuccessful, the *exo*-*p*-bromobenzyl esters of the mixture (*exo*/*endo* = 91:9) were successfully separated using chromatography followed by recrystallization from benzene/hexane to afford enantiomerically pure (>99% ee) *exo*-*p*-bromobenzyl ester *exo*-**11**. The subsequent ring-opening of *exo*-**11** was effectively carried out in CH_2Cl_2 using Et_3SiH in the presence of $BF_3{\cdot}OEt_2$ to give the corresponding alcohol **12** as a single stereoisomer. As a note, analysis using chiral HPLC confirmed that racemization did not occur during the ring-opening step.

On the basis of our results, the sequence of asymmetric cycloaddition followed by ring-opening was applied toward the synthesis of (+)-tashiromine,[5] an indolizidine alkaloid isolated from the stems of a leguminous plant *Maackia tashiroi*. Alcohol **12** was effectively transformed into the corresponding deoxy compound **14** with removal of *p*-Br substituent via treatment with phenyl chlorothionoformate and pyridine and then reduced using tributyltin hydride and AIBN. Next, the benzyl ester moiety and the lactam ring were simultaneously reduced using $LiAlH_4$ to give (+)-tashiromine in a 27% overall yield from cycloadduct *exo*-**4a**. Optical rotation ($[\alpha]_D^{20}$ = +44.3°, *c* 1.1, EtOH) and NMR spectra of our synthetic (+)-tashiromine were in good agreement with those reported in the literature (lit.[6] $[\alpha]_D^{20}$ = +44.7°, *c* 1.1, EtOH).[7]

Furthermore, the functional group of alcohol **12**[8] can be manipulated to afford related compounds (Scheme 5). Upon protection of the hydroxyl group of **12** as its TBS ether, the *p*-bromobenzyl ester moiety was readily converted to the corresponding Weinreb amide **16** and then treated with a methyl Grignard reagent, followed by 10% hydrochloric acid work up to give γ-hydroxylmethyl ketone **18** in a good yield. Moreover, an oxygen functionality can be introduced at the 8-position via Baeyer−Villiger oxidation of **18** to give the corresponding acetate **19** in 52% yield. Acetate **19** could be an important intermediate for the synthesis of 8-hydroxy substituted indorilizidines, which are a well-known substitution pattern in indorilizidine alkaloids such as (+)-castanospermine and (−)-swainsonine (Scheme 1). Thus, these functional group manipulations would serve as a novel route to 8-acyl and 8-hydroxy indolizidine derivatives.

Chart 1. Cycloaddition Reactions in the presence of (4*S*,5*S*)-Pybox-Ph_2-M$(OTf)_3$ between 3-(2-Alkenoyl)-2-oxazolidinones 2a−f and the Carbonyl Ylides, Which Were Derived from *N*-Diazoacetyl Lactams 6 and 7[a,b]



[a]The reactions were carried out similar to the reactions of **1** with **2a−f** at 10 °C. [b]Enantiomeric excess of the *exo*-adduct was determined using chiral HPLC after conversion to the corresponding *p*-bromobenzyl ester. [c]The reaction was carried out at −10 °C. [d]Enantiomeric excess of *exo*-adduct **9f** was determined using chiral HPLC.

CONCLUSIONS

We have developed highly enantioselective cycloaddition reactions, catalyzed by (4*S*,5*S*)-Pybox-Ph_2-lanthanide triflate complexes (10 mol %), between 3-(2-alkenoyl)-2-oxazolidi-

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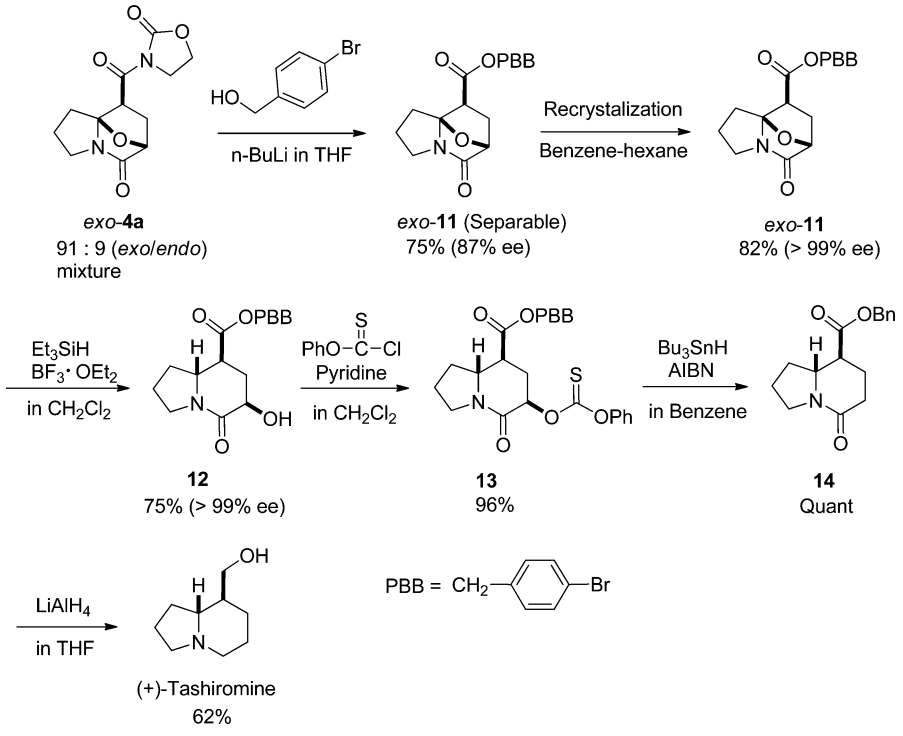
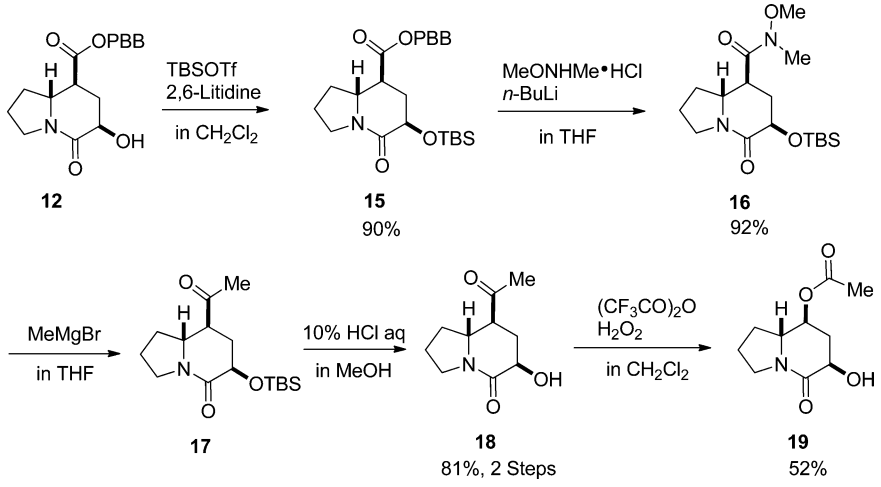
Scheme 4. Stereoselective Ring-opening of Epoxy-bridge and Synthetic Application to (+)-Tashiromine



Scheme 5. Functional Group Conversions of Alcohol 12



nones and carbonyl ylides that were derived from *N*-diazoacetyl lactams. The scope of our cycloaddition methodology is broad with respect to 5-, 6-, and 7-membered *N*-diazoacetyl lactams for diazo substrates and a range of 3-(2-alkenoyl)-2-oxazolidinones as dipolarophiles. Regio- and stereoselective ring-opening of the epoxy-bridge of the indolizidine cycloadduct was carried out to give the corresponding alcohol as a single isomer. Our synthetic methodology involving the sequence of asymmetric cycloaddition followed by ring-opening was actually effective in reflecting the important stereochemical outcome of the cycloaddition step and effectively applied to the total synthesis of (+)-tashiromine. Further applications toward the synthesis of other indolizidine and quinolizidine alkaloids are currently underway.

EXPERIMENTAL SECTION

General Methods. Melting points were determined on a melting point apparatus and are uncorrected. IR spectra were taken with a FT/IR spectrophotometer. ^{1}H NMR spectra were recorded on 300, 400, and 500 MHz spectrometers. Chemical shifts are expressed in parts per million downfield from tetramethylsilane as an internal standard. ^{13}C NMR spectra were recorded on 75, 100, and 125 MHz spectrometers using broadband proton decoupling. Chemical shifts are expressed in parts per million using the middle resonance of $CDCl_3$ (77.0 ppm) as an internal standard. Hydrogen multiplicity (C, CH, CH_2, CH_3) information was obtained from carbon DEPT spectrum. For preparative column chromatography, 45−75 μm silica gel was employed. High-resolution mass spectra were obtained on EI and ESI-TOF spectrometers. Elemental analyses were performed on a CHN recorder. Optical rotations were recorded with a polarimeter. All reactions were carried out under an argon atmosphere in dried glassware.

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Materials. *N*-Diazoacetyl-2-pyrrolidinone (**1**) was prepared according to the procedure in the previous paper.[4a] 3-Acryloyl-2-oxazolidinone (**2a**),[9] 3-crotonoyl-2-oxazolidinone (**2b**),[10] 3-(2-pentenoyl)-2-oxazolidinone (**2c**),[11] 3-(2-hexenoyl)-2-oxazolidinone (**2d**),[10] 3-(4-methyl-2-pentenoyl)-2-oxazolidinone (**2e**),[10] 3-[3-(acetoxy)-propenoyl]-2-oxazolidinone (**2f**),[12] and 2-acryloyl-1-benzyl-5,5-dimethyl-3-pyrazolidinone (**3a**)[13] were prepared according to the procedure reported in the literature. 2,6-Bis[(4*S*,5*S*)-4,5-diphenyl-2-oxazolin-2-yl]pyridine ((4*S*,5*S*)-Pybox-Ph_2)[14] and (*R*)-*N*,*N*′-Bis(2-quinolylmethylene)-1,1′-binaphthyl-2,2′-diamine ((*R*)-BINIM-2QN)[15] were prepared by the procedure reported previously. Powdered 4 Å molecular sieves (MS 4 Å) are commercially available (Aldrich) and dried in vacuo at 200 °C for 12 h before use. Lanthanide triflates and $Ni(ClO_4)_2{\cdot}6H_2O$ are commercially available and used without further purification. CH_2Cl_2 was purified by distillation first from $CaCl_2$ and then CaH_2 under argon before use.

General Procedure for the Asymmetric Cycloaddition Reactions Was Exemplified by the Reaction of *N*-Diazoacetyl-2-pyrrolidinone (1) with 3-Acryloyl-2-oxazolidinone (2a) Catalyzed by (4*S*,5*S*)-Pybox-Ph_2−Sm(III) complex. A solution of (4*S*,5*S*)-Pybox-Ph_2 (26.1 mg, 0.05 mmol) in THF (1.5 mL) was added to a solution of $Sm(OTf)_3$ (29.8 mg, 0.05 mmol) and *i*-PrOH (3.8 μL, 0.05 mmol) in THF (1 mL). After stirring the mixture for 2 h, the solvent was removed under reduced pressure, and resulting solid was dried in vacuo at room temperature for 5 h. 3-Acryloyl-2-oxazolidinone (**2a**) (141.1 mg, 1.0 mmol), MS 4 Å (0.5 g), $Rh_2(OAc)_4$ (4.4 mg, 0.01 mmol), and CH_2Cl_2 (4 mL) were successively added to the prepared Sm(III)−Pybox complex. After cooling the mixture to 10 °C, a solution of *N*-diazoacetyl-2-pyrrolidinone (**1**) (76.6 mg, 0.50 mmol) in CH_2Cl_2 (5 mL) was added over a period of 6 h using a syringe pump. The syringe was washed with CH_2Cl_2 (1 mL). After removal of MS 4 Å through Celite, the reaction mixture was filtered through a plug of silica gel (3 cm) with AcOEt (80 mL) as an eluent. The solvent was removed in vacuo, and the residue was purified by silica gel column chromatography (12 g) with $CHCl_3$ to provide 133.1 mg (quant) of *exo*-**4a** and *endo*-**4a** (*exo*-**4a**:*endo*-**4a** = 92:8, ^{1}H NMR analysis). The enantiomeric excess of *exo*-**4a** was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH (10:1 vol/vol), detector: UV 225 nm, Flow rate = 0.5 mL/min, 35 °C) after conversion to the corresponding *p*-bromobenzyl ester. t_{major} = 70.0 min, t_{minor} = 93.5 min.

Cycloadducts *exo*-**4b** and *endo*-**4b** (140.1 mg, quant. *exo*-**4b**:*endo*-**4b** = 75:25, ^{1}H NMR analysis) were synthesized according to the general procedure. Cycloadducts *exo*-**4b** (98.1 mg, 70%) and *endo*-**4b** (23.9 mg, 17%) could be separated from the mixture of *exo*-**4b** and *endo*-**4b** by careful column chromatography.

Cycloadducts *exo*-**4c** (79.2 mg, 54%) and *endo*-**4c** (44.6 mg, 30%) were synthesized according to the general procedure (total yield; 84%). *exo*/*endo* ratio (*exo*-**4c**:*endo*-**4c** = 64:36) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**4d** (69.2 mg, 45%) and *endo*-**4d** (44.6 mg, 20%) were synthesized according to the general procedure (total yield; 65%). *exo*/*endo* ratio (*exo*-**4d**:*endo*-**4d** = 77:23) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**4e** (62.4 mg, 41%) and *endo*-**4e** (5.2 mg, 3%) were synthesized according to the general procedure (total yield; 44%). *exo*/*endo* ratio (*exo*-**4e**:*endo*-**4e** = 95:5) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**4f** and *endo*-**4f** (97.3 mg, 60%, *exo*-**4f**:*endo*-**4f** = 99:1, ^{1}H NMR analysis) were synthesized according to the general procedure. Cycloadduct *exo*-**4f** (89.1 mg, 55%) could be separated from the mixture of *exo*-**4f** and *endo*-**4f** by careful column chromatography.

