# Supporting Information 

for

# Addition of lithiated enol ethers to nitrones and subsequent Lewis acid induced cyclizations to enantiopure 3,6-dihydro-2H-pyrans - An approach to carbohydrate mimetics <br> Fabian Pfrengle and Hans-Ulrich Reissig* 

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Experimental procedures, characterization data, ${ }^{1} \mathrm{H}$ NMR and ${ }^{13} \mathrm{C}$ NMR spectra of synthesized compounds

## General methods:

Reactions were, in general, performed under argon in flame-dried flasks, and the components were added by syringe. Methanol was purchased in p . a. quality and stored under argon over molecular sieves ( $4 \AA$ ). Tetrahydrofuran and dichloromethane were obtained from the solvent purification system MB-SPS-800 (M. Braun). Products were purified by flash chromatography on silica gel (230-400 mesh, Merck). Unless otherwise stated, yields refer to analytically pure samples. ${ }^{1} \mathrm{H}$ NMR $\left[\mathrm{CHCl}_{3}(\delta=7.26 \mathrm{ppm})\right.$, TMS $(\delta=0.00 \mathrm{ppm}), \mathrm{CD}_{3} \mathrm{OD}(\delta=3.31 \mathrm{ppm})$, DMF$d_{7}(\delta=8.02 \mathrm{ppm})$ or $\mathrm{D}_{2} \mathrm{O}(\delta=4.79 \mathrm{ppm})$ as internal standards $]$ and ${ }^{13} \mathrm{C}$ NMR spectra $\left[\mathrm{CDCl}_{3}(\delta=\right.$ $77.0 \mathrm{ppm})$, DMF- $d_{7}(\delta=162.6 \mathrm{ppm})$ or $\mathrm{CD}_{3} \mathrm{OD}(\delta=49.0 \mathrm{ppm})$ as internal standards] were recorded on Bruker AC 250, ECP 400, AC 500, AVIII 700, or Joel Eclipse 500 instruments in $\mathrm{CDCl}_{3}, \mathrm{CD}_{3} \mathrm{OD}, \mathrm{DMF}-d_{7}$ or $\mathrm{D}_{2} \mathrm{O}$ solution. Integrals are in accord with assignments; coupling constants are given in Hz. IR spectra were measured with an FT-IR spectrometer Nicolet 5 SXC or with a Nexus FT-IR equipped with a Nicolet Smart DuraSamplIR ATR. MS and HRMS analyses were performed on Finnigan Varian Ionspec QFT-7 (ESI-FT-ICR) and Agilent ESI-TOF $6210(4 \mu \mathrm{~L} / \mathrm{min}, 1 \mathrm{bar}, 4000 \mathrm{~V})$ instruments. Elemental analyses were obtained with "ElementalAnalyzers" (Perkin-Elmer or Carlo Erba). Melting points were measured with a Reichert apparatus (Thermovar) and are uncorrected. Optical rotations ( $[\alpha]_{\mathrm{D}}$ ) were determined with Perkin-Elmer 241 polarimeter at the temperatures given. Commercially available chemicals were used without further purification unless otherwise stated.

## Experimental procedures and characterization data:

Due to hindered rotation of the bulky $-N(\mathrm{OTBS}) \mathrm{Bn}$ moiety some signals in the ${ }^{1} \mathrm{H}$ NMR or ${ }^{13} \mathrm{C}$ NMR spectra of the compounds containing this group are broadened or could not be detected.

## $N$-Benzyl- $O$-(tert-butyldimethylsilyl)- $N$-((S)-1-((S)-2,2-dimethyl-1,3-dioxolan-4-yl)-2ethoxyallyl)hydroxylamine (syn-4a)



Ethylvinylether ( $445 \mu \mathrm{~L}, 4.62 \mathrm{mmol}$ ) was dissolved in THF ( 8 mL ) and cooled to $-78{ }^{\circ} \mathrm{C} . t \mathrm{BuLi}$ (1.6 M in pentane, $2.89 \mathrm{~mL}, 4.62 \mathrm{mmol}$ ) was added and the reaction mixture stirred for 1 h during which time it was allowed to warm to $0{ }^{\circ} \mathrm{C}$. After further stirring for 1 h at this temperature, it was cooled once more to $-78{ }^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}$ ( $725 \mathrm{mg}, 3.08 \mathrm{mmol}$ ) in THF ( 2 mL ) was added dropwise over a period of 15 min . The mixture was stirred at this temperature for 1 h and the reaction quenched by the addition of $\mathrm{H}_{2} \mathrm{O}$. After the mixture reached room temperature, it was extracted three times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 844 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(7 \mathrm{~mL})$, and 2,6-lutidine ( $641 \mu \mathrm{~L}, 5.50 \mathrm{mmol}$ ) and TBSOTf ( $946 \mu \mathrm{~L}, 4.13 \mathrm{mmol}$ ) were added slowly at $0^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and then the reaction was quenched by the addition of a sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The layers were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1)$ yielded syn-4a (800 mg, 61\%) and anti-4a (115 mg, 9\%) as colorless oils. syn-4a: $[\alpha]_{D}{ }^{22}$ $=-27.2\left(\mathrm{c}=0.20, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=0.10\left(\mathrm{~s}, 6 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.88(\mathrm{~s}, 9 \mathrm{H}$, $t \mathrm{Bu}), 1.28(\mathrm{t}, J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}), 1.33,1.36(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $3.29(\mathrm{~s}$ br, $1 \mathrm{H}, 3-\mathrm{H}), 3.57(\mathrm{t}, J=$ $7.9 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.66,3.72\left(2 \mathrm{td}, J=7.0,9.4 \mathrm{~Hz}, 1 \mathrm{H}\right.$ each, Et), $3.85\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.99$ (dd, $J=6.8,7.9 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 4.03(\mathrm{~d}, J=1.6 \mathrm{~Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 4.12\left(\mathrm{~d}, J=13.2 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.16$ $(\mathrm{d}, J=1.6 \mathrm{~Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 4.40(\mathrm{td}, J=6.8,7.9 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 7.20-7.42(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $176 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.2$, $-4.8\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.6(\mathrm{q}, \mathrm{Et}), 17.9,26.2(\mathrm{~s}, \mathrm{q}, \mathrm{tBu}), 25.6$, 26.7 ( $2 \mathrm{q}, \mathrm{Me}$ ), 60.5 ( $\mathrm{t}, \mathrm{NCH}_{2}$ ), 62.2 (t, Et), 67.6 (t, C-5), 71.5 (d, C-3), 74.1 (d, C-4), 87.4 (t, C-1), 109.2 (s, C-2'), 126.9, 127.9, 129.8, 138.0 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 157.3 ( $\mathrm{s}, \mathrm{C}-2$ ) ppm. IR (film): 3100-2850 $\mathrm{cm}^{-1}$ (=C-H, C-H). ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{Na}]^{+} 444.2541$, found 444.2546. Anal. calc. for $\mathrm{C}_{23} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (421.7): C 65.52, H 9.32, N 3.32, found: C 65.39, H 9.37, N 3.36.

## $N$-Benzyl- $O$-(tert-butyldimethylsilyl)- $N$-((R)-1-((S)-2,2-dimethyl-1,3-dioxolan-4-yl)-2ethoxyallyl)hydroxylamine (anti-4a)



Ethylvinylether ( $409 \mu \mathrm{~L}, 4.25 \mathrm{mmol}$ ) was dissolved in THF ( 8 mL ) and cooled to $-78{ }^{\circ} \mathrm{C} . t \mathrm{BuLi}$ (1.6 M in pentane, $2.66 \mathrm{~mL}, 4.25 \mathrm{mmol}$ ) was added and the reaction mixture stirred for 1 h during which time it was allowed to warm to $0{ }^{\circ} \mathrm{C}$. After further stirring for 3 h at this temperature, it was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}$ ( $200 \mathrm{mg}, 0.850 \mathrm{mmol}$ ) in THF ( 2 mL ) was treated with $\mathrm{Et}_{2} \mathrm{AlCl}(1 \mathrm{M}$ in hexane, $850 \mu \mathrm{~L}, 0.850 \mathrm{mmol})$ for 5 min . The prepared solution was added dropwise over a period of 15 min . The mixture was then stirred at this temperature for a further 15 min and the reaction quenched by the addition of 2 M NaOH solution. After the mixture reached room temperature it was extracted three times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 250 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(3 \mathrm{~mL})$, and 2,6-lutidine ( $180 \mu \mathrm{~L}, 1.22 \mathrm{mmol}$ ) and TBSOTf ( $268 \mu \mathrm{~L}$, 1.63 mmol ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and then the reaction was quenched by the addition of sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded syn-4a $(14 \mathrm{mg}, 4 \%)$ and anti-4a (171 $\mathrm{mg}, 48 \%$ ) as colorless oils. anti-4a: $[\alpha]_{\mathrm{D}}{ }^{22}=+26.7\left(\mathrm{c}=0.22, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \mathrm{NMR}(500 \mathrm{MHz}$, $\left.\mathrm{CDCl}_{3}\right): \delta=-0.40\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right),-0.01\left(\mathrm{~s}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.85(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.34\left(\mathrm{~m}_{\mathrm{c}}, 3 \mathrm{H}, \mathrm{Et}\right)$, 1.35 ( $\mathrm{s}, 6 \mathrm{H}, \mathrm{Me}$ ), 3.31 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}$ ), 3.80-3.90 (m, $4 \mathrm{H}, \mathrm{NCH}_{2}, \mathrm{OCH}_{2}, 3-\mathrm{H}$ ), 4.01 ( $\mathrm{m}_{\mathrm{c}}, 1 \mathrm{H}, 5-$ H), $4.11(\mathrm{dd}, J=5.8,8.4 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 4.16(\mathrm{~d}, J=1.9 \mathrm{~Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 4.31(\mathrm{~d}, J=1.9 \mathrm{~Hz}, 1 \mathrm{H}$, $1-\mathrm{H}), 4.42(\mathrm{td}, J=5.8,9.9 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 7.20-7.34(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( 126 MHz , $\mathrm{CDCl}_{3}$ ): $\delta=-4.8,-4.6\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.6(\mathrm{q}, \mathrm{Et}), 17.8,26.1(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 25.7,26.9(2 \mathrm{q}, \mathrm{Me}), 60.8$ ( $\mathrm{t}, \mathrm{NCH}_{2}$ ), 62.4 (t, Et), 67.9 ( $\mathrm{t}, \mathrm{C}-5$ ), 74.0 (d, C-4), 88.1 (t, C-1), 108.2 ( $\mathrm{s}, \mathrm{C}-2$ '), 127.2, 128.0, 130.2, 138.1 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 157.3 (s, C-2) ppm. IR (film): 3120-2840 $\mathrm{cm}^{-1}$ (=C-H, C-H). ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{Na}]^{+} 444.2541$, found 444.2523. Anal. calc. for $\mathrm{C}_{23} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (421.7): C 65.52, H 9.32, N 3.32, found: C 64.93, H 8.60, N 3.52.
$N$-Benzyl-O-(tert-butyldimethylsilyl)-N-[(S)-(3,4-dihydro-2H-pyran-6-yl)((S)-2,2-dimethyl-1,3-dioxolan-4-yl)methyl]hydroxylamine (syn-4b)


3,4-Dihydropyran ( $444 \mu \mathrm{~L}, 5.37 \mathrm{mmol}$ ) was dissolved in THF ( 5 mL ) and cooled to $-78{ }^{\circ} \mathrm{C}$. $t \mathrm{BuLi}(1.6 \mathrm{M}$ in pentane, $3.04 \mathrm{~mL}, 4.86 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0{ }^{\circ} \mathrm{C}$. After further stirring for 1 h at this temperature the mixture was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}$ ( $840 \mathrm{mg}, 3.58$ mmol ) in THF ( 2 mL ) was added dropwise over a period of 15 min . The mixture was then stirred at this temperature for 1 h and the reaction quenched by the addition of $\mathrm{H}_{2} \mathrm{O}$. After the mixture reached rt it was extracted 3 times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 980 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ ( 8 mL ), and 2,6-lutidine ( $1.07 \mathrm{~mL}, 9.18 \mathrm{mmol}$ ) and TBSOTf ( $1.40 \mathrm{~mL}, 6.11 \mathrm{mmol}$ ) were added slowly at $0^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and then the reaction was quenched by the addition of sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded $\operatorname{syn}-\mathbf{4 b}(682 \mathrm{mg}, 44 \%)$ and anti-4b $(276 \mathrm{mg}, 18 \%)$ as colorless oils. syn-4b: $[\alpha]_{\mathrm{D}}{ }^{22}=-39.5\left(\mathrm{c}=2.3, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-0.08\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$, $\mathrm{SiMe}_{2}$ ), $0.09\left(\mathrm{~s}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.87(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.32,1.35$ ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.72-1.82 (m, 2 H , DHP), 2.02-2.10 (m, 2 H, DHP), 3.17 ( $\left.\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.62(\mathrm{dd}, J=6.9,7.9 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.84-$ $3.95\left(\mathrm{~m}, 3 \mathrm{H}, \mathrm{DHP}, \mathrm{NCH}_{2}\right), 4.00(\mathrm{dd}, J=6.9,7.9 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 4.09(\mathrm{~d}, J=13.1 \mathrm{~Hz}, 1 \mathrm{H}$, $\left.\mathrm{NCH}_{2}\right), 4.36(\mathrm{td}, J=6.9,8.9 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 4.69\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 1-\mathrm{H}\right), 7.16-7.41(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.2$, $-4.8\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right.$ ), 17.8, 26.1 (s, q, $t \mathrm{Bu}$ ), 20.2, 22.3 ( 2 t , DHP), 25.6, 26.7 ( 2 q, Me), 60.6 (t, NCH2), 65.3 (t, DHP), 67.6 (t, C-5), 74.2 (d, C-4), 102.8 (d, C-1), 109.1 ( $\mathrm{s}, \mathrm{C}-2$ '), 126.8, 127.9, 129.8 ( $3 \mathrm{~d}, \mathrm{Ph}$ ), 149.4 ( $\mathrm{s}, \mathrm{C}-2$ ) ppm. IR (film): 3090-2820 $\mathrm{cm}^{-1}(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{Na}]^{+} 456.2541$, found 456.2538. Anal. calc. for $\mathrm{C}_{24} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (433.7): C 66.47, H 9.06, N 3.23; found: C 66.51, H 9.06, N 3.31.
$N$-Benzyl- $O$-(tert-butyldimethylsilyl)- N -[(R)-(3,4-dihydro-2H-pyran-6-yl)((S)-2,2-dimethyl-1,3-dioxolan-4-yl)methyl]hydroxyl-amine (anti-4b)


