Supporting Information

Synthesis of Polysubstituted Cyclic 1,2-Diketones Enabled by Iterative Sulfoxide-Mediated Arylation

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I. General Information

Unless otherwise stated, all solvents were distilled from appropriate drying agents prior to use. All reagents were used as received from commercial suppliers unless otherwise indicated. Cyclic 1,2-Diketones\(^1\) and sulfoxides\(^2\) were prepared according to reported procedures. Reactions were monitored using Thin Layer Chromatography (TLC) carried out on Merck silica gel plates (60F-254) using UV light as the visualizing agent and High Performance Liquid Chromatography (HPLC) with UV detection at 254 nm. For HPLC yields, UV response factors relative to an internal standard (1-nitronaphthalene). Flash column chromatography was performed using silica gel 60 (200-300 mesh). HRMS data were recorded on Agilent 6500 QTOFMS-ESI or Waters GCT Premier TOFMS-EI. All \(^1\)H NMR, \(^{13}\)C NMR spectra were recorded on Bruker DRX-600 and AMX-400 instruments. Chemical shifts were given in parts per million (ppm, \(\delta\)), referenced to the solvent peak of CDCl\(_3\), defined at \(\delta = 7.26\) (\(^1\)H NMR), defined at \(\delta = 77.16\) (\(^{13}\)C NMR). Coupling constants were quoted in Hz (J). \(^1\)H NMR Spectroscopy splitting patterns were designated as singlet (s), doublet (d), triplet (t), quartet (q). Splitting patterns that could not be interpreted or easily visualized were designated as multiplet (m) or broad (br).
II. General Program for the Reaction of 1,2-Diketone with Sulfoxide

Table S1. Optimization of Reaction Conditions$^a$

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<th>time (h)</th>
<th>yield (%)$^b$</th>
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$^a$The reactions were run with 1 (0.15 mmol), 2 (0.1 mmol), and TFAA (0.15 mmol).

$^b$Yields were determined by HPLC analysis.

TFAA (0.15 mmol, 1.5 equiv) was added to a solution of cyclic 1,2-diketones$^1$ (0.15 mmol, 1.5 equiv) and sulfoxide$^2$ (0.1 mmol, 1 equiv) in DCE (0.8 mL, 0.125 M) at -10 °C. After 4 hours, the reaction mixture was concentrated under reduced pressure and purified by column chromatography (eluent: petroleum ether/ethyl acetate = 9/1) to afford product.

5-(2-((4-Bromophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (3)
White solid, 34.7 mg, 91% yield. (Rf = 0.59, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.49 (d, $J = 5.6$ Hz, 1H), 7.34 (d, $J = 8.5$ Hz, 2H), 7.19 (d, $J = 5.6$ Hz, 1H), 6.91 (d, $J = 8.5$ Hz, 2H), 6.35 (t, $J = 3.1$ Hz, 1H), 5.55 (s, 1H), 2.68 (dd, $J = 17.9, 2.8$ Hz, 1H), 2.60 (dd, $J = 17.9, 3.3$ Hz, 1H), 1.57 (s, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 205.6, 150.4, 150.2, 136.8, 131.9, 130.6, 129.0, 128.5, 127.8, 125.7, 124.8, 47.3, 41.4, 26.1.

HRMS-ESI (m/z) [M-H]$^-$ calculated for C$_{16}$H$_{12}$BrO$_2$S$_2$ 378.9468, found 378.9453.

2-Hydroxy-5-methyl-5-(2-(o-tolylthio)thiophen-3-yl)cyclopent-2-en-1-one (4)

White solid, 28.5 mg, 90% yield. (Rf = 0.62, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.47 (d, $J = 5.6$ Hz, 1H), 7.21 (d, $J = 5.6$ Hz, 1H), 7.13 – 7.10 (m, 1H), 7.07 – 7.02 (m, 2H), 6.75 (dd, $J = 7.2, 2.0$ Hz, 1H), 6.32 (t, $J = 3.1$ Hz, 1H), 5.72 (s, 1H), 2.80 (dd, $J = 17.9, 2.9$ Hz, 1H), 2.58 (dd, $J = 17.9, 3.4$ Hz, 1H), 2.33 (s, 3H), 1.57 (s, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 204.2, 148.9, 147.9, 135.9, 133.2, 128.3, 126.9, 124.9, 124.5, 124.33, 124.25, 123.9, 123.3, 45.7, 39.4, 24.4, 18.0.