Cycloadducts *exo*-**9a** (60.8 mg, 44%) and *endo*-**9a** (16.3 mg, 11%) were synthesized according to the general procedure (total yield; 55%). *exo*/*endo* ratio (*exo*-**9a**:*endo*-**9a** = 79:21) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**9b** (97.6 mg, 66%) and *endo*-**9b** (17.3 mg, 12%) were synthesized according to the general procedure (total yield; 78%). *exo*/*endo* ratio (*exo*-**9b**:*endo*-**9b** = 85:15) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**9c** (91.3 mg, 59%) and *endo*-**9c** (13.7 mg, 9%) were synthesized according to the general procedure (total yield; 68%). *exo*/*endo* ratio (*exo*-**9c**:*endo*-**9c** = 87:13) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**9d** (87.2 mg, 54%) and *endo*-**9d** (13.0 mg, 8%) were synthesized according to the general procedure (total yield; 62%). *exo*/*endo* ratio (*exo*-**9d**:*endo*-**9d** = 87:13) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**9f** and *endo*-**9f** (91.4 mg, 54%. *exo*-**9f**:*endo*-**9f** = 87:13, ^{1}H NMR analysis) were synthesized according to the general procedure. Cycloadduct *exo*-**9f** (74.5 mg, 45%) could be separated from the mixture of *exo*-**9f** and *endo*-**9f** by careful column chromatography.

Cycloadducts *exo*-**10a** (72.4 mg, 49%) and *endo*-**10a** (5.9 mg, 4%) were synthesized according to the general procedure (total yield; 53%). *exo*/*endo* ratio (*exo*-**10a**:*endo*-**10a** = 93:7) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**10b** (109.0 mg, 71%) and *endo*-**10b** (8.3 mg, 5%) were synthesized according to the general procedure (total yield; 76%). *exo*/*endo* ratio (*exo*-**10b**:*endo*-**10b** = 93:7) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**10c** (109.9 mg, 68%) and *endo*-**10c** (10.8 mg, 7%) were synthesized according to the general procedure (total yield; 75%). *exo*/*endo* ratio (*exo*-**10c**:*endo*-**10c** = 91:9) was determined by ^{1}H NMR analysis.

Cycloadducts *exo*-**10d** (89.5 mg, 53%) and *endo*-**10d** (18.1 mg, 11%) were synthesized according to the general procedure (total yield; 64%). *exo*/*endo* ratio (*exo*-**10d**:*endo*-**10d** = 83:17) was determined by ^{1}H NMR analysis.

*9-exo- and 9-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4a** and endo-**4a**).* R_f = 0.42 (EtOAc). Colorless amorphous: $[\alpha]_D^{25}$ +73.49 (*c* 1.00, $CHCl_3$) (*exo*:*endo* = 92:8, 87% ee (*exo*)); IR (KBr) 2978, 1774, 1728, 1701 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) *exo*-**4a** δ 2.02−2.18 (3H × 92/100, m), 2.33 (1H × 92/100, ddd, *J* = 4.1, 5.6, 12.6 Hz), 2.40−2.54 (2H × 92/100, m), 3.09 (1H × 92/100, m), 3.66 (1H × 92/100, m), 4.00−4.11 (2H × 92/100, m), 4.25 (1H × 92/100, dd, *J* = 4.1, 8.5 Hz), 4.41−4.50 (2H × 92/100, m), 4.61 (1H × 92/100, d, *J* = 5.6 Hz); *endo*-**4a** δ 2.01−2.19 (3H × 2/100, m), 2.20−2.27 (2H × 2/100, m), 2.84 (1H × 2/100, ddd, *J* = 5.8, 10.9, 12.6 Hz), 3.23 (1H × 2/100, ddd, *J* = 7.6, 9.0, 11.2 Hz), 3.71 (1H × 2/100, m), 3.96−4.05 (2H 2/100, m), 4.09 (1H × 2/100, dd, *J* = 5.4, 10.9 Hz), 4.40−4.50 (2H × 2/100, m), 4.59 (1H × 2/100, d, *J* = 5.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) *exo*-**4a** δ 26.4 (CH_2), 28.0 (CH_2), 31.1 (CH_2), 42.5 (CH_2), 42.7 (CH_2), 48.2 (CH), 62.2 (CH_2), 79.4 (CH), 104.8 (C), 153.1 (C), 171.0 (C), 176.0 (C); *endo*-**4a** δ 26.5 (CH_2), 27.9 (CH_2), 30.8 (CH_2), 42.6 (CH_2), 43.0 (CH_2), 47.7 (CH), 62.3 (CH_2), 80.3 (CH), 104.4 (C), 152.8 (C), 170.6 (C), 175.6 (C); MS (EI) *m*/*z* 266 (M^+), 248, 223, 179, 161, 151, 123, 121, 108; HRMS (EI) Calcd for $C_{12}H_{14}N_2O_5$ (M^+) 266.0903, found 266.0899.

*8-endo-Methyl-9-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4b**).* R_f = 0.34 (EtOAc). Colorless prisms: mp 179.0−181.0 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −4.20 (*c* 0.20, $CHCl_3$, *exo*:*endo* = 75:25, 95% ee (*exo*)); IR (KBr) 3020, 1778, 1732, 1701, 1386 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.24 (3H, d, *J* = 7.1 Hz), 1.96−2.16 (3H, m), 2.24 (1H, m), 2.92 (1H, ddq, *J* = 3.9, 5.6, 7.1 Hz), 3.15 (1H, m), 3.69 (1H, m), 4.05−4.12 (2H, m), 4.11 (1H, d, *J* = 3.9 Hz), 4.43−4.50 (2H, m), 4.49 (1H, d, *J* = 5.6 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.4 (CH_3), 26.2 (CH_2), 28.0 (CH_2), 39.1 (CH), 42.9 (CH_2), 43.1 (CH_2), 54.3 (CH), 62.0 (CH_2), 83.8 (CH), 105.7 (C), 153.4 (C), 171.2 (C), 175.4 (C); MS (EI) *m*/*z* 280 (M^+), 262, 223, 193, 176, 166, 136, 125, 110, 94, 81, 70, 53, 37, 24, 13; HRMS (EI) Calcd for $C_{13}H_{16}N_2O_5$ (M^+) 280.1059, found 280.1074. Anal. Calcd for $C_{13}H_{16}N_2O_5$: C, 55.71; H, 5.75; N, 9.99%. Found: C, 56.04; H, 5.79; N, 9.63%.

*8-exo-Methyl-9-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**4b**).* R_f = 0.27 (EtOAc). Colorless oil: IR (KBr) 3020, 1780, 1716, 1653 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29 (3H, d, *J* = 7.1 Hz), 1.91−2.18 (3H, m), 2.31 (1H, m), 2.80 (1H, dq, *J* = 4.6, 7.1 Hz), 2.96 (1H, m), 3.65 (1H, ddd, *J*

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= 3.4, 7.6, 11.7 Hz), 3.97−4.12 (2H, m), 4.22 (1H, s), 4.25 (1H, d, J = 4.6 Hz), 4.45 (2H, t, J = 8.1 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.4 (CH_3), 26.2 (CH_2), 28.2 (CH_2), 39.3 (CH), 42.6 (CH_2), 43.1 (CH_2), 54.2 (CH), 61.9 (CH_2), 87.1 (CH), 105.9 (C), 153.2 (C), 169.7 (C), 174.8 (C); MS (EI) m/z 280 (M^+), 262, 223, 193, 176, 166, 136, 125, 108, 87, 67, 41, 24; HRMS (EI) Calcd for $C_{13}H_{16}N_2O_5$ (M^+) 280.1059, found 280.1038.

*8-endo-Ethyl-9-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4c**).* R_f = 0.45 (EtOAc). Colorless prisms: mp 145.0−147.0 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −6.26 (c 0.60, $CHCl_3$, 92% ee); IR (KBr) 2973, 1771, 1385, 1290, 1224, 1119, 1044, 959 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.98 (3H, t, J = 7.3 Hz), 1.46−1.72 (2H, m), 1.95−2.24 (4H, m), 2.85 (1H, m), 3.15 (1H, m), 3.68 (1H, m), 4.05−4.14 (2H, m), 4.18 (1H, d, J = 4.1 Hz), 4.47 (2H, t, J = 8.3 Hz), 4.59 (1H, d, J = 5.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$), δ 12.7 (CH_3), 24.2 (CH_2), 26.2 (CH_2), 27.7 (CH_2), 42.8 (CH_2), 43.1 (CH_2), 46.4 (CH), 52.8 (CH), 62.0 (CH_2), 82.9 (CH), 105.6 (C), 153.4 (C), 171.1 (C), 175.2 (C); MS (EI) m/z 294 (M^+), 265, 223, 207, 196, 178, 152, 136, 125, 110, 95, 81, 67, 52, 41, 28; HRMS (EI) Calcd for $C_{14}H_{18}N_2O_5$ (M^+) 294.1216, found 294.1216. Anal. Calcd for $C_{14}H_{18}N_2O_5$: C, 57.13; H, 6.16; N, 9.52%. Found: C, 57.33; H, 6.20; N, 9.29%.

*8-exo-Ethyl-9-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**4c**).* R_f = 0.34 (EtOAc). Colorless amorphous: IR (neat) 2962, 1728, 1387, 1222, 1041, 940 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$), δ 0.95 (3H, t, J = 7.6 Hz), 1.57−1.70 (2H, m), 1.93 (1H, m), 1.99−2.20 (2H, m), 2.31 (1H, m), 2.65 (1H, dt, J = 4.6, 7.6 Hz), 2.92 (1H, m), 3.64 (1H, m), 3.96−4.15 (2H, m), 4.34 (1H, s), 4.34 (1H, d, J = 4.6 Hz), 4.46 (2H, t, J = 7.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.4 (CH_3), 26.2 (CH_2), 26.6 (CH_2), 28.2 (CH_2), 42.6 (CH_2), 43.2 (CH_2), 46.5 (CH), 52.5 (CH), 61.9 (CH_2), 85.0 (CH), 105.6 (C), 153.3 (C), 169.7 (C), 175.1 (C); MS (EI) m/z 294 (M^+), 266, 224, 208, 178, 150, 136, 125, 110, 95, 81, 67, 53, 41, 28; HRMS (EI) Calcd for $C_{14}H_{18}N_2O_5$ (M^+) 294.1216, found 294.1200.

*9-exo-[(2-Oxo-3-oxazolidinyl)carbonyl]-8-endo-propyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4d**).* R_f = 0.46 (EtOAc). Colorless prisms: mp 154.5−156.0 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −19.13 (c 1.15, $CHCl_3$, 92% ee); IR (KBr) 2958, 1768, 1394, 1208, 1116, 1037, 958 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.91 (3H, t, J = 7.3 Hz), 1.28−1.46 (2H, m), 1.48−1.60 (2H, m), 1.96−2.22 (4H, m), 2.93 (1H, m), 3.16 (1H, m), 3.68 (1H, m), 4.06−4.14 (2H, m), 4.18 (1H, d, J = 4.1 Hz), 4.47 (2H, t, J = 8.5 Hz), 4.57 (1H, d, J = 5.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1 (CH_3), 21.6 (CH_2), 26.3 (CH_2), 27.8 (CH_2), 33.1 (CH_2), 42.9 (CH_2), 43.2 (CH_2), 44.5 (CH), 53.1 (CH), 62.0 (CH_2), 83.1 (CH), 105.6 (C), 153.4 (C), 171.3 (C), 175.3 (C); MS (EI) m/z 308 (M^+), 265, 223, 209, 196, 178, 165, 151, 138, 125, 110, 94, 81, 69, 52, 41, 28; HRMS (EI) Calcd for $C_{15}H_{20}N_2O_5$ (M^+) 308.1372, found 308.1377. Anal. Calcd for $C_{15}H_{20}N_2O_5$: C, 58.43; H, 6.54; N, 9.09%. Found: C, 58.56; H, 6.56; N, 8.93%.

*9-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-8-exo-propyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**4d**).* R_f = 0.39 (EtOAc). Colorless oil: IR (neat) 2958, 1769, 1385, 1041, 942 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.91 (3H, t, J = 7.1 Hz), 1.27−1.39 (2H, m), 1.48−1.67 (2H, m), 1.91 (1H, m), 1.98−2.19 (2H, m), 2.31 (1H, m), 2.74 (1H, dt, J = 4.6, 7.8 Hz), 2.91 (1H, m), 3.64 (1H, m), 3.96−4.15 (2H, m), 4.32 (1H, s), 4.34 (1H, d, J = 4.4 Hz), 4.46 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.0 (CH_3), 21.0 (CH_2), 26.2 (CH_2), 28.2 (CH_2), 35.8 (CH_2), 42.6 (CH_2), 43.2 (CH_2), 44.5 (CH), 52.7 (CH), 61.9 (CH_2), 85.3 (CH), 105.6 (C), 153.3 (C), 169.6 (C), 175.1 (C); MS (EI) m/z 308 (M^+), 265, 223, 194, 178, 165, 149, 138, 125, 109, 94, 81, 67, 55, 41, 27; HRMS (EI) Calcd for $C_{15}H_{20}N_2O_5$ (M^+) 308.1372, found 308.1360.

*8-endo-Isopropyl-9-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4e**).* R_f = 0.49 (EtOAc). Colorless prisms: mp 146.5−147.0 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −30.58 (c 0.93, $CHCl_3$, 93% ee); IR (KBr) 2980, 1731, 1396, 1222, 1113, 1046, 1012, 968 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.93 (3H, d, J = 6.6 Hz), 1.04 (3H, d, J = 6.6 Hz), 1.59 (1H, m), 1.95−2.21 (4H, m), 2.71 (1H, ddd, J = 4.2, 5.4, 9.8 Hz), 3.18 (1H, m), 3.67 (1H, m), 4.04−4.19 (2H, m), 4.31 (1H, d, J = 4.2 Hz), 4.48 (2H, t, J = 8.1 Hz), 4.62 (1H, d, J = 5.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.9 (CH_3), 22.3 (CH_3), 26.3 (CH_2), 27.6 (CH_2), 30.8 (CH), 42.9 (CH_2), 43.2 (CH_2), 52.3 (CH), 52.6 (CH), 62.0 (CH_2), 82.8 (CH), 105.7 (C), 153.5 (C), 171.2 (C), 175.1 (C); MS (EI) m/z 308 (M^+), 265, 223, 209, 196, 178, 166, 151, 138, 125, 110, 95, 81, 67, 52, 41, 27, 15; HRMS (ESI-TOF) Calcd for $C_{15}H_{20}N_2O_5Na$ [(M + Na)$^+$] 331.1264, found 331.1261.

