Azatriquinanes. Part 4.[1] The chemistry of azatriquinenamine and its bromination products †

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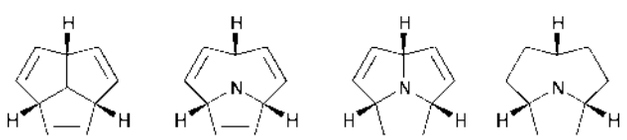
Azatriquinenamine (**5**) is the entry point into the azatriquinane heterocycles. Its convex morphology and enamine function involving a bridgehead double bond lead to unusual reactivity. Bromination of **5** gives either a mono- (**7**) or tetrabromo (**8**) derivative depending on conditions, the latter of which is highly congested sterically and undergoes unexpected ring opening, rearrangement, and hydrolysis reactions. Careful elimination of HBr from **8** gives a potential precursor (**14**) to azatriquinene **6**, and a dehydrobromination, bromination protocol leads to a potential precursor (**18**) to azatriquinacene **2**.

Introduction

Triquinacene§ **1**, the hemispherical, tricyclic $C_{10}H_{10}$ hydrocarbon first prepared by Woodward in 1964 and subject of enduring interest since that time,[2] has been the inspiration for the recent synthesis of its aza analogue 10-azatriquinacene **2**,[3] as well as the corresponding diene **3** and saturated tricycle **4**,[4] whose hydrocarbon counterparts are also known. The nitrogen at the apex of these novel heterocycles distinguishes them chemically from their hydrocarbon relatives, which raises intriguing new questions regarding electronic properties and reactivity. Indeed, issues of the homoaromaticity of **2**,[5] and the aromaticity of the azaacepentalene anion (the hypothetical 2 e^- oxidation product of **2**)[6] have already been addressed in the literature. The functional 'handle' present in **2**–**4** also allows for derivatization (N-quaternization, *exo* metal coordination or Lewis acid complexation) to directly give analogues of synthetically nontrivial *centro*-substituted triquinacenes.[7]



1 **2** **3** **4**

The point of entry into the azatriquinacene ring system is the so-called azatriquinenamine **5**,¶ (Scheme 1) which we differentiate in name from azatriquinene **6**, the only unsaturated azatriquinane we have not yet prepared. Compound **5**, which has no known hydrocarbon counterpart, is produced by distillation of its precursor pyrrolizidinone from soda lime, and is stable at room temperature in the absence of moisture.[4] It does not isomerize to **6** under conditions which would be expected to migrate strained double bonds (t-BuOK–DMSO). Despite its bridgehead position, the double bond in **5** is strongly conjugated to the nitrogen as indicated by the NMR chemical shifts

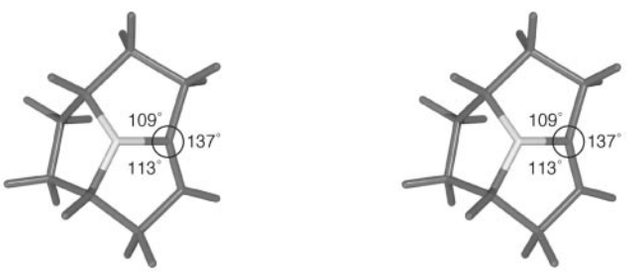
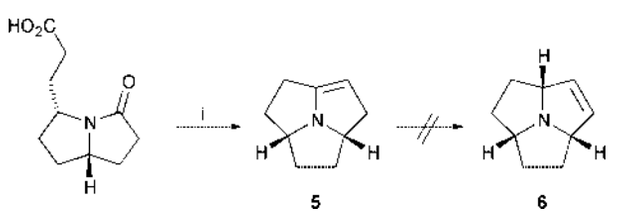


Fig. 1 Stereoview (cross-eye) of the B3LYP/6-311+G** optimized structure of **5** with selected bond angles.



Scheme 1 *Reagents and conditions*: i, soda lime, Δ.

of the proton and carbon at the β position (δ 4.32 and 93.2 ppm, respectively), characteristic of enamines. However, the unusual bond angles and energies associated with the convexity of the triquinane framework (*vide infra*) also lend **5** a unique reactivity, the features of which are the subject of this paper.

