



HAL
open science

From Enynyl Esters to Functionalized Polycyclic Derivatives via Cycloisomerization and Post-Functionalization

Simon Guelen, Max Blazejak, Virginie Mouriès-Mansuy, Louis Fensterbank

► **To cite this version:**

Simon Guelen, Max Blazejak, Virginie Mouriès-Mansuy, Louis Fensterbank. From Enynyl Esters to Functionalized Polycyclic Derivatives via Cycloisomerization and Post-Functionalization. *Synthesis: Journal of Synthetic Organic Chemistry*, 2016, 48 (19), pp.3199 - 3206. 10.1055/s-0035-1561488 . hal-01400636

HAL Id: hal-01400636

<https://hal.sorbonne-universite.fr/hal-01400636>

Submitted on 22 Nov 2016

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

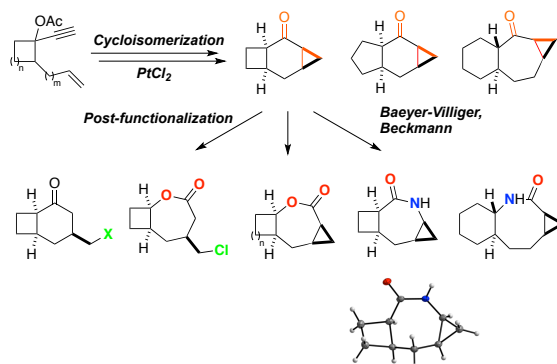
From Enynyl Esters to Functionalized Polycyclic Derivatives via Cycloisomerization and Post-Functionalization

Simon Guelen
Max Blazejak
Virginie Mouriès-Mansuy*
Louis Fensterbank*

Institut Parisien de Chimie Moléculaire, UMR CNRS 8232,
Sorbonne Universités UPMC Univ Paris 06, 4 Place Jussieu,
CC 229, F-75252 Paris Cedex 05, France

virginie.mansuy@upmc.fr; louis.fensterbank@upmc.fr

Dedicated to Jean F. Normant with admiration



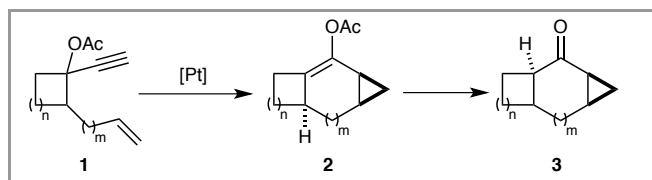
Received:
Accepted:
Published online:
DOI:

Abstract: The post-functionalization of ketone products originating from the PtCl_2 -catalyzed cycloisomerization of enynyl esters is described. Postfunctionalization has been accomplished via diastereoselective alkylation, regioselective cyclopropane opening and regioselective Baeyer Villiger and Beckmann rearrangements to provide functionalized polycycles.

Key words: cycloisomerization, platinum, enynyl ester, polycyclic ketone, Baeyer-Villiger, Beckmann rearrangement, lactones, lactams

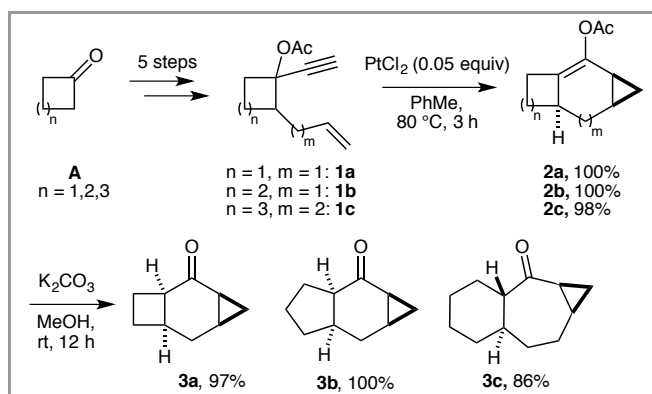
Since the serendipitous rediscovery by us in 2002¹ of the PtCl_2 catalyzed 1,2-OAc migration of propargyl acetates to generate platinum carbenoid intermediates,² this chemistry has witnessed intense investigations notably for conducting valuable enyne cycloisomerizations leading to molecular complexity³ from readily available precursors.⁴ The possibility to use gold⁵ and more rarely other metals such as rhodium as catalysts,⁶ in each case bringing in their specific features, have greatly contributed to these developments.

The tandem 1,2-OAc migration–intramolecular cyclopropanation of substrates **1** to polycycles **2** is one of the iconic synthetic sequences that has been extensively studied by several groups⁷ including ours.^{1,8} Besides intriguing mechanistic manifolds,⁹ the carbocyclic platforms obtained in a highly diastereoselective manner are rich in synthetic potential, notably after a hydrolysis treatment which liberates versatile ketone derivatives **3** (Scheme 1). Herein, we focus on a series of these ketone substrates and notably examine their post functionalization leading to various types of functionalized products.



Scheme 1 Cycloisomerization of monocyclic enynyl esters

Synthesis of the platforms was carried out following the literature route (Scheme 2).¹⁰ Starting from the corresponding cyclic ketones **A**, allyl cyclobutyl (**1a**), allyl cyclopentyl (**1b**) enyne acetate as well as the cyclohexyl derivative bearing a homoallyl group (**1c**) were obtained in a five step synthesis (formation of dimethylhydrazone, alkylation and hydrolysis, addition of TMS-acetylene, cleavage of TMS group and acetylation). All three were then cyclized to the tricyclic enol acetates **2a-c** using 5 mol % PtCl_2 and saponified with potassium carbonate in methanol to the ketones **3a-c** in excellent yields and as single diastereomers.^{8d}

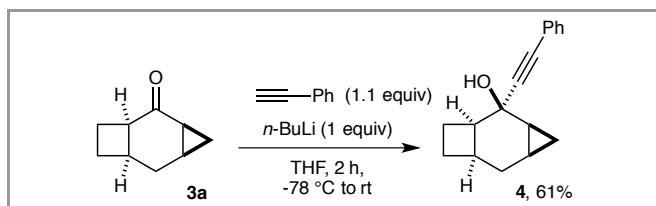


Scheme 2 Synthesis of ketones **3a-c**

In order to establish the relative stereochemistry of these derivatives, ketones **3a** and **3c**, which were obtained as oils, were then condensed with 2,4-dinitrophenylhydrazine in refluxing methanol in the presence of *p*-toluenesulfonic acid to give the corresponding 2,4-dinitrophenylhydrazones **3a**-DNPH and **3c**-DNPH as crystalline solids in 68% and 71% yield respectively. Structure and relative configuration of these compounds, and thus of **3a** and **3c**, were confirmed through single crystal X-ray analysis (Figure 1).¹¹

It is noticeable, that in **3a** all four bridging hydrogens are *cis*-configured with a *syn*-configuration of the four- and three-membered ring, whereas in **3c** the bridging hydrogens of the six-membered ring are in *trans*-configuration. This suggests that during the enol acetate hydrolysis the ring strain confines the four-membered ring in **3a** to give the *cis*-isomer, while the six-membered ring of **3c** is large and flexible enough to form the more stable *trans*-isomer with a perfect chair conformation. Based on the fact that the favored ring junction between a cyclohexanone and a five-membered ring is *cis*,¹² we hypothesized the same for **3b** and thus a relative stereochemistry as seen for **3a**.