*8-exo-Isopropyl-9-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**4e**).* R_f = 0.39 (EtOAc). Colorless oil: IR (neat) 2979, 1781, 1721, 1387, 1205, 943 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.91 (3H, d, J = 6.8 Hz), 0.99 (3H, d, J = 6.8 Hz), 1.76 (1H, m), 1.91 (1H, m), 1.96−2.12 (2H, m), 2.31 (1H, m), 2.52 (1H, dd, J = 5.1, 9.0 Hz), 2.89 (1H, ddd, J = 6.6, 8.8, 11.2 Hz), 3.63 (1H, ddd, J = 2.9, 7.6, 11.2 Hz), 4.08−4.16 (2H, m), 4.44 (1H, s), 4.39−4.55 (3H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.6 (CH_3), 21.0 (CH_3), 26.2 (CH_2), 28.2 (CH_2), 30.7 (CH), 42.7 (CH_2), 43.2 (CH_2), 50.7 (CH), 52.0 (CH), 61.9 (CH_2), 83.7 (CH), 105.5 (C), 153.3 (C), 169.7 (C), 175.5 (C); MS (EI) m/z 308 (M^+), 265, 223, 178, 166, 150, 138, 126, 109, 95, 81, 69, 56, 42, 27; HRMS (EI) Calcd for $C_{15}H_{20}N_2O_5$ (M^+) 308.1372, found 308.1407.

*8-endo-Acetoxy-9-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**4f**).* R_f = 0.40 (EtOAc). Colorless solid: $[\alpha]_D^{25}$ −5.89 (c 0.50, $CHCl_3$, 81% ee); IR (KBr) 2965, 1739, 1392, 1294, 1235, 1132, 1044, 971 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.01−2.29 (4H, m), 2.09 (3H, s), 3.22 (1H, m), 3.74 (1H, m), 4.04−4.22 (2H, m), 4.42 (1H, d, J = 2.4 Hz), 4.48 (2H, t, J = 7.8 Hz), 4.74 (1H, d, J = 5.4 Hz), 5.55 (1H, dd, J = 2.4, 5.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.7 (CH_3), 26.1 (CH_2), 27.7 (CH_2), 42.9 (CH_2), 43.2 (CH_2), 54.2 (CH), 62.2 (CH_2), 73.5 (CH), 80.1 (CH), 105.7 (C), 153.4 (C), 168.9 (C), 170.4 (C), 173.0 (C); HRMS (EI) Calcd for $C_{14}H_{16}N_2O_7$ (M^+) 324.0958, found 324.0948. The enantiomeric excess of *exo*-**4f** was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH, 4:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 60.2 min, t_{minor} = 66.8 min.

*8-exo-Acetoxy-9-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**4f**).* Although *endo*-**4f** could not be separated by chromatography from a mixture with major *exo*-**4f**, it could be characterized by ^{1}H NMR: R_f = 0.35 (EtOAc); ^{1}H NMR ($CDCl_3$) δ 1.95−2.27 (4H, m), 2.09 (3H, s), 3.01 (1H, m), 3.75 (1H, m), 3.99−4.22 (2H, m), 4.40−4.52 (2H, m), 4.58 (1H, d, J = 3.2 Hz), 4.74 (1H, s), 5.35 (1H, d, J = 3.2 Hz).

*10-exo-[(2-Oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo-[6.2.1.0^{1,6}]undecan-7-one (exo-**9a**).* R_f = 0.37 (EtOAc). Colorless prisms: mp 121−123 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −5.89 (c 0.50, $CHCl_3$, 87% ee); IR (KBr) 2957, 1773, 1712, 1383, 1257, 1039 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.50−1.56 (2H, m), 1.82−1.88 (2H, m), 1.97 (1H, m), 2.06 (1H, m), 2.13 (1H, dd, J = 12.3, 8.5 Hz), 2.38 (1H, dt, J = 12.3, 5.2 Hz), 2.79 (1H, m), 3.81 (1H, m), 4.04−4.14 (2H, m), 4.46 (2H, t, J = 8.2 Hz), 4.59 (1H, dd, J = 5.2, 8.5 Hz), 4.69 (1H, d, J = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.1 (CH_2), 23.4 (CH_2), 27.1 (CH_2), 32.7 (CH_2), 38.1 (CH_2), 43.0 (CH_2), 44.0 (CH), 61.9 (CH_2), 77.4 (CH), 96.8 (C), 153.5 (C), 171.8 (C), 173.4 (C); MS (EI) m/z 280 (M^+), 252, 237, 208, 194, 181, 164, 139, 110, 95, 82; HRMS (ESI-TOF) Calcd for $C_{13}H_{16}N_2O_5Na$ [(M + Na)$^+$] 303.0951, found 303.0950.

*10-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo-[6.2.1.0^{1,6}]undecan-7-one (endo-**9a**).* R_f = 0.29 (EtOAc). Colorless prisms: mp 151−153 °C (EtOAc−Hexane); IR (KBr) 2959, 1773, 1709, 1378, 1254, 1185, 1037 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.27 (1H, m), 1.53 (1H, m), 1.77 (1H, m), 1.90 (1H, m), 2.00 (1H, dt, J = 4.6, 13.6 Hz), 2.05 (1H, dd, J = 4.7, 12.3 Hz), 2.48 (1H, m), 2.53 (1H, ddd, J = 5.7, 9.9, 12.3 Hz), 2.86 (1H, m), 3.80 (1H, m), 3.98−4.10 (2H, m), 4.40 (1H, dd, J = 4.7, 9.9 Hz), 4.42−4.49 (2H, m), 4.61 (1H, d, J = 5.7 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.3 (CH_2), 22.9 (CH_2), 29.0 (CH_2), 32.1 (CH_2), 39.3 (CH_2), 42.9 (CH_2), 48.9 (CH), 62.0 (CH_2), 78.4 (CH), 95.7 (C), 153.3 (C), 171.3 (C), 172.8 (C); MS (EI) m/z 280 (M^+), 280, 252, 208, 194, 181, 139, 110, 95, 82;

HRMS (ESI-TOF) Calcd for $C_{13}H_{16}N_2O_5Na$ [(M + Na)$^+$] 303.0951, found 303.0953.

*9-endo-Methyl-10-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (exo-**9b**).* R_f = 0.40 (EtOAc). Colorless prisms: mp 148−150 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −9.05 (*c* 0.50, 87% ee); IR (KBr) 2963, 1764, 1715, 1409, 1379, 1292, 1020 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.13 (3H, d, *J* = 7.3 Hz), 1.44−1.56 (2H, m), 1.82−1.95 (4H, m), 2.84 (1H, m), 2.91 (1H, ddq, *J* = 4.7, 5.2, 7.3 Hz), 3.85 (1H, ddd, *J* = 1.7, 3.2, 13.7 Hz), 4.05−4.16 (2H, m), 4.29 (1H, d, *J* = 4.7 Hz), 4.46 (2H, t, *J* = 8.2 Hz), 4.52 (1H, d, *J* = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.4 (CH_3), 20.0 (CH_2), 23.5 (CH_2), 27.5 (CH_2), 37.7 (CH_2), 41.5 (CH), 43.1 (CH_2), 51.6 (CH), 61.9 (CH_2), 81.3 (CH), 97.1 (C), 153.6 (C), 171.9 (C), 172.1 (C); MS (EI) *m*/*z* 294 (M$^+$), 243, 208, 192, 178, 139, 124, 109, 83, 69; HRMS (ESI-TOF) Calcd for $C_{14}H_{18}N_2O_5Na$ [(M + Na)$^+$] 317.1108, found 317.1122.

*9-exo-Methyl-10-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (endo-**9b**).* R_f = 0.31 (EtOAc). Colorless prisms: mp 152−154 °C (EtOAc−Hexane); IR (KBr) 2963, 1778, 1716, 1690, 1410, 1379, 1189, 1020 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.06 (1H, m), 1.26 (3H, d, *J* = 7.1 Hz), 1.48 (1H, m), 1.73 (1H, m), 1.91−1.99 (2H, m), 2.55 (1H, m), 2.61 (1H, dq, *J* = 4.3, 7.1 Hz), 2.71 (1H, dt, *J* = 4.3, 13.6 Hz), 3.80 (1H, ddd, *J* = 1.3, 5.5, 13.6 Hz), 3.99 (1H, ddd, *J* = 7.4, 8.4, 11.4 Hz), 4.12 (1H, ddd, *J* = 7.4, 8.4, 11.4 Hz), 4.16 (1H, d, *J* = 4.3 Hz), 4.23 (1H, s), 4.46 (2H, dd, *J* = 7.4, 8.4 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.1 (CH_3), 20.7 (CH_2), 23.0 (CH_2), 29.3 (CH_2), 39.6 (CH_2), 41.0 (CH), 43.1 (CH_2), 56.5 (CH), 61.9 (CH_2), 84.2 (CH), 96.9 (C), 153.4 (C), 171.0 (C), 172.8 (C); MS (EI) *m*/*z* 294 (M$^+$), 279, 243, 215, 167, 149, 139, 97, 69; HRMS (ESI-TOF) Calcd for $C_{14}H_{18}N_2O_5Na$ [(M + Na)$^+$] 317.1108, found 317.1125.

*9-endo-Ethyl-10-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (exo-**9c**).* R_f = 0.48 (EtOAc). Colorless prisms: mp 154−157 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −16.89 (*c* 0.50, $CHCl_3$, 86% ee); IR (KBr) 2963, 1767, 1716, 1693, 1381, 1220, 1043 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.95 (3H, t, *J* = 7.4 Hz), 1.38−1.53 (4H, m), 1.82−1.90 (4H, m), 2.76−2.86 (2H, m), 3.84 (1H, m), 4.06−4.17 (2H, m), 4.33 (1H, d, *J* = 4.7 Hz), 4.46 (2H, t, *J* = 8.2 Hz), 4.61 (1H, d, *J* = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.9 (CH_3), 20.0 (CH_2), 23.3 (CH_2), 23.5 (CH_2), 27.6 (CH_2), 37.6 (CH_2), 43.1 (CH_2), 49.4 (CH), 50.4 (CH), 61.9 (CH_2), 80.4 (CH), 97.0 (C), 153.6 (C), 172.0 (C), 172.1 (C); MS (EI) *m*/*z* 308 (M$^+$), 279, 222, 192, 139, 82; HRMS (ESI-TOF) Calcd for $C_{15}H_{20}N_2O_5Na$ [(M + Na)$^+$] 331.1264, found 331.1263.

*9-exo-Ethyl-10-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (endo-**9c**).* R_f = 0.39 (EtOAc). Colorless prisms: mp 139−142 °C (EtOAc−Hexane); IR (KBr) 2952, 1777, 1712, 1688, 1457, 1410, 1359, 1186 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.94 (3H, t, *J* = 7.4 Hz), 1.06 (1H, m), 1.48 (1H, m), 1.54−1.74 (3H, m), 1.91−1.99 (2H, m), 2.43 (1H, dt, *J* = 4.4, 7.6 Hz), 2.54 (1H, m), 2.71 (1H, dt, *J* = 4.1, 12.9 Hz), 3.81 (1H, m), 4.00 (1H, dt, *J* = 8.0, 11.4 Hz), 4.12 (1H, dt, *J* = 8.0, 11.4 Hz), 4.23 (1H, d, *J* = 4.4 Hz), 4.33 (1H, s), 4.46 (2H, t, *J* = 8.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 2.3 (CH_3), 20.8 (CH_2), 23.0 (CH_2), 26.5 (CH_2), 29.3 (CH_2), 39.7 (CH_2), 43.1 (CH_2), 48.5 (CH), 54.8 (CH), 61.9 (CH_2), 82.3 (CH), 96.5 (C), 153.4 (C), 171.2 (C), 172.9 (C); MS (EI) *m*/*z* 308 (M$^+$), 279, 222, 192, 139, 123, 82; HRMS (ESI-TOF) Calcd for $C_{15}H_{20}N_2O_5Na$ [(M + Na)$^+$] 331.1264, found 331.1271.

*10-exo-[(2-Oxo-3-oxazolidinyl)carbonyl]-9-endo-propyl-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (exo-**9d**).* R_f = 0.50 (EtOAc). Colorless prisms: mp 130−132 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −20.31 (*c* 0.50, $CHCl_3$, 84% ee); IR (KBr) 2934, 1772, 1723, 1687, 1420, 1389, 1225, 1040 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.89 (3H, t, *J* = 7.1 Hz), 1.28−1.53 (6H, m), 1.81−1.90 (4H, m), 2.81−2.88 (2H, m), 3.84 (1H, m), 4.05−4.16 (2H, m), 4.33 (1H, d, *J* = 4.9 Hz), 4.46 (2H, t, *J* = 8.0 Hz), 4.59 (1H, d, *J* = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.9 (CH_3), 20.0 (CH_2), 21.8 (CH_2), 23.5 (CH_2), 27.6 (CH_2), 32.2 (CH_2), 37.6 (CH_2), 43.1 (CH_2), 47.4 (CH), 50.6 (CH), 61.9 (CH_2), 80.5 (CH), 97.0 (C), 153.6 (C), 172.07 (C), 172.10 (C); MS (EI) *m*/*z* 322 (M$^+$), 279, 236, 206, 194, 139, 122, 82; HRMS (ESI-TOF) Calcd for $C_{16}H_{22}N_2O_5Na$ [(M + Na)$^+$] 345.1421, found 345.1437.