2,3-Dihydropyran ( $2.91 \mathrm{~mL}, 31.8 \mathrm{mmol}$ ) was dissolved in THF ( 30 mL ) and cooled to $-78{ }^{\circ} \mathrm{C}$. $t \mathrm{BuLi}(1.6 \mathrm{M}$ in pentane, $19.9 \mathrm{~mL}, 31.8 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0^{\circ} \mathrm{C}$. After further stirring for 3 h at this temperature, it was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}(1.50 \mathrm{~g}, 6.36 \mathrm{mmol})$ in THF ( 10 mL ) was treated with $\mathrm{Et}_{2} \mathrm{AlCl}(1 \mathrm{M}$ in hexane, $6.36 \mu \mathrm{~L}, 6.36 \mathrm{mmol})$ for 5 min . The prepared solution was added dropwise over a period of 15 min . The mixture was then stirred at this temperature for a further 15 min and the reaction was quenched by addition of 2 M NaOH solution. After the mixture reached room temperature it was extracted 3 times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 2.15 g ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(30 \mathrm{~mL})$, and 2,6-lutidine ( $1.57 \mathrm{~mL}, 13.5 \mathrm{mmol}$ ) and TBSOTf ( $2.33 \mathrm{~mL}, 10.1 \mathrm{mmol}$ ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and the reaction quenched by the addition of a sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded syn-4b (215 $\mathrm{mg}, 8 \%)$ and anti-4b $(1.54 \mathrm{~g}, 56 \%)$ as colorless oils. anti-4b: $[\alpha]_{\mathrm{D}}^{22}=+39.1\left(\mathrm{c}=0.80, \mathrm{CHCl}_{3}\right)$. ${ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-0.37\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right),-0.03\left(\mathrm{~s}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.84(\mathrm{~s}, 9 \mathrm{H}$, $t \mathrm{Bu}$ ), 1.33, 1.35 (2 s, 3 H each, Me), 1.81-1.94 (m, 2 H, DHP), 2.06-2.21 (m, 2 H, DHP), 3.18 ( $\left.\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.81\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.85\left(\mathrm{~d}, J=11.5 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.95-4.11(\mathrm{~m}, 4 \mathrm{H}, \mathrm{DHP}$, $5-\mathrm{H}), 4.36(\mathrm{dt}, J=5.7,9.4 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 4.77(\mathrm{t}, J=3.6 \mathrm{~Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 7.20-7.32(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph})$ ppm. ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.8,-4.5\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.8,26.1(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 20.4,22.5$ ( $2 \mathrm{t}, \mathrm{DHP}$ ), 25.9, $27.0(2 \mathrm{q}, \mathrm{Me}), 61.0\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 65.4$ (t, DHP), 67.9 (t, C-5), 73.6 (d, C-4), 103.2 (d, C-1), 108.8 (s, C-2'), 127.2, 128.0, 130.2, 138.1 (3 d, s, Ph), 148.5 (s, C-2) ppm. IR (film): 3090-2800 $\mathrm{cm}^{-1}(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{Na}]^{+} 456.2541$, found 456.2523 . Anal. calc. for $\mathrm{C}_{24} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (433.7): C 66.47, H 9.06, N 3.23; found: C 66.12, H 8.90, N 3.32.

## $N$-Benzyl-O-(tert-butyldimethylsilyl)- $N$-[(S)-(4,5-dihydrofuran-2-yl)((S)-2,2-dimethyl-1,3-dioxolan-4-yl)methyl]hydroxylamine (syn-4c)



2,3-Dihydrofuran ( $726 \mu \mathrm{~L}, 9.60 \mathrm{mmol}$ ) was dissolved in THF ( 10 mL ) and cooled to $-78{ }^{\circ} \mathrm{C}$. $t \mathrm{BuLi}(1.6 \mathrm{M}$ in pentane, $6.00 \mathrm{~mL}, 9.60 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0^{\circ} \mathrm{C}$. After further stirring for 1 h at this temperature, it was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}(1.50 \mathrm{~g}, 6.40 \mathrm{mmol})$ in THF ( 4 mL ) was added dropwise over a period of 15 min . The mixture then was stirred at this temperature for 1 h and the reaction quenched by the addition of $\mathrm{H}_{2} \mathrm{O}$. After the mixture reached room temperature it was extracted three times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. The crude product $(1.91 \mathrm{~g})$ was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(15 \mathrm{~mL})$, and 2,6-lutidine ( $1.46 \mathrm{~mL}, 12.5 \mathrm{mmol}$ ) and TBSOTf ( $2.15 \mathrm{~mL}, 9.39 \mathrm{mmol}$ ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and the reaction was then quenched by the addition of sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded syn-4c ( $1.57 \mathrm{~g}, 58 \%$ ) and anti-4c (260 $\mathrm{mg}, 10 \%$ ) as colorless oils. syn-4c: $[\alpha]_{\mathrm{D}}{ }^{22}=-63.7\left(\mathrm{c}=0.19, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR ( 500 MHz , $\left.\mathrm{CDCl}_{3}\right): \delta=-0.30\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.10\left(\mathrm{~s}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.88(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.28,1.33(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $2.65\left(\mathrm{~m}_{\mathrm{c}}, 2 \mathrm{H}, \mathrm{DHF}\right), 3.36\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.61(\mathrm{t}, \mathrm{J}=7.5 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.86,4.06(2$ $\mathrm{m}_{\mathrm{c}}, 1 \mathrm{H}$ each, $\mathrm{NCH}_{2}$ ), $3.98\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 5-\mathrm{H}\right), 4.22-4.36(\mathrm{~m}, 3 \mathrm{H}, \mathrm{DHF}, 4-\mathrm{H}), 4.89(\mathrm{t}, J=2.1 \mathrm{~Hz}, 1 \mathrm{H}$, 1-H), 7.15-7.48 (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.8\left(\mathrm{q}, \mathrm{SiMe}_{2}\right), 17.8,26.1$ (s, q, $t \mathrm{Bu}$ ), 25.5, 26.7 ( $2 \mathrm{q}, \mathrm{Me}$ ), 30.0 (t, DHF), 61.1 (t, NCH ${ }_{2}$ ), 67.5 (t, C-5), 69.0 (t, DHF), 74.2 (d, C-4), 99.9 (d, C-1), 109.2 (s, C-2'), 127.0, 128.0, 129.7 (3 d, Ph) ppm. IR (film): 3100-2820 $\mathrm{cm}^{-1}$ (=C-H, C-H). ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{23} \mathrm{H}_{37} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 442.2379$, found 442.2380 .

## $N$-Benzyl- $O$-(tert-butyldimethylsilyl)- $N$-[(R)-(4,5-dihydrofuran-2-yl)((S)-2,2-dimethyl-1,3-dioxolan-4-yl)methyl]hydroxylamine (anti-4c)



2,3-Dihydrofuran ( $802 \mu \mathrm{~L}, 10.6 \mathrm{mmol}$ ) was dissolved in THF ( 10 mL ) and cooled to $-78{ }^{\circ} \mathrm{C}$. $t \mathrm{BuLi}(1.6 \mathrm{M}$ in pentane, $6.63 \mathrm{~mL}, 10.6 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0^{\circ} \mathrm{C}$. After further stirring for 3 h at this temperature, it was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}(500 \mathrm{mg}, 2.12 \mathrm{mmol})$ in THF ( 4 mL ) was treated with $\mathrm{Et}_{2} \mathrm{AlCl}(1 \mathrm{M}$ in hexane, $2.12 \mu \mathrm{~L}, 2.12 \mathrm{mmol}$ ) for 5 min . The prepared solution was added dropwise over a period of 15 min . The mixture was then stirred at this temperature for another 15 min and the reaction quenched by the addition of 2 M NaOH solution. After the mixture reached room temperature it was extracted 3 times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 680 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(10 \mathrm{~mL}$ ), and 2,6-lutidine ( $519 \mu \mathrm{~L}, 4.45 \mathrm{mmol}$ ) and TBSOTf ( $268 \mu \mathrm{~L}, 3.35 \mathrm{mmol}$ ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and the reaction was then quenched by the addition of a sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded syn-4c ( $77 \mathrm{mg}, 9 \%$ ) and anti-4c (478 mg, $54 \%$ ) as colorless oils. anti-4c: $[\alpha]_{\mathrm{D}}{ }^{22}=+46.8(\mathrm{c}=0.41$, $\mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.24\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right),-0.19\left(\mathrm{~s}, 3 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.85(\mathrm{~s}$, $9 \mathrm{H}, t \mathrm{Bu}), 1.31,1.33\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), 2.73 ( $\left.\mathrm{m}_{\mathrm{c}}, 2 \mathrm{H}, \mathrm{DHF}\right), 3.39\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.83\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}\right.$, $5-\mathrm{H}), 3.83,3.94\left(2 \mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}\right.$ each, $\mathrm{NCH}_{2}$ ), 4.06 (dd, $\left.J=5.9,8.5 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}\right), 4.32-4.39(\mathrm{~m}, 2 \mathrm{H}$, DHF, 4-H) 4.42 (q, $J=8.9 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{DHF}), 4.97(\mathrm{t}, J=2.4 \mathrm{~Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 7.19-7.37(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph})$ ppm. ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.6\left(\mathrm{q}, \mathrm{SiMe}_{2}\right.$ ), 17.8, $26.0(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 25.7,26.9(2 \mathrm{q}$, Me), 30.2 (t, DHF), 67.9 (t, C-5), 69.3 (t, DHF), 74.3 (d, C-4), 109.1 ( s, C-2'), 127.3, 128.1, 130.2, 137.8 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ) ppm. IR (film): 3100-2820 $\mathrm{cm}^{-1}$ (=C-H, C-H). ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{23} \mathrm{H}_{37} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 442.2379$, found 442.2377.

N -Benzyl- O -(tert-butyldimethylsilyl)- N -((S)-2-ethoxy-1-((S)-1,4-dioxaspiro[4.5]decan-2yl)allyl)hydroxylamine (syn-4d)


Ethylvinylether ( $289 \mu \mathrm{~L}, 3.00 \mathrm{mmol}$ ) was dissolved in THF $(6 \mathrm{~mL})$ and cooled to $-78{ }^{\circ} \mathrm{C} . t \mathrm{BuLi}$ ( 1.6 M in pentane, $1.88 \mathrm{~mL}, 3.00 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0{ }^{\circ} \mathrm{C}$. After further stirring for 1 h at this temperature, it was once more cooled to $-78{ }^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 b}(550 \mathrm{mg}, 2.00 \mathrm{mmol})$ in THF ( 2 mL ) was added dropwise over a period of 15 min . The mixture was then stirred at this temperature for 1 h and the reaction quenched by the addition of $\mathrm{H}_{2} \mathrm{O}$. After the mixture reached room temperature it was extracted three times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 600 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(5 \mathrm{~mL}$ ), and 2,6-lutidine ( $303 \mu \mathrm{~L}, 2.60 \mathrm{mmol}$ ) and TBSOTf ( $499 \mu \mathrm{~L}, 2.17$ mmol ) were added slowly at $0^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and was the reaction quenched by the addition of a sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded syn-4d $(648 \mathrm{mg}, 70 \%, \mathrm{dr}>95: 5)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-12.1\left(\mathrm{c}=0.10, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR $\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=0.01(\mathrm{~s}, 6 \mathrm{H}$, $\mathrm{SiMe}_{2}$ ), 0.87 ( $\mathrm{s}, 9 \mathrm{H}, \mathrm{tBu}$ ), 1.27 (t, $J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}$ ), 1.30-1.37 (m, $2 \mathrm{H}, \mathrm{Cy}$ ), 1.45-1.70 (m, 8 $\mathrm{H}, \mathrm{Cy}), 3.25\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.55\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 5-\mathrm{H}\right), 3.64-3.73(\mathrm{~m}, 2 \mathrm{H}, \mathrm{Et}), 3.98\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 5-\mathrm{H}\right)$, $4.01\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 1-\mathrm{H}\right), 4.10-4.18\left(\mathrm{~m}, 2 \mathrm{H}, 1-\mathrm{H}, \mathrm{NCH}_{2}\right), 4.38(\mathrm{td}, J=6.7,9.1 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 7.15-$ $7.41(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.1,-4.8\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.5(\mathrm{t}, \mathrm{Et})$, 17.9, 26.2 ( s, q, $t \mathrm{Bu}$ ), 24.0, 25.7, 35.2, $36.5(4 \mathrm{t}, \mathrm{Cy}), 60.4\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 62.2(\mathrm{t}, \mathrm{Et}), 67.3(\mathrm{t}, \mathrm{C}-5)$, 73.8 (d, C-4), 87.3 (t, C-1), 109.8 ( s, C-2'), 126.9, 127.9, 129.6, 138.4 (3 d, s, Ph), 157.3 (s, C-2) ppm. IR (film): 3100-2820 $\mathrm{cm}^{-1}(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{36} \mathrm{H}_{43} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+}$ 484.2854, found 484.2854.
$N$-Benzyl- $O$-(tert-butyldimethylsilyl)- $N$-((1S)-2-ethoxy-1-((4S,4'R)-2,2,2',2'-tetramethyl-4,4'-bi(1,3-dioxolan)-5-yl)allyl)hydroxylamine (anti-4e)