Structure

Due to its modest size, we have been able to carry out a high level density functional geometry optimization (B3LYP/6-311+G**) of **5**, the result of which is shown in Fig. 1.[8] The accuracy of the structure shown is supported by the agreement between calculated and experimentally determined vibrational and ^{13}C NMR frequencies.[9] It can be seen that the predicted bond angles around the sp^2 carbon C-1 in **5** vary considerably, and despite the presence of the stabilizing enamine functional group,[10] simple comparison of the energies between **5** and its double bond isomer **6** shows that they are the same to within <1 kcal mol^{-1}, the offsetting factor being angle strain in **5**. This is supported by an evaluation of their respective energies using molecular mechanics, where **5** is predicted to be about 6 kcal

† Electronic supplementary information (ESI) available: ^{1}H-NMR spectra for all new compounds described in this work. See http://www.rsc.org/suppdata/p1/b1/b107707d/

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§ The IUPAC name for triquinacene is 2a,4a,6a,6b-tetrahydrocyclopenta[*cd*]pentalene.

¶ Formally, *rel*-(4*R*,7*S*)-10-azatricyclo[5.2.1.$0^{1,10}$]dec-1-ene.

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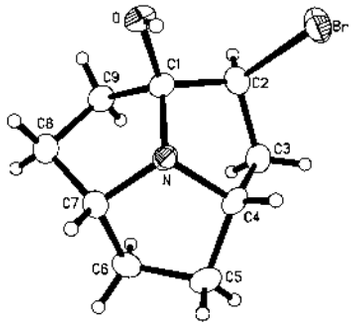


Fig. 2 X-Ray crystal structure of **7**.

mol^{-1} less stable than **6** due to elevated 'bend' and 'improper torsion' terms.[11] If **5** can be considered a classic enamine, the fact that it has an α branch and is essentially unhindered at the β position will also contribute to its reactivity.[12]

Reactivity

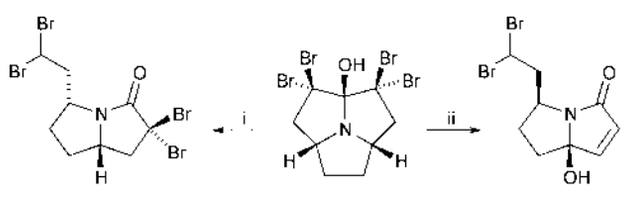
We first sought to derivatize **5** by straightforward bromination of the enamine function with NBS, which gave monobromo hemiaminal **7** on hydrolysis of the intermediate iminium salt (Scheme 2). It had been our intention to approach azatriquinene

5 **7**

Scheme 2 *Reagents and conditions*: i, NBS, CH_2Cl_2, −78 °C⟶RT; ii, $CHCl_3$–conc. HCl, Δ.

6 *via* dehydrohalogenation of **7**. However, all attempts to eliminate HBr using a variety of bases failed, apparently due to the inaccessibility of the *endo* proton *anti* to the bromine, the disposition of which could be seen in the X-ray crystal structure (Fig. 2).

Bromination of **5** using molecular bromine had previously been shown to exhaustively substitute the β positions to give the remarkable tetrabromohemiaminal **8** after aqueous workup.[3] We had assumed that because *exo* hydrogens in **8** were available for E2 reaction, elimination with base would be a straightforward matter. Instead, deprotonation of the OH by *tert*-butoxide led exclusively to the ring-opened product **9** (Scheme 3). Attempts to effect elimination using a gentler base (DBU)



9 **8** **10**

Scheme 3 *Reagents and conditions*: i, t-BuOK, THF, 0 °C; ii, DBU, THF.

resulted mainly in decomposition, although a small amount of a post-ring-opening bis-elimination product (**10**) was observed, the pyrrolizidine structure of which was confirmed by X-ray crystallography (Fig. 3). Remarkably, repeating the above reaction at −78 °C led to yet another unique product **11** (Scheme 4), the identification of which was also facilitated by a crystal structure determination (Fig. 4). We interpret the reaction mechanistically as shown, with transposition of the oxygen from the bridgehead position to the adjacent carbon *via* an

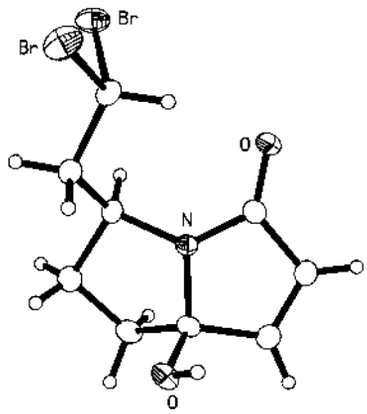


Fig. 3 X-Ray crystal structure of **10**.