Because of its very specific structure featuring marked concave and convex faces, we looked at addition reactions on the carbonyl moiety anticipating highly diastereoselective processes. To probe this, we looked at the 1,2-addition of a lithium acetylide. After deprotonation with *n*-BuLi, phenylacetylene reacted with **3a** to give alcohol **4** in 61% yield, as a single diastereomer (Scheme 3). Its relative stereochemistry was established by NOESY of the corresponding *O*-allyl (**4-Oallyl**) derivative and confirmed an exclusive attack from the convex face.



Scheme 3 Diastereoselective alkylation of ketone **3a**

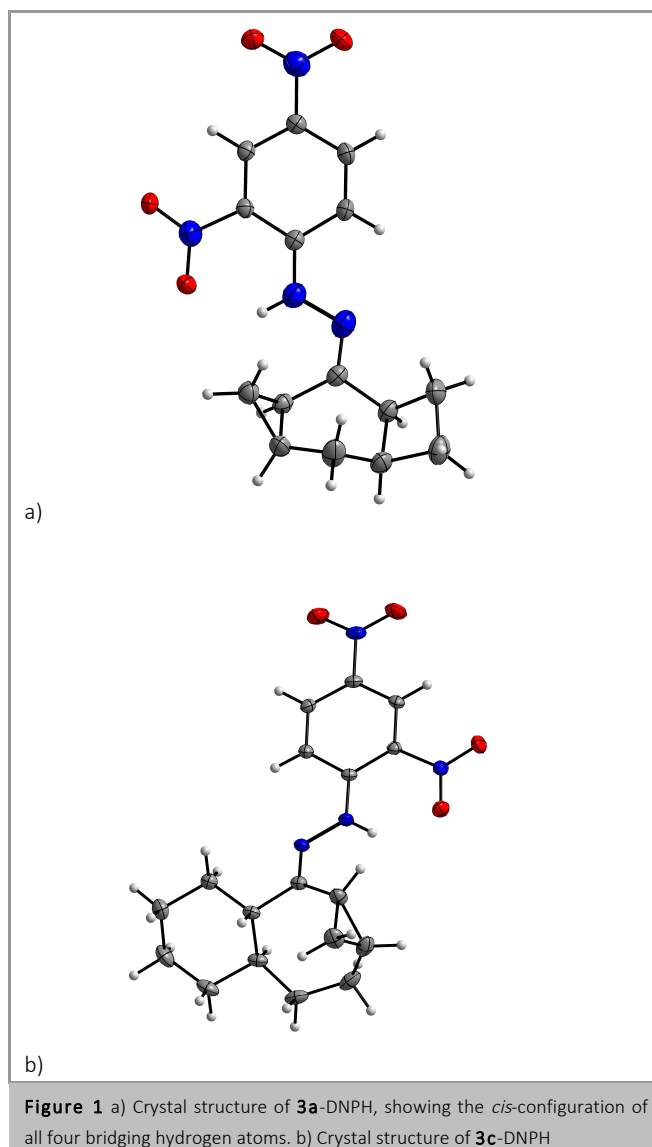
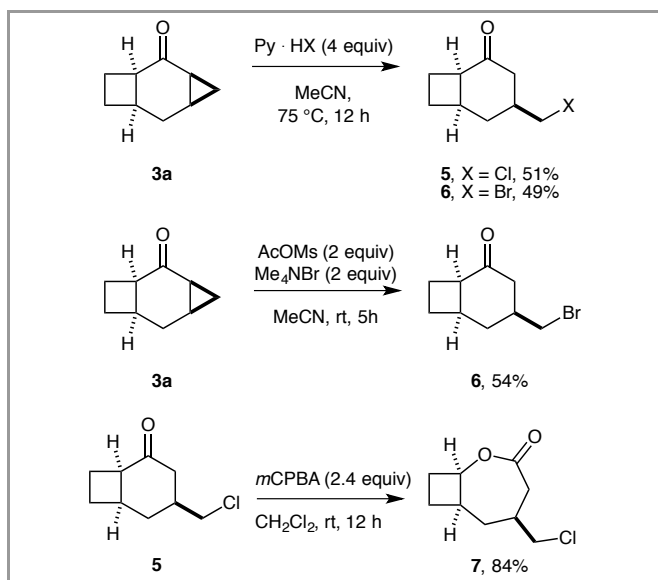


Figure 1 a) Crystal structure of **3a**-DNPH, showing the *cis*-configuration of all four bridging hydrogen atoms. b) Crystal structure of **3c**-DNPH

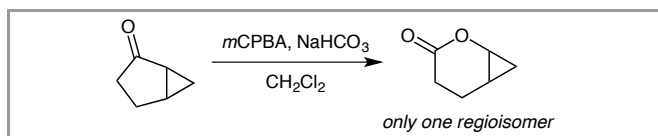
After derivatizing the carbonyl moiety, we focused our attention on the cyclopropyl moiety. Indeed, a potentially valuable way to introduce functionality onto the platform would be the selective opening of the strained cyclopropyl moiety with halides. Interestingly, Tardella and coworkers used pyridinium hydrochloride as halide source to open a related bicyclic ketone in a selective manner.¹³ In our hands, using pyridinium salts as halide source (Scheme 4), a C-C cleavage reaction took place cleanly to give the respective bicyclic chloro- and bromoketones **5** and **6** as single diastereomers.



Scheme 4 Regioselective cyclopropyl opening of ketone **3a** and subsequent Baeyer-Villiger oxidation

Although the yields were only average, other tested methods did not prove to be more successful. Acetylmethanesulfonate, which in combination with tetramethylammonium bromide had also been used successfully in the literature¹⁴ as an activating agent to open cyclopropyl ketones for example, gave bromide **6** in 54% yield. Further heterofunctionalization could be brought on chloroketone **5** through a regioselective Baeyer-Villiger (BV) reaction to give lactone **7** in good yield.

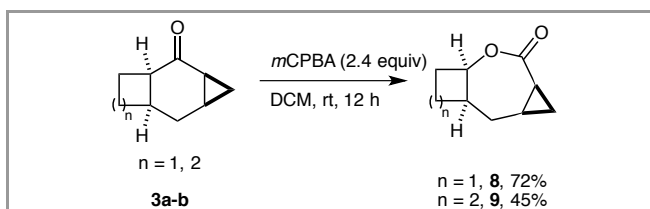
From a regioselectivity point of view, the BV oxidation of **3a** appeared highly intriguing. It had been shown by the group of Wiberg,¹⁵ that this reaction is completely regioselective for the bicyclic ketone cyclopropyl-cyclopentanone, where only the cyclopropyl group is migrating (Scheme 5).



Scheme 5 Regioselectivity of the Baeyer-Villiger oxidation of cyclopropyl-cyclopentanone reported by Wiberg *et al.*¹⁵

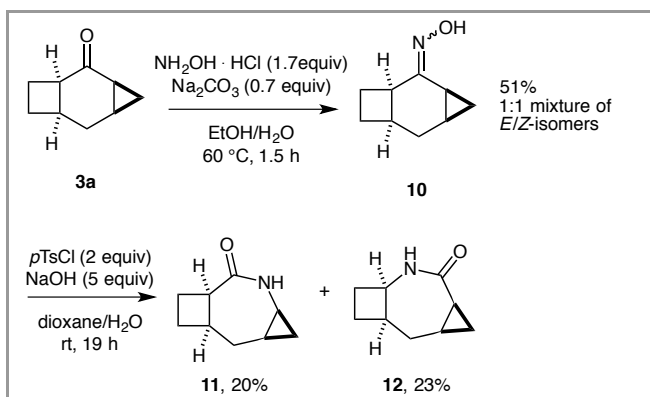
BV reactions of **3a** and **3b** were thus carried out in standard conditions using *m*CPBA in dichloromethane (Scheme 6). Gratifyingly, lactones **8** and **9** were formed as single regioisomers, which structures could be assigned by 2D NMR. Consistent with Wiberg's results, only the larger cyclobutyl (**8a**) and cyclopentyl (**8b**) groups migrated.