HRMS-ESI (m/z) [M-H]$^-$ calculated for C$_{15}$H$_{15}$O$_2$S$_2$ 315.0519, found 315.0516.

2-Hydroxy-5-methyl-5-(2-(m-tolylthio)thiophen-3-yl)cyclopent-2-en-1-one (5)

White solid, 30.6 mg, 97% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.44 (d, $J = 5.6$ Hz, 1H), 7.18 (d, $J = 5.6$ Hz, 1H), 7.12 (t, $J = 7.7$ Hz, 1H), 6.95 (d, $J = 7.5$ Hz, 1H), 6.92 (s, 1H), 6.86 (dd, $J = 7.9, 0.5$ Hz, 1H), 6.34 (t, $J = 3.1$ Hz, 1H), 5.69 (s, 1H), 2.76 (dd, $J = 17.9, 2.9$ Hz, 1H), 2.60 (dd, $J = 17.9, 3.4$ Hz, 1H), 2.28 (s, 3H), 1.57 (s, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 205.9, 150.4, 149.5, 138.7, 138.1, 130.1, 128.7, 128.3, 127.2, 126.9, 126.0, 125.8, 123.8, 47.4, 41.2, 26.1, 21.4.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{15}$H$_{15}$O$_2$S$_2$ 317.0664, found 317.0663.

2-Hydroxy-5-methyl-5-(2-(p-tolylthio)thiophen-3-yl)cyclopent-2-en-1-one (6)

White solid, 27.5 mg, 87% yield. (Rf = 0.63, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.42 (d, $J = 5.6$ Hz, 1H), 7.16 (d, $J = 5.6$ Hz, 1H), 7.05 (d, $J = 8.1$ Hz, 2H), 7.01 – 6.98 (m, 2H), 6.35 (t, $J = 3.1$ Hz, 1H), 5.69 (s, 1H), 2.74 (dd, $J = 17.9, 2.9$ Hz, 1H), 2.60 (dd, $J = 17.9, 3.4$ Hz, 1H), 2.29 (s, 3H), 1.57 (s, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 205.8, 150.3, 149.1, 136.1, 134.6, 129.7, 128.2, 127.2, 126.6, 125.7, 125.6, 47.3, 41.3, 26.2, 20.9.

HRMS-ESI (m/z) [M-H]$^-$ calculated for C$_{16}$H$_{15}$O$_2$S$_2$ 315.0519, found 315.0521.
5-(2-((4-Ethylphenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (7)

White solid, 31.8 mg, 96% yield. (Rf = 0.65, petroleum ether/ethyl acetate = 9/1)

1H NMR (600 MHz, CDCl3) δ 7.42 (d, J = 5.6 Hz, 1H), 7.16 (d, J = 5.6 Hz, 1H), 7.09 – 7.06 (m, 2H), 7.04 – 7.00 (m, 2H), 6.35 (t, J = 3.1 Hz, 1H), 5.77 (s, 1H), 2.75 (dd, J = 17.9, 2.9 Hz, 1H), 2.60 (dd, J = 17.9, 3.4 Hz, 1H), 2.59 (q, J = 7.6 Hz, 2H), 1.57 (s, 3H), 1.53 (s, 3H), 1.20 (t, 3H).

13C NMR (150 MHz, CDCl3) δ 205.9, 150.4, 149.1, 142.4, 134.8, 129.8, 128.5, 128.2, 127.2, 126.6, 125.8, 47.3, 41.3, 28.3, 26.2, 15.4.

HRMS-ESI (m/z) [M-H]− calculated for C18H16O2S5 329.0675, found 329.0668.