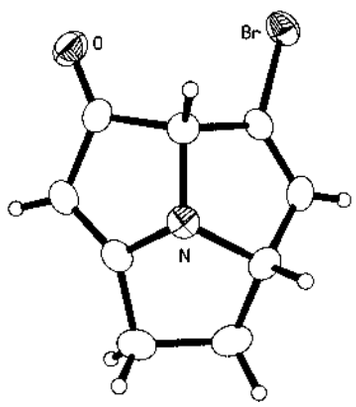
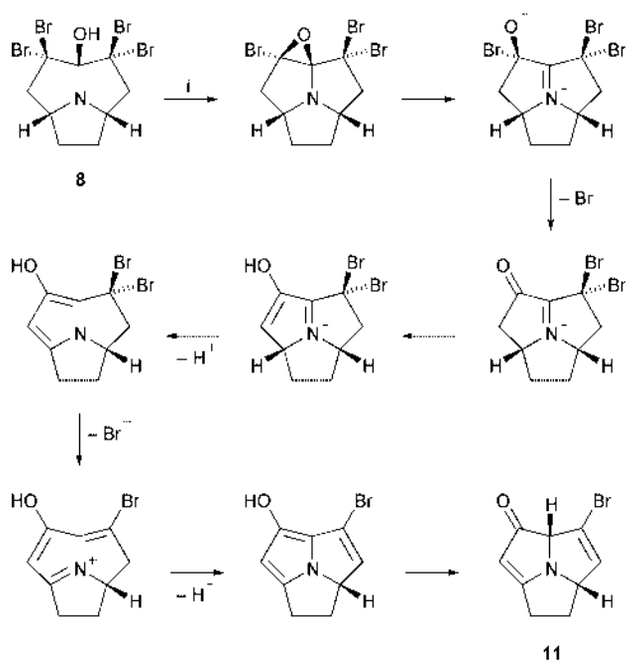


Fig. 4 X-Ray crystal structure of **11**.



Scheme 4 *Reagents and conditions*: i, DBU, THF, −78 °C.

intramolecular S_N2, although a number of variations in the sequence of events are possible.

The strain imposed on the ring by the four bromine substituents in **8** was apparently responsible for the unusual elimination and rearrangement chemistry which was being observed. It was contemplated whether substitution of one or more of the bromides for chloride might lead to more predictable behaviour. Finkelstein reactions of *gem* dibromides have been described,[13] but treating **8** with chloride in aqueous acetonitrile

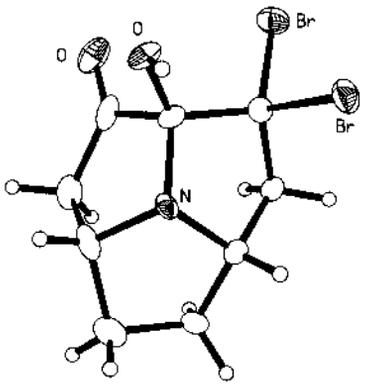
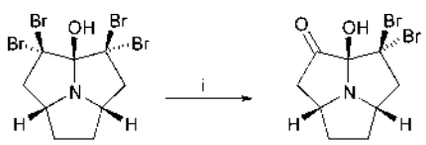


Fig. 5 X-Ray crystal structure of **12**.

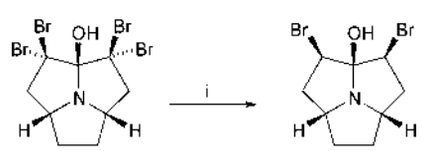
under literature conditions led only to hydrolysis of the dibromomethylene function on one side of the molecule to give **12** (Scheme 5). Since *gem* dihalides are not typically hydrolyzed



Scheme 5 *Reagents and conditions*: i, sat. aq. NaCl–MeCN, Δ.

in neutral, aqueous solution, participation from the neighboring hemiaminal oxygen in the mechanism of the reaction (*cf.* Scheme 4) is likely. The X-ray crystal structure of **12** is shown in Fig. 5.

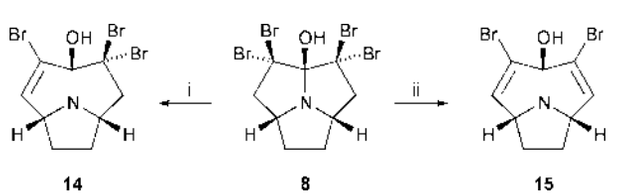
Reductive cleavage of one or more of the bromines in **8** was another strategy aimed at relieving steric congestion. Treatment of **8** with diphenyl phosphite under conditions described for the reduction of *gem* dibromocyclopropanes[14] led to the dibromohemiaminal **13** (Scheme 6), a product not available by direct



Scheme 6 *Reagents and conditions*: i, $(PhO)_2POH$, Et_3N.

bromination of **5**. Spectroscopic indications were however that both bromines in **13** were on the *exo* face of the tricycle, an assignment supported by the lack of reactivity of **13** towards elimination.

