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Note

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Annulation Reactions of Allenyl Esters: An Approach to Bicyclic Diones and Medium-Sized Rings

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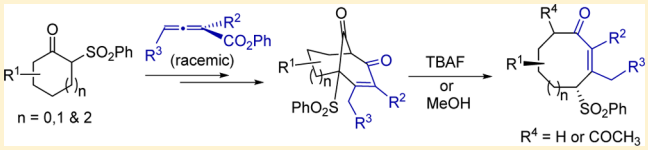
Supporting Information

ABSTRACT: A flexible approach to construct sterically congested bicyclo-alkenedione frameworks is reported. Under the action of potassium carbonate, α-sulphonyl cycloalkanones are added to functionalized allenyl esters, leading to a lactone intermediate that is subsequently reduced to initiate an intramolecular aldol cyclization to [3.2.1], [3.3.1], and [4.3.1] bicycles. Oxidation then affords bicyclic diones in good three-step yields. Under exceptionally mild conditions, these bicycles are converted to highly functionalized medium-sized rings through a Grob-type fragmentation.



Bridged bicyclic natural products have received considerable attention in recent years owing to their architectural complexity and biological activity. Among this class, vitisinol D containing the bicyclo[3.2.1]octane system has attracted our interest due to its unusual blood clot inhibitory activity (Figure 1).[1] This [3.2.1] skeleton is also present in a variety of other

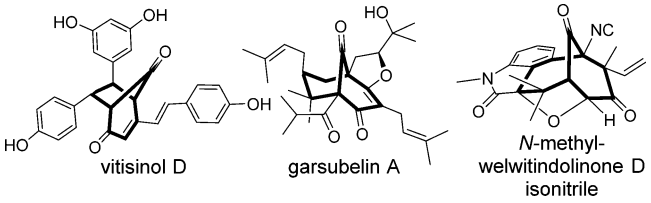


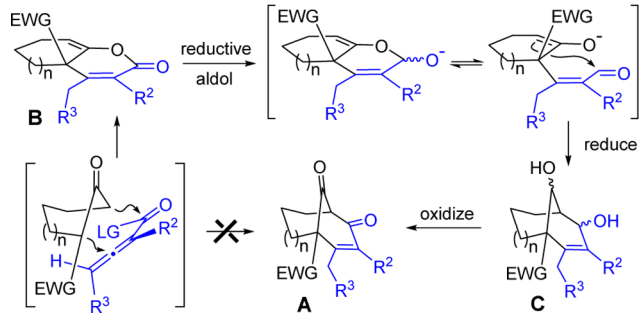
Figure 1. Representative bridged bicyclic natural products.

pharmacologically important natural products such as enaimeone A and cinerin C.[2] Far more numerous are bicyclo[3.3.1]-nonane diketones such as garsubellin A,[3] the target of numerous successful synthesis programs.[4] Though more rare, the [4.3.1] diketone natural product family system includes *N*-methyl-welwitindolinone D isonitrile, the goal of many total synthesis programs for the past two decades.[5]

Many [3.3.1] bicyclic phloroglucinol natural products have succumbed to total synthesis,[4] most recently by Mehta and Bera[6] and Plietker et al.[7] General strategies to these various bicyclic systems are also beginning to emerge,[8] including an elegant approach by Barriault and co-workers involving a gold-catalyzed intramolecular cyclization to afford a variety of bicyclic products.[9] Because of our continuing interest in the synthesis and reactivity of allenyl esters and ketones,[10] we sought to utilize these unique axially chiral compounds[11] in the construction of vitisinol D.

Our earliest efforts to create [3.2.1] bicycles involved a double enamine addition to an allenyl ketone.[12] However, we turned to allenyl esters for the synthesis of the dione system of vitisinol D anticipating that this approach would allow us to access bicyclic diketone core **A** directly from cyclic ketones and allenyl esters in one step (Scheme 1). We quickly realized that the preferred

Scheme 1. Allene Annulation Strategy to Bridged Bicycles



double addition product was enol-lactone **B** (EWG = CO_2Et and n = 0).[13] However, this unsaturated intermediate **B** was successfully transformed to the corresponding [3.2.1] bicyclic structure **C** via a two-step reductive aldol[14] using 2 equiv of reducing agent. A subsequent oxidation step afforded desired bicyclic diketone **A** in good two-step yields. We next sought to determine the generality of the annulation strategy using allenes, which is the topic of the present paper.

Our initial studies began with the readily accessible 2-(phenylsulphonyl)-cyclohexanone (**2a**).[15] In the presence of K_2CO_3, **2a** reacted with phenyl allenyl ester **4a** in acetone to afford enol lactone **6a**. This transformation likely proceeds via Michael addition to the reactive sp-hybridized allene-carbon, followed by ester-enolate cyclization and double bond isomerization (Scheme 2). We have previously observed similar lactone formation with 2-(ethoxycarbonyl)-cyclopentanone.[13] However,

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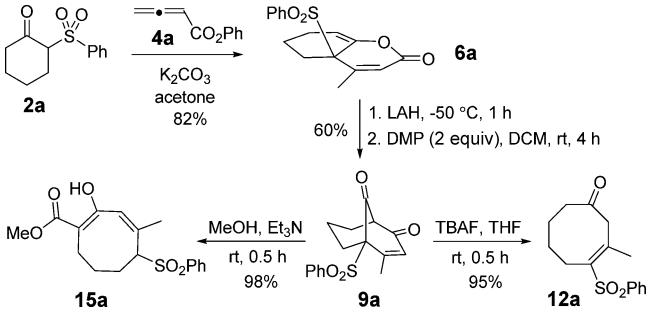
Scheme 2. Initial Studies



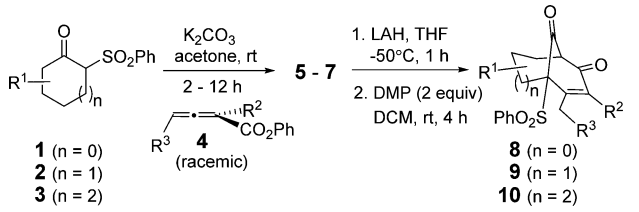
in this cyclohexanone system, the ester (as well as a ketone) electron-withdrawing group at the α-position failed to give the expected lactone. Lactone **6a** was further treated with $LiAlH_4$ (LAH) at −50 °C to afford a diol intermediate as a mixture of diastereomers. Subsequent oxidation with Dess−Martin periodinane (DMP) resulted in bicyclic diketone **9a** as the exclusive product in a 60% two-step yield.[16]