2-Hydroxy-5-(2-((4-methoxyphenyl)thio)thiophen-3-yl)-5-methylcyclopent-2-en-1-one (8)

White solid, 32.2 mg, 97% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

1H NMR (600 MHz, CDCl3) δ 7.37 (d, J = 5.6 Hz, 1H), 7.14 – 7.09 (m, 3H), 6.83 – 6.78 (m, 2H), 6.38 (t, J = 3.1 Hz, 1H), 5.71 (s, 1H), 3.77 (s, 3H), 2.75 (dd, J = 17.9, 2.9 Hz, 1H), 2.60 (dd, J = 17.9, 3.4 Hz, 1H), 1.57 (s, 3H).

13C NMR (150 MHz, CDCl3) δ 206.1, 158.7, 150.5, 148.1, 129.9, 129.1, 128.3, 128.2, 128.1, 125.8, 114.6, 55.3, 47.3, 41.3, 26.0.

HRMS-ESI (m/z) [M-H]− calculated for C19H18O2S5 331.0468, found 331.0460.

5-(2-((2-Bromophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (9)

White solid, 32.0 mg, 84% yield. (Rf = 0.60, petroleum ether/ethyl acetate = 9/1)

1H NMR (600 MHz, CDCl3) δ 7.54 (d, J = 5.6 Hz, 1H), 7.47 (dd, J = 7.9, 0.8 Hz, 1H), 7.25 (d, J = 5.6 Hz, 1H), 7.18 – 7.12 (m, 1H), 6.98 (td, J = 7.9, 1.3 Hz, 1H), 6.66 (dd, J = 8.0, 1.2 Hz, 1H), 6.37 (t, J = 3.1 Hz, 1H), 5.30 (s, 1H), 2.82 (dd, J = 18.0, 2.9 Hz, 1H), 2.65 (dd, J = 17.9, 3.3 Hz, 1H), 1.57 (s, 3H);

13C NMR (150 MHz, CDCl3) δ 205.8, 150.9, 150.8, 139.9, 132.5, 131.3, 128.9, 127.7, 126.8, 126.7, 126.5, 123.7, 119.6, 47.42, 41.2, 26.1.

HRMS-ESI (m/z) [M-H]− calculated for C16H13BrO2S5 378.9468, found 378.9474.

5-(2-((3-Bromophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (10)

White solid, 36.2 mg, 95% yield. (Rf = 0.58, petroleum ether/ethyl acetate = 9/1)

1H NMR (600 MHz, CDCl3) δ 7.52 (dd, J = 5.6, 0.7 Hz, 1H), 7.28 (dd, J = 3.8, 2.9 Hz, 1H), 7.25 – 7.18 (m, 2H), 7.11 (t, J = 7.9 Hz, 1H), 7.03 – 6.95 (m, 1H), 6.38 (dd, J = 4.5, 1.8 Hz, 1H), 5.63 (s, 1H), 2.71 (dd, J = 17.9, 2.8 Hz, 1H), 2.61 (dd, J = 17.9, 3.3 Hz, 1H), 1.59 (s, 3H).
**13C NMR** (150 MHz, CDCl₃) δ 205.7, 150.5, 150.4, 140.7, 130.9, 130.2, 129.0, 128.8, 128.7, 125.8, 124.9, 123.9, 122.9, 47.3, 41.3, 26.1.

**HRMS-ESI (m/z) [M+H]** calculated for C₁₀H₁₄BrO₂S₂ 380.9613, found 380.9602.

2-Hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (11)

![Structural formula of 2-Hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one](image)

White solid, 29.0 mg, 96% yield. (Rₜ = 0.60, petroleum ether/ethyl acetate = 9/1)

**1H NMR** (600 MHz, CDCl₃) δ 7.46 (d, J = 5.6 Hz, 1H), 7.23 (dd, J = 10.9, 4.6 Hz, 2H), 7.19 (d, J = 5.6 Hz, 1H), 7.14 (dd, J = 10.6, 4.2 Hz, 1H), 7.08 – 7.05 (m, 2H), 6.33 (t, J = 3.1 Hz, 1H), 2.73 (dd, J = 17.9, 2.9 Hz, 1H), 2.59 (dd, J = 17.9, 3.4 Hz, 1H), 1.57 (s, 3H).