Surprisingly, **3c** did not react at all under identical BV oxidation conditions and only starting material was recovered.¹⁶ Although the reason for this remains unclear, it might be possible that the formation of an eight-membered ring lactone is unfavorable. The different configuration of the ring junction of **3c** compared to **3a** and **3b** could also play a role.



Scheme 6 Regioselective Baeyer-Villiger oxidation of ketones **3a** and **3b**

To compare the BV oxidation to another ring expansion reaction, we explored the possibility of a Beckmann rearrangement, which would convert, after oxime formation, the cyclic ketone to the corresponding lactams.¹⁷ At first, this task seemed challenging, as in several experiments using hydroxylammonium chloride and sodium acetate in methanol no oxime at all was formed. Here a switch to different bases and solvent systems helped. Oxime **10** could be synthesized using pyridine in ethanol, NaOH in ethanol-water or with sodium carbonate in ethanol-water, which gave the best yield (51% of **10**, see Scheme 7).



Scheme 7 Oxime formation with following Beckmann rearrangement of ketone **3a**

The oxime **10** was obtained as an inseparable 1:1 mixture of *E/Z*-isomers. Beckmann rearrangement then proceeded smoothly.¹⁸ Although the rearrangement itself is probably regioselective, starting from **10** two regioisomeric amide products **11** and **12** were obtained. As they showed a surprisingly large difference in polarity, they were easily separable by chromatography. Amide **11** gave crystals suitable for X-ray diffraction analysis,¹⁹ which allowed for an unequivocal assignment of both isomers (Figure 2). A direct Beckmann rearrangement starting from **3a** with $\text{NH}_2\text{SO}_3\text{H}$ in formic acid was possible, too, but gave slightly lower yields.²⁰

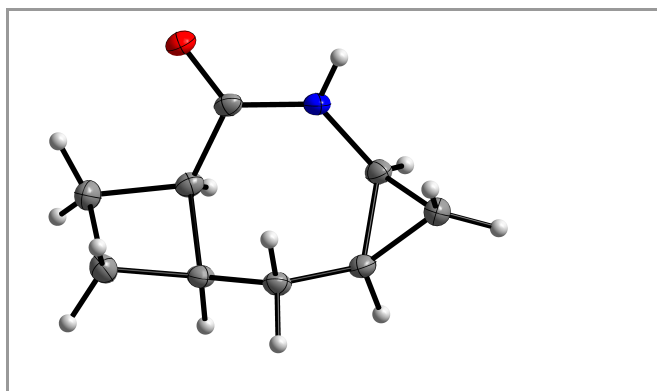
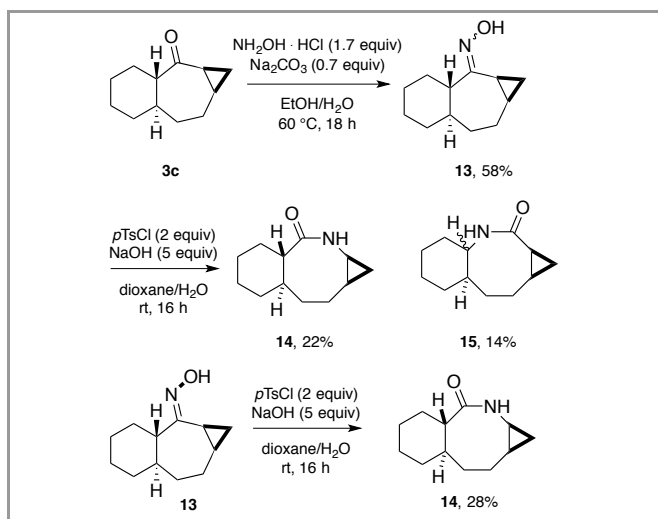


Figure 2 Crystal structure of 11

With **3c**, which as mentioned before did not react under the BV conditions, oxime formation and Beckmann rearrangement were possible (Scheme 8).



Scheme 8 Oxime formation and Beckmann rearrangement of ketone **3c**

Again, oxime **13** was obtained as a 1:1 mixture of both (*E*)- and (*Z*)-isomer, and although they were not completely separable, this time some of the more polar oxime could be isolated by column chromatography. While the (*E/Z*)-mixture of **13**, as before, yielded two regioisomeric amides **14** and **15** (as a mixture of diastereomers) in the Beckmann rearrangement, oxime **13** as a single diastereomer gave only **14** in 28% yield. This strongly hints that the reaction is regioselective with respect to the oxime conformation.

In summary, based on our works on catalytic enyne cycloisomerizations, structurally interesting tricyclic ketones were synthesized, fully characterized and studied as a precursor for regio- and diastereoselective reactions. Nucleophilic attack of the tricyclic ketone by a lithium acetylide turned out to be completely diastereoselective. Selective cyclopropyl opening in the 3-position was easily possible using a pyridinium salt as halide source. The well-known Baeyer-Villiger ring expansion reaction showed full regioselectivity and only migration of the larger ring occurred. Beckmann rearrangement from the corresponding oximes could provide valuable polycyclic amides.

The experimental section has no title; please leave this line here.

Unless otherwise noted, reactions were carried out under argon atmosphere. Methanol was dried overnight over freshly activated molecular sieves (4 Å), THF and diethyl ether were distilled from sodium/benzophenone. Other reagents and chemicals were purchased from commercial sources and used as received. Infrared (IR) spectra were recorded on a Bruker Tensor 27 (ATR diamond) spectrophotometer. Melting points were determined on a melting point apparatus SMP3 (Stuart scientific) and are uncorrected. NMR spectra were recorded at room temperature on Bruker AVANCE 600, 400 or 300 spectrometers. Chemical shifts (δ) are reported in parts per million (ppm) and coupling constants (*J*) are given in Hertz (Hz). ^1H and ^{13}C NMR assignments were based on COSY, HSQC and HMBC experiments. Abbreviations used for peak multiplicity are: s (singlet); bs (broad singlet); d (doublet); t (triplet); q (quartet); p (quintuplet), m (multiplet) and for assignments: cp (cyclopropyl); cb (cyclobutyl); cpe (cyclopentyl); ch (cyclohexyl). High resolution mass spectrometry was performed on a microTOF (ESI). Thin layer chromatography (TLC) was performed on Merck silica gel 60 F 254 and detected with a UV lamp ($\lambda = 254$ nm) and KMnO_4 or *p*-anisaldehyde staining. Flash column chromatography was performed on silica Geduran® Si 60 Å (40 – 63 μm).

Compounds 3a-c; General Procedure

To a stirred solution of the corresponding tricyclic acetate^{8d} **2a-c** (1 equiv.) in dry methanol (0.15 M) at rt under argon was added potassium carbonate (2 equiv.) portion wise and the mixture was stirred at rt for 12 h. The reaction mixture was quenched with saturated ammonium chloride solution. The aqueous phase was extracted three times with diethylether. The combined organic layers were washed with brine, dried over MgSO_4 and concentrated under reduced pressure to give the desired product.

