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Synthesis of seven-membered oxacycle containing triquinane derivatives *via* olefin metathesis

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Seven-membered oxacylce containing triquinane derivatives have been synthesized in good yields by employing ring-closing metathesis (RCM), ring-opening metathesis (ROM), and the ring-rearrangement metathesis (RRM) as key steps. All the compounds have been characterized by NMR data. The key building blocks have been obtained starting with a commercially available dicyclopentadiene.

Keywords: Triquinane, RCM, 7-Membered ring, RRM, Oxacycles

Polyquinanes containing heterocycles are a significant class of compounds containing a heteroatom such as oxygen or nitrogen. These compounds exhibit a unique blend of structural flexibility and reactivity, making them useful in various chemical and biological contexts. Their application in natural products, pharmaceuticals, and synthetic intermediates highlights their importance in organic chemistry[1]. In biological systems, seven-membered oxacyclic compounds often exhibit remarkable activity, such as antimicrobial, antifungal, and anticancer properties. Their ability to interact with biological targets, such as enzymes and receptors, has made them a focus in medicinal chemistry and drug discovery[2]. The synthesis of seven-membered oxacyclic compounds is challenging due to the inherent ring strain and flexibility of the medium-sized ring. However, various strategies have been developed to efficiently construct these compounds, often tailored to specific functional groups and desired substitution patterns[3]. Among the diverse strategies for synthesizing seven-membered heterocyclic compounds, ring-closing metathesis (RCM) and ring rearrangement metathesis (RRM) have emerged as a highly efficient and versatile approach.

The norbornene derivatives with suitably substituted olefinic tether actively participate in RCM and RRM to generate highly fused molecules. Kotha and group have reported synthetic routes to 7-membered heterocyclic compounds starting with norbornene derivatives[4]. We have mentioned in Fig. 1, some common norbornene derivatives used to construct various polyquinanes *via* RRM and RCM.

Results and Discussion

We began our journey by preparing three stereochemically different known DA adducts **4** (*endo-anti-exo*), **5** (*endo-anti-endo*), and **6** (*exo-anti-exo*) from *endo*-dicyclopentadiene-1-one **2** and *exo*-dicyclopentadiene-1-one **3**, which were prepared from commercially available dicyclopentadiene (DCPD) **1** by following the literature procedure[5] (Fig. 2). Although these compounds are well known, a detailed experimental procedure with exact yields and/or ratios was not found. A general synthetic procedure for **4**, **5**, and **6** has been provided in our previous work[6].

Our focus was to generate oxacycles from the norbornene derivatives **4** and **5**. Therefore, the *endo-anti-exo* compound **4** was reduced to hydroxyl derivative **7** using sodium borohydride in tetrahydrofuran/methanol or diisobutylaluminium hydride (DIBAL-H) in DCM in 88% and 96% yield respectively[7]. Using a similar condition, the *endo* derivative **5** was reduced to the corresponding hydroxy derivative **8** in good yields. Then, the compounds **7** and **8** were treated with allyl bromide in the presence of potassium hydride to obtain O-allyl derivatives **9** and **10**

# These authors contributed equally to this work.

in 82% and 92% yield, respectively. Having compounds **9** and **10** in hand, the next task was to attempt RRM. So, compounds **9** and **10** were exposed to Grubb's 2nd generation catalyst (G-II) in toluene, in the presence of ethylene gas to afford the triquinanes containing oxacycles **11** and **12** in 86% and 84% yield respectively (Scheme 1).

Later, the *exo-anti-exo* derivative **6** was treated with reducing agents like $NaBH_4$ or DIBAL-H to obtain the hydroxyl derivative **13** (Ref. 7), which was then subjected to ring-opening metathesis (ROM) using Grubb's 1st generation catalyst (G-I) and ethylene gas in the presence of titanium(IV) isopropoxide to deliver triquinane **14** in 88% yield. The triquinane **14** was further treated with allyl bromide and potassium hydride to generate the ring-closing metathesis (RCM) precursor **15** in 88% yield. We successfully synthesized 7-membered oxacycle fused triquinane **16**, by treating compound **15** with G-I catalyst in dichloromethane, in 93% yield (Scheme 2).

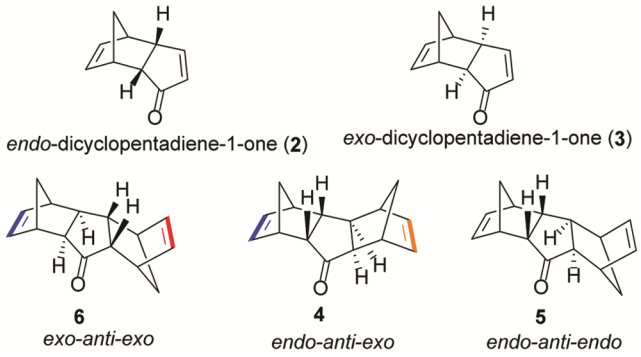


Fig. 1 — Selected DA adducts for the metal hydride reduction reaction

We shifted our focus towards synthesizing the 7-membered carbocyclic system after successfully synthesizing 7-membered oxacyclic systems **11**, **12**, and **16**. The norbornene derivative **6** was treated with G-I catalyst in the presence of ethylene gas to produce the ROM product **17** in 88% yield (Scheme 2) [6].