*10-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-9-exo-propyl-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (endo-**9d**).* R_f = 0.40 (EtOAc). Colorless prisms: mp 136−138 °C (EtOAc−Hexane); IR (KBr) 2958, 1776, 1718, 1413, 1386, 1216, 1028 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.90 (3H, t, *J* = 7.3 Hz), 1.05 (1H, m), 1.31 (2H, sext, *J* = 7.3 Hz), 1.43−1.62 (3H, m), 1.72 (1H, m), 1.91−1.98 (2H, m), 2.49−2.56 (2H, m), 2.70 (1H, dt, *J* = 4.3, 13.1 Hz), 3.80 (1H, m), 4.00 (1H, dt, *J* = 11.9, 8.0 Hz), 4.11 (1H, dt, *J* = 11.9, 8.0 Hz), 4.22 (1H, d, *J* = 4.3 Hz), 4.31 (1H, s), 4.46 (2H, t, *J* = 8.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.9 (CH_3), 20.8 (CH_2), 21.0 (CH_2), 23.0 (CH_2), 29.3 (CH_2), 35.6 (CH_2), 39.6 (CH_2), 43.1 (CH_2), 46.5 (CH), 55.0 (CH), 61.9 (CH_2), 82.6 (CH), 96.5 (C), 153.4 (C), 171.1 (C), 172.8 (C); MS (EI) *m*/*z* 322 (M$^+$), 279, 236, 206, 194, 139, 122, 95, 82; HRMS (ESI-TOF) Calcd for $C_{16}H_{22}N_2O_5Na$ [(M + Na)$^+$] 345.1421, found 345.1417.

*9-endo-Acetoxy-10-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (exo-**9f**).* R_f = 0.38 (EtOAc). Colorless prisms: mp 134−136 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −9.21 (*c* 0.50, $CHCl_3$, 78% ee); IR (KBr) 2966, 1771, 1742, 1725, 1697, 1394, 1231, 1121, 1050, 968 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.51−1.56 (2H, m), 1.84−1.94 (4H, m), 2.07 (3H, s), 2.89 (1H, m), 3.91 (1H, m), 4.10 (1H, ddd, *J* = 7.4, 9.0, 11.2 Hz), 4.21 (1H, ddd, *J* = 6.9, 9.3, 11.2 Hz), 4.43−4.51 (2H, m), 4.55 (1H, d, *J* = 3.3 Hz), 4.76 (1H, d, *J* = 5.2 Hz), 5.32 (1H, dd, *J* = 3.3, 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.8 (CH_2), 20.5 (CH_3), 23.3 (CH_2), 27.7 (CH_2), 38.2 (CH_2), 43.0 (CH_2), 51.7 (CH), 62.0 (CH_2), 76.1 (CH), 77.2 (CH), 97.2 (C), 153.7 (C), 170.0 (C), 170.1 (C), 171.1 (C); MS (EI) *m*/*z* 338 (M$^+$), 264, 192, 139, 112, 83, 59; HRMS (ESI-TOF) Calcd for $C_{15}H_{18}N_2O_7Na$ [(M + Na)$^+$] 361.1006, found 361.1012. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH, 7:3 v/v, detector: UV 225 nm, Flow rate = 0.5 mL/min, 35 °C). t_{major} = 26.33 min, t_{minor} = 43.64 min.

*9-exo-Acetoxy-10-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (endo-**9f**).* Although *endo*-**9f** could not be separated by chromatography from a mixture with major *exo*-**9f**, it could be characterized by ^{1}H NMR: R_f = 0.33 (EtOAc); ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.50−1.57 (4H, m), 1.80−1.96 (2H, m), 2.09 (3H, s), 2.90 (1H, m), 3.93 (1H, m), 4.05−4.25 (2H, m), 4.42−4.50 (2H, m), 4.54 (1H, d, *J* = 2.9 Hz), 4.69 (1H, s), 5.05 (1H, d, *J* = 2.9 Hz).

*11-exo-[(2-Oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo-[7.2.1.0^{1,7}]dodecan-8-one (exo-**10a**).* R_f = 0.40 (EtOAc). Colorless prisms: mp 161−163 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −7.81 (*c* 0.50, $CHCl_3$, 85% ee); IR (KBr) 2954, 1769, 1712, 1698, 1417, 1389, 1258, 1191 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.29 (1H, m), 1.40 (1H, m), 1.65 (1H, m), 1.76−1.84 (2H, m), 1.92−2.04 (2H, m), 2.00 (1H, dd, *J* = 8.2, 12.1 Hz), 2.13 (1H, m), 2.56 (1H, ddd, *J* = 4.7, 5.5, 12.1 Hz), 2.83 (1H, m), 3.88 (1H, m), 4.03−4.13 (2H, m), 4.35 (1H, dd, *J* = 4.7, 8.2 Hz), 4.43−4.52 (2H, m), 4.74 (1H, d, *J* = 5.5 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.2 (CH_2), 30.1 (CH_2), 30.3 (CH_2), 30.8 (CH_2), 30.9 (CH_2), 38.7 (CH_2), 43.0 (CH_2), 48.1 (CH), 62.1 (CH_2), 77.9 (CH), 101.3 (C), 153.9 (C), 171.0 (C), 173.1 (C); MS (EI) *m*/*z* 294 (M$^+$), 208, 153, 124, 109, 96, 83; HRMS (ESI-TOF) Calcd for $C_{14}H_{18}N_2O_5Na$ [(M + Na)$^+$] 317.1108, found 317.1125.

*11-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo-[7.2.1.0^{1,7}]dodecan-8-one (endo-**10a**).* R_f = 0.31 (EtOAc). Colorless prisms: mp 136−139 °C (EtOAc−Hexane); IR (KBr) 2932, 1777, 1712, 1424, 1389, 1255, 1221, 1041 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.20−1.40 (2H, m), 1.67 (1H, m), 1.77−1.87 (2H, m), 1.92−2.04 (2H, m), 1.94 (1H, dd, *J* = 5.0, 12.3 Hz), 2.30 (1H, m), 2.63 (1H, ddd, *J* = 5.7, 10.4, 12.3 Hz), 2.76 (1H, ddd, *J* = 1.3, 12.3, 13.7 Hz), 3.98−4.04 (3H, m), 4.16 (1H, dd, *J* = 5.0, 10.4 Hz), 4.40−4.49 (2H, m), 4.65 (1H, d, *J* = 5.7 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.5 (CH_2), 30.3 (CH_2), 30.9 (CH_2), 31.4 (CH_2), 32.9 (CH_2), 40.9 (CH_2), 42.8 (CH_2), 49.9 (CH), 62.1 (CH_2), 78.2 (CH), 100.3 (C), 153.1 (C), 171.2 (C), 173.3 (C); MS (EI) *m*/*z* 294 (M$^+$), 208, 153, 139, 124, 109, 96, 83, 69; HRMS (ESI-TOF) Calcd for $C_{14}H_{18}N_2O_5Na$ [(M + Na)$^+$] 317.1108, found 317.1107.

*10-endo-Methyl-11-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (exo-**10b**).* R_f = 0.42 (EtOAc). Colorless prisms: mp 128−130 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −12.75 (*c* 0.50, 88% ee); IR (KBr) 2929, 1774, 1719, 1692, 1383, 1265, 1113 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.09 (3H, t, *J* = 7.1 Hz), 1.27 (1H, m), 1.41 (1H, m), 1.62 (1H, m), 1.73−1.84 (2H, m), 1.92 (1H, dd, *J* = 11.5, 15.1 Hz), 1.93 (1H, m), 2.05 (1H, dd, *J* = 7.4, 15.1 Hz), 2.87 (1H, t, *J* = 12.9 Hz), 3.08 (1H, m), 3.92 (1H, d, *J* = 4.7 Hz), 3.94 (1H, m), 4.04−4.15 (2H, m), 4.43−4.52 (2H, m), 4.57 (1H, d, *J* = 5.4 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.4 (CH_3), 23.0 (CH_2), 30.2 (CH_2), 30.4 (CH_2), 31.0 (CH_2), 38.6 (CH_2), 38.9 (CH), 43.1 (CH_2), 56.0 (CH), 62.1 (CH_2), 81.7 (CH), 101.5 (C), 153.9 (C), 171.1 (C), 172.8 (C); MS (EI) *m*/*z* 308 (M^+), 294, 208, 192, 153, 139, 124, 96, 83, 69; HRMS (ESI-TOF) Calcd for $C_{15}H_{20}N_2O_5Na$ $[(M + Na)^+]$ 331.1264, found 331.1281.

*10-exo-Methyl-11-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (endo-**10b**).* R_f = 0.32 (EtOAc). Colorless prisms: mp 148−151 °C (EtOAc−Hexane); IR (KBr) 2929, 1782, 1719, 1684, 1425, 1389, 1230 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.17 (1H, m), 1.24 (3H, d, *J* = 7.1 Hz), 1.35 (1H, m), 1.65 (1H, m), 1.73−1.86 (3H, m), 1.93 (1H, m), 2.25 (1H, m), 2.45 (1H, m), 2.56 (1H, dq, *J* = 4.1, 7.1 Hz), 3.97−4.02 (2H, m), 4.09 (1H, ddd, *J* = 7.6, 8.7, 11.4 Hz), 4.17 (1H, d, *J* = 4.1 Hz), 4.28 (1H, s), 4.44−4.47 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 19.1 (CH_3), 23.3 (CH_2), 30.3 (CH_2), 30.8 (CH_2), 33.4 (CH_2), 40.1 (CH), 40.6 (CH_2), 43.1 (CH_2), 56.5 (CH), 61.8 (CH_2), 84.3 (CH), 101.6 (C), 153.4 (C), 170.6 (C), 172.8 (C); MS (EI) *m*/*z* 308 (M^+), 294, 249, 208, 192, 153, 139, 124, 96, 81, 69; HRMS (ESI-TOF) Calcd for $C_{15}H_{20}N_2O_5Na$ $[(M + Na)^+]$ 331.1264, found 331.1257.

*10-endo-Ethyl-11-exo-[(2-oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (exo-**10c**).* R_f = 0.47 (EtOAc). Colorless prisms: mp 131−133 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −21.44 (*c* 0.50, $CHCl_3$, 87% ee); IR (KBr) 2928, 1774, 1719, 1691, 1421, 1383, 1265, 1113 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.93 (3H, t, *J* = 7.4 Hz), 1.23−1.53 (4H, m), 1.63 (1H, m), 1.72−1.84 (2H, m), 1.88−1.93 (2H, m), 2.04 (1H, m), 2.85 (1H, ddd, *J* = 1.4, 12.3, 14.2 Hz), 2.93 (1H, m), 3.92 (1H, m), 3.95 (1H, d, *J* = 4.9 Hz), 4.04−4.15 (2H, m), 4.42−4.52 (2H, m), 4.65 (1H, d, *J* = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.0 (CH_3), 23.0 (CH_2), 23.5 (CH_2), 30.2 (CH_2), 30.3 (CH_2), 31.0 (CH_2), 38.5 (CH_2), 43.1 (CH_2), 46.9 (CH), 54.6 (CH), 62.0 (CH_2), 80.8 (CH), 101.3 (C), 153.9 (C), 171.3 (C), 171.7 (C); MS (EI) *m*/*z* 322 (M^+), 293, 236, 206, 194, 153, 123, 109, 96, 83, 69; HRMS (ESI-TOF) Calcd for $C_{16}H_{22}N_2O_5Na$ $[(M + Na)^+]$ 345.1421, found 345.1419.

*10-exo-Ethyl-11-endo-[(2-oxo-3-oxazolidinyl)carbonyl]-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (endo-**10c**).* R_f = 0.35 (EtOAc). Colorless prisms: mp 147−149 °C (EtOAc−Hexane); IR (KBr) 2932, 1780, 1713, 1687, 1416, 1384, 1187 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.93 (3H, t, *J* = 7.3 Hz), 1.17 (1H, m), 1.35 (1H, m), 1.51−1.63 (3H, m), 1.73−1.85 (3H, m), 1.93 (1H, m), 2.20 (1H, m), 2.39 (1H, dt, *J* = 4.3, 7.6 Hz), 2.45 (1H, m), 3.97−4.03 (2H, m), 4.12 (1H, dt, *J* = 11.0, 8.4 Hz), 4.25 (1H, d, *J* = 4.3 Hz), 4.38 (1H, s), 4.45−4.48 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.5 (CH_3), 23.3 (CH_2), 26.4 (CH_2), 30.4 (CH_2), 30.8 (CH_2), 33.4 (CH_2), 40.6 (CH_2), 43.1 (CH_2), 47.5 (CH), 54.8 (CH), 61.8 (CH_2), 82.4 (CH), 101.3 (C), 153.4 (C), 170.7 (C), 172.8 (C); MS (EI) *m*/*z* 322 (M^+), 279, 236, 206, 169, 153, 96, 69; HRMS (ESI-TOF) Calcd for $C_{16}H_{22}N_2O_5Na$ $[(M + Na)^+]$ 345.1421, found 345.1430.

*11-exo-[(2-Oxo-3-oxazolidinyl)carbonyl]-10-endo-propyl-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (exo-**10d**).* R_f = 0.49 (EtOAc). Colorless prisms: mp 125−127 °C (EtOAc−Hexane); $[\alpha]_D^{25}$ −27.51 (*c* 0.50, $CHCl_3$, 84% ee); IR (KBr) 2933, 1773, 1722, 1686, 1422, 1388, 1226 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.89 (3H, t, *J* = 7.3 Hz), 1.24−1.49 (6H, m), 1.62 (1H, m), 1.70−1.84 (2H, m), 1.88−1.93 (2H, m), 2.04 (1H, m), 2.86 (1H, ddd, *J* = 1.4, 12.3, 14.2 Hz), 3.00 (1H, m), 3.92 (1H, m), 3.95 (1H, d, *J* = 4.9 Hz), 4.04−4.14 (2H, m), 4.43−4.52 (2H, m), 4.62 (1H, d, *J* = 5.2 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.9 (CH_3), 21.8 (CH_2), 23.0 (CH_2), 30.2 (CH_2), 30.4 (CH_2), 31.0 (CH_2), 32.3 (CH_2), 38.5 (CH_2), 43.1 (CH_2), 44.9 (CH), 54.8 (CH), 62.0 (CH_2), 81.0 (CH), 101.3 (C), 153.9 (C), 171.3 (C), 171.8 (C); MS (EI) *m*/*z* 336 (M^+), 293, 250, 208, 180, 153, 118, 83, 96, 69; HRMS (ESI-TOF) Calcd for $C_{17}H_{24}N_2O_5Na$ $[(M + Na)^+]$ 359.1577, found 359.1600.