(±)-(3R,5R)-tricyclo[5.2.0.0^{3,5}]nonan-2-one (**3a**)

Scale: 3.8 g, 21.3 mmol; Yield: 2.83 g (97%); Brown oil; $R_f = 0.11$ (petroleum ether/EtOAc, 95:5).

IR (ATR): 2924, 2847, 1683, 1663, 1440, 1349, 1251, 1009, 934, 839, 745 cm^{-1} .

^1H NMR (400MHz, CDCl_3) $\delta = 2.97$ -2.92 (m, 2H), 2.49-2.42 (m, 1H), 2.32-2.25 (m, 1H), 1.98-1.90 (m, 3H), 1.85-1.79 (m, 2H), 1.73-1.71 (m, 1H), 1.25-1.21 (m, 1H), 0.91-0.84 (m, 1H).

^{13}C NMR (100MHz, CDCl_3) $\delta = 213.1$, 41.4 (CCO cb), 32.3, 25.1, 25.0, 23.5, 22.4, 21.9 (CCO cp), 13.9.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_9\text{H}_{12}\text{ONa}$: 159.0780; found: 159.0779.

(±)-(1aR,6aR)-octahydrocyclopropa[*f*]inden-2(1H)-one (**3b**)

Scale: 0.15 g, 0.78 mmol; Yield: 0.12 g (quant); Yellow oil; $R_f = 0.4$ (petroleum ether/EtOAc, 90:10).

IR (ATR): 2959, 2856, 1689, 1366, 1234, 885 cm^{-1} .

^1H NMR (400MHz, CDCl_3) $\delta = 2.36$ (ddd, $J = 13.4$, 7.8, 5.2 Hz, 1H), 2.06-1.99 (m, 1H), 1.89-1.76 (m, 3H), 1.74-1.62 (m, 4H), 1.61-1.51 (m, 1H), 1.42-1.36 (m, 1H), 1.32-1.26 (m, 1H), 1.21-1.09 (m, 1H), 0.93 (q, $J = 5.1$ Hz, 1H).

^{13}C NMR (100MHz, CDCl_3) $\delta = 210.8$, 50.9, 50.4, 32.5, 30.3, 27.0, 22.6, 22.5, 21.7, 20.0.

HRMS (ESI): m/z $[M+Na]^+$ calcd for $C_{10}H_{14}ONa$: 173.0937; found: 173.0939.

(±)-decahydrobenzo[*a*]cyclopropa[*d*][7]annulen-2(1*H*)-one (3c)

Scale: 0.19 g, 0.92 mmol; Yield: 0.130 g (86%); Brown oil; R_f = 0.4 (petroleum ether/EtOAc, 99:1).

IR (ATR): 2916, 2851, 1669, 1445, 1253, 1025, 848, 702 cm^{-1} .

1H NMR (400MHz, $CDCl_3$) δ = 2.08–1.99 (m, 1H), 1.94–1.87 (m, 3H), 1.76–1.56 (m, 6H), 1.54–1.48 (m, 1H), 1.36–0.95 (m, 7H),.

^{13}C NMR (100MHz, $CDCl_3$) δ = 212.8, 50.4, 38.1, 35.1, 33.4, 30.3, 27.6, 26.1, 25.1, 25.0, 19.7, 12.5.

HRMS (ESI): m/z $[M+Na]^+$ calcd for $C_{12}H_{18}ONa$: 201.1250; found: 201.1251.

Dinitrophenylhydrazone formation of 3a and 3c; General Procedure

To a stirred solution of the ketone **3a-c** (1 equiv.) in dry methanol (0.08 M) at rt under argon was added paratoluenesulfonic acid (0.05 equiv.). 2,4-dinitrophenylhydrazine (1.6 equiv.) was then added and the yellow solution was stirred at reflux for 3 h, cooled down to rt and concentrated under reduced pressure. Purification by column chromatography on silica gel using petroleum ether/EtOAc (96/4) as eluent or recrystallization from ethanol afforded the desired product.

(±)-(Z)-1-(2,4-dinitrophenyl)-2-((3*R*,5*R*)-tricyclo[5.2.0.0^{3,5}]nonan-2-ylidene)hydrazine (3a-DNPH)

Scale: 0.056 g, 0.4 mmol; Yield: 0.088 g (68%); Orange solid; R_f = 0.39 (petroleum ether/EtOAc, 96:4); mp: 188 °C.

IR (ATR): 3284, 3102, 2920, 2850, 1613, 1585, 1519, 1499, 1416, 1331, 1305, 1276, 1221, 1135, 1071, 920, 832, 741 cm^{-1} .

1H NMR (400MHz, $CDCl_3$) δ = 9.14 (d, J = 2.6 Hz, 1H), 8.27 (ddd, J = 9.6, 2.6, 0.8 Hz, 1H), 7.92 (d, J = 9.6 Hz, 1H), 3.44–3.38 (m, 1H, CHCN cb), 2.79–2.69 (m, 1H), 2.56–2.46 (m, 1H), 2.43–2.36 (m, 1H), 2.31–2.21 (m, 2H), 1.51–1.33 (m, 4H), 0.77–0.69 (m, 1H), 0.35 (q, J = 4.4 Hz, 1H).

^{13}C NMR (100MHz, $CDCl_3$) δ = 164.0, 145.0, 137.6, 130.0, 129.0, 123.8, 116.6, 38.5 (CHCN cb), 36.8, 30.8, 26.0, 24.2, 13.6, 13.5, 8.3 (CHCN cp).

HRMS (ESI): m/z $[M-H]^+$ calcd for $C_{15}H_{15}N_4O_4$: 315.1095; found: 315.1088.

(±)-(Z)-1-(decahydrobenzo[*a*]cyclopropa[*d*][7]annulen-2(1*H*)-ylidene)-2-(2,4-dinitrophenyl)hydrazine (3c-DNPH)

Scale: 0.083 g, 0.47 mmol; Yield: 0.120 g (71%); Orange red solid; R_f = 0.9 (petroleum ether/EtOAc, 50:50); mp: 170 °C.

IR (ATR): 3312, 2922, 2850, 1617, 1579, 1504, 1418, 1330, 1306, 1268, 1129, 1070, 920, 836, 743 cm^{-1} .

1H NMR (400MHz, $CDCl_3$) δ = 11.67 (s, 1H), 9.14 (d, J = 2.6 Hz, 1H), 8.27 (dd, J = 9.6, 2.6 Hz, 1H), 7.93 (d, J = 9.6 Hz, 1H), 2.17–2.10 (m, 1H), 2.01–1.51 (m, 10H), 1.36–1.23 (m, 4H), 1.13–1.01 (m, 2H), 0.73 (q, J = 5.3 Hz, 1H).

^{13}C NMR (100MHz, $CDCl_3$) δ = 206.9, 164.2, 145.0, 129.8, 123.7, 116.4, 77.2, 48.1, 39.3, 34.4, 34.3, 33.3, 30.9, 27.2, 26.4, 26.1, 15.5, 13.8, 11.2.

HRMS (ESI): m/z $[M-H]^+$ calcd for $C_{18}H_{21}N_4O_4$: 357.1568; found: 357.1566.