Having compound **17** in hand, further, we treated compound **17** with n-pentenyl bromide and potassium hydride to deliver the RCM precursor **18** in 91% yield. Next, compound **18** was exposed with the G-II catalyst to generate the biheptacyclic derivative **19** in 90% yield (Scheme 3).

Experimental Section

All the chemical solvents were purchased from Merck's company and were used without further purification. Reagents like KH, allyl magnesium bromide and allyl bromide were obtained from commercial sources such as Aldrich, SDFCL and Spectrochem and used as such except allyl bromide (freshly distilled and stored over 3Å molecular sieves). Anhydrous and air-sensitive reactions were carried out in anhydrous and/or degassed solvents.

Tetrahydrofuran (THF) was dried over sodium wire/*p*-benzophenone and distilled before use. Anhydrous toluene (PhMe) was obtained from a solvent purification system (MBraun MB-SPS 5). Dichloromethane (DCM) was dried from calcium hydride (CaH_2) and stored over activated molecular sieves (3Å). For all heating/reflux reactions, paraffin oil (paraffin liquid heavy, purchased from Merck)-bath used and maintained the continuous water outflow by connecting the double surface condenser with the water tap to ensure the cool water

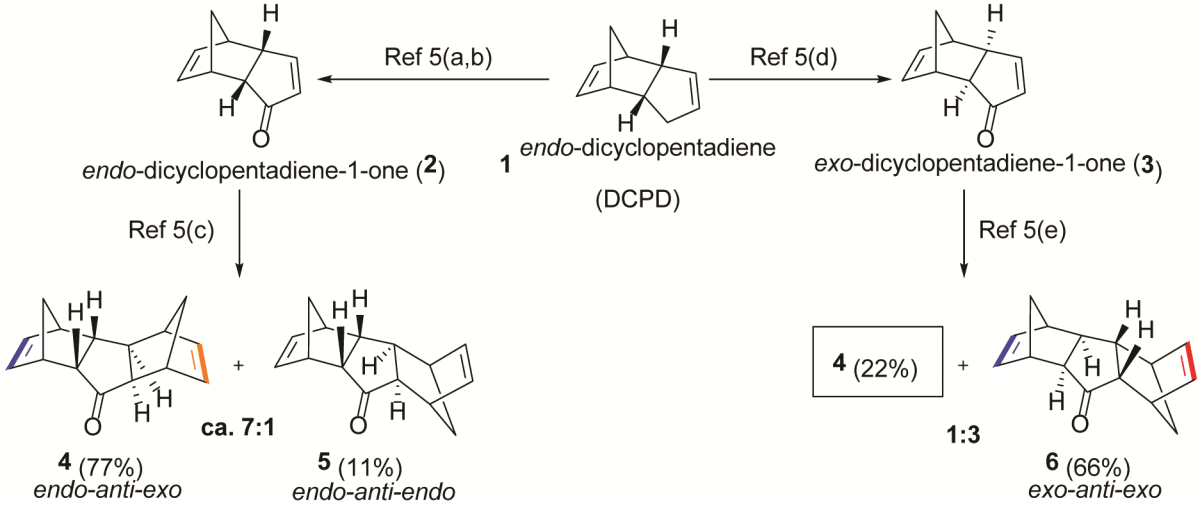
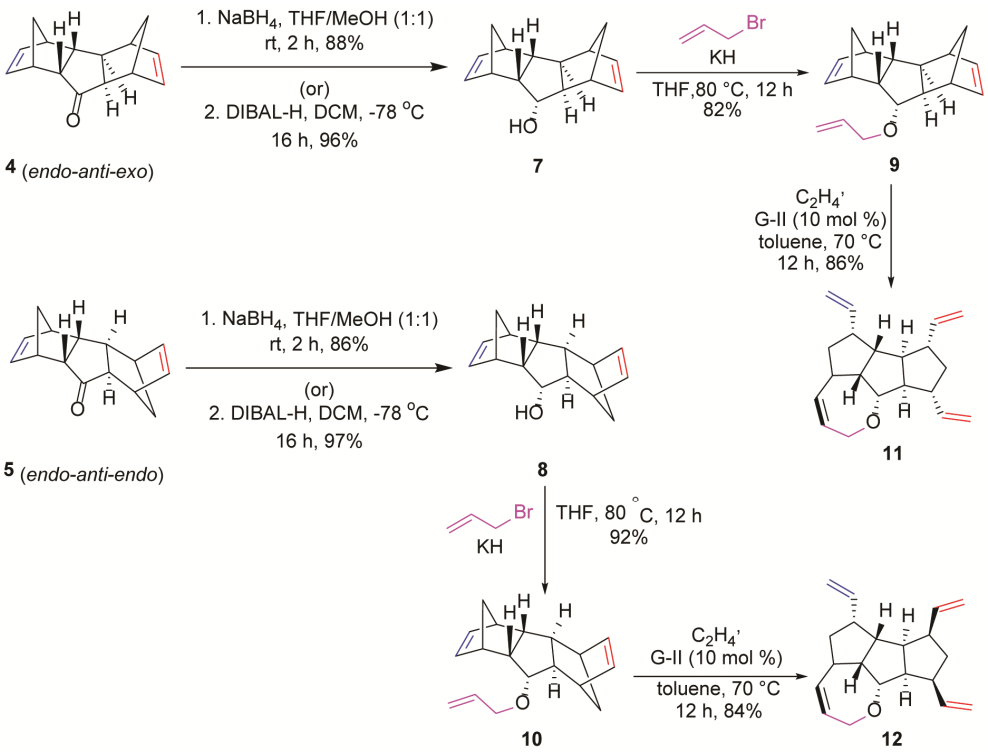
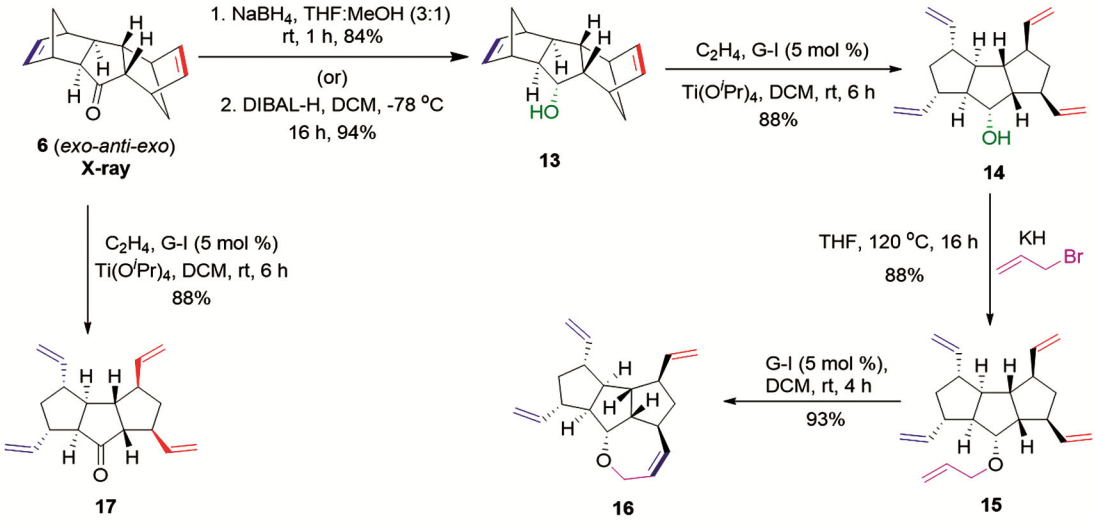