*11-endo-[(2-Oxo-3-oxazolidinyl)carbonyl]-10-exo-propyl-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (endo-**10d**).* R_f = 0.37 (EtOAc). Colorless prisms: mp 146−148 °C (EtOAc−Hexane); IR (KBr) 2934, 1780, 1716, 1418, 1389, 1229, 1045 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.89 (3H, t, *J* = 7.3 Hz), 1.16 (1H, m), 1.28−1.40 (3H, m), 1.47−1.69 (3H, m), 1.73−1.85 (3H, m), 1.93 (1H, m), 2.19 (1H, ddd, *J* = 1.3, 12.3, 13.9 Hz), 2.43−2.49 (2H, m), 3.97−4.02 (2H, m), 4.09 (1H, m), 4.24 (1H, d, *J* = 4.3 Hz), 4.37 (1H, s), 4.46 (2H, t, *J* = 8.4 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.9 (CH_3), 21.0 (CH_2), 23.3 (CH_2), 30.3 (CH_2), 30.8 (CH_2), 33.4 (CH_2), 35.6 (CH_2), 40.6 (CH_2), 43.1 (CH_2), 45.6 (CH), 54.9 (CH), 61.8 (CH_2), 82.7 (CH), 101.3 (C), 153.4 (C), 170.6 (C), 172.8 (C); MS (EI) *m*/*z* 336 (M^+), 293, 250, 208, 180, 153, 96, 81, 69; HRMS (ESI-TOF) Calcd for $C_{17}H_{24}N_2O_5Na$ $[(M + Na)^+]$ 359.1577, found 359.1573.

General Procedure for the Conversion of Cycloadducts to the Corresponding *p*-Bromobenzyl Esters Was Exemplified by the Reaction of Cycloadduct *exo*-4a and *endo*-4a (*exo*-4a:*endo*-4a = 92:8). To a solution of *p*-bromobenzyl alcohol (168.3 mg, 0.90 mmol) in THF (4.0 mL) was added *n*-BuLi (1.6 mol/L in hexane, 0.42 mL, 0.68 mmol) at −78 °C, and then the mixture was stirred at −20 °C for 10 min. A solution of cycloadducts *exo*-**4a** and *endo*-**4a** (*exo*-**4a**:*endo*-**4a** = 91:9, 119.8 mg, 0.45 mmol) in THF (5 mL) was added to the mixture, and then stirring was continued at same temperature for 3 h. The reaction was quenched with saturated NH_4Cl solution (15 mL), and the mixture was extracted with CH_2Cl_2 (10 mL × 3). The combined CH_2Cl_2 extracts were dried over Na_2SO_4. After evaporation of the solvent under reduced pressure, the residue was chromatographed on silica gel with hexane−ethyl acetate (85:15 v/v) to give 112.1 mg (67.5%) of *exo*-*p*-bromobenzyl ester *exo*-**11** and 13.2 mg (7.5%) of *endo*-*p*-bromobenzyl ester.

Cycloadduct *exo*-**4b** (98.1 mg, 0.35 mmol) was converted to the corresponding *p*-bromobenzyl ester (73.2 mg, 55%) according to the general procedure.

Cycloadduct *exo*-**4c** (79.2 mg, 0.27 mmol) was converted to the corresponding *p*-bromobenzyl ester (70.9 mg, 67%) according to the general procedure.

Cycloadduct *exo*-**4d** (69.2 mg, 0.22 mmol) was converted to the corresponding *p*-bromobenzyl ester (45.8 mg, 51%) according to the general procedure.

Cycloadduct *exo*-**4e** (62.4 mg, 0.20 mmol) was converted to the corresponding *p*-bromobenzyl ester (31.4 mg, 38%) according to the general procedure.

Cycloadduct *exo*-**9a** (60.8 mg, 0.22 mmol) was converted to the corresponding *p*-bromobenzyl ester (51.8 mg, 62%) according to the general procedure.

Cycloadduct *exo*-**9b** (97.6 mg, 0.33 mmol) was converted to the corresponding *p*-bromobenzyl ester (84.6 mg, 65%) according to the general procedure.

Cycloadduct *exo*-**9c** (91.3 mg, 0.30 mmol) was converted to the corresponding *p*-bromobenzyl ester (83.2 mg, 68%) according to the general procedure.

Cycloadduct *exo*-**9d** (87.2 mg, 0.27 mmol) was converted to the corresponding *p*-bromobenzyl ester (68.5 mg, 60%) according to the general procedure.

Cycloadduct *exo*-**10a** (72.4 mg, 0.25 mmol) was converted to the corresponding *p*-bromobenzyl ester (60.2 mg, 61%) according to the general procedure.

Cycloadduct *exo*-**10b** (109.0 mg, 0.35 mmol) was converted to the corresponding *p*-bromobenzyl ester (95.7 mg, 67%) according to the general procedure.

Cycloadduct *exo*-**10c** (109.9 mg, 0.34 mmol) was converted to the corresponding *p*-bromobenzyl ester (100.8 mg, 70%) according to the general procedure.

Cycloadduct *exo*-**10d** (89.5 mg, 0.27 mmol) was converted to the corresponding *p*-bromobenzyl ester (74.1 mg, 63%) according to the general procedure.

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*9-exo-[(p-Bromobenzyloxy)carbonyl]-10-oxa-5-azatricyclo-[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from exo-**4a**, exo-**11**).* R_f = 0.40 (EtOAc). Colorless prisms: mp 118.0−120.0 °C (Benzene−Hexane); $[\alpha]_D^{25}$ +33.94 (*c* 1.00, $CHCl_3$, >99% ee); IR (KBr) 3018, 1732, 1653 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.03−2.21 (4H, m), 2.24 (1H, dd, *J* = 8.5, 12.9 Hz), 2.54 (1H, ddd, *J* = 3.9, 5.8, 12.9 Hz), 3.01 (1H, m), 3.07 (1H, dd, *J* = 3.9, 8.5 Hz), 3.65 (1H, m), 4.61 (1H, d, *J* = 5.8 Hz), 5.09 (1H, d, *J* = 12.5 Hz), 5.13 (1H, d, *J* = 12.5 Hz), 7.21−7.26 (2H, m), 7.48−7.52 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.4 (CH_2), 28.0 (CH_2), 29.3 (CH_2), 43.0 (CH_2), 49.0 (CH), 66.3 (CH_2), 79.3 (CH), 105.2 (C), 122.6 (C), 130.1 (CH), 131.8 (CH), 134.3 (C), 170.8 (C), 176.7 (C); MS (EI) *m*/*z* 367 [(M + 2)$^+$], 365 (M$^+$), 196, 171, 169, 153, 140, 125, 108, 96; HRMS (EI) Calcd for $C_{16}H_{16}BrNO_4$ (M$^+$) 365.0303, found 365.0263. Anal. Calcd for $C_{16}H_{16}BrNO_4$: C, 52.48; H, 4.40; N, 3.82%. Found: C, 52.42; H, 4.39; N, 3.89%. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 70.0 min, t_{minor} = 93.5 min.

*9-endo-[(p-Bromobenzyloxy)carbonyl]-10-oxa-5-azatricyclo-[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from endo-**4a**).* R_f = 0.62 (EtOAc). Colorless prisms: mp 118.3−119.8 °C (Hexane); IR (KBr) 3018, 2401, 1730, 1647 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.89−2.13 (2H, m), 2.18 (1H, ddd, *J* = 2.7, 8.0, 14.1 Hz), 2.35−2.53 (3H, m), 2.71 (1H, ddd, *J* = 6.7, 10.0, 11.3 Hz), 3.20 (1H, dd, *J* = 5.3, 9.5 Hz), 3.57 (1H, ddd, *J* = 2.2, 8.0, 11.3 Hz), 4.56 (1H, dd, *J* = 0.9, 4.9 Hz), 5.03 (1H, d, *J* = 12.2 Hz), 5.12 (1H, d, *J* = 12.2 Hz), 7.17−7.24 (2H, m), 7.44−7.55 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 26.3 (CH_2), 27.7 (CH_2), 28.9 (CH_2), 43.4 (CH_2), 48.1 (CH), 66.1 (CH_2), 80.4 (CH), 104.5 (C), 122.6 (C), 130.1 (CH), 131.8 (CH), 134.3 (C), 169.6 (C), 176.2 (C); MS (EI) *m*/*z* 367 [(M + 2)$^+$], 365 (M$^+$), 196, 171, 169, 153, 140, 125, 112, 108, 96. Anal. Calcd for $C_{16}H_{16}BrNO_4$: C, 52.48; H, 4.40; N, 3.82%. Found: C, 52.64; H, 4.38; N, 3.77%. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate =0.5 mL/min, 35 °C), t_{major} = 54.5 min, t_{minor} = 57.6 min.

*9-exo-[(p-Bromobenzyloxy)carbonyl]-8-endo-methyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from exo-**4b**).* R_f = 0.60 (EtOAc). Colorless oil: $[\alpha]_D^{25}$ +40.29 (*c* 0.50, $CHCl_3$, 95%ee); IR (neat) 3038, 2993, 2970, 2953, 1745, 1595, 1489, 1454 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.22 (3H, d, *J* = 7.0 Hz), 1.97−2.24 (4H, m), 2.59 (1H, d, *J* = 4.1 Hz), 2.90 (1H, ddq, *J* = 4.1, 5.6, 7.0 Hz), 3.04 (1H, m), 3.69 (1H, m), 4.44 (1H, d, *J* = 5.6 Hz), 5.10 (1H, d, *J* = 12.2 Hz), 5.13 (1H, d, *J* = 12.2 Hz), 7.24−7.27 (2H, m), 7.47−7.53 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 15.5 (CH_3), 26.1 (CH_2), 28.5 (CH_2), 38.0 (CH), 43.2 (CH_2), 56.6 (CH), 66.1 (CH_2), 83.5 (CH), 105.3 (C), 122.4 (C), 129.9 (CH), 131.7 (CH), 134.3 (C), 170.8 (C), 175.7 (C); MS (EI) *m*/*z* 381 [(M + 2)$^+$], 379 (M$^+$), 311, 192, 172, 170, 167, 149, 131; HRMS (EI) Calcd for $C_{17}H_{18}BrNO_4$ (M$^+$) 379.0419, found 379.0443. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 55.5 min, t_{minor} = 80.7 min.

*9-exo-[(p-Bromobenzyloxy)carbonyl]-8-endo-ethyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from exo-**4c**).* R_f = 0.66 (EtOAc). Colorless oil: $[\alpha]_D^{25}$ +35.01 (*c* 1.23, $CHCl_3$, 92% ee); IR (neat) 2963, 1731, 1595, 1489, 1380, 1092, 1011 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.01 (3H, t, *J* = 7.3 Hz), 1.56 (2H, quint, *J* = 7.3 Hz), 1.96−2.25 (4H, m), 2.63 (1H, d, *J* = 4.2 Hz), 2.73 (1H, m), 3.03 (1H, m), 3.69 (1H, m), 4.52 (1H, d, *J* = 5.4 Hz), 5.11 (1H, d, *J* = 12.2 Hz), 5.14 (1H, d, *J* = 12.2 Hz), 7.21−7.26 (2H, m), 7.48−7.53 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.7 (CH_3), 24.4 (CH_2), 26.1 (CH_2), 28.4(CH_2), 43.2 (CH_2), 45.6 (CH), 55.1 (CH), 66.0 (CH_2), 82.6 (CH), 105.0 (C), 122.3 (C), 129.8 (CH), 131.6 (CH), 134.2 (C), 170.9 (C), 175.6 (C); MS (EI) *m*/*z* 395 [(M + 2)$^+$], 393 (M$^+$), 310, 295, 225, 206, 197, 181, 169, 152, 136, 125, 112, 90, 79, 67, 55, 41, 28, 15. Anal. Calcd for $C_{18}H_{20}BrNO_4$: C, 54.84; H, 5.11; N, 3.55%. Found: C, 54.91; H, 5.11; N, 3.48%. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 39.2 min, t_{minor} = 46.4 min.

*9-exo-[(p-Bromobenzyloxy)carbonyl]-8-endo-propyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from exo-**4d**).* R_f = 0.67 (EtOAc). Colorless oil: $[\alpha]_D^{25}$ + 29.89 (*c* 0.78, $CHCl_3$, 92%ee); IR (neat) 2957, 1731, 1489, 1382, 1012 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.90 (3H, t, *J* = 7.1 Hz), 1.34−1.56 (4H, m), 1.95−2.24 (4H, m), 2.62 (1H, d, *J* = 3.9 Hz), 2.81 (1H, m), 3.03 (1H, m), 3.69 (1H, m), 4.50 (1H, d, *J* = 5.4 Hz), 5.11 (1H, d, *J* = 12.2 Hz), 5.14 (1H, d, *J* = 12.2 Hz), 7.21−7.26 (2H, m), 7.47−7.54 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.1 (CH_3), 21.4 (CH_2), 26.1 (CH_2), 28.4 (CH_2), 33.3 (CH_2), 43.2 (CH_2), 43.6 (CH), 55.3 (CH), 66.1 (CH_2), 82.7 (CH), 105.0 (C), 122.4 (C), 130.0 (CH), 131.6 (CH), 134.2 (C), 170.9 (C), 175.7 (C); MS (EI) *m*/*z* 409 [(M + 2)$^+$], 407 (M$^+$), 238, 169, 150, 138, 125, 112, 90, 69, 52, 41, 28. Anal. Calcd for $C_{19}H_{22}BrNO_4$: C, 55.89; H, 5.43; N, 3.43%. Found: C, 55.78; H, 5.48; N, 3.50%. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 31.0 min, t_{minor} = 40.3 min.