Clean elimination of HBr from **8** ultimately succeeded by reaction with an excess of the kinetically strong base potassium hexamethyldisilazane (KHMDS) at −78 °C and gave, depending on the reaction time, either the mono- (**14**) or bis-elimination product (**15**) in good yields (Scheme 7 and Fig. 6).



Scheme 7 *Reagents and conditions*: i, KHMDS, −78 °C⟶RT, 20 min; ii, KHMDS, −78 °C⟶RT, 12 h.

The achievement of **15** was the basis for the eventual synthesis of azatriquinadiene **3**.[3] With **14** in hand, the prospect of reductively cleaving the bromines to afford a precursor of the

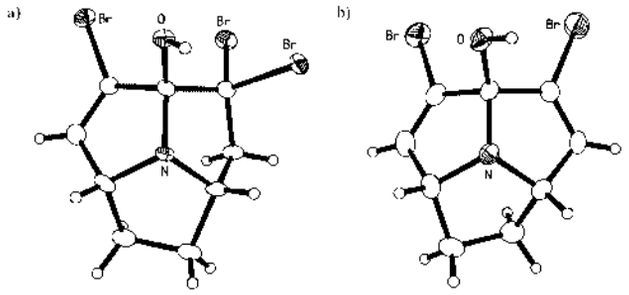
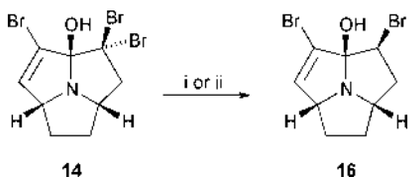


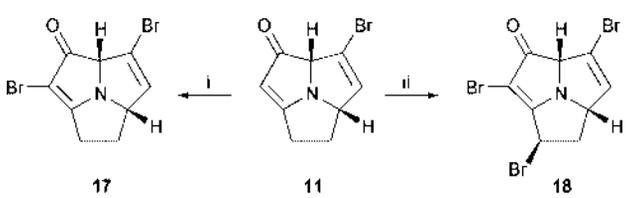
Fig. 6 X-Ray crystal structures of (a) **14** and (b) **15**.

unknown monoene **6** seemed attractive. However, treatment of **14** with either tributyltin hydride or lithium triethylborohydride ('superhydride') led surprisingly to the removal of only a single bromine to give **16** in modest yield in each case (Scheme 8).



Scheme 8 *Reagents and conditions*: i, $LiEt_3BH$, THF, Δ; ii, Bu_3SnH, AIBN, PhH, Δ.

Studies toward the synthesis of azatriquinacene **2** were continued from the enaminone **11**. The strategy was to gain functionality in all three rings, which was ultimately accomplished in high yield by treatment of **11** with NBS; a reaction which could be controlled to give selective mono- (**17**) or dibromination (**18**) of the enaminone function depending on reaction time (Scheme 9). Despite the impressive degree of functionality



Scheme 9 *Reagents and conditions*: i, NBS, CH_2Cl_2, 10 min; ii, NBS, CH_2Cl_2, 7 h.

about the azatriquinane tricycle realized in **18**, elaboration to the triene **2** has not yet been achieved by this route, but rather by direct oxidation of **4**.[3]

Conclusion

The hemispherical morphology of the azatriquinane tricycles leads in many instances to unforeseen and interesting reactivity, some of which has been described here, with much undoubtedly remaining to be discovered. A line of investigation which suggests itself here is the extension of this chemistry to the synthesis of the still unknown monoene **6**, and to new routes to azatriquinacene **2**. Work along these lines will be reported in due course.