Fig. 2 — Synthetic route for Diels-alder (DA) adducts **4**, **5**, and **6**

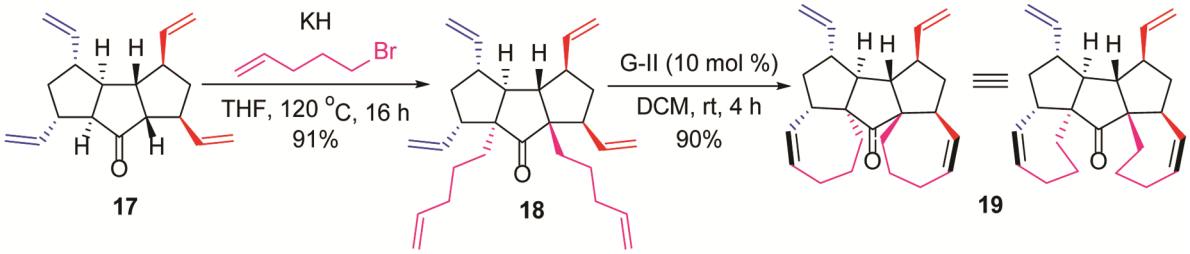


Scheme 1 — RCM route to 7-membered oxacycle fused triquinane **11** and **12**



Scheme 2 — RCM route to 7-membered oxacycle fused triquinane **16**

throughout the reaction. The reaction progress was monitored by thin-layer chromatography (TLC; 7.5×2.5 cm or 8.0×4.0 cm glass plate coated with Merck's silica gel GF 254 and 2.0×4.0 cm alumina plates) using appropriate solvent systems. Iodine chamber and TLC stain solutions (prepared freshly) such as $KMnO_4$ and PMA were used to visualize the UV inactive spots. After successive solvent extraction, the combined organic layer was washed with brine (aqueous saturated NaCl solution) and dried over oven-dried anhydrous sodium sulphate (Na_2SO_4), and concentrated under reduced pressure using a rotary evaporator. The column chromatography of all impure compounds and compound mixture was done by using silica gel (100–200 mesh) as a stationary phase and appropriate



Scheme 3 — RCM route to 7-membered carbocycle fused triquinane **19**

solvent mixture as an eluent. NMR spectra of all newly synthesised compounds were obtained by using Bruker (AVANCE IIITM) 500 MHz and Bruker (AVANCE IIITM) 400 MHz spectrometers and solvent residual peaks as an internal standard (^{1}H NMR: $CDCl_3$ at 7.26 ppm; $^{13}C\{^1H\}$ NMR: $CDCl_3$ at 77.2 ppm). ^{1}H NMR data expressed in chemical shift (δ ppm), multiplicity (s, bs, d, t, q, quint, sext, sept, and m, refer to singlet, broad singlet, doublet, triplet, quartet, quintet, sextet, septet and multiplet respectively), coupling constants (*J*) in Hz. High-resolution mass spectrometric (HRMS) measurements of unknown compounds done by using Bruker (Maxis Impact) or Micromass Q-ToF spectrometers. Infrared (IR) spectra were collected from Nicolet Impact-400 FTIR spectrometer. The melting points (mp) of solid compounds were obtained from Veego/Buchi 560 melting point apparatus and are uncorrected.[§]