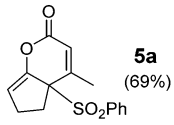
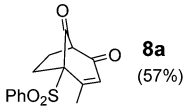
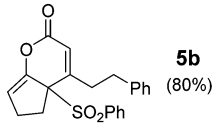
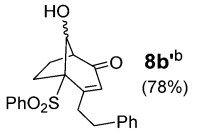
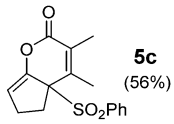
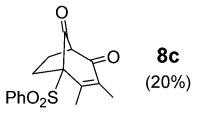
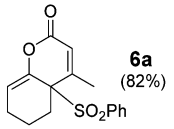
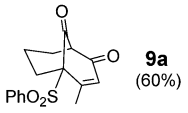
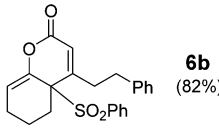
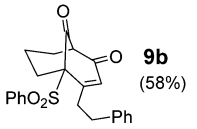
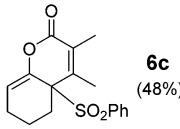
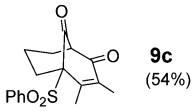
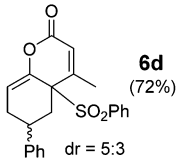
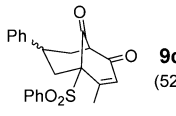
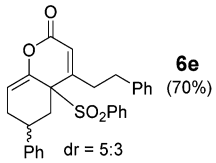
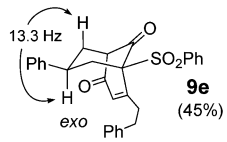
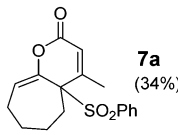
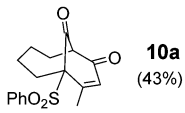
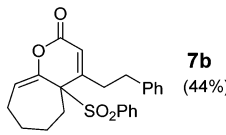
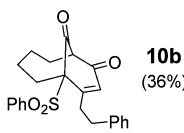
With an optimized route to bridged bicycle **9a** established, we next sought to convert it into a medium-sized ring structure. As part of this effort, we uncovered an interesting Grob-type fragmentation to convert **9a** into functionalized monocyclic rings under mild conditions. We initially treated **9a** with TBAF·$3H_2O$ in THF at room temperature, expecting to obtain an α-carboxylic acid ring-opened product. However, this reaction led to a rapid decarboxylation and double bond migration to afford compound **12a** in quantitative yield. After examining a variety of conditions, we discovered that Et_3N in MeOH led to highly conjugated medium-sized ring **15a**, which retains the carbonyl from the original carbon framework of **9a**.

We further evaluated the scope of this annulation strategy using 2-(phenylsulphonyl)-cycloalkanones **1**−**3** and variously substituted phenyl allenyl esters **4** (Table 1). These reactions delivered lactones **5**−**7** in good yields except with an α-substituted allenyl ester **4c** ($R^2 = CH_3$; $R^3 = H$). Specifically, the formation of lactone **6c** with an α-substituted allene gave only a modest yield (48%) even after an extended reaction time (24 h). Lactones **6d** and **6e**, though obtained in good yields, are unstable and represent a mixture of inseparable diastereomers (approximately 5:3 and 3:1 ratios, respectively). The reactions of allenyl esters with cycloheptanone substrates to produce lactones **7a** and **7b** were also slow and of modest yield (entries 9 and 10). Nevertheless, with the exception of **5b**, **5c**, and **7b**, the reduction of all lactones (**5**−**7**) using LAH and their subsequent DMP oxidation led to the formation of bridged bicyclic diones **8**−**10** in reasonable two-step yields. In the case of compound **9d**, the two diastereomers (5:3 ratios) were inseparable. On the other hand, the reductive aldol/oxidation sequence starting from **6e** afforded a product with an isolable major diastereomer **9e**. An NMR analysis of this major isomer reveals that the hydrogen connected to the carbon bearing the phenyl substituent on the bicycle is strongly correlated to the adjacent C−H bond. The magnitude of the coupling constant (13.3 Hz) is only consistent with a structure in which both protons are in the axial position, which argues in favor of the *exo*-diastereomer (Table 1, entry 8).

Bridged bicyclic ring-opening reactions are precedented and often an excellent entry into functionalized medium-sized ring systems.[17] Thus, we sought to access carbocyclic 7-, 8-, and 9-membered rings starting from the bicyclic products described in the present note. We were initially surprised by the mild conditions that were sufficient to rapidly achieve the various

Table 1. Generality Studies of Annulation Reaction[a,b]



Entry	Lactone (yield)[a]	Bridged Bicycle (yield)[a]
1	 **5a** (69%)	 **8a** (57%)
2	 **5b** (80%)	 **8b'**[b] (78%)
3	 **5c** (56%)	 **8c** (20%)
4	 **6a** (82%)	 **9a** (60%)
5	 **6b** (82%)	 **9b** (58%)
6	 **6c** (48%)	 **9c** (54%)
7	 **6d** (72%) dr = 5:3	 **9d** (52%) dr = 5:3
8	 **6e** (70%) dr = 5:3	 **9e** (45%)
9	 **7a** (34%)	 **10a** (43%)
10	 **7b** (44%)	 **10b** (36%)

[a]Yield after column chromatography. [b]Oxidation of the one-carbon bridged carbinol was problematic. Unoptimized two-step yields leading to the bicyclic dione (**8b**) was 27%.

monocycles (Table 2). The use of TBAF·$3H_2O$ converted bicycles **9** and **10** into monocycles **12** and **13** with concomitant

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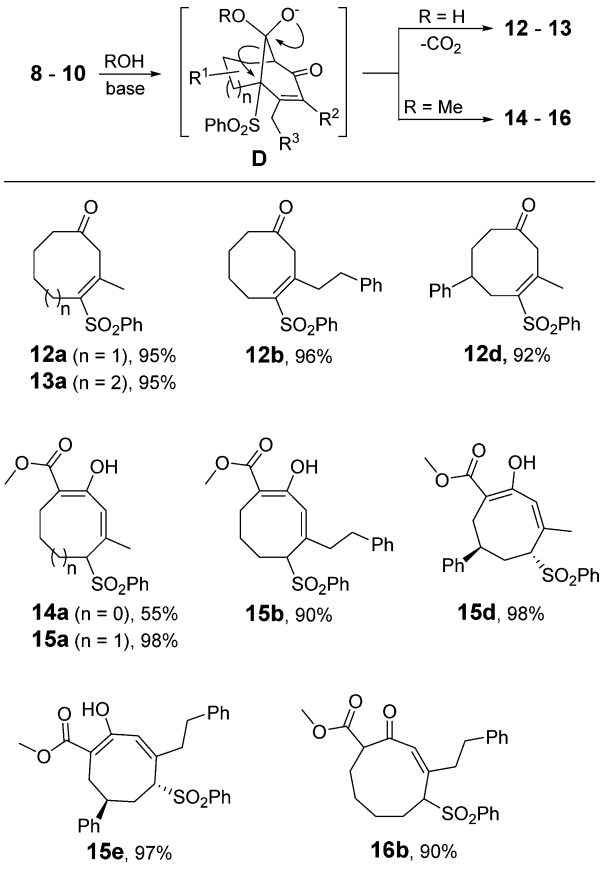
Table 2. Medium Ring Formation