(±)-(2*R*,3*R*,5*R*)-2-(phenylethynyl)tricyclo[5.2.0.0^{3,5}]nonan-2-ol (4)

To a stirred solution of phenylacetylene (0.06 mL, 0.5 mmol, 1.1 equiv.) in THF (1.5 mL) at –78 °C under argon was added *n*BuLi (0.18 mL, 2.5 M

in hexane, 0.46 mmol, 1 equiv.) dropwise and the mixture was stirred at –78 °C for 1 h. To this white suspension was cannulated ketone **3a** (0.062 g, 0.46 mmol, 1 equiv.) in THF (1.5 mL) dropwise. The yellow suspension was allowed to warm to rt for 2 h and quenched with saturated ammonium chloride solution. The aqueous phase was extracted three times with diethyl ether. The combined organic layers were washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography on silica gel using pentane/Et₂O (97/3) as eluent afforded the desired product as only one diastereoisomer.

Yield: 0.066 g (61%); Colorless oil; R_f = 0.35 (pentane/Et₂O, 95:5).

IR (ATR): 3564, 2925, 2853, 1489, 1442, 1148, 937, 753, 689 cm^{-1} .

1H NMR (400MHz, $CDCl_3$) δ = 7.45–7.41 (m, 2H), 7.30–7.28 (m, 3H), 2.79–2.70 (m, 1H, CHCO cb), 2.66–2.55 (m, 1H), 2.24–2.07 (m, 4H), 1.87 (s, 1H, OH), 1.64–1.53 (m, 1H), 1.34–1.27 (m, 1H, CHCO cp), 1.08–0.89 (m, 2H), 0.76–0.66 (m, 2H).

^{13}C NMR (100MHz, $CDCl_3$) δ = 131.8 (2 C), 128.3 (2 C), 128.2, 123.1, 94.6, 82.5, 62.3, 42.9 (CHCO cb), 32.2, 27.2, 26.4, 20.4, 19.6 (CHCO cp), 10.0, 8.2.

HRMS (ESI): m/z $[M+Na]^+$ calcd for $C_{17}H_{18}ONa$: 261.1250; found: 261.1246.

(±)-(2*R*,3*R*,5*R*)-2-(allyloxy)-2-(phenylethynyl)tricyclo[5.2.0.0^{3,5}]nonane (4-Oallyl)

To a stirred suspension of sodium hydride (0.013 g, 60% in oil, 0.32 mmol, 1.5 equiv.), sodium iodide (0.003 g, 0.021 mmol, 0.1 equiv.) in dry DMF (3.2 mL) was added allyl bromide (0.04 mL, 0.42 mmol, 2 equiv.) at 0 °C under argon. To this was cannulated alcohol **9** (0.050 g, 0.21 mmol, 1 equiv.) in DMF (0.5 mL) and the reaction mixture was stirred at rt for 18 h. The reaction was quenched with water (15 mL) and extracted three times with diethyl ether. The combined organic layers were washed with brine, dried over $MgSO_4$ and concentrated under reduced pressure. Purification by column chromatography on silica gel using petroleum ether/EtOAc (98/2) as eluent afforded the desired product.

Yield: 0.046 g (79%); Colorless oil; R_f = 0.29 (petroleum ether/EtOAc, 98:2).

IR (ATR): 2927, 2853, 1734, 1645, 1490, 1443, 1256, 1142, 1060, 914, 753, 689, 618 cm^{-1} .

1H NMR (400MHz, $CDCl_3$) δ = 7.45–7.42 (m, 2H), 7.31–7.29 (m, 3H), 6.00 (ddt, J = 17.2, 10.3, 5.1 Hz, 1H), 5.34 (dq, J = 17.2, 1.8 Hz, 1H), 5.14 (dq, J = 10.5, 1.6 Hz, 1H), 4.22 (qdt, J = 12.9, 5.0, 1.7 Hz, 2H), 2.92–2.86 (m, 1H, CHCO cb), 2.71–2.61 (m, 1H), 2.31–2.23 (m, 1H), 2.17–2.08 (m, 2H), 1.68–1.62 (m, 1H), 1.27–1.19 (m, 3H, CHCO cp), 1.05–0.99 (m, 1H), 0.78–0.73 (m, 2H).

^{13}C NMR (100MHz, $CDCl_3$) δ = 135.7, 131.8 (2 C), 128.3 (2 C), 128.1, 123.4, 115.5, 92.6, 84.8, 71.6, 65.5, 41.9 (CHCO cb), 31.4, 26.6, 25.7, 19.7, 18.5 (CHCO cp), 10.9, 9.2.

HRMS (ESI): m/z $[M+Na]^+$ calcd for $C_{20}H_{22}ONa$: 301.1563; found: 301.1559.

Halide cyclopropane opening; General Procedure

To a stirred solution of tricycle ketone (1 equiv.) in acetonitrile (0.25 M) at rt under argon was added dry pyridinium hydrochloride (4 equiv.) portion wise and the reaction mixture was stirred at reflux for 12 h. The reaction mixture was then poured into a saturated sodium chloride solution. The aqueous phase was extracted three times with

diethylether. The combined organic layers were washed with brine, dried over MgSO₄ and concentrated under reduced pressure. Purification by column chromatography on silica gel using pentane/Et₂O (90/10) as eluent afforded the desired product.

(±)-4-(chloromethyl)bicyclo[4.2.0]octan-2-one (5)

Scale: 0.201 g, 1.48 mmol; Yield: 0.12 g (48%); Yellow oil; R_f = 0.58 (pentane/Et₂O, 60:40).

IR (ATR): 2942, 2863, 1697, 1442, 1290, 1199, 1056, 931, 723, 691, 563 cm⁻¹.

¹H NMR (400MHz, CDCl₃) δ = 3.47 (d, *J* = 5.2 Hz, 2H, CH₂Cl), 3.03-2.96 (m, 1H, CHCO cb), 2.74-2.66 (m, 1H), 2.51-2.47 (m, 1H), 2.35-2.18 (m, 4H), 2.12-2.07 (m, 2H), 1.59-1.50 (m, 1H), 1.48-1.39 (m, 1H).

¹³C NMR (75MHz, CDCl₃) δ = 213.1, 49.3 (CH₂Cl), 43.7 (CHCO cb), 43.0 (CH₂CO), 37.7, 34.8, 32.8, 26.1, 24.2.

HRMS (ESI): *m/z* [M+Na]⁺ calcd for C₉H₁₃ClO₂Na: 195.0547; found: 195.0548.

(±)-4-(bromomethyl)bicyclo[4.2.0]octan-2-one (6)

Scale: 0.175 g, 1.28 mmol; Yield: 0.136 g (49%); Brown oil; R_f = 0.8 (petroleum ether/EtOAc, 50:50).

IR (ATR): 2935, 2856, 1698, 1445, 1275, 1222, 916, 638 cm⁻¹.

¹H NMR (400MHz, CDCl₃) δ = 3.37 (d, *J* = 5.5 Hz, 2H, CH₂Br), 3.04-2.97 (m, 1H, CHCO cb), 2.77-2.67 (m, 1H), 2.56-2.50 (m, 1H), 2.38-2.06 (m, 6H), 1.62-1.53 (m, 1H), 1.48-1.39 (m, 1H).

¹³C NMR (75MHz, CDCl₃) δ = 212.9, 44.1 (CHCO cb), 43.7 (CH₂CO), 38.5 (CH₂Br), 37.5, 34.8, 34.0, 26.2, 24.2.

HRMS (ESI): *m/z* [M+Na]⁺ calcd for C₉H₁₃BrO₂Na: 239.0042; found: 239.0039.

(±)-5-(chloromethyl)-2-oxabicyclo[5.2.0]nonan-3-one (7)

Scale: 0.100 g, 0.58 mmol; Yield: 0.096 g (84%); Colorless oil; R_f = 0.22 (cyclohexane/EtOAc, 80:20).