(1S,4R,4aS,4bS,8aS,9aS)-4,4a,4b,5,8,8a,9,9a-Octahydro-1*H*-1,4:5,8-dimethanofluoren-9-ol, **13**: Reaction conditions: DA **6** (500 mg, 2.355 mmol), $NaBH_4$ (356 mg, 9.420 mmol), THF/MeOH (30 /10 mL), RT, 1 h. Eluent: 5.0–6.0% EtOAc/PE. Appearance: White fluffy solid (m.p.130–131°C). Yield 475 mg, 94%. R_f 0.49 (7.5×2.5 cm^2 glass TLC plate; 10.0% EtOAc/PE); ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.12–6.02 (m, 4H), 3.92 (dd, *J* = 9.14, 3.70 Hz, 1H), 2.91 (s, 1H), 2.75 (s, 1H), 2.67 (s, 1H), 2.53 (s, 1H), 2.37–2.33 (m, 1H), 2.06–2.04 (m, 1H), 1.67–1.63 (m, 2H), 1.55 (bs, 1OH), 1.43–1.35 (m, 3H), 1.19 (d, *J* = 8.81 Hz, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 138.5 (CH), 138.3 (CH), 137.8 (CH), 137.0 (CH), 77.3 (CH), 61.5 (CH), 55.3 (CH), 52.1 (CH), 50.8 (CH), 49.0 (CH), 48.0 (CH), 47.8 (CH), 45.3 (CH_2), 44.5 (CH_2), 42.2 (CH); DEPT-135 NMR (100 MHz, $CDCl_3$): δ 138.5 (CH), 138.3 (CH), 137.8 (CH), 137.0 (CH), 77.3 (CH), 61.5 (CH), 55.3 (CH), 52.1 (CH), 50.8 (CH), 49.0 (CH), 48.0 (CH), 47.8 (CH), 45.3 (CH_2), 44.5 (CH_2), 42.2 (CH); HRMS (ESI, Q-ToF): *m/z* $[M]^+$ Calcd for $C_{15}H_{18}O$ 214.3105. Found 214.3110; IR (neat): 3287, 3054, 2928, 2881, 2717, 2306, 1571, 1458, 1337, 1325, 1307, 1267, 1217, 1114, 1086, 1041, 1019, 957, 908, 887, 734, 635, 556, 484 cm^{-1}.

§ Note: For experimental procedures and data of hydroxy derivatives, please see the Ref. 7.

General procedure for alkylation: **Synthesis of RRM (9 and 10) and RCM precursors 15 and 18**

An oven-dried, two-neck round-bottom flask (RBF) equipped with a double-surface condenser and a rubber septum or glass stopper was maintained under a nitrogen (N_2) atmosphere. After cooling to room temperature (RT), the flask was charged with sodium hydride (NaH, 60% dispersion in paraffin oil, 3.0–18.0 equiv) or potassium hydride (KH, 30% dispersion in paraffin oil, 6.0–24.0 equiv). The base was activated by washing with dry petroleum ether (2×10 mL per gram of base) under stirring for 10 min. The stirring was then stopped, and the petroleum ether layer was carefully removed using a syringe without disturbing the settled base. Anhydrous tetrahydrofuran (THF, 10–20 mL) was then added *via* syringe. To the stirring suspension at 0°C, a solution of the ketone or hydroxy compound in anhydrous THF (5–10 mL) was added dropwise under a nitrogen atmosphere. The mixture was stirred at RT for 10 min before the dropwise addition of allyl bromide or pentenyl bromide (2.5–12.0 equiv). The reaction mixture was then refluxed (70–145°C) for 3–72 h. Upon completion (monitored by thin-layer chromatography, TLC), the reaction was quenched by adding a cold, saturated aqueous ammonium chloride (NH_4Cl) solution (10–20 mL) and stirred for 5 min. The aqueous layer was extracted with ethyl acetate (EtOAc) (2–3 times), and the combined organic layers were concentrated under reduced pressure. The crude product was purified by column chromatography using an appropriate mixture of EtOAc and petroleum ether as the eluent, affording the pure alkylated compounds.

General procedure for *O*-allylation

KH (30% dispersed in paraffin, 6 equiv) was washed with anhyd. hexane (2×20 mL) and dried

under N_2 before being suspended in anhyd. THF (20 mL). To this suspension, hydroxy compounds **7**, **8**, or **14** (100 mg, 1 equiv) were added and stirred for 10 min at RT. After the reaction mixture was cooled to 0°C, allyl bromide (3 equiv) was added and allowed to stir overnight at RT. After the completion of the reaction, THF was removed and the residue was suspended in EtOAc (30 mL). The suspension was washed with H_2O (2×20 mL), the organic layer was separated, and dried (Na_2SO_4). Solvents were removed under reduced pressure to obtain the *O*-alkylated compounds as pure products.