decarboxylation in excellent yields. Using MeOH/Et_3N, a rapid ring-opening reaction led to esters **14**–**16** in good yields. This ring-opening reaction likely occurs via an attack of hydroxide or methanol on the carbonyl bridge, resulting in intermediate **D**. Subsequent collapse of this tetrahedral intermediate leads to a sulphonyl-stabilized carbanion that is rapidly protonated to give monocyclic products. In the case of TBAF·$3H_2O$-mediated fragmentation, decarboxylation is followed by a simple double bond migration to afford more substituted double bond products **12a**, **12b**, **12d**, and **13a**. For reactions in methanol, the carbanion is immediately quenched by a proton to result in the formation of resonance stabilized dienol-containing rings **14**–**15** exclusively. However, in the case of dione **10b**, methanol addition led to the formation of cyclononanone **16b** as a single diastereomer. Other ring expansion reactions also exhibited stereoselectivity. Specifically, bicyclic diones **9d** and **9e** under the action of methanol/Et_3N were converted to monocycles **15d** and **15e**, respectively, as single diastereomers (Table 2). A NOESY experiment was performed on **15d** and revealed a missing correlation between the protons on the phenyl- and sulphonyl-substituted carbons. Molecular modeling reveals that these two hydrogens in the cis diastereomer should be fairly close to each other (<3 Å) and thus should exhibit a strong NOE. The absence of this NOE strongly suggests the trans isomer (which is also thermodynamically favored). We assume that **15e** is also a trans isomer given its similarity to **15d**.

In conclusion, we have developed an efficient annulation strategy to generate [3.2.1], [3.3.1], and [4.3.1] bicycles using allenyl esters as coupling partners. The attractive feature of this method lies in its flexibility to construct an array of substituted bridged bicycles. Using these bicycles, medium-sized ring products can also be produced under mild conditions in good yields.

EXPERIMENTAL SECTION

General Information. Reactions were carried out under an argon atmosphere (unless otherwise stated) in oven-dried glassware with magnetic stirring. Purification of reaction products was carried out using flash silica gel 40–63 μ. Analytical thin-layer chromatography was performed on 200 μm silica gel 60 F-254 plates. Visualization of TLC plates was accomplished with UV light, followed by staining with vanillin or potassium permanganate and drying with a heat gun. ^{1}H NMR were recorded on a 400 MHz spectrometer and are reported in ppm (parts per million) using solvent as an internal standard ($CDCl_3$ at 7.26 ppm). Data are reported as b = broad, s = singlet, d = doublet, t = triplet, q = quartet, p = pentet, m = multiplet; coupling constants in hertz (Hz). ^{13}C{1H} NMR were recorded on a 100 MHz spectrometer. Chemical shifts are reported in ppm, with solvent resonance employed as the internal standard ($CDCl_3$ at 77.0 ppm). High-resolution mass spectra were recorded by an ESI-TOF MS spectrometer (DART ion source). All reagents were purchased from commercially available sources and were used without further purification. All solvents were dried over activated 3 Å molecular sieves.

Compounds **1**–**3**[18,19] and **4a**[20] were prepared following previously reported procedures.

Phenyl 5-Phenylpenta-2,3-dienoate (4b). A solution of phenyl-(triphenylphosphoranylidene)acetate (5.9 g, 15 mmol) and triethylamine (2.2 mL, 15.6 mmol) in dichloromethane (40 mL) was charged to a round-bottom flask. To it was added hydrocinnamoyl chloride (2.4 mL, 16.2 mmol) in dichloromethane (15 mL) using an addition funnel over a period of 5–10 min. The reaction was stirred at room temperature until it turned into a dark orange color solution. This solution was concentrated under reduced pressure to about a quarter of its volume, and then diethyl ether was added to precipitate the triphenylphosphine oxide formed during the reaction. Triphenylphosphine oxide was removed by filtration, and the filtrate was concentrated under reduced pressure. The crude residue was purified using silica gel chromatography to give phenyl 5-phenylpenta-2,3-dienoate (**4b**) (the minor product, an alkyne isomer, was also formed as an inseparable impurity) using ethyl acetate/hexanes (1:20). The product was obtained as a clear oil in 88% yield (3.278 g): ^{1}H NMR (400 MHz, $CDCl_3$) δ 3.54 (ddd, 2H, J = 7.4, 4.7, 2.7 Hz), 5.78–5.81 (m, 1H), 5.90 (td, 1H, J = 7.4, 6.3 Hz), 7.11–7.16 (m, 2H), 7.24–7.27 (m, 2H), 7.30–7.33 (m, 3H), 7.37–7.43 (m, 3H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 34.0, 88.3, 95.4, 121.5, 125.8, 126.7, 128.5, 128.5, 129.4, 138.3, 150.8, 164.4, 213.8; HRMS calc. for $C_{17}H_{14}O_2$ $[M + NH_4]^+$: 268.1332. Found 268.1334.

Phenyl 2-Methylbuta-2,3-dienoate (4c). A solution of phenyl 2-(triphenylphosphanylidene)propanoate (6.16 g, 15 mmol) and triethylamine (2.2 mL, 15.6 mmol) in dichloromethane (40 mL) was charged to a round-bottom flask. To it was added acetyl chloride (1.15 mL, 16.2 mmol) in dichloromethane (15 mL) through an addition funnel over a period of 5–10 min. The reaction was stirred at room temperature until it turned into a dark orange color solution. The solution was concentrated under reduced pressure to about a quarter of its volume, and diethyl ether was added to precipitate the triphenylphosphine oxide. Triphenylphosphine oxide was then removed through filtration, and the filtrate was concentrated under reduced pressure. The crude residue was purified using silica gel chromatography to give phenyl 2-methylbuta-2,3-dienoate (**4c**) (the minor alkyne isomer was also formed as an inseparable impurity) using ethyl acetate/hexanes (1:20). The product was obtained as a clear oil in 45% yield (0.901g): ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.98 (t, 3H, J = 3.1 Hz), 5.20 (q, 2H, J = 3.1 Hz), 7.12 (d, 2H, J = 7.4 Hz), 7.22 (t, 1H, J = 7.4 Hz), 7.38 (t, 2H, J = 7.4 Hz; ^{13}C NMR (100 MHz, $CDCl_3$) δ 14.7, 78.4, 95.0, 121.5, 125.7, 129.3, 151.0, 166.2, 214.7; HRMS calc. for $C_{11}H_{10}O_2$ $[M + NH_4]^+$: 192.1019. Found 192.1023.

General Procedure for the Preparation of Compounds 5a–5c. To a solution of **1** (0.37–2.0 mmol, 1 equiv) in acetone (5 mL mmol^{-1}) was added K_2CO_3 (0.37–2.0 mmol, 1 equiv) and **4** (0.44–2.4

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mmol, 1.2 equiv). The reaction mixture was stirred at room temperature for 0.25−2 h. Upon reaction completion (as monitored by TLC), the crude reaction mixture was filtered and the filtrate was evaporated and purified using silica gel column chromatography with ethyl acetate/hexanes (3:7) to give pure **5a**−**5c** in 56−80% yields.