Ethyl vinyl ether ( $717 \mu \mathrm{~L}, 7.45 \mathrm{mmol}$ ) was dissolved in THF ( 12 mL ) and cooled to $-78{ }^{\circ} \mathrm{C}$. $t \mathrm{BuLi}(1.6 \mathrm{M}$ in pentane, $4.66 \mathrm{~mL}, 7.45 \mathrm{mmol}$ ) was added and the reaction mixture was stirred for 1 h during which time it was allowed to warm to $0^{\circ} \mathrm{C}$. After further stirring for 3 h at this temperature, it was once more cooled to $-78^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 c}(500 \mathrm{mg}, 1.49 \mathrm{mmol})$ in THF ( 3 mL ) was treated with $\mathrm{Et}_{2} \mathrm{AlCl}(1 \mathrm{M}$ in hexane, $1.49 \mathrm{~mL}, 1.49 \mathrm{mmol}$ ) for 5 min . The prepared solution was added dropwise over a period of 15 min . Then, the mixture was stirred at this temperature for another 15 min and the reaction quenched by the addition of 2 M NaOH solution. After the mixture reached room temperature it was extracted 3 times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 570 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(6 \mathrm{~mL})$, and 2,6-lutidine ( $310 \mu \mathrm{~L}, 2.10 \mathrm{mmol}$ ) and TBSOTf ( $462 \mu \mathrm{~L}, 2.81 \mathrm{mmol}$ ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and the reaction quenched by the addition of sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=20: 1$ ) yielded anti-4e (205 $\mathrm{mg}, 26 \%$, d.r. $>95: 5$ ) as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-12.3\left(\mathrm{c}=0.20, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR ( 500 MHz , $\left.\mathrm{CDCl}_{3}\right): \delta=-0.18\left(\mathrm{~s}_{\mathrm{br}}, 6 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.81(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.32(\mathrm{t}, J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}), 1.35,1.38$, $1.39,1.41$ (4 s, 3 H each, Me), 3.73 (d, $J=6.0 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}$ ), 3.76-3.82 (m, $2 \mathrm{H}, \mathrm{Et}$ ), 3.90-4.02, 4.10-4.20, 4.25-4.30, 4.48-4.53 (4 m, 9 H, 1-H, 4-H, 5-H, 6-H, 7-H, NCH $)_{2}$, 7.19-7.38 (m, 5 H , $\mathrm{Ph}) \mathrm{ppm}$. Characteristic signals in ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-6.2,-4.8\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.6$ (q, Et), 17.8, 26.2 (s, q, $t \mathrm{Bu}$ ), 25.5, 26.15, 26.16, 26.5 ( $4 \mathrm{q}, \mathrm{Me}$ ), 60.4 (t, $\mathrm{NCH}_{2}$ ), 62.4 (t, Et), 77.8 (t, C-7), 87.4 (t, C-1), 109.7, 109.8 ( $2 \mathrm{~s}, \underline{\mathrm{CMe}} \mathrm{Cl}_{2}$ ), 126.9, 127.7, 130.8, 139.0 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 157.0 (s, C-2) ppm. IR (ATR): $3100-2830 \mathrm{~cm}^{-1}$ (=C-H, C-H). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{28} \mathrm{H}_{48} \mathrm{NO}_{6} \mathrm{Si}[\mathrm{M}+$ $\mathrm{Na}]^{+} 544.3065$, found 544.3074 . pyran-2-yl)methanol (cis-5a)


To a solution of syn-4a ( $135 \mathrm{mg}, 0.321 \mathrm{mmol}$ ) in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(2 \mathrm{~mL})$ at $-30^{\circ} \mathrm{C}$, was added TMSOTf $(119 \mu \mathrm{~L}, 0.643 \mathrm{mmol})$, and the resulting solution stirred until it slowly reached room temperature (6 h). The reaction was then quenched by the addition of water. After separation of the layers, the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=6: 1$ ) yielded cis-5a $(106 \mathrm{mg}, 79 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-118.6(\mathrm{c}=$ $0.25, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $400 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.05,0.03\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), $0.79(\mathrm{~s}, 9 \mathrm{H}$, $t \mathrm{Bu}), 1.24,1.31(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $1.37(\mathrm{t}, J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}), 3.55(\mathrm{dd}, J=2.1,7.1 \mathrm{~Hz}, 1 \mathrm{H}$, $3-\mathrm{H}), 3.75$ (q, $J=7.0 \mathrm{~Hz}, 2 \mathrm{H}, \mathrm{Et}$ ), 3.89-3.98 (m, $3 \mathrm{H}, 2-\mathrm{H}, \mathrm{OH}$ ), 4.11 ( $\mathrm{m}_{\mathrm{c}}, 2 \mathrm{H}, 1-\mathrm{H}$ ), 4.73 ( $\mathrm{s}, 1$ $\mathrm{H}, 5-\mathrm{H}), 7.21-7.26(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.0\left(\mathrm{q}, \mathrm{SiMe}_{3}\right), 14.9(\mathrm{q}$, Et), 17.8, 26.1 (s, q, $t \mathrm{Bu}$ ), 25.9, 30.3 (2 q, Me), 62.0 (t, C-1), 62.3 (t, Et), 64.2 (d, C-3), 73.0 ( $\mathrm{s}, \mathrm{C}-$ 6), 73.4 (d, C-2), 106.7 (d, C-5), 127.2, 128.0, 130.6, 139.0 (3 d, s, Ph), 149.8 (s, C-4) ppm. IR (film): $3450 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2840(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1660(\mathrm{C}=\mathrm{C})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $[\mathrm{M}+\mathrm{H}]^{+}$ 422.2727, found 422.2753. Anal. calc. for $\mathrm{C}_{23} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (421.7): C 65.52, H 9.32, N 3.32, found: C 65.12, H 9.54, N 3.37.
((2S,3R)-3-[Benzyl(tert-butyldimethylsiloxy)amino]-4-ethoxy-6,6-dimethyl-3,6-dihydro-2H-pyran-2-yl)methanol (trans-5a)


To a solution of anti-4a ( $1.83 \mathrm{~g}, 4.34 \mathrm{mmol})$ in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(25 \mathrm{~mL})$ at $-30{ }^{\circ} \mathrm{C}$ was added TMSOTf $(1.60 \mu \mathrm{~L}, 8.27 \mathrm{mmol})$, and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. After separation of the layers, the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column
chromatography (silica gel, hexane/EtOAc $=6: 1$ ) yielded trans-5a ( $1.53 \mathrm{~g}, 84 \%$ ) as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=+69.7\left(\mathrm{c}=0.66, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.16,0.01(2 \mathrm{~s}, 3 \mathrm{H}$ each, $\mathrm{SiMe}_{2}$ ), $0.82(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.23,1.29\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), $1.41(\mathrm{t}, J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}), 2.81\left(\mathrm{~s}_{\mathrm{br}}, 1\right.$ $\mathrm{H}, \mathrm{OH}), 3.36\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.53\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 1-\mathrm{H}\right), 3.65-3.78(\mathrm{~m}, 2 \mathrm{H}, \mathrm{Et}), 3.82(\mathrm{td}, J=5.5,10.6$ $\mathrm{Hz}, 1 \mathrm{H}, 1-\mathrm{H}), 3.95\left(\mathrm{~d}, J=12.5 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.00\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 2-\mathrm{H}\right), 4.34\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.69$ $(\mathrm{d}, J=1.1 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 7.18-7.35(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.9$, $-4.7\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.9$ (q, Et), 17.8, 26.0 (s, q, $t \mathrm{Bu}$ ), 26.7, 31.2 ( $2 \mathrm{q}, \mathrm{Me}$ ), 61.0 (d, C-3), 62.2 (t, Et), 64.9 (t, C-1), 70.2 (d, C-2), 72.5 (s, C-6), 105.7 (d, C-5), 127.3, 128.1, 130.3, 137.9 (3 d, s, Ph), 151.5 ( $\mathrm{s}, \mathrm{C}-4$ ) ppm. IR (film): $3400 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2840(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1660(\mathrm{C}=\mathrm{C})$. ESITOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{H}]^{+} 422.2727$, found 422.2744. Anal. calc. for $\mathrm{C}_{23} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}$ (421.7): C 65.52, H 9.32, N 3.32, found: C 65.32, H 9.28, N 3.39 .
((7S,8S)-8-[Benzyl(tert-butyldimethylsiloxy)amino]-5,5-dimethyl-2,3,4,5,7,8-hexahydropyrano[4,3-b]pyran-7-yl)methanol (cis-5b)


To a solution of syn-4b ( $590 \mathrm{mg}, 1.36 \mathrm{mmol}$ ) in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(6 \mathrm{~mL})$ at $-30{ }^{\circ} \mathrm{C}$ was added TMSOTf ( $501 \mu \mathrm{~L}, 2.72 \mathrm{mmol}$ ), and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. The resulting mixture was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=6: 1$ ) yielded cis-5b $(434 \mathrm{mg}, 74 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-130.2(\mathrm{c}=$ $0.58, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-0.37\left(\mathrm{~s}_{\mathrm{br}}, 6 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.79(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.26$, 1.30 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.81-1.92 (m, $3 \mathrm{H}, \mathrm{DHP}$ ), 2.06 ( $\mathrm{m}_{\mathrm{c}}, 1 \mathrm{H}, \mathrm{DHP}$ ), 3.49 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 8-\mathrm{H}$ ), 3.64 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 7-\mathrm{CH}_{2}$ ), $3.87-3.97\left(\mathrm{~m}, 3 \mathrm{H}, 7-\mathrm{H}, 7-\mathrm{CH}_{2}, \mathrm{NCH}_{2} \text { ), 4.01-4.18(m,3 H, DHP, NCH }\right)^{2}$, 7.16-7.32 (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.3\left(\mathrm{q}, \mathrm{SiMe}_{2}\right), 17.7,26.0(\mathrm{~s}, \mathrm{q}$, $t \mathrm{Bu}$ ), 20.6, 22.6 ( $2 \mathrm{t}, \mathrm{DHP}$ ), 23.5, 27.7 ( $2 \mathrm{q}, \mathrm{Me}$ ), $64.0\left(\mathrm{t}, 7-\mathrm{CH}_{2}\right.$ ), 65.2 (t, DHP), 72.6 (d, C-7), 75.2 (s, C-5), 115.4 (s, C-4a), 127.0, 127.9, 130.6, 139.2 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 143.2 (s, C-8a) ppm. IR (film): $3450 \mathrm{~cm}^{-1}(\mathrm{OH}), 3100-2850(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1660(\mathrm{C}=\mathrm{C})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{24} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{H}]^{+} 434.2721$, found 434.2724.
((7S,8R)-8-(Benzyl(tert-butyldimethylsiloxy)amino)-5,5-dimethyl-2,3,4,5,6,7,8-
hexahydropyrano[4,3-b]pyran-7-yl)methanol (trans-5b)


To a solution of anti-4b ( $270 \mathrm{mg}, 0.622 \mathrm{mmol}$ ) in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(3 \mathrm{~mL})$ at $-30{ }^{\circ} \mathrm{C}$ was added TMSOTf ( $228 \mu \mathrm{~L}, 1.25 \mathrm{mmol}$ ), and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. The resulting mixture was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=6: 1$ ) yielded trans-5b $(221 \mathrm{mg}, 82 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}^{22}=+39.8(\mathrm{c}=$ $0.49, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.24,0.05\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), $0.85(\mathrm{~s}, 9 \mathrm{H}$, $t \mathrm{Bu}$ ), 1.23, 1.29 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.79-1.93 (m, 3 H, DHP), 2.02-2.10 (m, 1 H, DHP), 2.84 $\left(\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.36(\mathrm{~d}, J=7.4 \mathrm{~Hz}, 1 \mathrm{H}, 8-\mathrm{H}), 3.51\left(\mathrm{td}, J=5.2,10.6 \mathrm{~Hz}, 1 \mathrm{H}, 7-\mathrm{CH}_{2}\right), 3.81\left(\mathrm{~m}_{\mathrm{c}}, 1\right.$ $\left.\mathrm{H}, 7-\mathrm{CH}_{2}\right), 3.86\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, \mathrm{OCH}_{2}\right), 3.92\left(\mathrm{~d}, J=12.6 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.01\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 7-\mathrm{H}\right), 4.14$ $\left(\mathrm{m}_{\mathrm{c}}, 1 \mathrm{H}, \mathrm{OCH}_{2}\right), 4.33\left(\mathrm{~d}, J=12.6 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 7.16-7.34(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR (101 $\mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.0,-4.6\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.8,26.1(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 20.9,22.8(2 \mathrm{t}, \mathrm{DHP}), 24.4,28.7$ ( $2 \mathrm{q}, \mathrm{Me}$ ), $60.6\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 65.0\left(\mathrm{t}, \mathrm{OCH}_{2}\right), 65.1\left(\mathrm{t}, 7-\mathrm{CH}_{2}\right), 69.4(\mathrm{~d}, \mathrm{C}-7), 74.5(\mathrm{~s}, \mathrm{C}-5), 114.3(\mathrm{~s}$, C-4a), 127.2, 128.1, 130.3, 138.2 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 144.3 ( $\mathrm{s}, \mathrm{C}-8 \mathrm{a}$ ) ppm. IR (film): $3450 \mathrm{~cm}^{-1}(\mathrm{OH})$, 3100-2850 (=C-H, C-H), 1670 (C=C). ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{H}]^{+}$434.2721, found 434.2719.
((6S,7S)-7-[Benzyl(tert-butyldimethylsiloxy)amino]-4,4-dimethyl-3,4,6,7-tetrahydro-2H-furo[3,2-c]pyran-6-yl)methanol (cis-5c)


To a solution of syn-4c ( $1.52 \mathrm{~g}, 3.62 \mathrm{mmol}$ ) in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(15 \mathrm{~mL})$ at $-30{ }^{\circ} \mathrm{C}$ was added TMSOTf $(1.32 \mathrm{~mL}, 7.24 \mathrm{mmol})$, and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. The resulting
mixture was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=6: 1)$ yielded cis-5c $(1.29 \mathrm{~g}, 85 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-130.0(\mathrm{c}=$ $0.61, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.51,-0.25\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\left.\mathrm{SiMe}_{2}\right), 0.80(\mathrm{~s}, 9$ $\mathrm{H}, t \mathrm{Bu}), 1.26,1.32$ (2 s, 3 H each, Me), 2.53-2.66 (m, $2 \mathrm{H}, \mathrm{DHF}$ ), $3.28\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.64\left(\mathrm{~s}_{\mathrm{br}}, 1\right.$ $\mathrm{H}, 6-\mathrm{H}), 3.84\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.91\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.96\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 4-\mathrm{H}\right), 4.10(\mathrm{~d}, J=13.4 \mathrm{~Hz}, 1$ $\left.\mathrm{H}, \mathrm{NCH}_{2}\right), 4.13\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.37-4.45(\mathrm{~m}, 2 \mathrm{H}, \mathrm{DHF}), 7.17-7.32(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.3,-5.1\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.7,26.0(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 23.1,27.8(2 \mathrm{q}, \mathrm{Me})$, 29.6 (t, DHF), $60.8\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 62.6$ (d, C-7), $63.8\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 69.1$ (t, DHF), 73.1 (d, C-6), 74.1 ( s , C-4), 117.4 (s, C-3a), 127.1, 127.9, 130.6, 138.6 ( 3 d , s, Ph), 146.8 (s, C-7a) ppm. IR (film): 3460 $\mathrm{cm}^{-1}(\mathrm{OH}), 3100-2800(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1690(\mathrm{C}=\mathrm{C})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{23} \mathrm{H}_{37} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+$ $\mathrm{Na}]^{+} 442.2379$, found 442.2377 .
((6S,7R)-7-(Benzyl(tert-butyldimethylsiloxy)amino)-4,4-dimethyl-3,4,6,7-tetrahydro-2H-furo[3,2-c]pyran-6-yl)methanol (trans-5c)