9-(Allyloxy)-4,4a,4b,5,8,8a,9,9a-Octahydro-1*H*-1,4:5,8-dimethanofluorene, **9**: Reaction conditions: Hydroxy compound **7** (200 mg, 0.933 mmol), KH (336 mg, 8.39 mmol, 9 equiv), allyl bromide (0.5 mL, 5.59 mmol, 6 equiv), THF (40 mL), 80°C, 12 h. Appearance: colourless liquid, Yield (99 mg, 97%). Purification: Column chromatography; Eluent: 15% EtOAc in petroleum ether. Yield (194 mg, 82%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 6.23–6.21 (m, 1H), 6.07–6.01 (m, 2H), 5.96–5.90 (m, 2H), 5.33–5.28 (m, 1H), 5.17–5.14 (m, 1H), 3.98–3.97 (m, 2H), 3.50 (dd, J = 8.9, 4.30 Hz, 1H), 3.18–3.12 (m, 1H), 2.90 (s, 1H), 2.84 (s, 1H), 2.57 (s, 1H), 2.46 (s, 1H), 2.26–2.22 (m, 1H), 1.56–1.54 (m, 1H), 1.42–1.40 (m, 1H), 1.35–1.33 (m, 2H), 1.18 (d, J = 8.71 Hz, 1H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 138.4, 137.7, 136.3, 135.5, 133.5, 115.6, 85.4, 70.4, 57.4, 56.6, 51.5, 51.0, 49.7, 48.2, 47.1, 46.6, 46.1, 45.0; IR (neat): 3100, 2920, 1726, 1150, cm^{-1}; HRMS (ESI, Q-ToF): *m/z* $[M+K]^+$ Calcd for $C_{18}H_{22}KO$: 293.1302. Found: 293.1302.

9-(Allyloxy)-4,4a,4b,5,8,8a,9,9a-octahydro-1*H*-1,4:5,8-dimethanofluorene, **10**: Reaction conditions: Hydroxy compound **8** (160 mg, 0.746 mmol), KH (270 mg, 6.719 mmol, 9 equiv), allyl bromide (0.4 mL, 4.47 mmol, 6 equiv), THF (40 mL), 80°C, 12 h. Appearance: Colourless liquid. Purification: Column chromatography; Eluent: 10% EtOAc in petroleum ether. Yield (206 mg, 92%). ^{1}H NMR (500 MHz, $CDCl_3$): δ 6.04–6.02 (m, 3H), 5.99–5.91 (m, 1H), 5.34–5.30 (m, 1H), 5.18–5.16 (m, 1H), 4.03–4.0 (m, 2H), 3.52 (dd, J = 9.0, 4.0 Hz, 1H), 2.9 (s, 1H), 2.65 (s, 2H), 2.52 (s, 1H), 2.64 (s, 1H), 2.38 (t, J = 8.4 Hz, 1H), 2.16–2.14 (m, 1H), 1.64–1.61 (m, 2H), 1.47 (d, J = 8.6 Hz, 1H), 1.37–1.34 (m, 2H), 1.2 (d, J = 8.6 Hz, 1H); ^{13}C NMR (125 MHz, $CDCl_3$): δ 138.2 (CH), 138.1 (CH), 136.6 (CH), 135.3 (CH), 116.0 (CH_2), 84.0 (CH), 70.6 (CH_2), 57.6 (CH), 54.1 (CH), 51.1 (CH_2), 50.8 (CH), 49.2 (CH), 48.2 (CH), 47.5 (CH_2), 45.1 (CH_2), 44.4 (CH_2), 42.5 (CH); IR (neat): 3079, 2923, 1679, 1049, 957 cm^{-1}; HRMS (ESI, Q-ToF): *m/z* $[M+H]^+$ Calcd for $C_{18}H_{23}O$: 293.1302. Found: 293.1302.

(1S,3R,3aS,3bS,4R,6S,6aS,7aS)-7-(Allyloxy)-1,3,4,6-tetravinyldecahydro-1*H*-cyclopenta[a]pentalene, **15**: Reaction conditions: Triquinane **14** (35 mg, 0.129 mmol; 37.8 mM), KH (47 mg, 1.164 mmol), allyl bromide (94 mg; 67 µL, 0.776 mmol), dry THF (5 mL; 5 mL), 120°C, 16 h. Eluent: 1.0–2.0% EtOAc/PE. Appearance: Colorless liquid. Yield 35 mg, 88%. R_f 0.80 (4.0×2.0 cm^2 glass TLC plate; 5.0% EtOAc/PE mobile phase); ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.92–5.64 (m, 5H), 5.24 (dd, J = 17.20, 1.64 Hz, 1H), 5.12 (dd, J = 10.43, 1.33 Hz, 1H), 5.01–4.87 (m, 8H), 3.96–3.86 (m, 2H), 3.62 (dd, J = 7.01, 4.25 Hz, 1H), 2.96–2.88 (m, 1H), 2.52–2.47 (m, 1H), 2.37–2.22 (m, 3H), 2.14–2.05 (m, 1H), 2.02–1.94 (m, 4H), 1.34–1.25 (m, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 144.1 (CH), 142.6 (CH), 141.9 (CH), 141.7 (CH), 135.6 (CH), 116.0 (CH_2), 113.57 (CH_2), 113.53 (CH_2), 113.4 (CH_2), 112.4 (CH_2), 86.5 (CH), 70.8 (CH_2), 56.8 (CH), 55.8 (CH), 53.3 (CH), 52.4 (CH), 51.8 (CH), 51.6 (CH), 48.4 (CH), 42.2 (CH), 41.6 (CH_2), 41.0 (CH_2); DEPT-135 NMR (100 MHz, $CDCl_3$): δ 144.1 (CH), 142.6 (CH), 141.9 (CH), 141.7 (CH), 135.6 (CH), 116.0 (CH_2), 113.57 (CH_2), 113.53 (CH_2), 113.4 (CH_2), 112.4 (CH_2), 86.5 (CH), 70.8 (CH_2), 56.8 (CH), 55.8 (CH), 53.3 (CH), 52.4 (CH), 51.8 (CH), 51.6 (CH), 48.4 (CH), 42.2 (CH), 41.6 (CH_2), 41.0 (CH_2); HRMS (ESI, Q-ToF): *m/z* $[M + K]^+$ Calcd for $C_{22}H_{30}OK$ 349.1928. Found 349.1927; IR (neat): 3075, 2974, 2914, 2876, 1822, 1729, 1638, 1449, 1420, 1350, 1094, 992, 910, 650, 558 cm^{-1}.