*4-Methyl-4a-(phenylsulfonyl)-5,6-dihydrocyclopenta[b]pyran-2(4aH)-one (**5a**).* Obtained in 69% yield (402 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.08−2.34 (m, 3H), 2.23 (d, 3H, J = 1.2 Hz), 2.99 (dd, 1H, J = 14.1, 7.0 Hz), 5.50 (dd, 1H, J = 3.5, 2.3 Hz), 5.96 (q, 1H, J = 1.2 Hz), 7.54 (t, 2H, J = 7.8 Hz), 7.69 (t, 1H, J = 7.8 Hz), 7.86 (d, 2H, J = 7.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.3, 25.9, 29.6, 75.4, 114.9, 121.2, 128.9, 130.3, 133.9, 134.8, 146.0, 153.0, 159.0; HRMS calc. for $C_{15}H_{14}O_4S$ $[M + NH_4]^+$: 308.0951. Found 308.0959.

*4-Phenethyl-4a-(phenylsulfonyl)-5,6-dihydrocyclopenta[b]pyran-2(4aH)-one (**5b**).* Obtained in 80% yield (112 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.99−2.09 (m, 1H), 2.13−2.26 (m, 2H), 2.62−2.70 (m, 1H), 2.84−2.99 (m, 3H), 3.07−3.16 (m, 1H), 5.47 (s, 1H), 6.07 (t, 1H, J = 1.6 Hz), 7.21−7.28 (m, 3H), 7.34 (t, 2H, J = 7.4 Hz), 7.50 (t, 2H, J = 7.8 Hz), 7.67 (t, 1H, J = 7.4 Hz), 7.78 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.8, 29.4, 32.4, 33.0, 75.5, 114.8, 119.8, 126.5, 128.4, 128.6, 128.9, 130.3, 133.7, 134.7, 139.7, 145.8, 155.6, 159.2; HRMS calc. for $C_{22}H_{20}O_4S$ $[M + H]^+$: 381.1155. Found 381.1158.

*3,4-Dimethyl-4a-(phenylsulfonyl)-5,6-dihydrocyclopenta[b]pyran-2(4aH)-one (**5c**).* Obtained in 56% yield (99 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.86 (d, 3H, J = 1.2 Hz), 1.99−2.07 (m, 1H), 2.09−2.21 (m, 1H), 2.12 (d, 3H, J = 1.2 Hz), 2.25−2.33 (m, 1H), 2.95 (dd, 1H, J = 14.5, 7.0 Hz), 5.42 (dd, 1H, J = 2.7, 2 Hz), 7.51 (t, 2H, J = 7.4 Hz), 7.66 (t, 1H, J = 7.4 Hz), 7.80 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.9, 16.6, 25.6, 30.1, 75.7, 113.8, 128.2, 128.8, 130.0, 134.2, 134.6, 144.7, 145.3, 160.4; HRMS calc. for $C_{16}H_{16}O_4S$ $[M + H]^+$: 305.0842. Found 305.0835.

General Procedure for the Preparation of Compounds 6a−6e. To a solution of **2** (0.42−0.63 mmol, 1 equiv) in acetone (5 mL mmol^{-1}) was added K_2CO_3 (0.42−0.63 mmol, 1 equiv) and **4** (0.50−0.76 mmol, 1.2 equiv). The reaction mixture was refluxed for 6−24 h. Upon reaction completion (as monitored by TLC), the reaction mixture was filtered and the filtrate was evaporated under reduced pressure. The crude product formed was purified using silica gel column chromatography with ethyl acetate/hexanes (3:7) to give pure **6a**−**6e**.

*4-Methyl-4a-(phenylsulfonyl)-4a,5,6,7-tetrahydro-2H-chromen-2-one (**6a**).* Obtained in 82% yield (158 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.72−1.79 (m, 1H), 1.88 (td, 1H, 13.7, 3.9 Hz), 2.17 (s, 3H), 2.19−2.30 (m, 3H), 3.01 (dt, 1H, J = 14.5, 3.5 Hz), 5.76 (d, 1H, J = 1.2 Hz), 5.80 (t, 1H, J = 3.9 Hz), 7.51 (t, 2H, J = 7.8 Hz), 7.66 (t, 1H, J = 7.8 Hz), 7.83 (d, 2H, J = 7.8 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.0, 19.2, 22.6, 27.4, 67.9, 117.1, 121.8, 128.8, 130.2, 134.6, 135.5, 142.6, 153.1, 159.1; HRMS calc. for $C_{16}H_{16}O_4S$ $[M + NH_4]^+$: 322.1108. Found 322.1108.

*4-Phenethyl-4a-(phenylsulfonyl)-4a,5,6,7-tetrahydro-2H-chromen-2-one (**6b**).* Obtained in 82% yield (137 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.66−1.75 (m, 1H), 1.86 (td, 1H, 12.5, 3.5 Hz), 2.09−2.31 (m, 3H), 2.62−2.71 (m, 1H), 2.75−2.88 (m, 2H), 2.93−3.05 (m, 2H), 5.80 (dd, 1H, J = 4.5, 3.3 Hz), 5.87 (t, 1H, J = 1.6 Hz), 7.23−7.36 (m, 5H), 7.48 (t, 2H, J = 7.4 Hz), 7.64 (t, 1H, J = 7.4 Hz), 7.74 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.0, 22.5, 27.2, 32.4, 32.5, 68.1, 117.2, 120.2, 126.6, 128.4, 128.7, 128.8, 130.2, 134.5, 135.3, 139.6, 142.5, 155.7, 159.3; HRMS calc. for $C_{23}H_{22}O_4S$ $[M + NH_4]^+$: 412.1577. Found 412.1584.

*3,4-Dimethyl-4a-(phenylsulfonyl)-4a,5,6,7-tetrahydro-2H-chromen-2-one (**6c**).* Obtained in 48% yield (78 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.69 (s, 3H), 1.72−1.79, (m, 1H), 1.85 (t, 1H, 13.7 Hz), 2.07 (s, 3H), 2.11−2.36 (m, 3H), 3.03 (d, 1H, 14.5 Hz), 5.74 (s, 1H), 7.49 (t, 2H, J = 7.4 Hz), 7.63 (t, 1H, J = 7.4 Hz), 7.76 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 13.5, 15.6, 18.2, 22.6, 27.8, 68.4, 116.1, 128.5, 128.8, 129.8, 134.4, 135.9, 142.2, 145.2, 160.5; HRMS calc. for $C_{17}H_{18}O_4S$ $[M + NH_4]^+$: 336.1264. Found 336.1259.

*4-Methyl-6-phenyl-4a-(phenylsulfonyl)-4a,5,6,7-tetrahydro-2H-chromen-2-one (**6d**).* Obtained in 72% yield (140 mg) as a gummy compound. Compound **6d** represents a mixture of diastereomers that were not stable enough to be fully characterized by NMR. A crude product ^{1}H NMR spectrum is provided in the Supporting Information. HRMS calc. for $C_{22}H_{20}O_4S$ $[M + NH_4]^+$: 398.1421. Found 398.1446.

*4-Phenethyl-6-phenyl-4a-(phenylsulfonyl)-4a,5,6,7-tetrahydro-2H-chromen-2-one (**6e**).* Obtained in 70% yield (190 mg) as a gummy compound. Compound **6e** represents a mixture of diastereomers that were not stable enough to be fully be characterized by NMR. A crude product ^{1}H NMR spectrum is provided in the Supporting Information. HRMS calc. for $C_{29}H_{26}O_4S$ $[M - SO_2Ph]^+$: 329.1542. Found 329.1574.