*9-exo-[(p-Bromobenzyloxy)carbonyl]-8-endo-isopropyl-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (p-Bromobenzyl Ester Derived from exo-**4e**).* R_f = 0.70 (EtOAc). Colorless oil: $[\alpha]_D^{25}$ +32.32 (*c* 0.42, $CHCl_3$, 93% ee); IR (neat) 2960, 1732, 1595, 1489, 1381 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 0.99 (3H, d, *J* = 6.6 Hz), 1.04 (3H, d, *J* = 6.6 Hz), 1.52 (1H, m), 1.95−2.22 (4H, m), 2.49 (1H, ddd, *J* = 4.2, 5.4, 9.8 Hz), 2.69 (1H, d, *J* = 4.2 Hz), 3.03 (1H, m), 3.69 (1H, m), 4.55 (1H, d, *J* = 5.4 Hz), 5.11 (1H, d, *J* = 12.5 Hz), 5.14 (1H, d, *J* = 12.5 Hz), 7.20−7.26 (2H, m), 7.46−7.57 (2H, m); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.0 (CH_3), 22.3 (CH_3), 26.1 (CH_2), 28.4 (CH_2), 31.1 (CH), 43.2 (CH_2), 52.0 (CH), 54.8 (CH), 66.2 (CH_2), 82.5 (CH), 105.1 (C), 122.4 (C), 129.9 (CH), 131.6 (CH), 134.3 (C), 171.0 (C), 175.6 (C); MS (EI) *m*/*z* 409 [(M + 2)$^+$], 407 (M$^+$), 365, 307, 238, 220, 194, 180, 169, 150, 138, 125, 112, 90, 69, 52, 41, 28, 15; HRMS (EI) Calcd for $C_{19}H_{22}BrNO_4$ (M$^+$) 407.0732, found 407.0753. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 30.1 min, t_{minor} = 42.0 min.

*10-exo-[(p-Bromobenzyloxy)carbonyl]-11-oxa-6-azatricyclo-[6.2.1.0^{1,6}]undecan-7-one (p-Bromobenzyl Ester Derived from exo-**9a**).* R_f = 0.52 (EtOAc/Hexane, 1:1 v/v). Colorless prisms: mp 104−106 °C (Et_2O); $[\alpha]_D^{25}$ +32.55 (*c* 0.50, $CHCl_3$, 87% ee); IR (KBr) 3086, 2958, 1737, 1712, 1409, 1171, 990 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.46−1.54 (2H, m), 1.79−1.87 (4H, m), 1.96 (1H, dd, *J* = 8.4, 12.6 Hz), 2.52 (1H, m), 2.64 (1H, m), 2.99 (1H, dd, *J* = 4.7, 8.4 Hz), 3.80 (1H, m), 4.72 (1H, d, *J* = 5.6 Hz), 5.05 (1H, d, *J* = 12.2 Hz), 5.20 (1H, d, *J* = 12.2 Hz), 7.23−7.27 (2H, m), 7.49−7.53 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.4 (CH_2), 23.3 (CH_2), 27.4 (CH_2), 30.7 (CH_2), 38.3 (CH_2), 46.4 (CH), 66.3 (CH_2), 77.5 (CH), 96.4 (C), 122.8 (C), 130.3 (CH), 131.9 (CH), 134.3 (C), 170.8 (C), 173.6 (C); MS (EI) *m*/*z* 381 [(M + 2)$^+$], 379 (M$^+$), 301, 266, 208, 194, 169, 153, 139, 110, 96, 82; HRMS (ESI-TOF) Calcd for $C_{17}H_{18}NO_4BrNa$ [(M + Na)$^+$] 402.0311, found 402.0305. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{minor} = 55.8 min, t_{major} = 72.5 min.

*10-exo-[(p-Bromobenzyloxy)carbonyl]-9-endo-methyl-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (p-Bromobenzyl Ester Derived from exo-**9b**).* R_f = 0.45 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +30.78 (*c* 0.50, $CHCl_3$, 87% ee); IR (neat) 2961, 1725, 1408, 1288, 1164, 1011, 799 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.08 (3H, d, *J* = 7.3 Hz), 1.38−1.55 (2H, m), 1.74−1.84 (4H, m), 2.52 (1H, d, *J* = 4.9 Hz), 2.68 (1H, dt, *J* = 3.2, 13.1 Hz), 2.95 (1H, ddq, *J* = 4.9, 5.2, 7.3 Hz), 3.84 (1H, m), 4.49 (1H, d, *J* = 5.2 Hz), 5.06 (1H, d, *J* = 12.3 Hz), 5.20 (1H, d, *J* = 12.3 Hz), 7.24−7.26 (2H, m), 7.49−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.3 (CH_3), 20.4 (CH_2), 23.3 (CH_2), 27.7 (CH_2), 37.9 (CH_2), 39.1 (CH), 54.3 (CH), 66.3 (CH_2), 81.3 (CH), 96.5 (C), 122.7 (C), 130.3 (CH), 131.9 (CH), 134.4 (C), 171.0 (C), 172.2 (C); MS (EI) *m*/*z* 395 [(M + 2)$^+$], 393 (M$^+$), 368, 256, 236, 208, 169, 139, 124, 109, 90, 82, 69; HRMS (ESI-

TOF) Calcd for $C_{18}H_{20}NO_4BrNa$ [(M + Na)$^+$] 416.0468, found 416.0480. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{minor} = 60.7 min, t_{major} = 74.7 min.

*10-exo-[(p-Bromobenzyloxy)carbonyl]-9-endo-ethyl-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (p-Bromobenzyl Ester Derived from exo-**9c**).* R_f = 0.48 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +27.48 (*c* 0.30, $CHCl_3$, 86% ee); IR (neat) 2962. 1721, 1407, 1165, 1014 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.95 (3H, t, *J* = 7.4 Hz), 1.32−1.50 (4H, m), 1.77−1.81 (4H, m), 2.53 (1H, d, *J* = 4.9 Hz), 2.67 (1H, m), 2.78 (1H, m), 3.83 (1H, m), 4.57 (1H, d, *J* = 5.2 Hz), 5.07 (1H, d, *J* = 12.3 Hz), 5.20 (1H, d, *J* = 12.3 Hz), 7.23−7.26 (2H, m), 7.49−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.8 (CH_3), 20.4 (CH_2), 23.3 (CH_2), 23.4 (CH_2), 27.8 (CH_2), 37.9 (CH_2), 47.0 (CH), 53.1 (CH), 66.3 (CH_2), 80.5 (CH), 96.3 (C), 122.7 (C), 130.4 (CH), 131.8 (CH), 134.4 (C), 171.2 (C), 172.2 (C); MS (EI) *m*/*z* 409 [(M + 2)$^+$], 407 (M$^+$), 378, 299, 279, 222, 192, 169, 139, 112, 111, 90, 82; HRMS (ESI-TOF) Calcd for $C_{19}H_{22}NO_4BrNa$ [(M + Na)$^+$] 430.0624, found 430.0621. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{minor} = 49.1 min, t_{major} = 60.9 min.

*10-exo-[(p-Bromobenzyloxy)carbonyl]-9-endo-propyl-11-oxa-6-azatricyclo[6.2.1.0^{1,6}]undecan-7-one (p-Bromobenzyl Ester Derived from exo-**9d**).* R_f = 0.52 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +40.41 (*c* 0.50, $CHCl_3$, 84% ee); IR (neat) 2956, 1723, 1456, 1408, 1163, 967 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.88 (3H, t, *J* = 7.1 Hz), 1.23−1.55 (6H, m), 1.77−1.80 (4H, m), 2.53 (1H, d, *J* = 4.9 Hz), 2.68 (1H, m), 2.85 (1H, m), 3.83 (1H, m), 4.55 (1H, d, *J* = 5.2 Hz), 5.06 (1H, d, *J* = 12.3 Hz), 5.20 (1H, d, *J* = 12.3 Hz), 7.23−7.26 (2H, m), 7.49−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.8 (CH_3), 20.3 (CH_2), 21.6 (CH_2), 23.3 (CH_2), 27.7 (CH_2), 32.2 (CH_2), 37.8 (CH_2), 45.0 (CH), 53.3 (CH), 66.3 (CH_2), 80.5 (CH), 96.3 (C), 122.7 (C), 130.3 (CH), 131.8 (CH), 134.4 (C), 171.2 (C), 172.2 (C); MS (EI) *m*/*z* 423 [(M + 2)$^+$], 421 (M$^+$), 378, 343, 300, 252, 194, 169, 139, 91, 82; HRMS (ESI-TOF) Calcd for $C_{20}H_{24}NO_4BrNa$ [(M + Na)$^+$] 444.0781, found 444.0783. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{minor} = 42.8 min, t_{major} = 76.1 min.

*11-exo-[(p-Bromobenzyloxy)carbonyl]-12-oxa-7-azatricyclo-[7.2.1.0^{1,7}]dodecan-8-one (p-Bromobenzyl Ester Derived from exo-**10a**).* R_f = 0.47 (EtOAc/Hexane, 1:1 v/v). Colorless prisms: mp 110−113 °C (Et_2O); $[\alpha]_D^{25}$ +28.45 (*c* 0.50, $CHCl_3$, 85% ee); IR (KBr) 2932, 1708, 1416, 1265, 994 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.27 (1H, m), 1.41 (1H, m), 1.61 (1H, m), 1.74−1.83 (2H, m), 1.86−1.94 (2H, m), 2.01 (1H, dd, *J* = 8.2, 12.6 Hz), 2.03 (1H, m), 2.48 (1H, ddd, *J* = 4.4, 5.5, 12.6 Hz), 2.63 (1H, m), 2.82 (1H, dd, *J* = 4.4, 8.3 Hz), 3.86 (1H, m), 4.72 (1H, d, *J* = 5.5 Hz), 5.09 (1H, d, *J* = 12.9 Hz), 5.12 (1H, d, *J* = 12.9 Hz), 7.23−7.28 (2H, m), 7.49−7.54 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.2 (CH_2), 30.3 (CH_2, overlap), 30.6 (CH_2), 31.3 (CH_2), 38.8 (CH_2), 50.5 (CH), 66.3 (CH_2), 77.9 (CH), 100.8 (C), 122.7 (C), 130.4 (CH), 131.9 (CH), 134.3 (C), 170.9 (C), 173.1 (C); MS (EI) *m*/*z* 395 [(M + 2)$^+$], 393 (M$^+$), 322, 236, 206, 194, 180, 139, 108, 96, 82; HRMS (ESI-TOF) Calcd for $C_{18}H_{20}NO_4BrNa$ [(M + Na)$^+$] 416.0468, found 416.0462. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 52.3 min, t_{minor} = 57.5 min.

*11-exo-[(p-Bromobenzyloxy)carbonyl]-10-endo-methyl-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (p-Bromobenzyl Ester Derived from exo-**10b**).* R_f = 0.45 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +34.27 (*c* 1.00, $CHCl_3$, 88% ee); IR (neat) 2941, 1714, 1419, 1264, 985 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.09 (3H, d, *J* = 7.3 Hz), 1.25 (1H, m), 1.42 (1H, m), 1.59 (1H, m), 1.79−1.83 (3H, m), 1.92 (1H, m), 2.05 (1H, m), 2.35 (1H, d, *J* = 4.7 Hz), 2.66 (1H, m), 2.90 (1H, ddq, *J* = 4.7, 5.4, 7.3 Hz), 3.90 (1H, m), 4.54 (1H, d, *J* = 5.4 Hz), 5.09 (1H, d, *J* = 12.3 Hz), 5.12 (1H, d, *J* = 12.3 Hz), 7.24−7.26 (2H, m), 7.50−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 14.6 (CH_3), 23.0 (CH_2), 30.28 (CH_2), 30.30 (CH_2), 31.4 (CH_2), 38.7 (CH_2), 38.9 (CH), 58.3 (CH), 66.2 (CH_2), 81.7 (CH), 100.9 (C), 122.7 (C), 130.3 (CH), 131.9 (CH), 134.4 (C), 171.1 (C), 171.6 (C); MS (EI) *m*/*z* 409 [(M + 2)$^+$], 407 (M$^+$), 322, 222, 194, 169, 153, 139, 96, 69; HRMS (ESI-TOF) Calcd for $C_{19}H_{22}NO_4BrNa$ [(M + Na)$^+$] 430.0624, found 430.0640. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 60.1 min, t_{minor} = 74.9 min.

*11-exo-[(p-Bromobenzyloxy)carbonyl]-10-endo-ethyl-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (p-Bromobenzyl Ester Derived from exo-**10c**).* R_f = 0.51 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +28.71 (*c* 0.50, $CHCl_3$, 87% ee); IR (neat) 2931, 1717, 1420, 1164, 1011 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.94 (3H, t, *J* = 7.4 Hz), 1.21−1.51 (4H, m), 1.59 (1H, m), 1.70−1.82 (3H, m), 1.92 (1H, m), 2.05 (1H, dd, *J* = 7.6, 15.6 Hz), 2.37 (1H, d, *J* = 4.7 Hz), 2.64 (1H, m), 2.74 (1H, m), 3.88 (1H, m), 4.61 (1H, d, *J* = 5.2 Hz), 5.11 (2H, s), 7.24−7.26 (2H, m), 7.50−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 12.8 (CH_3), 23.0 (CH_2), 23.6 (CH_2), 30.3 (CH_2 overlap), 31.4 (CH_2), 38.6 (CH_2), 46.8 (CH), 57.0 (CH), 66.2 (CH_2), 80.8 (CH), 100.7 (C), 122.6 (C), 130.2 (CH), 131.8 (CH), 134.5 (C), 171.3 (C), 171.6 (C); MS (EI) *m*/*z* 423 [(M + 2)$^+$], 421 (M$^+$), 392, 343, 236, 206, 194, 169, 153, 96, 82, 69; HRMS (ESI-TOF) Calcd for $C_{20}H_{24}NO_4BrNa$ [(M + Na)$^+$] 444.0781, found 444.0767. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 41.8 min, t_{minor} = 54.9 min.