(1S,3R,3aS,3bS,4R,6S,6aS,7aS)-6a,7a-di(Pent-4-en-1-yl)-1,3,4,6-tetravinyldecahydro-7*H*-cyclopenta[a]pentalen-7-one, **18**: Reaction conditions: Triquinane **17** (200 mg, 0.745 mmol), KH (359 mg, 8.941 mmol), pentenyl bromide (541 mg; 0.43 mL, 4.470 mmol), dry THF (10 mL; 10 mL), 120°C, 16 h. Eluent: 1.0–2.0% EtOAc/PE. Appearance: Pale yellow liquid. Yield 274 mg, 91%. R_f 0.56 (4.0×2.0 cm^2 alumina TLC plate; 5.0% EtOAc/PE mobile phase); ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.91–5.68 (m, 6H), 5.10–5.92 (m, 12H), 2.62–2.51 (m, 3H), 2.12–1.95 (m, 8H), 1.70–1.54 (m, 5H), 1.38–1.10 (m, 6H); ^{13}C{^{1}H} NMR

(100 MHz, $CDCl_3$): δ 220.8 (CO), 142.7 (2×CH), 138.5 (2×CH), 136.2 (2×CH), 116.5 (2×CH_2), 114.9 (2×CH_2), 113.4 (2×CH_2), 64.3 (2×C), 56.8 (2×CH), 50.5 (2×CH), 48.6 (2×CH), 37.3 (2×CH_2), 34.3 (2×CH_2), 30.7 (2×CH_2), 25.1 (2×CH_2); DEPT-135 NMR (100 MHz, $CDCl_3$): δ 142.7 (2×CH), 138.5 (2×CH), 136.2 (2×CH), 116.5 (2×CH_2), 114.9 (2×CH_2), 113.4 (2×CH_2), 56.8 (2×CH), 50.5 (2×CH), 48.6 (2×CH), 37.3 (2×CH_2), 34.3 (2×CH_2), 30.7 (2×CH_2), 25.1 (2×CH_2); HRMS (ESI, Q-ToF): *m/z* $[M + H]^+$ Calcd for $C_{29}H_{41}O$ 405.3152. Found 405.3151; IR (neat): 3077, 2975, 2928, 2867, 1831, 1719, 1638, 1455, 1439, 1419, 1329, 1249, 1218, 1190, 1159, 1089, 993, 913, 757, 697, 667, 645, 555 cm^{-1}.

General procedure for Olefin metathesis

Method-A (ROM/RRM): Grubbs' catalyst (5–20 mol %; 0.05–0.20 equiv) was added to a magnetically stirred solution of RRM precursor (1.00 equiv) or ROM precursor (1.00 equiv) in anhydrous DCM (20–60 mL; 3.58–23.55 mM) or toluene (15–30 mL; 20.93–31.40 mM) which was purged with nitrogen (N_2) and ethylene (C_2H_4) gas for 10 min each and the reaction mixture (RM) was stirred at RT under ethylene gas atmosphere for 0.5–32 h. After completion of the reaction (by TLC monitoring), the volatiles were removed under reduced pressure and the resulted crude product was purified by column chromatography using an appropriate mixture of ethyl acetate and petroleum ether to deliver the corresponding pure products.

Method-B (RCM): Grubbs' catalyst (5–20 mol %; 0.05–0.20 equiv) was added to a magnetically stirred solution of RRM precursor (1.00 equiv) or ROM precursor (1.00 equiv) in anhydrous DCM (50–100 mL; 3.22–4.16 M) or toluene (50 mL; 2.86–9.66 mM) which was purged with nitrogen (N_2) for 10 min each and the RM was stirred at RT under ethylene N_2 gas atmosphere for 0.5–24 h. After completion of the reaction (by TLC monitoring), the volatiles were removed under reduced pressure and the resulting crude product was purified by column chromatography using an appropriate mixture of ethyl acetate and petroleum ether to deliver the corresponding pure ring closure products.

(4a1R,6R,6aR,6bR,7S,9R,9aR)-6,7,9-Trivinyl-2,4a,4a1,5,6,6a,6b,7,8,9,9a,9b dodecahydro cyclopenta[2,3]pentaleno[1,6-bc]oxepine, **11**: Reaction conditions: Method A (RRM), *O*-allylated compound **9** (130 mg, 0.511 mmol), G-II (40 mg, 0.0511 mmol, 10 mol%), toluene (30 mL), 70°C, 12h. Appearance: colorless liquid. Purification: Column chromatography; Eluent: 5% EtOAc in petroleum ether. Yield (120 mg, 86%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.94–5.86 (m, 1H), 5.80–5.68 (m, 3H), 5.38–5.34 (m, 1H), 5.02–4.82 (m, 6H), 4.45–4.40 (m, 1H), 4.12–4.07 (m, 1H), 3.80 (d, J = 6.94 Hz, 1H), 3.11–3.05 (m, 1H), 2.7 (s, 1H), 2.59–2.53 (m, 1H), 2.45–2.40 (m, 4H), 2.15–2.13 (m, 3H), 1.87–1.81 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.3 (CH), 141.9 (CH), 140.1 (CH), 129.2 (CH), 128.9 (CH), 114.2 (CH_2), 113.9 (CH_2), 112.0 (CH_2), 87.6 (CH), 72.4 (CH_2), 60.2 (CH), 55.9 (CH), 55.4 (CH), 51.3 (CH), 50.4 (CH), 47.7 (CH), 46.1 (CH), 41.2 (CH), 40.9 (CH_2), 40.1 (CH_2); IR (neat): 3079, 2923, 1725, 1600, 1100, 1049, 957 cm^{-1}; HRMS (ESI, Q-ToF): *m/z* $[M+K]^+$ Calcd for $C_{20}H_{26}KO$: 321.1615. Found: 321.1615.