To a solution of anti-4c (209 mg, 0.498 mmol$)$ in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(2 \mathrm{~mL})$ at $-30^{\circ} \mathrm{C}$ was added TMSOTf $(182 \mu \mathrm{~L}, 0.996 \mathrm{mmol})$, and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. After separation of the phases the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=6: 1$ ) yielded trans- $5 \mathbf{c}(115 \mathrm{mg}, 55 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=+56.5\left(\mathrm{c}=0.93, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-0.13,0.03\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), 0.86 ( $\mathrm{s}, 9 \mathrm{H}, t \mathrm{Bu}$ ), 1.24, 1.31 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 2.43-2.51 (m, $1 \mathrm{H}, \mathrm{DHF}$ ), 2.57$2.67(\mathrm{~m}, 1 \mathrm{H}, \mathrm{DHF}), 2.67\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.41\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 7-\mathrm{H}\right), 3.54\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.84\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}\right.$, $\left.6-\mathrm{CH}_{2}\right), 3.90-3.99\left(\mathrm{~m}, 2 \mathrm{H}, 6-\mathrm{H}, \mathrm{NCH}_{2}\right), 4.22-4.29\left(\mathrm{~m}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.34(\mathrm{q}, J=9.0 \mathrm{~Hz}, 1 \mathrm{H}$, DHF), 4.44 (ddd, $J=6.3,9.0,10.5 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{DHF}$ ), $7.18-7.39(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR (101 $\left.\mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-4.9,-4.6\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.7,26.0(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 24.5,28.1(2 \mathrm{q}, \mathrm{Me}), 29.7(\mathrm{t}$, DHF), $60.9\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 64.4\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 69.4$ (t, DHF), 70.3 (d, C-6), 73.4 ( $\mathrm{s}, \mathrm{C}-4$ ), 116.1 ( $\mathrm{s}, \mathrm{C}-3 \mathrm{a}$ ),
127.4, 128.0, 130.0, 137.7 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 148.2 (s, C-7a) ppm. IR (film): $3460 \mathrm{~cm}^{-1}(\mathrm{OH}), 3100-$ 2800 (=C-H, C-H), 1700 (C=C). ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{23} \mathrm{H}_{37} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 442.2379$, found 442.2357.
((2S,3S)-3-(Benzyl(tert-butyldimethylsiloxy)amino)-4-ethoxy-1-oxaspiro[5.5]undec-4-en-2yl)methanol (cis-5d)


To a solution of syn-4d (420 mg, 0.910 mmol$)$ in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(6 \mathrm{~mL})$ at $-30^{\circ} \mathrm{C}$ was added TMSOTf ( $331 \mu \mathrm{~L}, 1.82 \mathrm{mmol}$ ), and the resulting solution was stirred until it slowly reached room temperature ( 6 h ). The reaction was then quenched by the addition of water. After separation of the phases the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=10: 1$ ) yielded cis- $\mathbf{5 d}(380 \mathrm{mg}, 90 \%)$ as colorless crystals. $[\alpha]_{\mathrm{D}}{ }^{22}=-108.0\left(\mathrm{c}=0.14, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-0.51,-0.27(2 \mathrm{sbr}$, 3 H each, $\mathrm{SiMe}_{2}$ ), $0.80(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.21-1.81(\mathrm{~m}, 10 \mathrm{H}, \mathrm{Cy}), 1.37(\mathrm{t}, J=7.0 \mathrm{~Hz}, 3 \mathrm{H}, \mathrm{Et}), 3.45$ $\left(\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.55\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.75(\mathrm{q}, J=7.0 \mathrm{~Hz}, 2 \mathrm{H}, \mathrm{Et}), 3.82-3.96(\mathrm{~m}, 3 \mathrm{H}, 2-\mathrm{H}, 1-\mathrm{H}$, $\mathrm{NCH}_{2}$ ), 4.09-4.21 (m, 2 H, 1-H, $\mathrm{NCH}_{2}$ ), $4.77(\mathrm{~s}, 1 \mathrm{H}, 5-\mathrm{H}), 7.19-7.34(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.4,-5.2\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 14.7(\mathrm{q}, \mathrm{Et}), 17.6,25.9(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 21.7$, 22.1, 25.4, 33.3, 38.7 ( $5 \mathrm{t}, \mathrm{Cy}$ ), 60.6 (t, $\mathrm{NCH}_{2}$ ), 62.0 (t, Et), 64.0 (t, C-1), 65.3 (d, C-3), 72.3 ( $\mathrm{s}, \mathrm{C}-$ 6), 73.5 (d, C-2), 106.0 (d, C-5), 126.9, 127.7, 130.6, 139.0 (3 d, s, Ph), 150.1 (s, C-4) ppm. IR (film): $3450 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2840(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1660(\mathrm{C}=\mathrm{C})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $[\mathrm{M}+$ $\mathrm{Na}]^{+}$484.2848, found 484.2868. Anal. calc. for $\mathrm{C}_{26} \mathrm{H}_{43} \mathrm{NO}_{4} \mathrm{Si}$ (461.7): C 67.64, H 9.39, N 3.03, found: C 67.29, H 9.66, N 2.90 .

## N -Benzyl- O -(tert-butyldimethylsilyl)- N -((S)-((S)-2,2-dimethyl-1,3-dioxolan-4-yl)(furan-2yl)methyl)hydroxylamine (syn-4f)



Furan ( $279 \mu \mathrm{~L}, 3.84 \mathrm{mmol}$ ) was dissolved in THF ( 4 mL ) and cooled to $-78{ }^{\circ} \mathrm{C} . n \mathrm{BuLi}(2.5 \mathrm{M}$ in hexanes, $1.54 \mathrm{~mL}, 3.84 \mathrm{mmol}$ ) was added and the reaction mixture stirred for 1 h during which time it was allowed to warm to $0^{\circ} \mathrm{C}$. After further stirring for 1 h at this temperature, it was once more cooled to $-78{ }^{\circ} \mathrm{C}$. A solution of nitrone $\mathbf{2 a}(300 \mathrm{mg}, 1.28 \mathrm{mmol})$ in THF ( 1 mL ) was added dropwise over a period of 15 min . Then, the mixture was stirred at this temperature for 2 h and the reaction quenched by the addition of a sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. After the mixture reached room temperature it was extracted three times with $\mathrm{Et}_{2} \mathrm{O}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. The crude product ( 340 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(5 \mathrm{~mL})$, and 2,6-lutidine ( $190 \mu \mathrm{~L}, 1.63 \mathrm{mmol}$ ) and TBSOTf ( $281 \mu \mathrm{~L}, 1.22 \mathrm{mmol}$ ) were added slowly at $0{ }^{\circ} \mathrm{C}$. The mixture was stirred at room temperature for 30 min and then the reaction was quenched by the addition of sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution. The phases were separated and the aqueous phase was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane $/ E t O A c=20: 1)$ yielded $\operatorname{syn}-4 \mathbf{f}(294 \mathrm{mg}, 55 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-71.8(\mathrm{c}=$ $0.60, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=0.15,0.26\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), $0.93(\mathrm{~s}, 9 \mathrm{H}$, $t \mathrm{Bu}), 1.26,1.36\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), $3.43\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.59\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 5-\mathrm{H}\right), 3.75-3.90(\mathrm{~m}, 2 \mathrm{H}$, $\mathrm{NCH}_{2}$ ), $4.04\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 5-\mathrm{H}\right), 4.55\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 4-\mathrm{H}\right), 6.32(\mathrm{~d}, J=3.1 \mathrm{~Hz}, 1 \mathrm{H}, 3$ '-H), 6.38 (dd, $J=1.8$, $\left.3.1 \mathrm{~Hz}, 1 \mathrm{H}, 4^{\prime}-\mathrm{H}\right), 7.19-7.41\left(\mathrm{~m}, 6 \mathrm{H}, \mathrm{Ph}, 5^{\prime}-\mathrm{H}\right) \mathrm{ppm} .{ }^{13} \mathrm{C} \mathrm{NMR}\left(126 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=-4.8(\mathrm{q}$, $\mathrm{SiMe}_{2}$ ), 17.8, 26.1 (s, q, $t \mathrm{Bu}$ ), 25.6, 26.6 ( $2 \mathrm{q}, \mathrm{Me}$ ), $61.2\left(\mathrm{t}, \mathrm{NCH}_{2}\right.$ ), 67.3 (t, C-5), 74.7 (d, C-4), 109.4 ( $\mathrm{s}, \underline{\mathrm{CMe}} 2_{2}$ ), 128.2 (d, C-4'), 129.4 (d, C-3'), 127.2, 128.2, 129.4 (3 d, Ph), 141.8 (d, C-5') ppm. IR (film): $3100-2830 \mathrm{~cm}^{-1}(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{23} \mathrm{H}_{35} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+}$ 440.2228 , found 440.2223 .
(5S,6S)-5-[Benzyl(hydroxy)amino]-6-(hydroxymethyl)-2,2-dimethyldihydro-2H-pyran4(3H) one (8)


To compound cis-5a ( $350 \mathrm{mg}, 0.830 \mathrm{mmol}$ ), was added satd. methanolic $\mathrm{HCl}(20 \mathrm{~mL})$ and the resulting mixture stirred for 12 h at room temperature. Then the solvent was removed in vacuo and satd. $\mathrm{NaHCO}_{3}$ solution and $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ added to the residue. The layers were separated and the aqueous phase was extracted twice with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo to yield $\mathbf{8}(180 \mathrm{mg}, 78 \%)$ as a brownish oil. The product was used in the next step (preparation of 23) without further purification.
(3S,5S,6S)-5-[Benzyl(tert-butyldimethylsilyl)amino]-3-hydroxy-6-(hydroxymethyl)-2,2-dimethyldihydro-2H-pyran-4(3H)one (9)


To a solution of cis-5a ( $260 \mathrm{mg}, 0.616 \mathrm{mmol}$ ) in acetone ( 3 mL ), were added $\mathrm{H}_{2} \mathrm{O}(300 \mu \mathrm{~L})$, $\mathrm{K}_{2} \mathrm{OsO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}(16 \mathrm{mg}, 0.043 \mathrm{mmol})$ and $N$-methylmorpholine- N -oxide ( $50 \mathrm{wt} \%$ in $\mathrm{H}_{2} \mathrm{O}, 170 \mu \mathrm{~L}$, 0.840 mmol ). The reaction mixture was stirred for 3 d at room temperature. Solid $\mathrm{Na}_{2} \mathrm{SO}_{3}$ (106 $\mathrm{mg}, 0.840 \mathrm{mmol}$ ) was then added and the mixture was stirred for 1 h . The mixture was filtered through a pad of celite, dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=3: 1$ ) yielded $9(193 \mathrm{mg}, 76 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-6.0\left(\mathrm{c}=0.52, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=0.30\left(\mathrm{~s}_{\mathrm{br}}, 6 \mathrm{H}, \mathrm{SiMe}_{2}\right), 0.90(\mathrm{~s}$, $9 \mathrm{H}, t \mathrm{Bu}), 1.06,1.42\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), $1.94\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.36\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right), 3.63\left(\mathrm{~s}_{\mathrm{br}}, 2 \mathrm{H}\right), 3.79$ $(\mathrm{d}, J=12.1 \mathrm{~Hz}, 1 \mathrm{H}), 3.85-4.01(\mathrm{~m}, 2 \mathrm{H}), 4.12\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right), 4.40(\mathrm{~d}, J=3.3 \mathrm{~Hz}, 1 \mathrm{H}), 7.24-7.41(\mathrm{~m}$, $5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.7\left(\mathrm{q}, \mathrm{SiMe}_{2}\right), 18.0,28.2(2 \mathrm{q}, \mathrm{Me}), 18.6,25.9$ (s, q, $t \mathrm{Bu}$ ), 62.3, 63.6, 73.0, 83.6, 128.2, $128.8,130.0 \mathrm{ppm}$. IR (film): $3480 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-$ $2820(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $m / z$ calc. for $\mathrm{C}_{21} \mathrm{H}_{35} \mathrm{NO}_{5} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 432.2177$, found 432.2184.
(3S,5S,6S)-5-[Benzyl(tert-butyldimethylsiloxy)amino]-3-bromo-6-(hydroxymethyl)-2,2-dimethyldihydro-2H-pyran-4(3H)one (10) and (3S,5S,6S)-5-[Benzyl(hydroxy)amino]3-bromo-6-(hydroxymethyl)-3,3-dimethyldihydro-2H-pyran-4(3H)one (11)