Experimental

rel-(1*R*,2*R*,4*R*,7*S*)-2-Bromo-10-azatricyclo[5.2.1.$0^{1,10}$]-decan-1-ol 7

N-Bromosuccinimide (1.54 g, 8.65 mmol) was added portionwise to a stirred solution of enamine **5** (0.693 g, 5.13 mmol) in dichloromethane (20 ml) at −78 °C. When the addition was complete, the −78 °C bath was replaced by an ice bath and the mixture was stirred for 25 min. The reaction was then allowed

to come to room temperature and stirred for a further 10 min. The solvent was evaporated and the residue partitioned between dichloromethane (50 ml) and 2 M NaOH (30 ml). The aqueous phase was extracted with dichloromethane (2 × 40 ml) and the combined organic layer dried ($MgSO_4$). The solvent was evaporated to give a brown solid which was dissolved in a mixture of chloroform (50 ml) and conc. HCl (10 ml) and the mixture was heated for 14 h at reflux with stirring. The reaction was cooled to room temperature and water (30 ml) and dichloromethane (30 ml) were added. The layers were separated and the aqueous phase was extracted with dichloromethane (2 × 30 ml). The combined organic layer was dried ($MgSO_4$) and the solvent evaporated to give a solid residue which was chromatographed (10 : 1 CH_2Cl_2–MeOH) to give **7** (0.131 g, 11%) as a white solid, mp 118–121 °C (Found: (HRMS ES) M + H 232.0354, $C_9H_{15}NOBr$ requires 232.0337); ν_{max}/cm^{-1} 3564, 2943, 2870, 1463, 1355, 1293, 1140, 1106, 1078, 973; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 101.9, 64.9, 61.6, 58.7, 40.6, 36.0, 30.3, 30.0, 29.6.

rel-(5*R*,7a*S*)-2,2-Dibromo-5-(2,2-dibromoethyl)pyrrolizidin-3-one 9

Potassium *tert*-butoxide (69 mg, 0.61 mmol) was added portionwise over 15 min to a stirred solution of **8** (101 mg, 0.215 mmol) in THF (5 ml) at 0 °C under nitrogen. After 10 min the solvent was evaporated and the residue partitioned between water (10 ml) and dichloromethane (15 ml). After vigorous agitation the layers were separated and the aqueous layer was extracted with dichloromethane (2 × 10 ml). The combined organic phase was dried ($MgSO_4$) and the solvent evaporated to give **9** (59 mg, 58%) as a pale yellow solid, mp 134–136 °C (Found: (HRMS EI) M^+ 464.7557, $C_9H_{11}NOBr_4$ requires 464.7574); ν_{max}/cm^{-1} 2957, 2931, 2875, 1715, 1405, 1352, 1300, 908; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 164.3, 60.3, 60.0, 54.1, 53.0, 47.5, 42.5, 33.6, 28.0.

rel-(5*R*,7a*S*)-5-(2,2-Dibromoethyl)-7a-hydroxy-5,6,7,7a-tetrahydro-3*H*-pyrrolizin-3-one 10

DBU (2.80 ml, 2.85 g, 18.7 mmol) was added dropwise over 5 min to a stirred solution of **8** (1.73 g, 3.69 mmol) in THF (150 ml) at room temperature under nitrogen. After 20 min the solvent was evaporated and the residue partitioned between water (40 ml) and dichloromethane (60 ml). After vigorous agitation the layers were separated and the aqueous layer was extracted with dichloromethane (2 × 50 ml). The combined organic phase was dried ($MgSO_4$) and the solvent evaporated to give a brown oil which was chromatographed (5 : 1 EtOAc–petroleum ether) to give **10** (49 mg, 4%) as a colorless crystalline solid, mp 124–126 °C (Found: (HRMS ES) M + Na 345.9023, $C_9H_{11}NO_2Br_2Na$ requires 345.9054); ν_{max}/cm^{-1} 3579, 2947, 2876, 1711, 1593, 1458, 1366, 1347, 1296, 1100, 1001, 908; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(100 MHz; $CDCl_3$) 174.4, 150.2, 126.4, 98.7, 54.3, 53.5, 43.0, 34.3, 34.2.

rel-(1*R*,7*S*)-9-Bromo-10-azatricyclo[5.2.1.0^{1,10}]deca-3,8-dien-2-one 11

A solution of DBU (2.70 ml, 2.75 g, 18.1 mmol) in THF (5 ml) was added dropwise over 15 min to a stirred solution of **8** (2.83 g, 6.04 mmol) in THF (50 ml) at −78 °C under nitrogen. Stirring was continued for 4.5 h during which the mixture was allowed to come to room temperature. The solvent was evaporated and the residue partitioned between dichloromethane (50 ml) and water (35 ml). The aqueous phase was extracted with dichloromethane (3 × 30 ml), and the combined organic phase was washed with water (30 ml) and dried ($MgSO_4$). The solvent was evaporated to give a brown solid which was chromatographed (1 : 1 EtOAc–petroleum ether) to give **11** (312 mg, 23%) as orange crystals, mp 100–103 °C (Found: (HRMS EI) M^+ 224.9793, C_9H_8NOBr requires 224.9789); ν_{max}/cm^{-1} 2925, 1687, 1584, 1368, 890; δ_H(400 MHz; $CDCl_3$) See ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 202.3, 189.9, 132.7, 119.2, 101.1, 77.2, 65.6, 28.5, 27.3.