General Procedure for the Preparation of Compounds 7a−7b. To a solution of **3** (0.39−2.12 mmol, 1 equiv) in acetone (5 mL mmol^{-1}) was added K_2CO_3 (0.39−2.12 mmol, 1 equiv) and **4** (0.47−2.54 mmol, 1 equiv). The reaction mixture was refluxed for 24−48 h. Upon reaction completion (as monitored by TLC), the crude reaction mixture was filtered and the filtrate was evaporated under reduced pressure. The residue was purified through silica gel column chromatography with ethyl acetate/hexanes (3:7) to give pure **7a**−**7b**.

*4-Methyl-4a-(phenylsulfonyl)-5,6,7,8-tetrahydrocyclohepta[b]-pyran-2(4aH)-one (**7a**).* Obtained in 34% yield (228 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.35−1.46 (m, 1H), 1.51−1.68 (m, 2H), 1.73−1.88 (m, 2H), 1.88−1.98 (m, 1H), 2.17 (d, 3H, J = 1.6 Hz), 2.44 (dt, 2H, J = 5.8, 2.6), 5.70 (dd, 1H, J = 9.8, 5.8), 6.10 (s, 1H), 7.51 (t, 2H, J = 7.4 Hz), 7.65 (t, 1H, J = 7.4 Hz), 7.85 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.2, 19.5, 20.7, 23.5, 24.0, 74.6, 118.8, 123.9, 128.7, 130.5, 134.0, 134.5, 143.7, 151.4, 159.5; HRMS calc. for $C_{17}H_{18}O_4S$ $[M + NH_4]^+$: 336.1264. Found 336.1274.

*4-Phenethyl-4a-(phenylsulfonyl)-5,6,7,8-tetrahydrocyclohepta-[b]pyran-2(4aH)-one (**7b**).* Obtained in 44% yield (71 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.37−1.57 (m, 1H), 1.55−1.74, (m, 2H), 1.77−2.02 (m, 3H), 2.42 (m, 3H), 2.90 (t, 2H, 7.6 Hz), 3.00−3.09 (m, 1H), 5.76 (dd, 1H, J = 9.8, 5.5 Hz), 6.18 (s, 1H), 7.23−7.29 (m, 3H), 7.35 (t, 2H, J = 7.8 Hz), 7.51 (t, 2H, J = 7.4 Hz), 7.67 (t, 1H, J = 7.4 Hz), 7.81 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.46, 19.48, 23.2, 23.6, 32.7, 33.7, 75.0, 118.8, 112.4, 126.6, 128.4, 128.7, 128.8, 130.6, 134.0, 134.6, 139.7, 143.8, 153.7, 159.6; HRMS calc. for $C_{24}H_{24}O_4S$ $[M + NH_4]^+$: 426.1734. Found: 426.1722.

General Procedure for the Preparation of Compounds 8a−10b. To a solution of lactone (**5**−**7**) (0.041−1.1 mmol, 1 equiv) in anhydrous THF (5 mL mmol^{-1}) at −78 °C was added 2.4 M $LiAlH_4$ solution (0.041−1.1 mmol, 1 equiv), and the reaction mixture was stirred at −50 °C for 1−2 h. The reaction was quenched by adding acetone (2 mL) and stirred for an additional 1 h. The reaction mixture was then passed through a Celite pad and washed with CH_2Cl_2 (50 mL). The combined solvent was evaporated to dryness, and the crude product was subjected to oxidation without further purification. The crude product thus obtained was dissolved in CH_2Cl_2 (5 mL mmol^{-1}), and to it was added DMP (2.0 equiv, 0.3 M solution in CH_2Cl_2). The mixture was stirred overnight at room temperature. Upon reaction completion (as monitored by TLC), the reaction mixture was filtered through Celite. The filtrate was evaporated under reduced pressure, and the residue was purified using silica gel column chromatography with ethyl acetate/hexane (3:7) to give pure **8a**−**10b**.

(1R,5S*)-4-Methyl-5-(phenylsulfonyl)bicyclo[3.2.1]oct-3-ene-2,8-dione (**8a**).* Obtained in 57% yield (17 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.73 (ddd, 1H, J = 13.7, 10.6, 5.1 Hz), 2.20−2.38 (m, 2H), 2.62 (s, 3H), 2.76 (ddd, 1H, J = 13.4, 10.7, 5.7 Hz), 3.39 (d, 1H, J = 7.4 Hz), 6.18 (s, 1H), 7.59 (t, 2H, J = 7.4 Hz), 7.70 (t, 1H, J = 7.8 Hz), 8.16 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.6, 21.4, 29.7, 62.6, 78.2, 128.9, 130.0, 131.4, 134.8, 136.4, 160.2, 194.2, 195.2; HRMS calc. for $C_{15}H_{14}O_4S$ $[M + NH_4]^+$: 308.0951. Found: 308.0949.

(1S,5S*)-8-Hydroxy-4-phenethyl-5-(phenylsulfonyl)bicyclo-[3.2.1]oct-3-en-2-one (**8b′**).* This partial oxidation product was obtained in 78% yield (60 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.44 (ddd, 1H, J = 14.7, 9.6, 5.9 Hz), 1.93 (dddd, 1H, J = 14.2, 10.7, 7.5, 3.5 Hz), 2.04−2.12 (m, 1H), 2.17−2.25 (m, 1H), 2.90−3.06 (m, 2H), 3.13−3.30 (m, 2H), 4.02 (d, 1H, J = 5.5 Hz), 6.21 (s, 1H), 7.19−7.32 (m, 5H), 7.62 (t, 2H, J = 7.4 Hz), 7.75 (t, 1H, J = 7.4 Hz), 8.01 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.5, 30.4, 34.0, 35.3, 52.4, 74.2, 78.6, 126.3, 128.0, 128.4, 128.5, 129.3,

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130.3, 134.8, 134.9, 140.3, 156.8, 198.9; HRMS calc. for $C_{22}H_{22}O_4S$ [M + NH_4]$^+$: 400.1577. Found: 400.1527.

(1R,5S*)-4-Phenethyl-5-(phenylsulfonyl)bicyclo[3.2.1]oct-3-ene-2,8-dione (**8b**).* Obtained in 27% yield (11 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.63−1.70 (m, 1H), 2.17−2.32 (m, 2H), 2.78 (ddd, 1H, J = 13.5, 10.4, 5.5 Hz), 2.91−2.98 (m, 1H), 3.02−3.09 (m, 1H), 3.23−3.31 (m, 1H), 3.39 (d, 1H, J = 7.4 Hz), 3.47−3.55 (m, 1H), 6.26 (s, 1H), 7.24 (d, 3H, J = 7.4 Hz), 7.32 (t, 2H, J = 7.4 Hz), 7.58 (t, 2H, J = 7.4 Hz), 7.70 (t, 1H, J = 7.8 Hz), 8.16 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 20.6, 30.1, 34.3, 34.8, 62.8, 78.5, 126.5, 128.4, 128.6, 128.7, 128.9, 131.5, 134.8, 136.5, 139.7, 163.0, 194.3, 195.3; HRMS calc. for $C_{22}H_{20}O_4S$ [(M − CO + H_2) + NH_4]$^+$: 372.1628. Found: 372.1628.