and


To a solution of cis-5a (100 mg, 0.237 mmol$)$ in $\mathrm{MeCN}(2 \mathrm{~mL})$, were added $\mathrm{H}_{2} \mathrm{O}(200 \mu \mathrm{~L})$ and $N$-bromosuccinimide ( $42 \mathrm{mg}, 0.237 \mathrm{mmol}$ ). After stirring the reaction mixture for 15 min , a further quantity of $\mathrm{H}_{2} \mathrm{O}$ was added and the mixture extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=10: 1$ to $2: 1$ ) yielded 10 (28 $\mathrm{mg}, 25 \%)$ and $11(44 \mathrm{mg}, 52 \%)$ as colorless oils. 10: $[\alpha]_{\mathrm{D}}{ }^{22}=-3.0\left(\mathrm{c}=1.91, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=0.29,0.36\left(2 \mathrm{sbr}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), $0.92(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.27,1.52(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $3.33\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.59\left(\mathrm{~d}, J=8.9 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 3.84(\mathrm{~d}, J=11.6 \mathrm{~Hz}, 1 \mathrm{H}, 2-$ $\left.\mathrm{CH}_{2}\right), 3.88-3.98\left(\mathrm{~m}, 2 \mathrm{H}, 2-\mathrm{H}, \mathrm{NCH}_{2}\right), 4.03\left(\mathrm{~d}, J=11.6 \mathrm{~Hz}, 1 \mathrm{H}, 2-\mathrm{CH}_{2}\right), 5.03(\mathrm{~s}, 1 \mathrm{H}, 5-\mathrm{H})$, 7.22-7.40 (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CHCl}_{3}$ ): $\delta=-4.7,-3.6\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.9$, 25.9 (s, q, $t \mathrm{Bu}$ ), 20.7, 29.6 ( $2 \mathrm{q}, \mathrm{Me}$ ), 62.1 (t, $\mathrm{NCH}_{2}$ ), 63.2 (t, 2-CH2), 66.5 (d, C-3), 66.6 (d, C-5), 72.6 (d, C-2), 79.6 (s, C-6), 128.3, 128.9, 130.0, 135.5 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 197.0 ( $\mathrm{s}, \mathrm{C}-4$ ) ppm. IR (film): $3420 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2820(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1720(\mathrm{C}=\mathrm{O})$. ESI-TOF: $m / z$ calc. for $\mathrm{C}_{24} \mathrm{H}_{38} \mathrm{BrNO}_{4} \mathrm{Si}$ $[\mathrm{M}+\mathrm{Na}]^{+} 534.1640$, found 534.1655. 11: $[\alpha]_{\mathrm{D}}{ }^{22}=+64.4\left(\mathrm{c}=0.73, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR $(500 \mathrm{MHz}$, $\mathrm{CHCl}_{3}$ ): $\delta=1.30,1.54(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $3.44(\mathrm{~d}, J=4.4 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.79(\mathrm{~d}, J=13.2 \mathrm{~Hz}, 1$ $\mathrm{H}, \mathrm{NCH}_{2}$ ), 3.79 (dd, $J=4.4,12.1 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}$ ), $3.85\left(\mathrm{~d}, J=13.2 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right.$ ), 3.93 (dd, $J$ $\left.=4.4,12.1 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.01(\mathrm{q}, J=4.4 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}), 5.06(\mathrm{~s}, 1 \mathrm{H}, 3-\mathrm{H}), 6.15\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right)$, 7.22-7.38 (m, $5 \mathrm{H}, \mathrm{Ph})$ ppm. ${ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CHCl}_{3}$ ): $\delta=20.5,29.6(2 \mathrm{q}, \mathrm{Me}), 61.7(\mathrm{t}$, $\mathrm{NCH}_{2}$ ), $62.6\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 65.3$ (d, C-3), 71.8 (d, C-5), 72.1 (d, C-6), 80.0 (s, C-2), 127.8, 128.5, 129.4, 136.2 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 196.9 (s, C-4) ppm. IR (film): $3410 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2820$ (=C-H, CH), $1710(\mathrm{C}=\mathrm{O})$. ESI-TOF: $m / z$ calc. for $\mathrm{C}_{15} \mathrm{H}_{20} \mathrm{BrNO}_{4}[\mathrm{M}+\mathrm{Na}]^{+} 380.0462$, found 380.0478.
(3R,5R,6S)-5-[Benzyl(tert-butyldimethylsiloxy)amino]3-hydroxy-6-(hydroxymethyl)-2,2-dimethyldihydro-2H-pyran-4(3H)one (13) and (3R,4R,5R,6S)-5-[Benzyl(tert-butyldimethyl-siloxy)amino]4-ethoxy-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-3,4-diol (14)

and


To a solution of trans-5a ( $165 \mathrm{mg}, 0.391 \mathrm{mmol}$ ) in acetone ( 2 mL ), were added $\mathrm{H}_{2} \mathrm{O}(200 \mu \mathrm{~L})$, $\mathrm{K}_{2} \mathrm{OsO}_{4} \cdot 2 \mathrm{H}_{2} \mathrm{O}(24 \mathrm{mg}, 0.065 \mathrm{mmol})$ and $N$-methylmorpholine- $N$-oxide ( $50 \mathrm{wt} \%$ in $\mathrm{H}_{2} \mathrm{O}, 167 \mu \mathrm{~L}$, 0.825 mmol ). The reaction mixture was stirred for 3 d at room temperature. Solid $\mathrm{Na}_{2} \mathrm{SO}_{3}(50 \mathrm{mg}$, 0.391 mmol ) was then added and the mixture was stirred for 1 h . The mixture was filtered through a pad of celite, dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=3: 1$ ) gave starting material $(50 \mathrm{mg})$ and a mixture of the desired $\alpha$-hydroxyketone $\mathbf{1 3}$ and the hydroxylated hemiacetal 14 (108 mg, 1:1 ratio, 64\%) as a colorless oil. The components of the mixture could not been separated and was directly used in the next step (preparation of 29).
(3R,5R,6S)-5-[Benzyl(hydroxy)amino]3-bromo-6-(hydroxymethyl)-2,2-dimethyldihydro-2H-pyran-4(3H)one (15)


To a solution of trans-5a ( $500 \mathrm{mg}, 1.19 \mathrm{mmol}$ ) in $\mathrm{MeCN}(8 \mathrm{~mL})$, were added $\mathrm{H}_{2} \mathrm{O}(800 \mu \mathrm{~L})$ and $N$-bromosuccinimide ( $211 \mathrm{mg}, 1.19 \mathrm{mmol}$ ). After stirring the reaction mixture for 15 min , a further quantity of $\mathrm{H}_{2} \mathrm{O}$ was added and the mixture extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=2: 1$ ) yielded $15(298 \mathrm{mg}$, $70 \%$ ) as colorless crystals. M.p. $109-111{ }^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=-144.5\left(\mathrm{c}=0.38, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR (700 $\mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=1.40,1.42\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), 3.77 (dd, $J=3.6,11.6 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}$ ), 3.80 $\left(\mathrm{dd}, J=3.5,11.6 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.04(\mathrm{~s}, 1 \mathrm{H}, 3-\mathrm{H}), 4.17\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 6-\mathrm{H}\right), 4.20(\mathrm{~d}, J=12.8 \mathrm{~Hz}, 1$ $\left.\mathrm{H}, \mathrm{NCH}_{2}\right), 4.25(\mathrm{~d}, J=9.6 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 4.55\left(\mathrm{~d}, J=12.8 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 5.63\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right)$, 7.26-7.37 (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $176 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=22.7,28.0(2 \mathrm{q}, \mathrm{Me}), 59.2(\mathrm{~d}, \mathrm{C}-$
3), $62.5\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 63.6(\mathrm{~d}, \mathrm{C}-5), 63.7\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 73.6(\mathrm{~d}, \mathrm{C}-6), 74.8(\mathrm{~s}, \mathrm{C}-2), 127.8,128.5,129.1$, 136.7 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 202.1 ( $\mathrm{s}, \mathrm{C}-4$ ) ppm. IR (KBr): $3260 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2820(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1730$ (C=O). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{15} \mathrm{H}_{20} \mathrm{BrNO}_{4}[\mathrm{M}+\mathrm{Na}]^{+} 380.0462$, found 380.0453.
(3R,5R,6S)-5-(Benzyl(hydroxy)amino)-3-bromo-6-(hydroxymethyl)-3-(3-hydroxypropyl)-2,2-dimethyldihydro-2H-pyran-4(3H)one (16)


To a solution of trans-5b (1.15 g, 2.66 mmol$)$ in $\mathrm{MeCN}(15 \mathrm{~mL})$, were added $\mathrm{H}_{2} \mathrm{O}(1.5 \mathrm{~mL})$ and $N$-bromosuccinimide ( $472 \mathrm{mg}, 2.66 \mathrm{mmol}$ ). After stirring the reaction mixture for 30 min , a further quantity of $\mathrm{H}_{2} \mathrm{O}$ was added and the mixture extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, $\mathrm{CH}_{2} \mathrm{Cl}_{2} / \mathrm{EtOAc}=1: 1$ ) yielded $16(845 \mathrm{mg}$, $76 \%$, d.r. $>92: 8)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-59.8\left(\mathrm{c}=0.99, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \mathrm{NMR}(500 \mathrm{MHz}$, $\mathrm{CHCl}_{3}$ ): $\delta=1.31,1.46\left(2 \mathrm{~s}, 3 \mathrm{H}\right.$ each, Me), 1.66-1.73 (m, $1 \mathrm{H}, 1$ '-H), $1.73-1.81\left(\mathrm{~m}, 1 \mathrm{H}, 2^{\prime}-\mathrm{H}\right)$, 1.91-1.99 (m, 1 H, 2'-H), $2.05\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 1^{\prime}-\mathrm{H}\right), 3.62-3.71\left(\mathrm{~m}, 2 \mathrm{H}, \mathrm{OCH}_{2}\right), 3.77-3.84(\mathrm{~m}, 2 \mathrm{H}, 6-$ $\left.\mathrm{CH}_{2}\right), 4.13-4.20\left(\mathrm{~m}, 2 \mathrm{H}, \mathrm{NCH}_{2}, 6-\mathrm{H}\right), 4.52-4.58\left(\mathrm{~m}, 2 \mathrm{H}, \mathrm{NCH}_{2}, 5-\mathrm{H}\right), 5.90\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 7.18-$ 7.39 (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CHCl}_{3}$ ): $\delta=21.5$, 25.7 ( $2 \mathrm{q}, \mathrm{Me}$ ), $29.9(\mathrm{t}, \mathrm{C}-1$ '), $30.8\left(\mathrm{t}, \mathrm{C}-2\right.$ '), $62.4\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 62.5\left(\mathrm{t}, \mathrm{OCH}_{2}\right), 63.8\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 64.5(\mathrm{~d}, \mathrm{C}-5), 73.6(\mathrm{~d}, \mathrm{C}-6), 79.1$, 79.3 ( $2 \mathrm{~s}, \mathrm{C}-2, \mathrm{C}-3$ ), 127.6, 128.4, 129.1, 137.0 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ), 203.7 (s, C-4) ppm. Characteristic signals of minor diastereomer: ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CHCl}_{3}$ ): 1.41, $1.63(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me) ppm. IR (film): $3360 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2780(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1700(\mathrm{C}=\mathrm{O})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{18} \mathrm{H}_{26} \mathrm{BrNO}_{5}[\mathrm{M}+\mathrm{Na}]^{+} 438.0887$, found 438.0883.
(2S,3S,5S)-3-(Benzyl(tert-butyldimethylsiloxy)amino)-5-bromo-2-(hydroxymethyl)-1-oxa-spiro[5.5]undecan-4-one (17)


To a solution of cis-5d ( $330 \mathrm{mg}, 0.715 \mathrm{mmol}$ ) in $\mathrm{MeCN}(6 \mathrm{~mL})$ were added $\mathrm{H}_{2} \mathrm{O}(600 \mu \mathrm{~L})$ and N bromosuccinimide ( $127 \mathrm{mg}, 0.715 \mathrm{mmol}$ ). After stirring the reaction mixture for 10 min , a further quantity of $\mathrm{H}_{2} \mathrm{O}$ was added and the mixture extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=8: 1$ ) yielded $17(230 \mathrm{mg}, 63 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-10.4\left(\mathrm{c}=1.30, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR $\left(500 \mathrm{MHz}, \mathrm{CHCl}_{3}\right): \delta=0.28,0.34(2 \mathrm{sbr}$, 3 H each, $\mathrm{SiMe}_{2}$ ), $0.90(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.12-1.31$ (m, $2 \mathrm{H}, \mathrm{Cy}$ ), 1.41-1.59 (m, $3 \mathrm{H}, \mathrm{Cy}$ ), 1.59-1.78 (m, $4 \mathrm{H}, \mathrm{Cy}), 1.85\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 1.91-2.00(\mathrm{~m}, 1 \mathrm{H}, \mathrm{Cy}), 3.34\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 3-\mathrm{H}\right), 3.61\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right.$, $\mathrm{NCH}_{2}$ ), $3.79\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, 2-\mathrm{H}\right), 3.83\left(\mathrm{~d}, J=11.9 \mathrm{~Hz}, 1 \mathrm{H}, 2-\mathrm{CH}_{2}\right), 3.98-4.01\left(\mathrm{~m}, 2 \mathrm{H}, 2-\mathrm{CH}_{2}, \mathrm{NCH}_{2}\right)$, $4.96(\mathrm{~s}, 1 \mathrm{H}, 5-\mathrm{H}), 7.22-7.39(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CHCl}_{3}$ ): $\delta=-4.8,-3.6(2 \mathrm{q}$, $\mathrm{SiMe}_{2}$ ), 17.9, 25.9 (s, q, $t \mathrm{Bu}$ ), 20.3, 21.4, 24.7, 25.6, 36.8 (5 t, Cy), 62.2 (t, $\mathrm{NCH}_{2}$ ), 63.0 (t, 2$\mathrm{CH}_{2}$ ), 66.6 (d, C-3), 67.5 (d, C-5), 71.2 (d, C-2), 80.1 ( $\mathrm{s}, \mathrm{C}-6$ ), 128.1, 128.8, 129.9, 135.5 (3 d, s, Ph), 196.9 (s, C-4) ppm. IR (film): $3700-3400 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2830(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1720(\mathrm{C}=\mathrm{O})$. ESI-TOF: $m / z$ calc. for $\mathrm{C}_{24} \mathrm{H}_{38} \mathrm{BrNO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 534.1651$, found 534.1655.
((1S,4S,5S,6S)-5-(Benzyl(tert-butyldimethylsiloxy)amino)-3,7-dioxa-spiro[bicyclo[4.1.0]heptane-2,1'-cyclohexane]-4-yl)methanol (18)