rel-(1*R*,4*S*,7*R*)-9,9-Dibromo-1-hydroxy-10-azatricyclo-[5.2.1.0^{1,10}]decan-2-one 12

Compound **8** (48 mg, 0.10 mmol) was added to a stirred mixture of acetonitrile (30 ml) and sat. aqueous sodium chloride (30 ml) and the resulting suspension was heated at reflux for 2 h. The reaction was cooled to room temperature and dichloromethane (40 ml) and water (15 ml) were added. The mixture was stirred 5 min and the layers were separated. The aqueous phase was extracted with dichloromethane (2 × 30 ml) and the combined organic layer was dried ($MgSO_4$). The solvent evaporated to give a colorless crystalline solid which was chromatographed (3 : 1 EtOAc–petroleum ether) to give **12** (10 mg, 30%) as colorless crystals, mp 97–99 °C (Found: (HRMS ES) M + H 323.9210, $C_9H_{12}NO_2Br_2$ requires 323.9235); ν_{max}/cm^{-1} 3696, 3533, 2946, 1760, 1698, 1601, 1463, 1354, 1146, 1125, 1098, 968, 894; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(100 MHz; $CDCl_3$) 209.6, 97.4, 68.1, 62.7, 55.8, 55.6, 43.6, 32.5, 29.0; *m*/*z* (ES) 324 (M + H, 30%) 328 (25), 326 (100), 324 (30).

(1*R*,2*R*,4*R*,7*S*,9*S*)-2,9-Dibromo-10-azatricyclo[5.2.1.0^{1,10}]-decan-1-ol 13

Diphenyl phosphite (2.37 ml, 2.90 g, 12.4 mmol) was added dropwise to a stirred solution of **8** (1.02 g, 2.18 mmol) in THF (10 ml) at room temperature. The mixture was stirred for 5 min and then triethylamine (1.23 ml, 0.89 g, 8.82 mmol) was added dropwise. Stirring was continued for 30 min and the volatiles were removed under reduced pressure to give a residue which was partitioned between dichloromethane (40 ml) and water (20 ml). The organic phase was washed with brine (60 ml) and water (2 × 50 ml) and dried ($MgSO_4$). The solvent was evaporated to give an oily solid which was washed with ether (3 × 20 ml) to give **13** (249 mg, 37%) as a white solid, mp 138–140 °C (Found: (HRMS FAB) M + H 309.9420, $C_9H_{14}NOBr_2$ requires 309.9442); ν_{max}/cm^{-1} 3632, 3548, 2958, 2872, 1732, 1462, 1266, 1106, 1068, 1016, 950; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 100.0, 61.9, 53.6, 40.4, 29.8.

rel-(1*R*,4*S*,7*R*)-2,9,9-Tribromo-10-azatricyclo[5.2.1.0^{1,10}]dec-2-en-1-ol 14

A solution of KHMDS in toluene (0.50 M, 1.63 ml, 0.82 mmol) was added dropwise to a stirred solution of **8** (101 mg, 0.215 mmol) in THF (10 ml) at −78 °C over 5 min. The mixture was stirred for an additional 15 min and allowed to come to room temperature. Dichloromethane (20 ml) and water (10 ml) were added, the mixture was stirred for 5 min and the layers were separated. The aqueous phase was extracted with dichloromethane (2 × 20 ml) and then the combined organic layer was dried ($MgSO_4$) and the solvent evaporated to give **14** (69 mg, 83%) as orange crystals, mp 112–114 °C, (Found: (HRMS ES) M + H 385.8380, $C_9H_{11}NOBr_3$ requires 385.8391); ν_{max}/cm^{-1} 3546, 2927, 1616, 1462, 1343, 1112, 1074, 949; δ_H(400 MHz, DMSO-d_6) see ESI;‡ δ_C(100 MHz, DMSO-d_6) 138.7, 121.2, 105.1, 72.1, 68.6, 60.9, 54.3, 29.9, 28.3.