*11-exo-[(p-Bromobenzyloxy)carbonyl]-10-endo-propyl-12-oxa-7-azatricyclo[7.2.1.0^{1,7}]dodecan-8-one (p-Bromobenzyl Ester Derived from exo-**10d**).* R_f = 0.49 (EtOAc/Hexane, 1:2 v/v). Colorless oil: $[\alpha]_D^{25}$ +37.04 (*c* 0.50, $CHCl_3$, 84% ee); IR (neat) 2930, 1721, 1419, 1163, 1013 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.87 (3H, t, *J* = 7.3 Hz), 1.23−1.47 (6H, m), 1.59 (1H, m), 1.70−1.82 (3H, m), 1.91 (1H, m), 2.04 (1H, dd, *J* = 7.7, 15.8 Hz), 2.36 (1H, d, *J* = 4.7 Hz), 2.65 (1H, m), 2.81 (1H, m), 3.88 (1H, m), 4.59 (1H, d, *J* = 5.4 Hz), 5.11 (2H, s), 7.23−7.26 (2H, m), 7.50−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 13.8 (CH_3), 21.6 (CH_2), 23.0 (CH_2), 30.3 (CH_2 overlap), 31.4 (CH_2), 32.4 (CH_2), 38.7 (CH_2), 44.8 (CH), 57.2 (CH), 66.2 (CH_2), 80.9 (CH), 100.7 (C), 122.7 (C), 130.3 (CH), 131.8 (CH), 134.5 (C), 171.3 (C), 171.6 (C); MS (EI) *m*/*z* 437 [(M + 2)$^+$], 435 (M$^+$), 392, 266, 208, 169, 153, 96, 83, 69; HRMS (ESI-TOF) Calcd for $C_{21}H_{26}NO_4BrNa$ [(M + Na)$^+$] 458.0937, found 458.0949. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−EtOH, 10:1 v/v, detector: UV 225 nm, flow rate = 0.5 mL/min, 35 °C), t_{major} = 47.7 min, t_{minor} = 60.9 min.

General Procedure for the Asymmetric Cycloaddition Reactions Was Exemplified by the Reaction of *N*-Diazoacetyl-2-pyrrolidinone (1) with 2-Acryloyl-1-benzyl-5,5-dimethyl-3-pyrazolidinone (3a) Catalyzed by (*R*)-BINIM-2QN-Ni(II) Complex. A suspension of (*R*)-BINIM-2QN (28.1 mg, 0.05 mmol), powdered MS 4 Å (0.50 g) and $Ni(ClO_4)_2{\cdot}6H_2O$ (18.3 mg, 0.05 mmol) in $CHCl_3$ (2.5 mL) was stirred for 6 h at room temperature. 2-Acryloyl-1-benzyl-5,5-dimethyl-3-pyrazolidinone (**3a**) (258.3 mg, 1.0 mmol), $Rh_2(OAc)_4$ (4.4 mg, 0.01 mmol), and $CHCl_3$ (1.5 mL) were successively added to the solution of prepared (*R*)-BINIM-2QN-Ni(II) complex. After warming the mixture to 50 °C, a solution of *N*-diazoacetyl-2-pyrrolidinone (**1**) (76.6 mg, 0.50 mmol) in $CHCl_3$ (5 mL) was added over a period of 6 h using a syringe pump. The syringe was washed with $CHCl_3$ (1 mL). After removal of MS 4 Å through Celite, the reaction mixture was filtered through a plug of silica gel (3 cm) with AcOEt (80 mL) as an eluent. The solvent was removed in vacuo, and the residue was purified by silica gel column chromatography (12 g) with hexane−ethyl acetate (3:1 v/v) as an eluent to provide 155.8 mg (81%) of *exo*-**5a** and *endo*-**5a** (*exo*-**5a**:*endo*-**5a** = 80:20, ^{1}H NMR analysis). The enantiomeric excess of *exo*-**5a** was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH (6:1 vol/vol), detector: UV 225 nm, Flow rate = 0.5 mL/min, 35 °C). t_{minor} = 57.7 min, t_{major} = 115.3 min.

*9-exo-[(1-Benzyl-5,5-dimethyl-3-oxo-2-pyrazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (exo-**5a**).* R_f = 0.42 (EtOAc). Colorless amorphous: $[\alpha]_D^{25}$ = −50.78 (*c* 0.50, $CHCl_3$, 81%ee); IR (KBr) 2962, 1736, 1381, 1227 cm^{-1}; ^{1}H NMR (400 MHz,

$CDCl_3$) δ 1.25 (3H, s), 1.27 (3H, s), 1.94−2.20 (4H, m), 2.34−2.42 (2H, m), 2.63 (1H, d, J = 17.3 Hz), 2.69 (1H, d, J = 17.3 Hz), 3.01 (1H, m), 3.62 (1H, m), 3.98−4.14 (3H, m,), 4.54 (1H, d, J = 5.6 Hz), 7.23−7.39 (4H, m), 7.51 (1H, m); ^{13}C NMR (100 MHz, C_6D_6) δ 26.1 (CH_3), 26.4 (CH_2), 28.0 (CH_2), 31.3 (CH_2), 42.5 (CH_2), 43.5 (CH_2), 49.3 (CH), 57.0 (CH_2), 60.9 (C), 79.3 (CH), 104.8 (C), 127.3 (CH), 128.2 (CH), 129.0 (CH), 137.1 (C), 168.1 (C), 174.2 (C), 176.2 (C); MS (EI) m/z 383 (M^+), 204, 180, 152, 124, 91, 75, 56, 41, 27, 15; HRMS (EI) Calcd for $C_{21}H_{25}N_3O_4$ (M^+) 383.1845, found 383.1819.

*9-endo-[(1-Benzyl-5,5-dimethyl-3-oxo-2-pyrazolidinyl)carbonyl]-10-oxa-5-azatricyclo[5.2.1.0^{1,5}]decan-6-one (endo-**5a**).* R_f = 0.42 (EtOAc). Colorless amorphous: IR (KBr) 2974, 1728, 1385, 1230 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.25 (3H, s), 1.32 (3H, s), 1.81 (1H, dd, J = 5.6, 12.5 Hz), 2.02−2.06 (4H, m), 2.56 (1H, d, J = 17.3 Hz), 2.69−2.76 (2H, m), 3.14 (1H, m), 3.55−3.70 (2H, m), 3.93 (1H, d, J = 13.2 Hz), 4.11 (1H, d, J = 13.2 Hz), 4.51 (1H, d, J = 5.6 Hz), 7.23−7.39 (4H, m), 7.51 (1H, m); MS (EI) m/z 383 (M^+), 339, 204, 181, 152, 124, 108, 95, 77, 65, 55, 39, 27, 15; HRMS (EI) Calcd for $C_{21}H_{25}N_3O_4$ (M^+) 383.1845, found 383.1855.

Synthesis of Indolizidine Derivatives. *(6R,8S,9R)-6-Hydroxy-8-[(p-bromobenzyloxy)carbonyl]indolizidin-5-one (**12**).* Boron trifluoride diethyl etherate (190 μL, 1.50 mmol) and triethylsilane (410 μL, 2.52 mmol) were successively added to a cold (−20 °C) solution of *exo-p*-bromobenzyl ester *exo*-**11** (50.0 mg, 0.140 mmol) in CH_2Cl_2 (15 mL). After warming the mixture at room temperature, the mixture was stirred for 2 days and then diluted with saturated $NaHCO_3$ solution (15 mL) and extracted with CH_2Cl_2 (20 mL × 3). The combined CH_2Cl_2 extracts were dried (Na_2SO_4) and concentrated. The residue was chromatographed (silica gel 12 g, 10:1 hexane/ethyl acetate to 50:50:1 hexane/ethyl acetate/methanol) to give 38.7 mg (75%) of alcohol **12**. R_f = 0.27 (EtOAc). Colorless prisms: mp 121−123 °C (AcOEt); $[\alpha]_D^{25}$ +125.78 (c 1.00, $CHCl_3$, >99% ee); IR (KBr) 3388, 2965, 2878, 1731, 1618, 1447, 1272, 1161, 997 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.46 (1H, dq, J = 8.0, 11.8 Hz), 1.85 (1H, m), 1.95−2.05 (2H, m), 2.18 (1H, m), 2.54 −2.62 (2H, m), 3.40 (1H, d, J = 1.0 Hz), 3.44−3.59 (2H, m), 3.67 (1H, dt, J = 4.7, 10.9 Hz), 4.10 (1H, dd, J = 6.3, 11.7 Hz), 5.11 (1H, d, J = 12.5 Hz), 5.13 (1H, d, J = 12.5 Hz), 7.21−7.23 (2H, m), 7.50−7.52 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.3 (CH_2), 32.2 (CH_2), 32.4 (CH_2), 44.0 (CH), 44.4 (CH_2), 60.8 (CH), 66.0 (CH_2), 67.8 (CH), 122.7 (C), 129.9 (CH), 131.9 (CH), 134.3 (C), 169.4 (C), 171.2 (C); MS (EI) m/z 367 [(M + 2)$^+$], 369 (M^+), 349, 321, 271, 198, 169, 152, 136, 124, 108, 91, 70; HRMS (ESI-TOF) Calcd for $C_{16}H_{18}NO_4BrNa$ [(M + Na)$^+$] 390.0311, found 390.0308. The enantiomeric excess was determined by HPLC analysis (Daicel Chiralpak AD-H, hexane−*i*-PrOH, 9:1 v/v, detector: UV 225 nm, Flow rate = 0.5 mL/min, 35 °C). t_{major} = 60.84 min, t_{minor} = 70.08 min.

*(6R,8S,9R)-6-Phenoxythionocarbonyloxy-8-[(p-bromobenzyloxy)carbonyl]indolizidin-5-one (**13**).* To a cold (0 °C) solution of alcohol **12** (38.7 mg, 0.11 mmol) in CH_2Cl_2 (3 mL) was added pyridine (26 μL, 0.33 mmol), followed by dropwise addition of phenylthionochloroformate (15 μL, 0.165 mmol) by syringe. The resulting solution was stirred at 0 °C for 1 h and then at room temperature for 5 h, followed by addition of EtOAc (20 mL) and saturated NH_4Cl solution (15 mL), and extracted with EtOAc (15 mL × 3). The organic extracts were washed with 1 M hydrochloric acid, saturated $NaHCO_3$ solution, and brine, and dried (Na_2SO_4) and then concentrated. The residue was chromatographed (silica gel 10g, 9:1−1:1 hexane/ethyl acetate) to give 53.5 mg (96%) of thionocarbonate **13**. R_f = 0.44 (EtOAc/Hexane, 1:1 v/v). Pale yellow viscous oil: $[\alpha]_D^{25}$ +81.21 (c 0.50, $CHCl_3$); IR (neat) 2949, 1736, 1666, 1490, 1289, 1202, 1071 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.54 (1H, m), 1.84 (1H, m), 2.02 (1H, m), 2.18−2.29 (2H, m), 2.68 (1H, ddd, J = 3.0, 10.4, 13.1 Hz), 2.79 (1H, ddd, J = 3.0, 6.8, 12.6 Hz), 3.50−3.64 (2H, m), 3.74 (1H, dt, J = 5.0, 10.7 Hz), 5.11 (1H, d, J = 12.9 Hz), 5.14 (1H, d, J = 12.9 Hz), 5.87 (1H, dd, J = 6.8, 9.8 Hz), 7.14−7.17 (2H, m), 7.22−7.31 (3H, m), 7.39−7.44 (2H, m), 7.50−7.53 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.3 (CH_2), 30.0 (CH_2), 32.4 (CH_2), 44.3 (CH), 45.1 (CH_2), 60.2 (CH), 66.4 (CH_2), 77.0 (CH), 121.9 (CH), 122.8 (C), 126.6 (CH), 129.5 (CH), 130.1 (CH), 132.0 (CH), 134.1 (C), 153.6 (C), 163.3 (C), 170.7 (C), 195.0 (C); MS (EI) m/z 505 [(M + 2)$^+$], 503 (M^+), 394, 366, 322, 282, 238, 202, 169, 136, 108, 94, 84; HRMS (ESI-TOF) Calcd for $C_{23}H_{22}NO_5SBrNa$ [(M + Na)$^+$] 526.0294, found 526.0286.

*(8S,9R)-8-[(Benzyloxy)carbonyl]indolizidin-5-one (**14**).* To a degassed solution of thionocarbonate **13** (53.5 mg, 0.106 mmol) in benzene (10 mL) using three freeze/thaw cycles was added tributylstannane (90 μL, 0.318 mmol) and AIBN (2.0 mg, 0.010 mmol) successively. The solution was heated under reflux for 5 h. After cooling the mixture at room temperature, the mixture was concentrated under a vacuum. The residue was chromatographed on silica gel/K_2CO_3 (10:1, w/w, 11 g) eluted with hexane/ethyl acetate (9:1−1:1) to afford indolizidinone **14** (30.2 mg, quant). R_f = 0.34 (EtOAc/Hexane, 1:1 v/v). Colorless viscous oil: $[\alpha]_D^{25}$ +137.02 (c 0.50, $CHCl_3$); IR (neat) 2955, 1732, 1622, 1457, 1164, 742, 701 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.47 (1H, dq, J = 7.6, 11.8 Hz), 1.75 (1H, m), 1.90−1.99 (2H, m), 2.15−2.20 (2H, m), 2.33−2.42 (2H, m), 2.53 (1H, ddd, J = 1.7, 6.6, 18.1 Hz), 3.47 (1H, m), 3.54−3.62 (2H, m), 5.15 (1H, d, J = 12.3 Hz), 5.18 (1H, d, J = 12.3 Hz), 7.34−7.38 (5H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.0 (CH_2), 25.2 (CH_2), 30.6 (CH_2), 32.5 (CH_2), 45.0 (CH_2), 46.2 (CH), 60.1 (CH), 66.8 (CH_2), 128.2 (CH), 128.5 (CH), 128.7 (CH), 135.5 (C), 168.0 (C), 172.5 (C); MS (EI) m/z 273 (M^+), 245, 217, 182, 153, 139, 110, 91, 83; HRMS (ESI-TOF) Calcd for $C_{16}H_{20}NO_3$ [(M + H)$^+$] 274.1438, found 274.1444.