(1R,5S*)-3,4-Dimethyl-5-(phenylsulfonyl)bicyclo[3.2.1]oct-3-ene-2,8-dione (**8c**).* Obtained in 20% yield (19 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.57−1.71 (m, 1H)), 1.89 (s, 3H), 2.17−2.35 (m, 2H), 2.59 (s, 3H), 2.80 (ddd, 1H, J = 13.2, 10.7, 5.5 Hz), 3.46 (d, 1H, J = 7.4 Hz), 7.58 (t, 2H, J = 7.4 Hz), 7.69 (t, 1H, J = 7.8 Hz), 8.17 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.2, 17.2, 20.6, 29.4, 62.8, 79.4, 128.8, 131.4, 134.6, 135.3, 136.8, 153.5, 194.9, 195.5; HRMS calc. for $C_{16}H_{16}O_4S$ [M + NH_4]$^+$: 322.1108. Found 322.1112.

(1R,5S*)-4-Methyl-5-(phenylsulfonyl)bicyclo[3.3.1]non-3-ene-2,9-dione (**9a**).* Obtained in 60% yield (182 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.59−1.87 (m, 3H), 1.99−2.09 (m, 1H), 2.24 (td, 1H, J = 12.9, 4.3 Hz), 2.55 (s, 3H), 2.57−2.68 (m, 1H), 3.26 (t, 1H, J = 3.5 Hz), 6.50 (s, 1H), 7.56 (t, 2H, J = 7.4 Hz), 7.67 (t, 1H, J = 7.4 Hz), 8.15 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.2, 22.3, 30.8, 31.2, 62.6, 79.2, 128.5, 131.7, 134.3, 135.1, 138.2, 154.5, 194.6, 199.1; HRMS calc. for $C_{16}H_{16}O_4S$ [M + NH_4]$^+$: 322.1108. Found 322.1110.

(1R,5S*)-4-Phenethyl-5-(phenylsulfonyl)bicyclo[3.3.1]non-3-ene-2,9-dione (**9b**).* Obtained in 58% yield (87 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.39−1.50 (m, 1H), 1.69−1.78 (m, 2H), 1.99−2.09 (m, 1H), 2.24 (td, 1H, J = 12.5, 4.3 Hz), 2.60−2.66 (m, 1H), 3.05 (t, 2H, J = 7.4 Hz), 3.20−3.31 (m, 2H), 3.42−3.50 (m, 1H), 6.60 (s, 1H), 7.19−7.35 (m, 5H), 7.57 (t, 2H, J = 7.4 Hz), 7.68 (t, 1H, J = 7.4 Hz), 8.16 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 18.0, 30.6, 31.8, 34.2, 35.0, 62.6, 79.6, 126.5, 128.38, 128.44, 128.6, 131.8, 134.0, 134.3, 138.4, 139.8, 157.2, 194.8, 199.0; HRMS calc. for $C_{23}H_{22}O_4S$ [M + NH_4]$^+$: 412.1577. Found 412.1584.

(1R,5S*)-3,4-Dimethyl-5-(phenylsulfonyl)bicyclo[3.3.1]non-3-ene-2,9-dione (**9c**).* Obtained in 54% yield (26 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.44−1.53 (m, 1H), 1.70−1.84 (m, 2H), 1.95−2.07 (m, 1H), 1.99 (s, 3H), 2.27 (td, 1H, J = 13.3, 3.9 Hz), 2.54 (s, 3H), 2.61−2.71 (m, 1H), 3.32 (t, 1H, J = 3.9 Hz), 7.55 (t, 2H, J = 7.4 Hz), 7.65 (t, 1H, J = 7.4 Hz), 8.14 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 12.5, 17.4, 18.4, 30.6, 30.9, 62.6, 80.4, 128.4, 131.6, 134.1, 138.9, 140.6, 148.3, 194.7, 199.2; HRMS calc. for $C_{17}H_{18}O_4S$ [M + NH_4]$^+$: 336.1264. Found 336.1277.

(1R,5S*)-4-Methyl-7-phenyl-5-(phenylsulfonyl)bicyclo[3.3.1]-non-3-ene-2,9-dione (**9d**).* Obtained in 52% yield (76 mg) over two steps as a white solid. The compound was isolated as an inseparable mixture of diastereomers in a 5:3 ratio. Copies of ^{1}H NMR and ^{13}C NMR spectra of this inseparable diastereomeric mixture are included in the Supporting Information. HRMS calc. for $C_{22}H_{20}O_4S$ [M + NH_4]$^+$: 398.1421. Found 398.1449.

(1S,5S*,7S*)-4-Phenethyl-7-phenyl-5-(phenylsulfonyl)bicyclo-[3.3.1]non-3-ene-2,9-dione (**9e**).* Obtained in 45% yield (58 mg) over two steps as an oily liquid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.97 (td, 1H, J = 13.3, 4.3 Hz), 2.13−2.22 (m, 1H), 2.42−2.49 (m, 1H), 2.77−2.86 (m, 2H), 3.05−3.18 (m, 2H), 3.25−3.33 (m, 1H), 3.38 (t, 1H, J = 3.3 Hz), 3.57 (dt, 1H, J = 16.9, 8.2 Hz), 6.69 (s, 1H), 7.01 (d, 2H, J = 6.6 Hz), 7.20−7.37 (m, 8H), 7.60 (t, 2H, J = 7.4 Hz), 7.71 (t, 1H, J = 7.4 Hz), 8.18 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 34.1, 35.1, 36.2, 37.2, 38.2, 62.5, 79.2, 126.6, 127.0, 127.7, 128.4, 128.6, 128.8, 129.0, 131.8, 134.2, 134.4, 138.3, 139.7, 140.1, 157.6, 194.4, 198.6; HRMS calc. for $C_{29}H_{26}O_4S$ [M + NH_4]$^+$: 488.1890. Found 488.1878.

(1S,6R*)-9-Methyl-1-(phenylsulfonyl)bicyclo[4.3.1]dec-8-ene-7,10-dione (**10a**).* Obtained in 43% yield (17 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.15−1.29 (m, 1H), 1.33−1.48 (m, 1H), 1.67 (s, 1H), 1.78−1.89 (m, 1H), 1.90−2.01 (m, 1H), 2.21 (t, 2H, J = 13.3 Hz), 2.49 (s, 3H), 2.68 (td, 1H, J = 13.7, 3.1 Hz), 3.36 (dd, 1H, J = 11.3, 3.9 Hz), 6.38 (s, 1H), 7.52 (t, 2H, J = 7.4 Hz), 7.64 (t, 1H, J = 7.4 Hz), 7.84 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.4, 25.3, 25.6, 29.5, 32.0, 62.1, 81.2, 128.6, 130.5, 133.3, 134.2, 138.2, 153.6, 195.3, 199.8; HRMS calc. for $C_{17}H_{18}O_4S$ [M + NH_4]$^+$: 336.1264. Found 336.1269.