To a solution of 17 ( $195 \mathrm{mg}, 0.380 \mathrm{mmol}$ ) in $\mathrm{EtOH}(3 \mathrm{~mL})$, was added $\mathrm{NaBH}_{4}(70 \mathrm{mg}$, 0.252 mmol ) at $0{ }^{\circ} \mathrm{C}$. The mixture was then stirred for 1 h at room temperature, the solvent removed in vacuo and $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ added to the residue. The layers were separated and the aqueous phase was extracted two times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by recrystallization (hexane/ $\mathrm{Et}_{2} \mathrm{O}$ ) yielded $18(163 \mathrm{mg}, 99 \%)$ as colorless crystals. M.p. $134-136{ }^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=+2.1\left(\mathrm{c}=3.9, \mathrm{CHCl}_{3}\right)$.
${ }^{1} \mathrm{H}$ NMR $\left(500 \mathrm{MHz}, \mathrm{CHCl}_{3}\right): \delta=-0.80,0.00\left(2 \mathrm{sbr}, 3 \mathrm{Heach}, \mathrm{SiMe}_{2}\right), 0.79(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.16-$ 1.34 (m, $2 \mathrm{H}, ~ С y), ~ 1.44(\mathrm{~d}, J=13.3 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{Cy}), 1.49-1.56$ (m, $2 \mathrm{H}, \mathrm{Cy}$ ), 1.61-1.70 (m, 2 H , Cy), 1.86-2.06 (m, 3 H, Cy), 2.29 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}$ ), 3.62-3.93 (m, 3 H ), 4.07 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}$ ), 4.27-4.38 $(\mathrm{m}, 3 \mathrm{H}), 4.45\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right), 7.22-7.34(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR $\left(126 \mathrm{MHz}, \mathrm{CHCl}_{3}\right): \delta=-4.8$, -4.6 (2 q, $\mathrm{SiMe}_{2}$ ), 17.6, 25.9 (s, q, $t \mathrm{Bu}$ ), 20.5, 21.3, 24.8, 25.4, 36.5 ( $5 \mathrm{t}, \mathrm{Cy}$ ), 63.3, 63.6, 70.2, 77.3, 99.9 (s, C-6), 127.9, 128.3, 130.5, 137.3 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ) ppm. IR (KBr): $3460 \mathrm{~cm}^{-1}(\mathrm{OH}), 3100-$ 2820 (=C-H, C-H). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{24} \mathrm{H}_{39} \mathrm{NO}_{4} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 456.2541$, found 456.2532 .
$N$-Benzyl- $N$-((7S,8S)-7-(benzyloxymethyl)-5,5-dimethyl-2,3,4,5,7,8-hexahydropyrano[4,3-b]pyran-8-yl)-O-(tert-butyldimethylsilyl)hydroxylamine (19)


To a solution of cis-5b ( $600 \mathrm{mg}, 1.38 \mathrm{mmol}$ ) in THF ( 13 mL ), was added $\mathrm{NaH}(60 \%$ in paraffin oil, $84 \mathrm{mg}, 2.16 \mathrm{mmol}$ ) at $0^{\circ} \mathrm{C}$. The reaction mixture was stirred for 1 h at room temperature, then cooled to $0{ }^{\circ} \mathrm{C}$ and $\operatorname{BnBr}(247 \mu \mathrm{~L}, 1.98 \mathrm{mmol})$ added. The mixture was stirred for 12 h at room temperature. Sat. $\mathrm{NH}_{4} \mathrm{Cl}$ solution was added and the mixture extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{MgSO}_{4}\right)$ and concentrated. Purification by column chromatography (silica gel, hexane/EtOAc $=15: 1$ ) yielded $19(560 \mathrm{mg}, 78 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-103.9\left(\mathrm{c}=0.44, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR $\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=0.07,0.08(2 \mathrm{~s}$, 3 H each, $\mathrm{SiMe}_{2}$ ), 0.91 ( $\mathrm{s}, 9 \mathrm{H}, t \mathrm{Bu}$ ), 1.25, 1.26 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.86-1.97 (m, $3 \mathrm{H}, \mathrm{DHP}$ ), 2.04-2.13 (m, 1 H, DHP), 3.44 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, 8-\mathrm{H}$ ), 3.69 (dd, $J=3.8,10.5 \mathrm{~Hz}, 1 \mathrm{H}, 7-\mathrm{CH}_{2}$ ), 3.78-3.89 ( $\mathrm{m}, 3 \mathrm{H}, 7-\mathrm{H}, 7-\mathrm{CH}_{2}, \mathrm{NCH}_{2}$ ), $3.97\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, \mathrm{DHP}\right), 4.11-4.17\left(\mathrm{~m}, 2 \mathrm{H}, \mathrm{DHP}, \mathrm{NCH}_{2}\right), 4.24(\mathrm{~d}, J=$ $\left.11.1 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{OCH}_{2} \mathrm{Ph}\right), 4.40\left(\mathrm{~d}, J=11.1 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{OCH}_{2} \mathrm{Ph}\right), 7.04-7.10(\mathrm{~m}, 2 \mathrm{H}, \mathrm{Ph}), 7.15-7.42$ $(\mathrm{m}, 8 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.1,-4.9\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 18.3,26.0(\mathrm{~s}, \mathrm{q}$, $t \mathrm{Bu})$, 20.5, $22.7(2 \mathrm{t}, \mathrm{DHP}), 23.4,28.0(2 \mathrm{q}, \mathrm{Me}), 61.1\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 61.6(\mathrm{~d}, \mathrm{C}-8), 64.1\left(\mathrm{t}, 7-\mathrm{CH}_{2}\right)$, 65.1 (t, DHP), 73.4 (d, C-7), 74.8 ( $\mathrm{t}, \mathrm{OCH}_{2} \mathrm{Ph}$ ), 75.6 ( $\mathrm{s}, \mathrm{C}-5$ ), 115.3 ( $\mathrm{s}, \mathrm{C}-4 \mathrm{a}$ ), 126.8, 127.3, 127.9, $128.0,128.8,129.9,137.9,139.4$ ( $6 \mathrm{~d}, 2 \mathrm{~s}, \mathrm{Ph}$ ), 143.4 (s, C-8a) ppm. IR (film): 3100-2850 $\mathrm{cm}^{-1}$ $(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1670(\mathrm{C}=\mathrm{C})$. ESI-TOF: $m / z$ calc. for $[\mathrm{M}+\mathrm{H}]^{+}$546.3005, found 546.2981. Anal. calc. for $\mathrm{C}_{31} \mathrm{H}_{45} \mathrm{NO}_{4} \mathrm{Si}$ (523.8): C 71.09, H 8.66, N 2.67, found: C 71.21, H 8.65, N 2.82 .
(3S,4S)-3-[Benzyl(tert-butyldimethylsiloxy)amino]-4-(benzyloxymethyl)-6,6-dimethyl-1,5-dioxecane-2,7-dione (20)


To a solution of compound $19(100 \mathrm{mg}, 0.191 \mathrm{mmol})$ in $\mathrm{H}_{2} \mathrm{O}: \mathrm{CCl}_{4}: \mathrm{MeCN}(1.5: 1: 1,1.4 \mathrm{~mL})$, was added $\mathrm{RuCl}_{3}\left(0.1 \mathrm{M}\right.$ in $\left.\mathrm{H}_{2} \mathrm{O}, 57 \mu \mathrm{~L}, 5.73 \mu \mathrm{~mol}\right)$ and $\mathrm{NaIO}_{4}(168 \mathrm{mg}, 0.783 \mathrm{mmol})$. The mixture was stirred at room temperature for 2 h and the reaction then quenched by the addition of satd. $\mathrm{Na}_{2} \mathrm{~S}_{2} \mathrm{O}_{3}$ solution. The resulting mixture was extracted three times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic phases were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and concentrated to afford 94 mg of $20(94 \mathrm{mg}, 88 \%)$ as an analytically pure yellow oil. $[\alpha]_{\mathrm{D}}{ }^{22}=-43.8\left(\mathrm{c}=0.96, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \mathrm{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=$ 0.10, 0.11 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, $\mathrm{SiMe}_{2}$ ), 0.92 ( $\mathrm{s}, 9 \mathrm{H}, t \mathrm{Bu}$ ), 1.31, 1.35 ( $2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.82 ( $\mathrm{m}_{\mathrm{c}}, 1 \mathrm{H}$, $9-\mathrm{H}$ ), 2.01 (ddd, $J=1.3,11.6,16.7 \mathrm{~Hz}, 1 \mathrm{H}, 8-\mathrm{H}$ ), $2.58\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 9-\mathrm{H}\right), 2.94$ (ddd, $J=1.5,11.6$, $16.7 \mathrm{~Hz}, 1 \mathrm{H}, 8-\mathrm{H}), 3.72\left(\mathrm{dd}, J=5.0,9.4 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{CH}_{2}\right), 3.81(\mathrm{ddd}, J=2.0,7.3,10.9 \mathrm{~Hz}, 1 \mathrm{H}$, $10-\mathrm{H}), 3.96\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 4-\mathrm{H}\right), 4.11\left(\mathrm{t}, J=9.4 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{CH}_{2}\right), 4.22(\mathrm{~d}, J=3.3 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 4.29-$ $4.40\left(\mathrm{~m}, 3 \mathrm{H}, \mathrm{OCH}_{2} \mathrm{Ph}, \mathrm{NCH}_{2}\right), 4.69\left(\mathrm{~d}, J=13.8 \mathrm{~Hz}, 1 \mathrm{H}, \mathrm{NCH}_{2}\right), 4.91(\mathrm{dt}, J=6.0,10.9 \mathrm{~Hz}, 1 \mathrm{H}$, 10-H), 6.98-7.49 (m, $10 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-5.1\left(\mathrm{q}, \mathrm{SiMe}_{2}\right), 18.4$, 26.1 (s, q, $t \mathrm{Bu}$ ), 21.7 (t, C-9), 21.8, 26.0 ( $2 \mathrm{q}, \mathrm{Me}$ ), 31.4 (t, C-8), 60.0 (t, $\mathrm{NCH}_{2}$ ), 61.0 (t, C-10), 62.7 (t, 4-CH2), 66.7 (d, C-3), 75.7 (t, $\mathrm{OCH}_{2} \mathrm{Ph}$ ), 75.8 (d, C-4), 80.9 ( $\mathrm{s}, \mathrm{C}-6$ ), 127.2, 127.6, 128.1, 128.2, 128.7, 129.8, 137.2, 139.3 ( $6 \mathrm{~d}, 2 \mathrm{~s}, \mathrm{Ph}$ ), 169.9 (s, C-2), 209.3 (s, C-7) ppm. IR (film): $3100-2830 \mathrm{~cm}^{-1}(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1750,1710(\mathrm{C}=\mathrm{O})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{31} \mathrm{H}_{45} \mathrm{NO}_{6} \mathrm{Si}[\mathrm{M}+$ $\mathrm{Na}]^{+} 578.2903$, found 578.2911.
(2S,3R,Z)- $N$-Benzylidene-2-(hydroxymethyl)-6,6-dimethyl-4-oxotetrahydropyran-3-amine oxide (21)


To a solution of $\mathbf{1 5}(110 \mathrm{mg}, 0.307 \mathrm{mmol})$ in DMF ( 3 mL ), was added $\mathrm{NaN}_{3}(99 \mathrm{mg}, 1.52 \mathrm{mmol})$ and the reaction mixture was stirred for 12 h at room temperature. $\mathrm{H}_{2} \mathrm{O}$ was added and the resulting mixture extracted three times with ethyl acetate. The combined organic phases were
dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, $\left.\mathrm{CH}_{2} \mathrm{Cl}_{2} / \mathrm{EtOAc}=1: 1\right)$ yielded $21(74 \mathrm{mg}, 87 \%)$ as colorless crystals. M.p. $156{ }^{\circ} \mathrm{C}$. $[\alpha]_{\mathrm{D}}{ }^{22}=+73.8\left(\mathrm{c}=0.13, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR $\left(700 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=1.39,1.41(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $2.50,2.57\left(\mathrm{AB}\right.$ system, $J_{\mathrm{AB}}=14.5 \mathrm{~Hz}, 1 \mathrm{H}$ each, $\left.3-\mathrm{H}\right), 2.57\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 3.70(\mathrm{dd}, J=2.2,12.3$ $\left.\mathrm{Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.94\left(\mathrm{dd}, J=2.2,12.3 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.79(\mathrm{dt}, \mathrm{J}=2.2,9.7 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H})$, $4.83(\mathrm{~d}, J=9.7 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 7.39(\mathrm{~s}, 1 \mathrm{H}, \mathrm{N}=\mathrm{CHPh}), 7.40-7.45(\mathrm{~m}, 3 \mathrm{H}, \mathrm{Ph}), 8.23-8.26(\mathrm{~m}, 2 \mathrm{H}$, $\mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $176 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=24.3,30.3(2 \mathrm{q}, \mathrm{Me}), 51.8(\mathrm{t}, \mathrm{C}-3), 62.1\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right)$, 72.4 (d, C-6), 75.4 (s, C-2), 77.8 (d, C-5), 128.4, 128.9, 129.7, 131.0 (3 d, s, Ph), 138.2 (d, $\mathrm{N}=\underline{\mathrm{C}} \mathrm{HPh}$ ), 199.5 (s, C-4) ppm. IR (KBr): $3280 \mathrm{~cm}^{-1}(\mathrm{OH}), 3090-2860(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H}), 1720(\mathrm{C}=\mathrm{O})$. ESI-TOF: $m / z$ calc. for $\mathrm{C}_{15} \mathrm{H}_{19} \mathrm{NO}_{4}[\mathrm{M}+\mathrm{Na}]^{+} 300.1212$, found 300.1256.