(+)-Tashiromine. $LiAlH_4$ (39.5 mg, 1.04 mmol) was added to a solution of indolizidinone **14** (90.0 mg, 0.329 mmol) in THF (5 mL). The mixture was heated under reflux for 2 h. After cooling the mixture at room temperature, water (50 μL), 10% NaOH solution (150 μL), and water (50 μL) were added, and the mixture was stirred each for 10 min. The solvent was removed in vacuo, and the residue was purified by silica gel column chromatography (8 g) with $CHCl_3$ and $CHCl_3$/MeOH/NH_4OH (100:0:0 to 95:5:1 v/v) as an eluent to provide 31.5 mg (62%) of (+)-Tashiromine. R_f = 0.40 ($CHCl_3$/MeOH/NH_4OH, 4:1:0.1 v/v). Colorless oil: $[\alpha]_D^{20}$ = +44.3° (c 1.1, EtOH) (lit.[6] $[\alpha]_D^{20}$ = +44.7°, c 1.1, EtOH); ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.07 (1H, dq, J = 4.6, 11.8 Hz), 1.38−1.84 (7H, m), 1.84−2.00 (3H, m), 2.06 (1H, q, J = 9.1 Hz), 3.06−3.17 (2H, m), 3.50 (1H, dd, J = 6.7, 10.8 Hz), 3.68 (1H, dd, J = 4.6, 10.8 Hz), 5.53 (1H, brs, OH); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.7 (CH_2), 25.0 (CH_2), 27.6 (CH_2), 28.9 (CH_2), 44.4 (CH), 52.6 (CH_2), 54.0 (CH_2), 65.1 (CH_2), 66.4 (CH).

(6R,8S*,9R*)-6-(t-Butyldimethylsilyloxy)-8-[(p-bromobenzyloxy)carbonyl]indolizidin-5-one (**15**).* 2,6-Lutidine (180 μL, 1.55 mmol) and *t*-butyldimethylsilyl triflate (179 μL, 0.780 mmol) were successively added to a cold (0 °C) solution of alcohol **12** (143.0 mg, 0.390 mmol) in CH_2Cl_2 (5 mL). After stirring the mixture at 0 °C for 2 h, the mixture was diluted with 0.1 M hydrochloric acid (1 mL) and extracted with CH_2Cl_2 (5 mL × 3). The combined CH_2Cl_2 extracts were dried (Na_2SO_4) and concentrated. The residue was chromatographed (silica gel 12 g, 95:5−8:2 hexane/ethyl acetate) to give 167.0 mg (90%) of TBS ether **15**. R_f = 0.57 (EtOAc/Hexane, 1:2 v/v). Colorless oil: IR (neat) 2951, 2854, 1739, 1660, 1461, 1251, 1155, 838 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 0.14 (3H, s), 0.17 (3H, s), 0.90 (9H, s), 1.46 (1H, m), 1.79 (1H, m), 1.96 (1H, m), 2.11 (1H, ddd, J = 9.8, 11.8, 13.2 Hz), 2.16 (1H, m), 2.36 (1H, ddd, J = 3.9, 6.3, 13.2 Hz), 2.53 (1H, ddd, J = 3.9, 10.0, 11.8 Hz), 3.44−3.56 (2H, m), 3.74 (1H, dt, J = 5.2, 10.4 Hz), 4.17 (1H, dd, J = 6.3, 9.8 Hz), 5.10 (1H, d, J = 12.5 Hz), 5.13 (1H, d, J = 12.5 Hz), 7.22−7.25 (2H, m), 7.51−7.53 (2H, m); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.5 (CH_3), −4.5 (CH_3), 18.3 (C), 22.4 (CH_2), 25.8 (CH_3), 32.6 (CH_2), 34.6 (CH_2), 44.7 (CH), 44.8 (CH_2), 59.6 (CH), 66.0 (CH_2), 69.4 (CH), 122.6 (C), 123.0 (CH), 131.9 (CH), 134.4 (C), 168.5 (C), 171.6 (C); MS (EI) m/z 483 [(M + 2)$^+$], 481 (M^+), 466, 424, 346, 284, 210, 169, 136, 108, 91, 73; HRMS (ESI-TOF) Calcd for $C_{22}H_{33}NO_4SiBr$ [(M + H)$^+$] 482.1357, found 482.1357.

(6R,8S*,9R*)-6-(t-Butyldimethylsilyloxy)-8-(N-methoxy-N-methylcarbamoyl)indolizidin-5-one (**16**).* A solution of *n*-BuLi in hexane (1.6 M, 2.10 mmol, 1.31 mL) was added to a cold (−78 °C) solution of *N,O*-dimethylhydroxylamine hydrochrolide (102.4 mg, 1.05 mmol) in THF (2 mL), and the mixture was stirred at −78 °C for 30 min and then at room temperature for 30 min. After cooling the

mixture at −78 °C, a solution of TBS ether **15** (167 mg, 0.350 mmol) in THF (3 mL) was added to the mixture, and the stirring was continued for 30 min at the same temperature. The mixture was quenched with methanol (1 mL) at −78 °C. After warming the mixture at room temperature, the mixture was diluted with 0.1 M hydrochloric acid (5 mL) and extracted with CH_2Cl_2 (5 mL × 3). The combined CH_2Cl_2 extracts were washed with brine, dried (Na_2SO_4) and concentrated. The residue was chromatographed (silica gel 10 g, 8:2 hexane/ethyl acetate) to give 114.8 mg (92%) of Weinreb amide **16**. R_f = 0.40 (EtOAc/Hexane, 1:2 v/v). Colorless prisms: mp 104−107 °C (EtOAc−Hexane); IR (KBr) 2930, 1663, 1465, 1151, 837 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 0.16 (3H, s), 0.19 (3H, s), 0.90 (9H, s), 1.36 (1H, m), 1.80 (1H, m), 1.95 (1H, m), 2.03−2.15 (2H, m), 2.27 (1H, ddd, J = 3.2, 6.8, 13.1 Hz), 2.88 (1H, m), 3.22 (3H, s), 3.72 (3H, s), 3.45−3.57 (2H, m), 3.83 (1H, dt, J = 4.9, 10.6 Hz), 4.19 (1H, dd, J = 6.8, 10.6 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ −5.5 (CH_3), −4.4 (CH_3), 18.3 (C), 22.4 (CH_2), 25.7 (CH_3), 32.0 (CH_2), 32.1 (CH_3), 35.1 (CH_2), 41.3 (CH_3), 44.8 (CH_2), 60.3 (CH), 61.6 (CH), 69.6 (CH), 168.4 (C), 172.5 (C); MS (EI) m/z 356 (M^+), 299, 284, 224, 210, 169, 136, 108, 94, 73; HRMS (ESI-TOF) Calcd for $C_{17}H_{32}N_2O_4SiH$ [$(M + H)^+$] 357.2204, found 357.2219.

(6R,8S*,9R*)-8-Acetyl-6-hydroxyindolizidin-5-one* (**18**). To a cold (−78 °C) solution of Weinreb amide **16** (114.8 mg, 0.32 mmol) in THF (3 mL) was added a solution of MeMgBr in THF (1.0 M, 0.96 mL, 0.96 mmol), and the mixture was stirred at the same temperature for 5 min. After warming the mixture at room temperature, stirring was continued for 30 min. The mixture was diluted with 1.0 M hydrochloric acid (3 mL) and extracted with CH_2Cl_2 (5 mL × 3). The combined CH_2Cl_2 extracts were washed with brine, dried (Na_2SO_4) and concentrated. The residue was dissolved in methanol (3 mL). After cooling the resulting solution at 0 °C, 10% hydrochloric acid (500 μL) was added. After stirring the mixture for 30 min at 0 °C, the mixture was diluted with brine (3 mL) and extracted with CH_2Cl_2 (5 mL × 3). The combined CH_2Cl_2 extracts were washed with brine, dried (Na_2SO_4) and concentrated. The residue was chromatographed (silica gel 10 g, 100:1 chloroform/methanol) to give 51.1 mg (81%) of methyl ketone **18**. R_f = 0.42 ($CHCl_3$/MeOH, 20:1 v/v). Colorless prisms: mp 147−149 °C (EtOAc−Hexane); IR (KBr) 3276, 2968, 1704, 1613, 1479, 1272, 1092 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.35 (1H, dq, J = 8.0, 11.7 Hz), 1.81−1.91 (2H, m), 2.01 (1H, m), 2.21 (1H, m), 2.25 (3H, s), 2.52 (1H, ddd, J = 2.7, 6.2, 12.9 Hz), 2.64 (1H, m), 3.45 (1H, m), 3.56 (1H, m), 3.64 (1H, bs), 3.69 (1H, dt, J = 4.9, 10.3 Hz), 4.15 (1H, dd, J = 6.2, 11.4 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 22.5 (CH_2), 28.9 (CH_3), 31.9 (CH_2), 32.2 (CH_2), 44.2 (CH_2), 51.3 (CH), 60.2 (CH), 68.1 (CH), 169.3 (C), 206.6 (C); MS (EI) m/z 197 (M^+), 179, 154, 136, 108, 97, 70; HRMS (ESI-TOF) Calcd for $C_{10}H_{15}NO_3Na$ [$(M + Na)^+$] 220.0944, found 220.0942.

(6R,8S*,9R*)-8-Acetoxy-6-hydroxyindolizidin-5-one* (**19**). To a cold (0 °C) solution of 30% hydrogen peroxide solution (170 μL, 1.5 mmol) in CH_2Cl_2 (3 mL) was added trifluoroacetic anhydride (210.0 mg, 1.0 mmol), and the mixture was stirred at same temperature for 10 min. After adding a cold (0 °C) solution of ketone **18** (19.7 mg, 0.10 mmol) in CH_2Cl_2 (3 mL) to the mixture at 0 °C, stirring was continued for 20 h at room temperature. To the mixture was added a saturated solution of sodium sulfite (5 mL), and then the mixture was stirred for 10 min. The mixture was extracted with CH_2Cl_2 (5 mL × 3), and combined CH_2Cl_2 extracts were washed with brine, dried (Na_2SO_4) and concentrated. The residue was chromatographed (silica gel 8 g, 50:1 chloroform/methanol) to give 11.3 mg (53%) of indolizidinone **19**. R_f = 0.52 ($CHCl_3$/MeOH, 20:1 v/v). Colorless needles: mp 114−116 °C (EtOAc−Hexane); IR (KBr) 3401, 2964, 1748, 1630, 1473, 1232, 1034 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.58 (1H, m), 1.82 (1H, m), 1.92 (1H, q, J = 12.0 Hz), 2.03 (1H, m), 2.10 (3H, s), 2.13 (1H, m), 2.58 (1H, ddd, J = 3.5, 6.3, 12.0 Hz), 3.29 (1H, brs), 3.49−3.58 (3H, m), 4.17 (1H, ddd, J = 0.5, 6.3, 12.0 Hz), 4.87 (1H, ddd, J = 3.5, 9.5, 12.0 Hz); ^{13}C NMR (125 MHz, $CDCl_3$) δ 20.9 (CH_3), 22.4 (CH_2), 31.3 (CH_2), 34.9 (CH_2), 44.8 (CH_2), 62.7 (CH), 66.9 (CH), 69.7 (CH), 169.4 (C), 169.9 (C); MS (EI) m/z 213 (M^+), 182, 153, 139, 124, 96, 70; HRMS (ESI-TOF) Calcd for $C_{10}H_{16}NO_4$ [$(M + H)^+$] 214.1074, found 214.1071.

Synthesis of *N*-Diazoacetyl Lactams. *N*-Diazoacetyl-2-piperidinone (**6**) and *N*-diazoacetyl-ε-caprolactam (**7**) were prepared according to the procedure reported for the preparation of *N*-diazoacetyl-2-pyrrolidinone (**1**) in the previous paper.[4a]

N-Diazoacetyl-2-piperidinone (**6**) was synthesized from 2-piperidinone (1.98 g, 20.0 mmol) according to the procedure (overall yield; 48%, 1.60 g).

N-diazoacetyl-ε-caprolactam (**7**) was synthesized from ε-caprolactam (2.26 g, 20.0 mmol) according to the procedure (overall yield; 41%, 1.49 g).

N-Diazoacetyl-2-piperidinone (**6**). R_f = 0.47 (EtOAc/Hexane, 1:1 v/v). Yellow oil: IR (neat) 3147, 2953, 2112, 1689, 1629, 1344, 1135, 1013, 924, 736 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.83−1.85 (4H, m), 2.53−2.56 (2H, m), 3.79−3.82 (2H, m), 6.83 (1H, bs); ^{13}C NMR (125 MHz, $CDCl_3$) δ 9.7 (CH_2), 22.2 (CH_2), 34.3 (CH_2), 43.7 (CH_2), 52.8 (CH), 166.9 (C), 172.9 (C); MS (EI) m/z 139 [$(M - N_2)^+$], 129, 114, 100, 82; HRMS (ESI-TOF) Calcd for $C_7H_{10}NO_2$ [$(M - N_2 + H)^+$] 140.0706, found 140.0698.

N-Diazoacetyl-ε-caprolactam (**7**). R_f = 0.49 (EtOAc/Hexane, 1:1 v/v). Yellow prisms: mp 69−73 °C; IR (KBr) 3163, 2929, 2109, 1681, 1621, 1346, 1183, 972, 736 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.70−1.79 (6H, m), 2.69−2.72 (2H, m), 3.97−3.99 (2H, m), 6.77 (1H, bs); ^{13}C NMR (125 MHz, $CDCl_3$) δ 23.6 (CH_2), 28.5 (CH_2), 29.1 (CH_2), 39.7 (CH_2), 43.4 (CH_2), 52.8 (CH), 166.8 (C), 177.5 (C); MS (EI) m/z 153 [$(M - N_2)^+$], 138, 114, 102, 96, 85; HRMS (ESI-TOF) Calcd for $C_8H_{12}NO_2$ [$(M - N_2 + H)^+$] 154.0863, found 154.0871.

■ ASSOCIATED CONTENT

Ⓢ Supporting Information

Reactions between *N*-diazoacetyl-2-pyrrolidinone (**1**) and 3-acryloyl-2-oxazolidinone (**2a**) or 3-crotonoyl-2-oxazolidinone (**2b**) catalyzed by several (4*S*,5*S*)-Pybox-Ph_2-M$(OTf)_3$ complexes, and NMR spectra (^1H, and ^{13}C) for new compounds. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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