(1S,6R*)-9-Phenethyl-1-(phenylsulfonyl)bicyclo[4.3.1]dec-8-ene-7,10-dione (**10b**).* Obtained in 36% yield (6.0 mg) over two steps as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.14−1.19 (m, 2H), 1.30−1.40 (m, 1H), 1.67−1.85 (m, 2H), 2.11−2.22 (m, 2H), 2.63 (td, 1H, J = 13.7, 3.7 Hz), 2.85−3.00 (m, 2H), 3.12−3.15 (m, 1H), 3.34−3.46 (m, 2H), 6.58 (s, 1H), 7.22−7.36 (m, 5H), 7.50 (t, 2H, J = 7.4 Hz), 7.63 (t, 1H, J = 7.4 Hz), 7.80 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.42, 25.46, 29.4, 32.3, 33.9, 34.6, 62.0, 81.6, 126.5, 128.6, 128.62, 128.67, 130.6, 131.8, 124.1, 128.4, 140.2, 156.6, 195.4, 199.9; HRMS calc. for $C_{24}H_{24}O_4S$ [M + NH_4]$^+$: 426.1734. Found 426.1715.

General Procedure for the Preparation of Medium Rings 12−13. To a stirred solution of compound **9** or **10** (0.047−0.065 mmol, 1 equiv) dissolved in THF (2 mL mmol^{-1}) was added TBAF·3$H_2$0 (10 mol %), and the reaction was stirred at room temperature for 1 h. Upon reaction completion (as monitored by TLC), solvent was evaporated and the residue was purified using silica gel column chromatography with ethyl acetate/hexanes (3:7) to afford pure **12−13**.

*(E)-3-Methyl-4-(phenylsulfonyl)cyclooct-3-en-1-one (**12a**).* Obtained in 95% yield (17 mg) as a gummy compound. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.73−1.86 (m, 4H), 2.23 (s, 3H), 2.42−2.48 (m, 2H), 2.66−2.73 (m, 2H), 3.32 (s, 2H), 7.54 (t, 2H, J = 7.4 Hz), 7.60 (t, 1H, J = 7.4 Hz), 7.87 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.7, 23.4, 28.5, 29.1, 42.6, 52.9, 127.2, 129.2, 133.2, 137.6, 141.7, 144.8, 208.1; HRMS calc. for $C_{15}H_{18}O_3S$ [M + NH_4]$^+$: 296.1315. Found 396.1327.

*(E)-3-Phenethyl-4-(phenylsulfonyl)cyclooct-3-en-1-one (**12b**).* Obtained in 96% yield (18 mg) as a gummy compound. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.71−1.85 (m, 4H), 2.44−2.50 (m, 2H), 2.63−2.69 (m, 2H), 2.71−2.79 (m, 2H), 2.90−2.98 (m, 2H), 3.39 (s, 2H), 7.18−7.33 (m, 5H), 7.53 (t, 2H, J = 7.4 Hz), 7.61 (t, 1H, J = 7.4 Hz), 7.86 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 23.6, 28.2, 29.4, 34.4, 37.5, 42.6, 51.2, 126.3, 127.2, 128.4, 128.5, 129.3, 133.3, 138.0, 140.7, 141.6, 148.1, 208.6; HRMS calc. for $C_{22}H_{24}O_3S$ [M + NH_4]$^+$: 386.1784. Found 386.1794.

*(E)-3-Methyl-6-phenyl-4-(phenylsulfonyl)cyclooct-3-en-1-one (**12d**).* Obtained in 92% yield (17 mg) as a gummy compound. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.90−2.01 (m, 1H), 2.09−2.17 (m, 1H), 2.30 (s, 3H), 2.46−2.53 (m, 1H), 2.62−2.76 (m, 2H), 2.98 (d, 1H, J = 14.9 Hz), 3.04 (d, 1H, J = 14.9 Hz), 3.08−3.17 (m, 1H), 3.80 (d, 1H, J = 14.9 Hz), 7.18−7.24 (m, 2H), 7.32 (t, 3H, J = 7.4 Hz), 7.52 (t, 2H, J = 7.4 Hz), 7.61 (t, 1H, J = 7.4 Hz), 7.85 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.9, 31.6, 36.6, 40.1, 45.3, 52.8, 126.6, 126.7, 127.2, 128.7, 129.2, 133.3, 137.6, 141.4, 145.6 (2C), 208.4; HRMS calc. for $C_{21}H_{22}O_3S$ [M + NH_4]$^+$: 372.1628. Found 372.1645.

*(E)-3-Methyl-4-(phenylsulfonyl)cyclonon-3-en-1-one (**13a**).* Obtained in 95% yield (14 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.67−1.81 (m, 6H), 2.27 (s, 3H), 2.49 (dd, 2H, J = 7.4, 5.8 Hz), 2.78 (t, 2H, J = 6.6 Hz), 3.26 (s, 2H), 7.52 (t, 2H, J = 7.4 Hz), 7.59 (t, 1H, J = 7.4 Hz), 7.84 (d, 2H, J = 7.4 Hz); ^{13}C NMR (100 MHz, $CDCl_3$) δ 22.8, 23.0, 23.7, 26.2, 28.0, 44.4, 49.4, 127.0, 128.3, 129.0, 133.0, 142.0, 145.0, 208.7; HRMS calc. for $C_{16}H_{20}O_3S$ [M + NH_4]$^+$: 310.1471. Found 310.1480.

General Procedure for the Preparation of Compounds 14a−16b. Compounds **8−10** (0.040−0.060 mmol, 1 equiv) were dissolved in an anhydrous methanol:triethylamine solution (5:1 ratio, 2 mL mmol^{-1}), and the reactions were allowed to stir at room temperature for 1 h. Upon reaction completion (as monitored by TLC), the solvent was evaporated and the crude residue was purified using silica gel column chromatography with ethyl acetate/hexanes (3:7) to afford pure **14a−16b**.

*Methyl 2-Hydroxy-4-methyl-5-(phenylsulfonyl)cyclohepta-1,3-diene-1-carboxylate (**14a**).* Obtained in 55% yield (8.0 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 2.01 (d, 3H, J = 1.6 Hz),

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2.21−2.31 (m, 2H), 2.51−2.65 (m, 2H), 3.74 (s, 3H), 3.98 (dd, 1H, J = 8.2, 5.5 Hz), 6.03 (d, 1H, J = 1.6 Hz), 7.53 (t, 2H, J = 7.4 Hz), 7.64 (t, 1H, J = 7.4 Hz), 7.85 (d, 2H, J = 7.4 Hz), 12.07 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 21.5, 27.4, 32.3, 51.8, 69.9, 101.9, 128.8, 129.0, 129.4, 133.9, 137.6, 141.4, 166.5, 172.4; HRMS calc. for $C_{16}H_{18}O_5S$ $[M + NH_4]^+$: 340.1213. Found 340.1220.