IR (ATR): 2948, 2859, 1730, 1454, 1359, 1273, 1186, 1148, 1069, 1017, 935, 726 cm⁻¹.

¹H NMR (400MHz, CDCl₃) δ = 4.82 (q, *J* = 7.2 Hz, 1H, CHO cb) 3.43-3.42 (d, *J* = 7.3 Hz, 2H, CH₂Cl), 2.74-2.67 (m, 1H), 2.63-2.51 (m, 2H, CH₂CO), 2.45-2.35 (m, 1H), 2.26-2.00 (m, 3H), 1.97-1.92 (m, 1H), 1.72-1.63 (m, 1H), 1.51-1.41 (m, 1H).

¹³C NMR (100MHz, CDCl₃) δ = 171.2, 75.1 (CHO cb), 47.0 (CH₂Cl), 37.4, 35.6, 35.0 (CH₂CO), 31.4, 25.8, 21.2.

HRMS (ESI): *m/z* [M+Na]⁺ calcd for C₉H₁₃ClO₂Na: 211.0496; found: 211.0497.

Regioselective Baeyer-Villiger oxidation; General Procedure

To a stirred solution of tricyclic ketone (1 equiv.) in dry dichloromethane (0.17 M) at 0 °C under argon was added *m*CPBA (70%, 2.4 equiv.) portion wise and the mixture was stirred at rt for 12 h. The reaction mixture was quenched with 10% K₂CO₃ (4 x 10 mL) solution and saturated Na₂S₂O₃ (10 mL) solution. The aqueous phase was extracted with dichloromethane. The combined organic layers were dried over MgSO₄, filtered and concentrated under reduced pressure. Purification by column chromatography on silica gel using pentane/Et₂O (80/20) as eluent afforded the desired products.

(±)-(3R,5R)-7-oxatricyclo[6.2.0.0^{3,5}]decan-6-one (8)

Scale: 0.100 g, 0.73 mmol; Yield: 0.081 g (72%); Yellow oil; R_f = 0.26 (pentane/Et₂O, 80:20).

IR (ATR): 2941, 2860, 1724, 1288, 1174, 1115, 1032, 986 cm⁻¹.

¹H NMR (400MHz, CDCl₃) δ = 4.97-4.93 (m, 1H, CHO cb), 2.79-2.69 (m, 1H), 2.33-2.25 (m, 1H), 2.23-2.17 (m, 1H), 2.00-1.89 (m, 3H), 1.77-1.71 (m, 1H, CHCO cp), 1.03-0.93 (m, 2H), 0.78-0.68 (m, 1H), 0.62-0.56 (m, 1H).

¹³C NMR (100MHz, CDCl₃) δ = 173.4, 78.1 (CHO cb), 39.7, 31.8, 25.4, 25.2, 17.9 (CHCO cp), 12.6, 11.7.

HRMS (ESI): *m/z* [M+Na]⁺ calcd for C₉H₁₂O₂Na: 175.0729; found: 175.0730.

(±)-(1aR,7aR)-octahydrocyclopenta[*b*]cyclopropa[*e*]oxepin-2(1H)-one (9)

Scale: 0.100 g, 0.67 mmol; Yield: 0.024 g (22%); Yellow oil; R_f = 0.2 (pentane/Et₂O, 85:15).

IR (ATR): 2945, 2867, 1693, 1451, 1275, 1207, 1072, 1052, 866 cm⁻¹.

¹H NMR (400MHz, CDCl₃) δ = 4.32-4.27 (m, 1H, CHO cpe), 2.43 (ddd, *J* = 13.9, 9.1, 4.6 Hz, 1H), 2.12-1.91 (m, 4H), 1.85-1.78 (m, 2H), 1.74-1.64 (m, 1H), 1.60-1.47 (m, 2H), 1.29-1.13 (m, 3H).

¹³C NMR (100MHz, CDCl₃) δ = 174.3, 82.2 (CHO cpe), 45.3, 34.2, 32.7, 31.0, 22.4, 22.1 (CHCO cp), 18.4, 12.5.

HRMS (ESI): *m/z* [M+Na]⁺ calcd for C₁₀H₁₄O₂Na: 189.0886; found: 189.0889.

Oxime formation; General Procedure

The tricyclic ketone (1 equiv.) and hydroxylammonium hydrochloride (1.7 equiv.) were dissolved in ethanol (0.98 M) and heated to 60°C. After addition of a solution of Na₂CO₃ (0.7 equiv.) in water (4.9 M), the reaction was stirred at 60°C until TLC indicated complete conversion. After cooling to rt, the mixture was quenched with water and extracted with EtOAc. The combined organic layers were washed with brine, dried over MgSO₄ and concentrated under reduced pressure. Purification by column chromatography on silica gel using petroleum ether/EtOAc (6/1) as eluent afforded the desired product.

(±)-(3R,5R)-tricyclo[5.2.0.0^{3,5}]nonan-2-one oxime (10)

Scale: 0.200 g, 1.47 mmol; Yield: 0.113 g (51%) of a mixture of two diastereomers Z/E (1:1); Yellow oil; R_f = 0.1 (petroleum ether/EtOAc, 6:1).

IR (ATR): 3214, 2927, 2851, 1634, 1447, 1356, 1089, 984, 908, 727 cm⁻¹.

¹H NMR (600MHz, CDCl₃) δ = 3.57 (td, *J* = 9.8, 6.9 Hz, 1H), 3.19 (td, *J* = 10.0, 6.7 Hz, 1H), 2.76-2.70 (m, 1H), 2.69-2.63 (m, 1H), 2.54-2.48 (m, 1H), 2.39-2.33 (m, 1H), 2.20-2.04 (m, 5H), 2.01-1.96 (m, 1H), 1.94-1.88 (m, 1H), 1.70-1.62 (m, 3H), 1.43-1.38 (m, 3H), 1.36-1.32 (m, 1H), 1.25 (s, 1H, OH), 1.16-1.13 (m, 1H), 1.07 (q, *J* = 5.1 Hz, 1H), 0.98 (td, *J* = 8.8, 5.1 Hz, 1H), 0.87 (q, *J* = 5.1 Hz, 1H).

¹³C NMR (151MHz, CDCl₃) δ = 162.7, 162.4, 34.2, 32.5, 31.5, 30.8, 26.7, 26.1, 25.3, 24.8, 24.6, 24.6, 15.0, 13.5, 12.9, 12.8, 12.7, 9.1.

HRMS (ESI): *m/z* [M+H]⁺ calcd for C₉H₁₄NO: 152.1070; found: 152.1073.

(±)-decahydrobenzo[*a*]cyclopropa[*d*][7]annulen-2(1H)-one oxime (13)

Scale: 0.130 g, 0.73 mmol; Yield: 0.031 g (22%) of a mixture of two diastereomers Z/E (1:1); 0.051 g (36%) of a single diastereomer;

combined yield: 58%; Colorless solids; $R_f = 0.63, 0.56$ (petroleum ether/EtOAc, 50:50).

Analysis of one diastereomer:

Mp: 120–125 °C

IR (ATR): 3286, 2921, 2849, 1636, 1446, 1313, 1257, 1029, 943, 780, 656 cm^{-1} .

^1H NMR (300MHz, CDCl_3) $\delta = 8.20$ (br s, 1H), 2.65 (tdd, $J = 11.5, 3.6, 1.1$ Hz, 1H), 2.10–2.03 (m, 1H), 1.99–1.89 (m, 2H), 1.77–1.56 (m, 5H), 1.38–1.24 (m, 4H), 0.96–0.80 (m, 3H), 0.76–0.63 (m, 1H), 0.53 (q, $J = 4.8$ Hz, 1H).