## (4R,5R,6S)-5-[Benzyl(hydroxy)amino]-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-

 pyran-4-ol (23)

Crude ketone 8 ( $180 \mathrm{mg}, 0.645 \mathrm{mmol}$ ) was dissolved in ethanol ( 1 mL ) and cooled to $0{ }^{\circ} \mathrm{C}$. $\mathrm{NaBH}_{4}(36 \mathrm{mg}, 0.966 \mathrm{mmol})$ was added and the mixture stirred for 1 h at $0^{\circ} \mathrm{C}$. The solvent was then removed in vacuo and $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ added to the residue. The layers were separated and the aqueous phase was extracted twice with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by recrystallization (hexane/EtOAc) yielded the product $23(160 \mathrm{mg}, 88 \%)$ as colorless crystals. M.p. $86-88^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=+26.7(\mathrm{c}=$ $0.61, \mathrm{CHCl}_{3}$ ). ${ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=1.20,1.25(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.76 (dd, $J=5.6$, $12.8 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 1.96(\mathrm{t}, J=12.8 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 3.16(\mathrm{dd}, J=2.9,5.6 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.70(\mathrm{dt}$, $J=2.9,5.1 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}), 3.79\left(\mathrm{dd}, J=5.1,11.6 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.89(\mathrm{dd}, J=5.1,11.6 \mathrm{~Hz}, 1 \mathrm{H}$, $6-\mathrm{CH}_{2}$ ), $4.04(\mathrm{dt}, J=5.6,11.8 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 4.24\left(\mathrm{~s}, 2 \mathrm{H}, \mathrm{NCH}_{2}\right), 6.42\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 7.24-7.36$ (m, 5 H, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR (101 MHz, $\mathrm{CDCl}_{3}$ ): $\delta=23.1,31.4(2 \mathrm{q}, \mathrm{Me}), 42.3(\mathrm{t}, \mathrm{C}-3), 63.2(\mathrm{~d}$, $\mathrm{C}-5), 63.7\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 64.0\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 67.9$ (d, C-4), 71.9 (d, C-6), 73.4 ( $\mathrm{s}, \mathrm{C}-2$ ), 127.5, 128.4, 129.3, 138.0 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ) ppm. IR ( KBr ): 3390-3200 $\mathrm{cm}^{-1}(\mathrm{OH}), 3090-2840(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESITOF: $m / z$ calc. for $\mathrm{C}_{15} \mathrm{H}_{23} \mathrm{NO}_{4}[\mathrm{M}+\mathrm{H}]^{+} 282.1700$, found 282.1713. Anal. calc. for $\mathrm{C}_{15} \mathrm{H}_{23} \mathrm{NO}_{4}$ (281.3): C 64.03, H 8.24, N 4.98, found: C 63.77, H 7.86, N 4.98.


A suspension of palladium on charcoal ( $10 \% \mathrm{Pd}, 50 \mathrm{mg}$ ) in $\mathrm{MeOH}(4 \mathrm{~mL})$ was saturated with hydrogen for 1 h . After the addition of compound 23 ( $50 \mathrm{mg}, 0.178 \mathrm{mmol}$ ) in $\mathrm{MeOH}(2 \mathrm{~mL})$, hydrogen was bubbled through the mixture for a further 30 min . The reaction mixture was then stirred under an atmosphere of hydrogen for 24 h . Filtration through a short pad of celite and concentration of the solution yielded $24(28 \mathrm{mg}, 90 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=+70.9(\mathrm{c}=0.47$, $\mathrm{MeOH}) .{ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}$ ): $\delta=1.20,1.25(2 \mathrm{~s}, \mathrm{Me}), 1.49(\mathrm{t}, J=13.1 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H})$, $1.70(\mathrm{dd}, J=5.1,13.1 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 3.23(\mathrm{~d}, J=5.1 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.62(\mathrm{dd}, J=5.3 \mathrm{~Hz}, 11.5,1$ $\left.\mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.89\left(\mathrm{dd}, J=5.3,11.5 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.76(\mathrm{t}, J=5.3 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}), 4.07(\mathrm{td}, 5.1$, $13.1 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}$ ): $\delta=23.1,31.3(2 \mathrm{q}, \mathrm{Me}), 39.6$ (t, C-3), 53.2 (d, C-5), 63.5 (t, 6-CH2), 65.9 (d, C-4), 71.5 (d, C-6), 74.5 (s, C-2) ppm. IR (film): 3400$3100 \mathrm{~cm}^{-1}(\mathrm{OH}), 2950-2840(\mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{8} \mathrm{H}_{17} \mathrm{NO}_{3}[\mathrm{M}+\mathrm{H}]^{+} 176.1281$, found 176.1277.
(4S,5S,6S)-5-[Benzyl(hydroxy)amino]-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-4-ol (25)


To a solution of $21(70 \mathrm{mg}, 0.252 \mathrm{mmol})$ in $\mathrm{EtOH}(2 \mathrm{~mL})$, was added $\mathrm{NaBH}_{4}(24 \mathrm{mg}, 0.631$ mmol ) at $0^{\circ} \mathrm{C}$ and the mixture stirred for 1 h at room temperature. The solvent was then removed in vacuo and $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ added to the residue. The layers were separated and the aqueous phase was extracted two times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by column chromatography (silica gel, hexane/EtOAc $=1: 1$ ) yielded the product $25(63 \mathrm{mg}, 89 \%)$ as colorless crystals. M.p. $128-$ $129{ }^{\circ} \mathrm{C} \cdot[\alpha]_{\mathrm{D}}{ }^{22}=+40.0\left(\mathrm{c}=0.08, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(700 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=1.18,1.51(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 1.51 (dd, $J=3.1,14.3 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 1.88(\mathrm{dd}, J=3.1,14.3 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 2.61$ (dd, $J$
$=3.1,10.3 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.69\left(\mathrm{dd}, J=5.3,11.2 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.83(\mathrm{dd}, J=5.3,11.2 \mathrm{~Hz}, 1 \mathrm{H}$, $\left.6-\mathrm{CH}_{2}\right), 4.00,4.27\left(2 \mathrm{~d}, J=13.1 \mathrm{~Hz}, 1 \mathrm{H}\right.$ each, $\mathrm{NCH}_{2}$ ), $4.34(\mathrm{td}, J=5.3,10.3 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}), 4.79$ (q, $J=3.1 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}), 7.27-7.43(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR $\left(176 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=25.3$, 32.1 ( $2 \mathrm{q}, \mathrm{Me}$ ), $42.5(\mathrm{t}, \mathrm{C}-3), 61.2\left(\mathrm{t}, \mathrm{NCH}_{2}\right), 65.0(\mathrm{~d}, \mathrm{C}-5), 65.8\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 65.8(\mathrm{~d}, \mathrm{C}-6), 65.8(\mathrm{~d}$, C-4), 71.8 (s, C-2), 127.7, 128.5, 129.0, 136.9 ( $3 \mathrm{~d}, \mathrm{~s}, \mathrm{Ph}$ ) ppm. IR ( KBr ): $3440 \mathrm{~cm}^{-1}(\mathrm{OH})$, 3130-2850 (=C-H, C-H). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{15} \mathrm{H}_{23} \mathrm{NO}_{4}[\mathrm{M}+\mathrm{Na}]^{+} 304.1519$, found 304.1523.
(4S,5S,6S)-5-Amino-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-4-ol (26)


A suspension of palladium on charcoal ( $10 \% \mathrm{Pd}, 60 \mathrm{mg}$ ) in $\mathrm{MeOH}(4 \mathrm{~mL})$ was saturated with hydrogen for 1 h . After addition of compound 25 ( $60 \mathrm{mg}, 0.214 \mathrm{mmol}$ ) in MeOH ( 2 mL ), hydrogen was bubbled through the mixture for a further 30 min . The reaction mixture was then stirred under an atmosphere of hydrogen for 24 h . Filtration through a short pad of celite and concentration of the solution yielded $26(35 \mathrm{mg}, 94 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=+173.8$ ( $\mathrm{c}=1.8$, $\mathrm{MeOH}) .{ }^{1} \mathrm{H}$ NMR ( $700 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}$ ): $\delta=1.19,1.44(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me ), 1.66 (dd, $J=3.3,14.4$ $\mathrm{Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 1.87(\mathrm{dd}, J=3.3,14.4 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 2.84(\mathrm{dd}, J=3.3,10.0 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.70-$ $3.72\left(\mathrm{~m}, 2 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.80(\mathrm{td}, J=4.5,10.0 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}), 4.06(\mathrm{q}, J=3.3 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}) \mathrm{ppm}$. ${ }^{13} \mathrm{C}$ NMR ( $176 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}$ ): $\delta=25.4,32.3$ ( $2 \mathrm{q}, \mathrm{Me}$ ), 43.3 (t, C-3), 52.8 (d, C-5), 64.5 (t, 6$\mathrm{CH}_{2}$ ), 67.5 (d, C-4), 70.2 (d, C-6), 72.7 (s, C-2) ppm. IR (film): $3350 \mathrm{~cm}^{-1}(\mathrm{OH}), 2990-2850(\mathrm{C}-$ H). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{8} \mathrm{H}_{17} \mathrm{NO}_{3}[\mathrm{M}+\mathrm{H}]^{+}$176.1281, found 176.1278.
(3R,4S,5R,6S)-5-[Benzyl(tert-butyldimethylsiloxy)amino]-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-3,4-diol (27)


Compound 9 ( $90 \mathrm{mg}, 0.220 \mathrm{mmol}$ ) was dissolved in ethanol ( 1.5 mL ) and cooled to $-40{ }^{\circ} \mathrm{C}$. $\mathrm{CeCl}_{3}(164 \mathrm{mg}, 0.440 \mathrm{mmol})$ followed by $\mathrm{NaBH}_{4}(17 \mathrm{mg}, 0.440 \mathrm{mmol})$ were added and the mixture was stirred until it slowly reached room temperature ( 5 h ). $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ were then added. The layers were separated and the aqueous phase was extracted two times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$, filtered and concentrated. Purification by column chromatography (silica gel, hexane/EtOAc $=2: 1$ ) yielded the product $27(81 \mathrm{mg}, 86 \%)$ as colorless crystals. M.p. $94-96{ }^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=+85.7\left(\mathrm{c}=1.1, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-0.78,-0.03\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), $0.80(\mathrm{~s}, 9 \mathrm{H}, t \mathrm{Bu}), 1.20,1.34(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 2.56 $\left(\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}\right), 3.11\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right), 3.67-4.09(\mathrm{~m}, 6 \mathrm{H}), 4.25\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}\right), 4.43\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}\right) 7.21-7.34(\mathrm{~m}, 5 \mathrm{H}$, Ph) ppm. ${ }^{13} \mathrm{C}$ NMR ( $126 \mathrm{MHz}, \mathrm{CDCl}_{3}$ ): $\delta=-4.6\left(\mathrm{q}, \mathrm{SiMe}_{2}\right.$ ), 17.3, $28.6(2 \mathrm{q}, \mathrm{Me}), 17.6,26.0(\mathrm{~s}, \mathrm{q}$, $t \mathrm{Bu})$, 63.4, 63.7, 64.9, 71.4, 127.8, 128.3, 130.5, 137.5 (3 d, s, Ph) ppm. IR (KBr): $3080 \mathrm{~cm}^{-1}$ $(\mathrm{OH}), 3070-2830(=\mathrm{C}-\mathrm{H}, \mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{21} \mathrm{H}_{37} \mathrm{NO}_{5} \mathrm{Si}[\mathrm{M}+(2 \mathrm{H})-(\mathrm{TBS})]^{+}$ 298.1649, found 298.1414.
(3R,4S,5R,6S)-5-Amino-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-3,4-diol (28)


A suspension of palladium on charcoal ( $10 \% \mathrm{Pd}, 50 \mathrm{mg}$ ) in $\mathrm{MeOH}(3 \mathrm{~mL})$ was saturated with hydrogen for 1 h . After addition of compound 27 ( $50 \mathrm{mg}, 0.121 \mathrm{mmol}$ ) in MeOH ( 2 mL ), hydrogen was bubbled through the mixture for another 30 min . The reaction mixture was then stirred under an atmosphere of hydrogen for 24 h . Filtration through a short pad of celite and concentration of the solution yielded $28(21 \mathrm{mg}, 91 \%)$ as a colorless oil. $[\alpha]_{\mathrm{D}}{ }^{22}=+85.6(\mathrm{c}=0.36$, $\mathrm{MeOH}) .{ }^{1} \mathrm{H}$ NMR ( $500 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ ): $\delta=1.23,1.31(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), $3.41(\mathrm{~d}, J=10.3 \mathrm{~Hz}, 1 \mathrm{H}$, $3-\mathrm{H}$ ), 3.69 (dd, $J=1.4,4.6 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.72\left(\mathrm{~m}_{\mathrm{c}}, 2 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.02\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 6-\mathrm{H}\right), 4.04$ (dd, $J$ $=4.6,10.3 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( $101 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ ): $\delta=16.9,26.9(2 \mathrm{q}, \mathrm{Me}), 53.8(\mathrm{~d}, \mathrm{C}-$
5), $61.3\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 67.2(\mathrm{~d}, \mathrm{C}-4), 68.3$ (d, C-6), 73.2 (d, C-3), 77.5 (s, C-2) ppm. IR (film): 3400$3100 \mathrm{~cm}^{-1}(\mathrm{OH}, \mathrm{NH}), 2950-2800(\mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{8} \mathrm{H}_{17} \mathrm{NO}_{4}[\mathrm{M}+\mathrm{H}]^{+}$192.1230, found 192.1233.