*Methyl (1Z,3Z)-2-Hydroxy-4-methyl-5-(phenylsulfonyl)cycloocta-1,3-diene-1-carboxylate (**15a**).* Obtained in 98% yield (22 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.10−1.27 (m, 1H), 1.43−1.56 (m, 1H), 1.70 (dd, 1H, J = 14.5, 12.1 Hz), 1.84−1.95 (m, 1H), 2.07 (s, 3H), 2.30 (d, 1H, J = 12.9 Hz), 2.66 (dd, 1H, J = 14.7, 8.0 Hz), 3.78, (s, 3H), 4.12 (d, 1H, J = 9.4 Hz), 5.91 (s, 1H), 7.54 (t, 2H, J = 7.4 Hz), 7.64 (t, 1H, J = 7.4 Hz), 7.84 (d, 2H, J = 7.4 Hz), 12.16 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.3, 22.2, 24.5, 24.9, 52.0, 66.5, 102.7, 124.7, 128.2, 129.2, 133.7, 138.4, 139.5, 167.5, 173.0; HRMS calc. for $C_{17}H_{20}O_5S$ $[M + NH_4]^+$: 354.1370. Found 354.1383.

*Methyl (1Z,3Z)-2-Hydroxy-4-phenethyl-5-(phenylsulfonyl)cycloocta-1,3-diene-1-carboxylate (**15b**).* Obtained in 90% yield (19 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.04−1.18 (m, 1H), 1.38−1.51 (m, 2H), 1.76−1.91 (m, 1H), 2.29 (d, 1H, J = 12.1 Hz), 2.57 (dd, 1H, J = 14.7, 7.6 Hz), 2.69−2.85 (m, 4H), 3.78 (s, 3H), 4.16 (d, 1H, J = 9.4 Hz), 6.01 (s, 1H), 7.14−7.24 (m, 3H), 7.26−7.35 (m, 2H), 7.55 (t, 2H, J = 7.4 Hz), 7.64 (t, 1H, J = 7.4 Hz), 7.83 (d, 2H, J = 7.4 Hz), 12.21 (s, 1H); ^{13}C NMR (100 MHz,$CDCl_3$) δ 22.3, 24.2, 24.8, 32.4, 33.9, 52.0, 66.9, 102.8, 123.7, 126.2, 128.2, 128.40, 128.44, 129.2, 133.7, 138.4, 140.6, 142.5, 167.8, 173.0; HRMS calc. for $C_{24}H_{26}O_5S$ $[M + NH_4]^+$: 444.1839. Found 444.1860.

*Methyl (1Z,3Z,5R,7S)-2-Hydroxy-4-methyl-7-phenyl-5-(phenylsulfonyl)cycloocta-1,3-diene-1-carboxylate (**15d**).* Obtained in 98% yield (21 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.63−1.75 (m, 1H), 2.03−2.11 (m, 1H), 2.13 (d, 3H, J = 1.6 Hz), 2.43−2.53 (m, 2H), 2.75 (d, 1H, J = 14.5 Hz), 3.79 (s, 3H), 4.31 (d, 1H, J = 9.4 Hz), 5.98 (d, 1H, J = 1.6 Hz), 7.12 (d, 2H, J = 7.4 Hz), 7.23 (t, 1H, J = 7.4 Hz), 7.31 (t, 2H, J = 7.4 Hz), 7.56 (t, 2H, J = 7.4 Hz), 7.66 (t, 1H, J = 7.4 Hz), 7.85 (d, 2H, J = 7.4 Hz), 12.20 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 19.3, 29.8, 32.7, 42.8, 52.1, 66.0, 102.7, 124.8, 126.6, 128.2, 128.6, 129.2, 133.8, 138.2, 140.0, 146.2, 168.1, 173.0; HRMS calc. for $C_{23}H_{24}O_5S$ $[M + NH_4]^+$: 430.1683. Found 430.1666.

*Methyl (1Z,3Z,5R,7S)-2-Hydroxy-4-phenethyl-7-phenyl-5-(phenylsulfonyl)cycloocta-1,3-diene-1-carboxylate (**15e**).* Obtained in 97% yield (21 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.53 (td, 1H, J = 14.5, 9.4 Hz), 1.70 (dd, 1H, J = 14.5, 10.6 Hz), 2.36 (td, 1H, J = 11.2, 4.7 Hz), 2.46 (dd, 1H, J = 14.1, 4.7 Hz), 2.57 (d, 1H, J = 14.5 Hz), 2.72−3.06 (m, 4H), 3.76 (s, 3H), 4.32 (d, 1H, J = 9.4 Hz), 6.09 (s, 1H), 6.92 (d, 2H, J = 7.4 Hz), 7.14−7.38 (m, 8H), 7.56 (t, 2H, J = 7.4 Hz), 7.66 (t, 1H, J = 7.4 Hz), 7.84 (d, 2H, J = 7.4 Hz), 12.24 (s, 1H); ^{13}C NMR (100 MHz, $CDCl_3$) δ 29.8, 32.0, 32.2, 33.6, 42.8, 52.0, 66.4, 102.8, 123.9, 126.2, 126.5, 126.6, 128.2, 128.5, 128.6, 128.6, 129.3, 133.8, 138.3, 140.5, 142.4, 146.2, 168.4, 172.9; HRMS calc. for $C_{30}H_{30}O_5S$ $[M + NH_4]^+$: 520.2137. Found 520.2137.

*Methyl (1R,5R,Z)-2-Oxo-4-phenethyl-5-(phenylsulfonyl)cyclonon-3-ene-1-carboxylate (**16b**).* Obtained in 90% yield (19 mg) as a white solid. ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.29−1.41 (m, 1H), 1.47−1.66 (m, 2H), 1.78−1.90 (m, 2H), 1.91−2.02 (m, 1H), 2.17 (dd, 1H, J = 15.7, 10.6 Hz), 2.26−2.34 (m, 1H), 2.80 (t, 1H, J = 13.3 Hz), 3.06 (dd, 1H, J = 16.0, 8.6 Hz), 3.21 (dd, 1H, J = 16.4, 7.0 Hz), 3.34 (dd, 1H, J = 16.0, 7.4 Hz), 3.47 (d, 2H, J = 3.9 Hz), 3.72 (s, 3H), 5.27 (t, 1H, J = 6.5 Hz), 6.94 (d, 2H, J = 7.4 Hz), 7.16−7.25 (m, 3H), 7.36 (t, 2H, J = 7.4 Hz), 7.52 (t, 1H, J = 7.4 Hz), 7.92 (d, 2H, J = 7.4 Hz), ^{13}C NMR (100 MHz, $CDCl_3$) δ 25.0, 27.1, 28.3, 30.6, 33.2, 35.2, 42.0, 52.3, 84.7, 126.3, 126.4, 127.8, 128.3, 128.6, 131.7, 133.4, 136.5, 138.2, 140.0, 172.0, 205.7; HRMS calc. for $C_{25}H_{28}O_5S$ $[M + NH_4]^+$: 458.1996. Found 458.2001.

■ ASSOCIATED CONTENT

Supporting Information

Copies of ^{1}H and ^{13}C{1H} NMR spectra, and COSY and NOESY spectra for relative stereochemistry assignment of **9e** and **15d**. This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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