^{13}C NMR (75MHz, CDCl_3) $\delta = 164.5, 42.0, 37.3, 34.0, 29.5, 26.6, 26.4, 15.8, 12.0, 10.7$.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_{12}\text{H}_{19}\text{NONa}$: 216.1359; found: 216.1354.

Beckmann Rearrangement; General Procedure

To a solution of the oxime (1 equiv.) in 1,4-dioxane (0.15 M) were added water (0.11 M), NaOH (5 equiv.) and *p*-TsCl (2 equiv.). The reaction was stirred at rt for 19 h, quenched with water and extracted with DCM. The combined organic layers were washed with brine, dried over MgSO_4 and concentrated under reduced pressure. Purification by column chromatography on silica gel using petroleum ether/EtOAc (50/50 to pure EtOAc) afforded the desired products in two separated fractions.

(±)-(1S,3R,5R,8R)-6-azatricyclo[6.2.0.0^{3,5}]decan-7-one (11)

Scale: 0.113 g of **11**, 0.75 mmol; Yield: 0.023 g (20%); Colorless solid; $R_f = 0.3$ (petroleum ether/EtOAc, 50:50); mp 136 °C.

IR (ATR): 2922, 2853, 1645, 1399, 1344, 1279, 1211, 1032, 875, 801, 675 cm^{-1} .

^1H NMR (400MHz, CDCl_3) $\delta = 5.87$ (br s, 1H), 3.23–3.20 (m, 1H), 2.86–2.80 (m, 1H), 2.48–2.45 (m, 1H), 2.39–2.36 (m, 1H), 2.15–2.13 (m, 1H), 2.06–2.00 (m, 1H), 1.97–1.92 (m, 1H), 1.63 (p, $J = 10.1$ Hz, 1H), 0.98–0.88 (m, 3H), 0.36 (q, $J = 4.6$ Hz, 1H).

^{13}C NMR (151MHz, CDCl_3) $\delta = 175.7, 41.5, 36.0, 32.4, 26.7, 25.0, 19.6, 16.7, 16.1$.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_9\text{H}_{13}\text{NONa}$: 174.0889; found: 174.0891.

(±)-(1S,3R,5R,8R)-7-azatricyclo[6.2.0.0^{3,5}]decan-6-one (12)

Scale: 0.113 g of **11**, 0.75 mmol; Yield: 0.026 g (23%); Colorless solid; $R_f = 0.1$ (petroleum ether/EtOAc, 50:50); mp . 125–132 °C.

IR (ATR): 3273, 3194, 3063, 2994, 2928, 2854, 1643, 1406, 1338, 1303, 1239, 1158, 1022, 921, 789, 698, 649 cm^{-1} .

^1H NMR (400MHz, CDCl_3) $\delta = 5.45$ (br s, 1H), 4.17–4.14 (m, 1H), 2.68–2.58 (m, 1H), 2.43–2.34 (m, 1H), 2.23–2.17 (m, 1H), 2.09–2.01 (m, 1H), 1.89–1.79 (m, 1H), 1.63–1.53 (m, 2H), 0.97–0.78 (m, 3H), 0.54 (q, $J = 4.6$ Hz, 1H).

^{13}C NMR (151MHz, CDCl_3) $\delta = 174.3, 50.9, 37.7, 32.9, 26.0, 25.4, 18.2, 12.5, 11.1$.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_9\text{H}_{13}\text{NONa}$: 174.0889; found: 174.0892.

(±)-(1aR,3aS,7aS,9aR)-dodecahydro-3H-benzo[f]cyclopropa[b]azocin-3-one (14)

Scale: 0.034 g of **15**, 0.18 mmol, using 6.3 equiv. of NaOH; Yield: 0.008 g (22%); Colorless solid; $R_f = 0.21$ (petroleum ether/EtOAc, 50:50); mp. 132–134 °C

IR (ATR): 3262, 3192, 3054, 2996, 2917, 2846, 1633, 1446, 1407, 1344, 1292, 1234, 1172, 1112, 1079, 1033, 964, 880, 829, 785, 746, 705, 648 cm^{-1} .

^1H NMR (400MHz, CDCl_3) $\delta = 5.45$ (br s, 1H), 2.70 (td, $J = 6.8, 3.2$ Hz, 1H), 2.34–2.21 (m, 1H), 2.08–1.97 (m, 3H), 1.83–1.72 (m, 2H), 1.65–1.43 (m, 4H), 1.41–1.31 (m, 2H), 1.18–1.05 (m, 1H), 1.03–0.96 (m, 2H), 0.94–0.84 (m, 1H), 0.24 (ddd, $J = 6.5, 5.3, 3.3$ Hz, 1H).

^{13}C NMR (75MHz, CDCl_3) $\delta = 181.9, 54.3, 36.9, 35.4, 35.3, 33.7, 27.3, 26.7, 26.6, 23.4, 20.6, 15.2$.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_{12}\text{H}_{19}\text{NONa}$: 216.1359; found: 216.1362.

(±)-(1aR,3aS,7aS,9aR)-dodecahydro-2H-benzo[b]cyclopropa[f]-azocin-2-one (15)

Scale: 0.034 g of **13**, 0.18 mmol, using 6.3 equiv. of NaOH; Yield: 0.005 g (14%); Colorless solid; $R_f = 0.16$ (petroleum ether/EtOAc, 50:50); mp. 114–118 °C

IR (ATR): 3273, 3192, 3054, 3000, 2921, 2850, 1639, 1492, 1446, 1424, 1412, 1332, 1269, 1085, 1079, 1027, 1085, 1079, 1027, 935, 857, 813, 800, 729, 695, 636 cm^{-1} .

^1H NMR (300MHz, CDCl_3) $\delta = 5.88$ (br s, 1H), 5.77 (br s, 1H), 4.19 (d, $J = 9.9$ Hz, 1H), 2.70–2.59 (m, 1H), 2.48–2.37 (m, 1H), 2.17–2.04 (m, 2H), 1.92–1.69 (m, 13H), 1.56–1.43 (m, 3H), 1.33–1.23 (m, 5H), 1.05–0.85 (m, 8H), 0.74 (d, $J = 5.0$ Hz, 1H), 0.55 (q, $J = 5.9$ Hz, 1H).

^{13}C NMR (100MHz, CDCl_3) $\delta = 173.8, 173.2, 61.6, 49.1, 43.1, 38.5, 37.7, 35.6, 34.6, 31.3, 30.1, 27.0, 26.9, 26.0, 25.9, 25.7, 25.1, 21.1, 20.1, 20.0, 18.4, 16.7, 10.9, 7.7$.

HRMS (ESI): m/z $[\text{M}+\text{Na}]^+$ calcd for $\text{C}_{12}\text{H}_{19}\text{NONa}$: 216.1359; found: 216.1355.

Acknowledgment

The authors thank UPMC, CNRS and IUF. This work was supported by LabEx MiChem (Ph. D. grant for SG) part of French state funds managed by the ANR within the Investissements d'Avenir programme under reference ANR-11-IDEX-0004-02. A postdoctoral research grant to MB from the department of science and technology of the French embassy in Germany is gratefully acknowledged. We also thank Lise-Marie Chamoreau and Geoffrey Gontard for the XRD analyses (IPCM) and Ange Dole for running some experiments.