## (3S,4R,5S,6S)-5-[Benzyl(tert-butyldimethylsiloxy)amino]-6-(hydroxymethyl)-2,2-dimethyltetrahydro-2H-pyran-3,4-diol (29)



230 mg of the above described mixture of compounds $\mathbf{1 3}$ and $\mathbf{1 4}$ were dissolved in ethanol ( 5 mL ) and cooled to $0{ }^{\circ} \mathrm{C}$. $\mathrm{NaBH}_{4}(42 \mathrm{mg}, 1.13 \mathrm{mmol})$ was added and the mixture stirred for 1 h at room temperature. The solvent was then removed in vacuo and $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ and $\mathrm{H}_{2} \mathrm{O}$ added to the residue . The layers were separated and the aqueous phase was extracted two times with $\mathrm{CH}_{2} \mathrm{Cl}_{2}$. The combined organic layers were dried $\left(\mathrm{Na}_{2} \mathrm{SO}_{4}\right)$ and the solvent was removed in vacuo. Purification by recrystallization ( $\mathrm{Et}_{2} \mathrm{O}$ ) yielded 29 ( $190 \mathrm{mg}, 82 \%$ ) as colorless crystals. M.p. $127-128{ }^{\circ} \mathrm{C}$. $[\alpha]_{\mathrm{D}}{ }^{22}=+89.2\left(\mathrm{c}=0.44, \mathrm{CHCl}_{3}\right) .{ }^{1} \mathrm{H} \operatorname{NMR}\left(500 \mathrm{MHz}, \mathrm{CDCl}_{3}\right): \delta=0.21,0.22\left(2 \mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}\right.$ each, $\mathrm{SiMe}_{2}$ ), 0.91 ( $\mathrm{s}, 9 \mathrm{H}, t \mathrm{Bu}$ ), 1.12, 1.47 (2 s, 3 H each, Me), 2.10 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}$ ), 2.26 ( $\mathrm{s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}$ ), 2.72 (dd, $J=2.6,10.8 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.39-3.47\left(\mathrm{~m}, 2 \mathrm{H}, 3-\mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.84(\mathrm{~d}, J=11.3 \mathrm{~Hz}, 1 \mathrm{H}$, $6-\mathrm{CH}_{2}$ ), 4.09 (ddd, $\left.J=2.8,6.5,10.5 \mathrm{~Hz}, 1 \mathrm{H}, 6-\mathrm{H}\right), 4.17,4.27\left(2 \mathrm{~d}, J=12.4 \mathrm{~Hz}, 1 \mathrm{H}\right.$ each, $\mathrm{NCH}_{2}$ ), $4.66\left(\mathrm{~m}_{\mathrm{c}}, 1 \mathrm{H}, 4-\mathrm{H}\right), 5.18\left(\mathrm{~s}_{\mathrm{br}}, 1 \mathrm{H}, \mathrm{OH}\right), 7.19-7.31(\mathrm{~m}, 5 \mathrm{H}, \mathrm{Ph}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( 126 MHz , $\left.\mathrm{CDCl}_{3}\right): \delta=-5.1,-4.1\left(2 \mathrm{q}, \mathrm{SiMe}_{2}\right), 17.7,25.8(\mathrm{~s}, \mathrm{q}, t \mathrm{Bu}), 23.0,26.6(2 \mathrm{q}, \mathrm{Me}), 56.3(\mathrm{~d}, \mathrm{C}-5)$, 61.7 (t, NCH 2 ), 63.8 (t, 6- $\mathrm{CH}_{2}$ ), 67.3 (d, C-6), 70.2 (d, C-4), 74.1 (d, C-3), 74.3 (s, C-2), 128.0, 128.7, 129.2, 135.9 ( 3 d , s, Ph ) ppm. IR (KBr): $3440 \mathrm{~cm}^{-1}(\mathrm{OH})$, 3080-2830 (=C-H, C-H). ESITOF: $m / z$ calc. for $\mathrm{C}_{21} \mathrm{H}_{37} \mathrm{NO}_{5} \mathrm{Si}[\mathrm{M}+\mathrm{Na}]^{+} 434.2333$, found 434.2341.
(3S,4R,5R,6S)-5-Amino-6-(hydroxymethyl)-2,2-dimethyltetrahydropyran-3,4-diol (30)


A suspension of palladium on charcoal ( $10 \% \mathrm{Pd}, 60 \mathrm{mg}$ ) in $\mathrm{MeOH}(3 \mathrm{~mL})$ was saturated with hydrogen for 1 h . After addition of compound 29 ( $60 \mathrm{mg}, 0.146 \mathrm{mmol}$ ) in MeOH ( 2 mL ),
hydrogen was bubbled through the mixture for another 30 min . The reaction mixture was then stirred under an atmosphere of hydrogen for 24 h . Filtration through a short pad of celite and concentration of the solution yielded 30 ( 29 mg , quant.) as colorless crystals. M.p. $148-149{ }^{\circ} \mathrm{C}$. $[\alpha]_{\mathrm{D}}{ }^{22}=+64.4(\mathrm{c}=0.23, \mathrm{MeOH}) .{ }^{1} \mathrm{H}$ NMR ( $400 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ ): $\delta=1.09,1.30(2 \mathrm{~s}, 3 \mathrm{H}$ each, Me), 3.01 (dd, $J=3.7,9.9 \mathrm{~Hz}, 1 \mathrm{H}, 5-\mathrm{H}), 3.47(\mathrm{~d}, J=3.7 \mathrm{~Hz}, 1 \mathrm{H}, 3-\mathrm{H}), 3.58(\mathrm{dd}, J=5.3,11.9 \mathrm{~Hz}, 1$ $\left.\mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.65-3.75\left(\mathrm{~m}, 2 \mathrm{H}, 6-\mathrm{H}, 6-\mathrm{CH}_{2}\right), 3.90(\mathrm{t}, J=3.7 \mathrm{~Hz}, 1 \mathrm{H}, 4-\mathrm{H}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR (101 $\mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ ): $\delta=22.0,25.8$ ( $2 \mathrm{q}, \mathrm{Me}$ ), 46.6 (d, C-5), 61.3 (t, $6-\mathrm{CH}_{2}$ ), 67.2 (d, C-4), 68.3 (d, C-6), 73.2 (d, C-3), 75.4 (s, C-2) ppm. IR (film): $3460-3240 \mathrm{~cm}^{-1}$ (OH, NH), 2990-2830 (C-H). ESITOF: $m / z$ calc. for $\mathrm{C}_{8} \mathrm{H}_{17} \mathrm{NO}_{4}[\mathrm{M}+\mathrm{H}]^{+}$192.1230, found 192.1225.

## N1,N3,N5-tris ((2S,3R,4R)-4-hydroxy-2-hydroxymethyl-6,6-dimethyltetrahydro-2H-pyran-3-

 yl)benzene-1,3,5-tricarboxamide (31)

Compound 24 ( $120 \mathrm{mg}, 0.685 \mathrm{mmol}$ ) was dissolved in pyridine ( 3 mL ). After addition of HMDS $(460 \mu \mathrm{~L}, 3.43 \mathrm{mmol})$ and $\mathrm{TMSCl}(414 \mu \mathrm{~L}, 3.43 \mathrm{mmol})$, the reaction mixture was stirred at room temperature until TLC analysis indicated complete consumption of $\mathbf{2 4}$ (ca. 5 h ). The solvent was removed in vacuo and the product twice co-evaporated with toluene. The crude product ( 220 mg ) was directly used in the next step. The obtained compound ( 220 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}$ (4 mL ) and the solution cooled to $0{ }^{\circ} \mathrm{C}$. After the addition of $\mathrm{NEt}_{3}(137 \mu \mathrm{~L}, 0.988 \mathrm{mmol})$ and $1,3,5-$ benzenetricarboxylic acid chloride ( $61 \mathrm{mg}, 0.229 \mathrm{mmol}$ ), the reaction mixture was stirred for 3 h at room temperature. The solvent was removed in vacuo and the resulting crude product ( 296 mg ) used in the next step without purification. To the obtained compound ( 296 mg ), was added a mixture of methanol and TFA ( $5 \mathrm{~mL}, 9: 1$ ) and the reaction stirred for 3 h at room temperature. After removal of the solvent in vacuo, crystallization from methanol yielded $\mathbf{3 1}$ ( $120 \mathrm{mg}, 77 \%$
overall yield) as colorless crystals. M.p. $210{ }^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=+66.7\left(\mathrm{c}=0.40\right.$, DMF). ${ }^{1} \mathrm{H}$ NMR (700 MHz, DMF- $d_{7}$ ): $\delta=1.35$, 1.63 ( $2 \mathrm{~s}, 9 \mathrm{H}$ each, Me), 1.88 (dd, $J=3.0,14.1 \mathrm{~Hz}, 3 \mathrm{H}, 3-\mathrm{H}$ ), 2.06 (dd, $J=3.0 \mathrm{~Hz}, 14.1 \mathrm{~Hz}, 3 \mathrm{H}, 3-\mathrm{H}), 3.77-3.84\left(\mathrm{~m}, 6 \mathrm{H}, 6-\mathrm{CH}_{2}\right), 4.13\left(\mathrm{~m}_{\mathrm{c}}, 3 \mathrm{H}, 6-\mathrm{H}\right), 4.22\left(\mathrm{~m}_{\mathrm{c}}, 3\right.$ $\mathrm{H}, 5-\mathrm{H}), 4.36\left(\mathrm{~m}_{\mathrm{c}}, 3 \mathrm{H}, 4-\mathrm{H}\right), 8.31\left(\mathrm{~s}_{\mathrm{br}}, 3 \mathrm{H}, \mathrm{NH}\right), 8.84(\mathrm{~s}, 3 \mathrm{H}, \mathrm{Ar}) \mathrm{ppm} .{ }^{13} \mathrm{C}$ NMR ( 127 MHz , DMF- $d_{7}$ ): $\delta=24.9,32.1(2 \mathrm{q}, \mathrm{Me}), 42.7(\mathrm{t}, \mathrm{C}-3), 50.8(\mathrm{~d}, \mathrm{C}-5), 63.3\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 66.3$ (d, C-4), 69.7 (d, C-6), 71.3 (s, C-2), 129.3, 135.4 (d, s, Ar), 166.1 (s, NCOR) ppm. IR (ATR): $3370 \mathrm{~cm}^{-1}$ $(\mathrm{OH}), 3000-2840(\mathrm{C}-\mathrm{H})$. ESI-TOF: $\mathrm{m} / \mathrm{z}$ calc. for $\mathrm{C}_{33} \mathrm{H}_{51} \mathrm{~N}_{3} \mathrm{O}_{12}[\mathrm{M}+\mathrm{Na}]^{+} 704.3365$, found 704.3345.

## $N 1, N 3, N 5-\operatorname{tris}((2 S, 3 R, 4 S, 5 R)-4,5-d i h y d r o x y-2-h y d r o x y m e t h y l-6,6-d i m e t h y l t e t r a h y d r o-2 H-$ pyran-3-yl)benzene-1,3,5-tricarboxamide (32)



Compound 28 ( $112 \mathrm{mg}, 0.586 \mathrm{mmol}$ ) was dissolved in pyridine ( 2.5 mL ). After addition of HMDS ( $944 \mathrm{mg}, 5.86 \mathrm{mmol}$ ) and TMSCl $(749 \mu \mathrm{~L}, 5.86 \mathrm{mmol})$, the reaction mixture was stirred at room temperature until TLC analysis indicated complete consumption of 28 (ca. 5 h ). The solvent was removed in vacuo and the product twice co-evaporated with toluene. The crude product ( 201 mg ) was directly used in the next step. The obtained compound ( 201 mg ) was dissolved in $\mathrm{CH}_{2} \mathrm{Cl}_{2}(3 \mathrm{~mL})$ and the solution cooled to $0{ }^{\circ} \mathrm{C}$. After the addition of $\mathrm{NEt}_{3}(137 \mu \mathrm{~L}$, 0.988 mmol ) and $1,3,5$-benzenetricarboxylic acid chloride ( $43 \mathrm{mg}, 0.165 \mathrm{mmol}$ ), the reaction mixture was stirred for 3 h at room temperature. The solvent was removed in vacuo and the resulting crude product ( 162 mg ) used in the next step without purification. To 122 mg of the obtained compound, was added a mixture of methanol and TFA ( $1.5 \mathrm{~mL}, 9: 1$ ) and the reaction stirred for 3 h at room temperature. Crystallization from methanol yielded 32 ( $16 \mathrm{mg}, 16 \%$
overall yield) as colorless crystals. M.p. $262{ }^{\circ} \mathrm{C} .[\alpha]_{\mathrm{D}}{ }^{22}=+150.8\left(\mathrm{c}=0.7, \mathrm{H}_{2} \mathrm{O}\right) .{ }^{1} \mathrm{H}$ NMR (700 $\left.\mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}\right): \delta=1.35,1.42(2 \mathrm{~s}, 9 \mathrm{H}$ each, Me), $3.63(\mathrm{~d}, J=10.4 \mathrm{~Hz}, 3 \mathrm{H}, 3-\mathrm{H}), 3.67-3.74(\mathrm{~m}, 6$ $\mathrm{H}, 6-\mathrm{CH}_{2}$ ), 4.10-4.17 (m, 6 H, 6-H, 4-H), $4.75(\mathrm{dd}, J=3.2 \mathrm{~Hz}, 3 \mathrm{H}, 5-\mathrm{H}), 8.35(\mathrm{~s}, 3 \mathrm{H}, \mathrm{Ar}) \mathrm{ppm}$. ${ }^{13} \mathrm{C}$ NMR ( $127 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ ): $\delta=17.0,27.3(2 \mathrm{q}, \mathrm{Me}), 52.4(\mathrm{~d}, \mathrm{C}-5), 61.5\left(\mathrm{t}, 6-\mathrm{CH}_{2}\right), 69.7,71.3(2$ d, C-6, C-4), 74.3 (d, C-3), 77.4 ( $\mathrm{s}, \mathrm{C}-2$ ), 129.7, 134.8 (d, s, Ar) ppm. IR (film): $3350 \mathrm{~cm}^{-1}$ (OH, NH), 3000-2840 (C-H). ESI-TOF: $m / z$ calc. for $\mathrm{C}_{33} \mathrm{H}_{51} \mathrm{~N}_{3} \mathrm{O}_{15}[\mathrm{M}+\mathrm{Na}]^{+} 752.3212$, found 752.3196.

## ${ }^{1} \mathrm{H}$ and ${ }^{13} \mathrm{C}$ NMR spectra:

${ }^{13} \mathrm{C}$ NMR spectra recorded at 101 MHz show signals at $27.5,103.5$ and 179.1 ppm , which are caused by external electromagnetic interference.

$176 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$




$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$

$500 \mathrm{MHz}, \mathrm{CDCl}_{3}$ :


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$

$700 \mathrm{MHz}, \mathrm{CDCl}_{3}:$



$176 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$



$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


| 210.0 | 200.0 | 190.0 | 180.0 | 170.0 | 160.0 | 150.0 | 140.0 | 130.0 | 120.0 | 110.0 | 100.0 | 90.0 | 80.0 | 70.0 | 60.0 | 50.0 | 40.0 | 30.0 | 20.0 | 10.0 |
| :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- | :--- |


$176 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}:$


$176 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$176 \mathrm{MHz}, \mathrm{CD}_{3} \mathrm{OD}:$


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$126 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ :


$126 \mathrm{MHz}, \mathrm{CDCl}_{3}:$


$101 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ :

$700 \mathrm{MHz}, \mathrm{DMF}-d_{7}:$



176 MHz, DMF- $d_{7}:$

$700 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}$ :

$176 \mathrm{MHz}, \mathrm{D}_{2} \mathrm{O}:$