rel-(1*R*,4*R*,7*S*)-2,9-Dibromo-10-azatricyclo[5.2.1.0^{1,10}]dec-2-en-1-ol 16

A solution of lithium triethylborohydride in THF (1.0 M, 4.7 ml, 4.7 mmol) was added dropwise to a stirred solution of **14** (295 mg, 0.761 mmol) in THF (11 ml) at room temperature under nitrogen. The reaction was then heated at reflux for 48 h. The solvent was evaporated and the residue partitioned between water (10 ml) and conc. HCl (8 ml). The mixture was stirred vigorously at room temperature for 15 min, the layers

were separated, and the aqueous phase washed with dichloromethane (10 ml). The aqueous layer was then made basic with 2 M NaOH and extracted with dichloromethane (3 × 20 ml). Trifluoroacetic acid (3.4 ml, 5.0 g, 44 mmol) was added to the organic layer which was then dried ($MgSO_4$) and the solvent evaporated to give the trifluoroacetate salt of **16** (83 mg, 26%) as colorless crystals, mp 185–187 °C (Found: (HRMS ES) M + H 307.9276, $C_9H_{12}NOBr_2$ requires 307.9286); ν_{max}/cm^{-1} 3535, 2942, 1624, 1458, 1355, 1101, 907; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 135.9, 120.5, 103.6, 68.7, 63.0, 56.2, 40.9, 29.4, 29.2.

rel-(1*R*,7*S*)-3,9-Dibromo-10-azatricyclo[5.2.1.0^{1,10}]deca-3,8-dien-2-one 17

N-Bromosuccinimide (12 mg, 0.067 mmol) was added portionwise to a stirred solution of **11** (14 mg, 0.062 mmol) in dichloromethane (2 ml) at room temperature. The mixture was stirred for 10 min and dichloromethane (10 ml) and 2 M NaOH (8 ml) were added. After vigorous agitation the layers were separated and the aqueous phase was extracted with dichloromethane (2 × 10 ml). The combined organic layer was dried ($MgSO_4$) and the solvent evaporated to give **17** (18 mg, 95%) as an oily, pale yellow solid (Found: (HRMS EI) M^+ 302.8884, $C_9H_7NOBr_2$ requires 302.8894); ν_{max}/cm^{-1} 2925, 1703, 1588, 1360, 1064, 1043, 964, 882; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 194.4, 187.0, 133.2, 118.9, 97.6, 76.4, 66.6, 27.9, 27.0.

rel-(1*R*,5*R*,7*S*)-3,5,9-Tribromo-10-azatricyclo[5.2.1.0^{1,10}]deca-3,8-dien-2-one 18

N-Bromosuccinimide (59 mg, 0.33 mmol) was added portionwise to a stirred solution of **11** (15 mg, 0.066 mmol) in dichloromethane (2 ml) at room temperature. The mixture was stirred for 7 h and dichloromethane (10 ml) and 2 M NaOH (8 ml) were added. After vigorous agitation the layers were separated and the aqueous phase was extracted with dichloromethane (2 × 10 ml). The combined organic layer was dried ($MgSO_4$) and the solvent evaporated to give **18** (24 mg, 94%) as an oily orange solid (Found: (HRMS ES) M + H 381.8044, $C_9H_7NOBr_3$ requires 381.8078); ν_{max}/cm^{-1} 2926, 2852, 1715, 1594, 1359, 1048; δ_H(400 MHz; $CDCl_3$) see ESI;‡ δ_C(67.5 MHz; $CDCl_3$) 193.9, 182.6, 132.1, 118.7, 92.8, 75.5, 65.3, 40.8, 36.4.

X-Ray crystal data‖

Compound **7**: $C_9H_{14}BrNO$, M = 232.12, monoclinic, a = 7.5959(6), b = 11.2333(10), c = 10.9437(9) Å, β = 99.459(2)°, U = 921.10(13) Å^3, T = 150(2) K, space group $P2_1/n$ (*Alt.* $P2_1/c$, no. 14), Z = 4, D_c = 1.674 g cm^{-3}, μ(Mo-Kα) = 4.414 mm^{-1}, 2170 unique reflections measured, corrected for absorption (R_{int} 0.028), and used in all calculations. Final R_1 [1752 $F > 4\sigma(F)$] = 0.0289 and wR(all F^2) was 0.0731.