Supporting Information

^1H & ^{13}C NMR spectra and crystal data.

References

- (1) For pioneering discoveries, see: (a) Strickler, H.; Davis, J. B.; Ohloff, G. *Helv. Chim. Acta* **1976**, *59*, 1328. (b) Rautenstrauch, V. *J. Org. Chem.* **1984**, *49*, 950.
- (2) Mainetti, E.; Mouriès, V.; Fensterbank, L.; Malacria, M.; Marco-Contelles, J. *Angew. Chem. Int. Ed.* **2002**, *41*, 2132.
- (3) (a) Fürstner, A. *Chem. Soc. Rev.* **2009**, *38*, 3208; (b) Fensterbank, L.; Malacria, M. *Acc. Chem. Res.* **2014**, *47*, 953. (c) Dorel, R.; Echavarren, A. M. *Chem. Rev.* **2015**, *115*, 9028.
- (4) For recent reviews on propargyl acetate migrations, see: (a) Fensterbank, L.; Goddard, J.-P.; Malacria, M.; Simonneau, A. In *Gold Catalysis: An Homogenous Approach*; Toste, F. D.; Michelet, V., Eds.; Imperial College Press, London, **2014**, p. 331. (b) Shiroodi, R. K.

Gevorgyan, V. *Chem. Soc. Rev.* **2013**, *42*, 4991. (c) Day, P. D.; Chan, P. W. H. *Adv. Synth. Catal.* **2016**, *358*, 1368.

(5) For seminal reports, see: (a) Mamane, V.; Gress, T.; Krause, H.; Fürstner, A. *J. Am. Chem. Soc.* **2004**, *126*, 8654. (b) Johansson, M. J.; Gorin, D. J.; Staben, S. T.; Toste, F. D. *J. Am. Chem. Soc.* **2005**, *127*, 18002. (c) Marion, N.; de Frémont, P.; Lemièrre, G.; Stevens, E. D.; Fensterbank, L.; Malacria, M.; Nolan, S. P. *Chem. Commun.* **2006**, 2048.

(6) (a) Shu, X.-z.; Schienebeck, C. M.; Song, W.; Guzei, I. A.; Tang, W. *Angew. Chem. Int. Ed.* **2013**, *52*, (b) Fukuyama, T.; Ohta, Y.; Brancour, B.; Miyagawa, K.; Ryu, I.; Dhimane, A.-L.; Fensterbank, L.; Malacria, M. *Chem. Eur. J.* **2012**, *18*, 7243; Shu, X.-z.; Shu, D.; Schienebeck, C. M.; Tang, W. *Chem. Soc. Rev.* **2012**, *41*, 7698 and references therein.

(7) (a) Amjun, S.; Marco-Contelles, J. *Tetrahedron* **2005**, *61*, 4793. (b) Fürstner, A.; Hannen, P. *Chem. Eur. J.* **2006**, *12*, 3006. (c) C. Fehr, B. Winter, I. Magpantay, *Chem. Eur. J.* **2009**, *15*, 9773. (d) C. Fehr, M. Vuagnoux, A. Buzas, J. Arpagaus, J.; Sommer, H. *Chem. Eur. J.* **2011**, *17*, 6214. (e) Watson, I. D. G.; Ritter, S.; Toste, F. D. *J. Am. Chem. Soc.* **2009**, *131*, 2056. (f) Rao, W.; Chan, P. W. H. *Chem. Eur. J.* **2014**, *20*, 713.

(8) (a) Cariou, K.; Mainetti, E.; Fensterbank, L.; Malacria, M. *Tetrahedron* **2004**, *60*, 9745. (b) Harrak, Y.; Blaszykowski, C.; Bernard, M.; Cariou, K.; Mainetti, E.; Mouriès, V.; Dhimane, A.-L.; Fensterbank, L.; Malacria, M. *J. Am. Chem. Soc.* **2004**, *126*, 8656. (c) Blaszykowski, C.; Harrak, H.; Gonçalves, M.-H.; Cloarec, J.-M.; Dhimane, A.-L.; Fensterbank, L.; Malacria, M. *Org. Lett.* **2004**, *6*, 3771. (d) Moreau, X.; Goddard, J.-P.; Bernard, M.; Lemièrre, G.; López-Romero, J. M.; Mainetti, E.; Marion, N.; Mouriès, V.; Thorimbert, S.; Fensterbank, L.; Malacria, M. *Adv. Synth. Catal.* **2008**, *350*, 43;

(e) Moreau, X.; Hours, A.; Fensterbank, L.; Goddard, J.-P.; Malacria, M.; Thorimbert, S. *J. Organomet. Chem.* **2009**, *694*, 561-565. (f) Harrak, Y.; Makhlof, M.; Azzaro, S.; Mainetti, E.; Lopez Romero, J. M.; Cariou, K.; Gandon, V.; Goddard, J.-P.; Malacria, M.; Fensterbank, L. *J. Organometallic Chem.* **2011**, *696*, 388.

(9) For mechanistic insights, see: (a) Soriano, E.; Marco-Contelles, J. *Chem. Eur. J.* **2008**, *14*, 6771. (b) Marion, N.; Lemièrre, G.; Correa, A.; Ramon, R. S.; Moreau, X.; de Frémont, P.; Dahmane, R.; Hours, A.; Lesage, D.; Tabet, J.-C.; Goddard, J.-P.; Gandon, V.; Cavallo, L.; Fensterbank, L.; Malacria, M.; Nolan, S. P. *Chem. Eur. J.* **2009**, *15*, 3243 and refs 7b-d.

(10) Mino, T.; Masuda, S.; Nishio, M.; Yamashita, M. *J. Org. Chem.* **1997**, *62*, 2633.

(11) **3a-DNPH** CCDC 1481737; **3c-DNPH** CCDC 1481738.

(12) Gordon, H. L.; Freeman, S.; Hudlicky, T. *Synlett* **2005**, 2911.

(13) (a) Di Beello, N.; Pellacani, L.; Tardella, P. A. *Synthesis* **1978**, 227. See also: (b) Huang, H.; Forsyth, C. J. *Tetrahedron* **1997**, *53*, 48, 16341.

(14) Demuth, M.; Raghavan, *Helv. Chim. Acta* **1979**, *62*, 2338.

(15) Wiberg, K. B.; Snoonian, J. R. *J. Org. Chem.* **1998**, *63*, 1390.

(16) In forcing conditions (5 equiv. of mCPBA, 3 days reaction time), 50% conversion was observed giving presumable BV products, but not very cleanly.

(17) (a) Beckmann, E. *Berichte der deutschen chemischen Gesellschaft* **1886**, *19*, 988. (b) Winter, D. K.; Drouin, A.; Lessard, J.; Spino, C. *J. Org. Chem.* **2010**, *75*, 2610. (c) Donaruma, L. G.; Heldt, W. Z. *Org. React.* **2011**, *11:1*, 1-156. (d) Tandon, V. K.; Awasthi, A. K.; Maurya, H. K.; Mishra, P. *J. Heterocycl. Chem.* **2012**, *49*, 424. (e) Zhang, J.; Dong, C.; Du, C.; Luo, G. *Org. Proc. Res. & Dev.* **2015**, *19*, 352.

(18) Kotha, S.; Ravikumar, O.; Majhi, J. *Beilstein J. Org. Chem.* **2015**, *11*, 1503.

(19) **13** CCDC 1481739

(20) Olah, G. A.; Fung, A. P. *Org. Synth.* **1985**, *63*, 188.