(6R,6aR,6bR,7R,9S,9aR)-6,7,9-Trivinyl-2,4a,4a1,5,6,6a,6b,7,8,9,9a,9b-dodecahydro cyclopenta[2,3] pentaleno[1,6-bc]oxepine, **12**: Reaction conditions: Method A (RRM), *O*-allylated compound **10** (66 mg, 0.259 mmol), G-II (20 mg, 0.0259 mmol, 10 mol%), toluene (30 mL), 70°C, 12h. Appearance: Colourless liquid. Purification: Column chromatography; Eluent: 5% EtOAc in petroleum ether. Yield (48 mg, 84%). ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.89–5.74 (m, 2H), 5.71–5.63 (m, 2H), 5.44–5.41 (m, 1H), 5.05–4.85 (m, 7H), 4.36–4.31 (m, 1H), 4.15–4.09 (m, 1H), 3.98 (t, J = 7.4 Hz, 1H), 2.66–2.61 (m, 2H), 2.43–2.39 (m, 1H), 2.35–2.28 (m, 1H), 2.18–1.95 (m, 6H), 2.15–2.13 (m, 3H), 1.87–1.81 (m, 2H); ^{13}C NMR (100 MHz, $CDCl_3$): δ 143.0, 142.2, 141.2, 131.7, 128.7, 131.7, 128.7, 113.8, 112.0, 112.5, 89.9, 69.5, 59.1, 57.0, 55.1, 52.8, 51.7, 51.6, 48.0, 41.2, 40.6, 39.6; IR (neat): 3079, 2923, 1725, 1600, 1100, 1049, 957 cm^{-1}; HRMS (ESI, Q-ToF): *m/z* $[M+K]^+$ Calcd for $C_{20}H_{26}KO$: 321.1615. Found: 321.1615.

(1S,3R,3aS,3bS,4R,6S,6aS,7aS)-1,3,4,6-Tetravinyldecahydro-1*H*-cyclopenta[a]pentalen-7-ol, **14**: Reaction conditions: DA **13** (100 mg, 0.466 mmol), G-I (19 mg, 0.023 mmol; 5 mol %), Ti(O^iPr)$_4$ (6.6 mg; 6.8 µL, 0.023 mmol; 5 mol %), dry DCM (50 mL), RT, 6 h. Eluent: 3.0–5.0% EtOAc/PE. Yield 111 mg, 88%. ^{1}H NMR (400 MHz, $CDCl_3$): δ 5.89–5.77 (m, 2H), 5.74–5.64 (m, 2H), 5.06–4.88 (m, 8H), 4.08–4.05 (m, 1H), 2.84–2.76 (m, 1H), 2.49–2.36 (m, 2H), 2.31–2.22 (m, 2H), 2.16–2.07 (m, 1H), 2.05–1.95 (m, 4H), 1.62 (bs, 1OH), 1.30 (q, J = 11.82 Hz, 2H); ^{13}C{^{1}H} NMR (100 MHz, $CDCl_3$): δ 143.7 (CH), 142.8 (CH), 141.6

(CH), 141.6 (CH), 113.6 (CH_2), 113.5 (CH_2), 113.2 (CH_2), 113.1 (CH_2), 79.9 (CH), 59.4 (CH), 55.0 (CH), 54.2 (CH), 53.0 (CH), 52.3 (CH), 51.6 (CH), 47.8 (CH), 43.1 (CH), 41.6 (CH_2), 40.9 (CH_2); DEPT-135 NMR (100 MHz, $CDCl_3$): δ 143.7 (CH), 142.8 (CH), 141.6 (CH), 141.6 (CH), 113.6 (CH_2), 113.5 (CH_2), 113.2 (CH_2), 113.1 (CH_2), 79.9 (CH), 59.4 (CH), 55.0 (CH), 54.2 (CH), 53.0 (CH), 52.3 (CH), 51.6 (CH), 47.8 (CH), 43.1 (CH), 41.6 (CH_2), 40.9 (CH_2); HRMS (ESI, Q-ToF): *m/z* $[M + Na]^+$ Calcd for $C_{19}H_{26}ONa$ 293.1876. Found 293.1875; IR (neat): 3400, 3079, 2976, 2911, 1825, 1638, 1449, 1420, 1341, 1216, 1167, 1063, 991, 911, 758, 654 cm^{-1}.