Compound **10**: $C_9H_{11}Br_2NO_2$, M = 325.01, monoclinic, a = 7.9285(7), b = 15.3908(13), c = 8.6507(7) Å, β = 92.781(2)°, U = 1054.4(2) Å^3, T = 150(2) K, space group $P2_1/n$ (*Alt.* $P2_1/c$, no. 14), Z = 4, D_c = 2.047 g cm^{-3}, μ(Mo-Kα) = 7.661 mm^{-1}, 2518 unique reflections measured, corrected for absorption (R_{int} 0.049), and used in all calculations. Final R_1 [2181 $F > 4\sigma(F)$] = 0.0260 and wR(all F^2) was 0.0675.

Compound **11**: C_9H_8BrNO, M = 226.07, triclinic, a = 7.471(3), b = 7.526(4), c = 9.411(4) Å, α = 70.19(3), β = 68.20(3), γ = 62.54(3)°, U = 426.8(3) Å^3, T = 298(2) K, space group $P\bar{1}$ (No. 2), Z = 2, D_c = 1.759 g cm^{-3}, μ(Mo-Kα) = 4.671 mm^{-1}, 1658 unique reflections measured, corrected for absorption (R_{int} 0.047), and used in all calculations. Final R_1 [1360 $F > 4\sigma(F)$] = 0.0426 and wR(all F^2) was 0.0986.

Compound **12**: $C_9H_{11}Br_2NO_2$, M = 325.01, triclinic, a = 6.5196(9), b = 8.2050(10), c = 10.465(2) Å, α = 100.683(2), β = 97.512(3), γ = 112.135(3)°, U = 497.04(13) Å^3, T = 150(2) K, space group $P\bar{1}$ (No. 2), Z = 2, D_c = 2.172 g cm^{-3}, μ(Mo-Kα) = 8.126 mm^{-1}, 1885 unique reflections measured, corrected for absorption (R_{int} 0.033), and used in all calculations. Final R_1 [1574 $F > 4\sigma(F)$] = 0.0439 and wR(all F^2) was 0.125.

Compound **14**: $C_9H_{10}Br_3NO$, M = 387.91, triclinic, a = 7.0950(14), b = 7.944(2), c = 10.663(2) Å, α = 77.401(4), β = 79.163(3), γ = 66.936(3)°, U = 536.2(2) Å^3, T = 150(2) K, space group $P\bar{1}$ (No. 2), Z = 2, D_c = 2.403 g cm^{-3}, μ(Mo-Kα) = 11.251 mm^{-1}, 2337 unique reflections measured, corrected for absorption (R_{int} 0.003), and used in all calculations. Final R_1 [2039 $F > 4\sigma(F)$] = 0.0425 and wR(all F^2) was 0.115.

Compound **15**: $C_9H_9Br_2NO$, M = 306.99, monoclinic, a = 11.049(3), b = 14.876(4), c = 13.085(3) Å, β = 109.177(5)°, U = 2031.4(9) Å^3, T = 150(2) K, space group $P2_1/c$ (No. 14), Z = 8, D_c = 2.008 g cm^{-3}, μ(Mo-Kα) = 7.940 mm^{-1}, 4806 unique reflections measured, corrected for absorption (R_{int} 0.070), and used in all calculations. Final R_1 [3269 $F > 4\sigma(F)$] = 0.0338 and wR(all F^2) was 0.0603.

‖ CCDC reference numbers 170513–170518. See http://www.rsc.org/suppdata/p1/b1/b107707d/ for crystallographic files in .cif or other electronic format.

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9 The calculated infrared absorption for the double bond in **5** is 1672 cm^{-1} when scaled using the method of Yoshida *et al.* (H. Yoshida, A. Ehara and H. Matsuura, *Chem. Phys. Lett.*, 2000, **325**, 477), which compares well to the experimental value of 1660 cm^{-1}. A GIAO magnetic shielding tensor calculation (B3LYP/6-311+G**) showed a remarkably good linear relationship with the experimental ^{13}C shifts of **5**, with correlation = 0.999, mean $\Delta\delta$ = 1.6 ppm and $\Delta\delta$ range 0.4–3.5 ppm.
10 Conjugation of the nitrogen to the double bond is supported by an N–C1–C2–H dihedral angle of 178.1° in the calculated structure. The stabilization gained by conjugation can be demonstrated by comparing the energies of the Δ^2- and Δ^3-pyrrolines, the former of which is about 5 kcal mol^{-1} lower in energy at the B3LYP/6-311+G**//B3LYP/6-311+G** level of theory.
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