(4aS,4a1S,6R,6aS,6bS,7R,9S,9aS,9bR)-6,7,9-Trivinyl-2,4a,4a1,5,6,6a,6b,7,8,9,9a,9b-dodecahydrocyclopenta[2,3]pentaleno[1,6-bc]oxepine, **16**: Reaction conditions: O-allyl derivative **10** (30 mg, 0.096 mmol), G-I (4 mg, 0.004 mmol; 5 mol %), dry DCM (30 mL), RT, 4 h. Eluent: 2.0–3.0% EtOAc/PE. Physical appearance: Colorless liquid. Yield 25 mg, 93%. R_f 0.54 (4.0×2.0 cm^2 glass TLC plate; 5.0% EtOAc/PE mobile phase). ^1H NMR (400 MHz, $CDCl_3$): δ 5.90–5.61 (m, 4H), 5.44–5.41 (m, 1H), 5.05–4.85 (m, 6H), 4.36–4.31 (m, 1H), 4.14–4.10 (m, 1H), 3.98 (t, *J* = 7.48 Hz, 1H), 2.97 (s, 1H), 2.67–2.60 (m, 2H), 2.43–2.38 (m, 1H), 2.35–2.27 (m, 1H), 2.18–1.95 (m, 5H), 1.37–1.29 (m, 1H), 1.23–1.14 (m, 1H); $^{13}C\{^1H\}$ NMR (100 MHz, $CDCl_3$): δ 143.1 (CH), 142.3 (CH), 141.3 (CH), 131.9 (CH), 128.8 (CH), 114.0 (CH_2), 112.78 (CH_2), 112.72 (CH_2), 90.1 (CH), 69.7 (CH_2), 59.3 (CH), 57.2 (CH), 55.3 (CH), 53.0 (CH), 51.8 (CH), 51.7 (CH), 48.2 (CH), 41.4 (CH_2), 40.7 (CH), 39.7 (CH_2); DEPT-135 NMR (100 MHz, $CDCl_3$): δ 143.1 (CH), 142.3 (CH), 141.3 (CH), 131.9 (CH), 128.8 (CH), 114.0 (CH_2), 112.78 (CH_2), 112.72 (CH_2), 90.1 (CH), 69.7 (CH_2), 59.3 (CH), 57.2 (CH), 55.3 (CH), 53.0 (CH), 51.8 (CH), 51.7 (CH), 48.2 (CH), 41.4 (CH_2), 40.7 (CH), 39.7 (CH_2); HRMS (ESI, Q-ToF): *m/z* $[M + H]^+$ Calcd for $C_{20}H_{27}O$ 283.2056. Found 283.2056.

(5aR,7R,7aS,7bS,8R,14aR,15aR)-7,8-Divinyl-1,2,3,5a,6,7,7a,7b,8,9,9a,12,13,14-tetradecahydro-15*H*-cyclopenta[2,1-c:3,4-c']diazulen-15-one, **19**: Reaction conditions: Pentenyl derivative **13** (50 mg, 0.123 mmol), G-II (10.5 mg, 0.012 mmol; 10 mol %), dry DCM (50 mL), RT, 4 h. Eluent: 1.0–2.0% EtOAc/PE. Physical appearance: Colorless oily liquid. Yield 39 mg, 90%. R_f 0.50 (4.0×2.0 cm^2 glass TLC plate; 5.0% EtOAc/PE mobile phase). ^1H NMR (500 MHz, $CDCl_3$): δ 5.74 (qd, *J* = 17.33, 7.37 Hz, 2H), 5.59–5.48 (m, 4H), 5.05–4.97 (m, 4H), 2.75–2.70 (m, 2H), 2.47–2.40 (m, 2H), 2.23–2.14 (m, 4H), 2.08–1.96 (m, 6H), 1.69–1.60 (m, 6H), 1.52–1.45 (m, 2H); $^{13}C\{^1H\}$ NMR (125 MHz, $CDCl_3$): δ 226.4 (CO), 140.5 (2×CH), 130.1 (2×CH), 128.6 (2×CH), 114.5 (2×CH_2), 63.7 (2×C), 55.3 (2×CH), 50.7 (2×CH), 46.2 (2×CH), 42.9 (2×CH_2), 35.4 (2×CH_2), 28.0 (2×CH_2), 20.4 (2×CH_2); DEPT-135 NMR (125 MHz, $CDCl_3$): δ 140.5 (2×CH), 130.1 (2×CH), 128.6 (2×CH), 114.5 (2×CH_2), 55.3 (2×CH), 50.7 (2×CH), 46.2 (2×CH), 42.9 (2×CH_2), 35.4 (2×CH_2), 28.0 (2×CH_2), 20.4 (2×CH_2); HRMS (ESI, Q-ToF): *m/z* $[M + H]^+$ Calcd for $C_{25}H_{33}O$ 349.2526. Found 349.2526; IR (neat): 2924, 1708, 1448, 1217, 994, 917, 760, 669 cm^{-1}.

Conclusions

In a major program directed towards synthesizing heterocycles and polycycles *via* a C-X or/ and C-C bond formation, we identified different approaches to 7-membered oxacyclic and carbocyclic fused triquinanes. We designed suitable starting material for RRM precursors to proceed with our plan. Oxacyclic compounds **11**, **12**, and **16**, containing triquinane frameworks were successfully synthesized and characterized *via* RRM/RCM as a key step. Carbocycle **19** was also reported *via* RCM strategy. More importantly, we have demonstrated that the Diels-Alder reaction, combined with RRM/RCM strategy, generated the complexity in the target molecules very quickly.

Supplementary Information

Supplementary information is available in the website http://nopr.niscpr.res.in/handle/123456789/58776.

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