**13C NMR** (150 MHz, CDCl₃) δ 205.8, 150.4, 149.7, 138.33, 130.2, 128.9, 128.4, 126.6, 125.9, 125.7, 125.5, 47.3, 41.2, 26.1.

**HRMS-ESI (m/z) [M-H]** calculated for C₁₀H₁₄O₂S₂ 301.0362, found 301.0358.

5-(2-((4-Chlorophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (12)

![Structural formula of 5-(2-((4-Chlorophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one](image)

White solid, 29.3 mg, 87% yield. (Rₜ = 0.64, petroleum ether/ethyl acetate = 9/1)

**1H NMR** (600 MHz, CDCl₃) δ 7.49 (d, J = 5.6 Hz, 1H), 7.25 – 7.15 (m, 3H), 7.04 – 6.98 (m, 2H), 6.37 (t, J = 3.1 Hz, 1H), δ 2.69 (dd, J = 17.9, 2.9 Hz, 1H), 2.59 (dd, J = 17.9, 3.4 Hz, 1H), 1.58 (s, 3H).

**13C NMR** (150 MHz, CDCl₃) δ 206.0, 150.6, 150.3, 136.9, 131.9, 130.5, 129.0, 128.6, 127.8, 126.0, 124.7, 47.3, 41.4, 26.0.

**HRMS-ESI (m/z) [M-H]** calculated for C₁₀H₁₄ClO₂S₂ 334.9973, found 334.9970.

5-(2-((4-Acetylphenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (13)

![Structural formula of 5-(2-((4-Acetylphenyl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one](image)

White solid, 31.7 mg, 92% yield. (Rₜ = 0.64, petroleum ether/ethyl acetate = 9/1)

**1H NMR** (600 MHz, CDCl₃) δ 7.86 – 7.73 (m, 2H), 7.53 (d, J = 5.6 Hz, 1H), 7.23 (d, J = 5.6 Hz, 1H), 7.10 – 7.00 (m, 2H), 6.32 (t, J = 3.1 Hz, 1H), 5.50 (s, 1H), 2.71 (dd, J = 17.9, 2.9 Hz, 1H), 2.60 (dd, J = 17.9, 3.4 Hz, 1H), 2.54 (s, 3H), 1.57 (s, 3H).

**13C NMR** (150 MHz, CDCl₃) δ 205.4, 197.1, 151.0, 150.4, 145.3, 134.5, 131.3, 128.83, 128.76, 125.6, 125.4, 122.9, 47.3, 41.4, 26.5, 26.0.

**HRMS-ESI (m/z) [M-H]** calculated for C₁₀H₁₄O₂S₂ 343.0468, found 343.0460.

2-Hydroxy-5-methyl-5-(2-(thiophen-2-ylthio)thiophen-3-yl)cyclopent-2-en-1-one (14)

![Structural formula of 2-Hydroxy-5-methyl-5-(2-(thiophen-2-ylthio)thiophen-3-yl)cyclopent-2-en-1-one](image)
White solid, 24.6 mg, 80% yield. \((R_\ell = 0.62, \text{petroleum ether/ethyl acetate} = 9/1)\)

**\(^1H\) NMR** (600 MHz, CDCl\(_3\)) \(\delta\) 7.35 – 7.28 (m, 2H), 7.10 (dd, \(J = 3.6, 1.2\) Hz, 1H), 7.05 (d, \(J = 5.5\) Hz, 1H), 6.93 (dd, \(J = 5.3, 3.6\) Hz, 1H), 6.51 (t, \(J = 3.1\) Hz, 1H), 5.73 (s, 1H), 2.91 (dd, \(J = 18.0, 2.9\) Hz, 1H), 2.71 (dd, \(J = 18.0, 3.4\) Hz, 1H), 1.60 (s, 3H).

**\(^13C\) NMR** (150 MHz, CDCl\(_3\)) \(\delta\) 206.1, 150.5, 146.6, 135.2, 131.9, 130.0, 129.3, 128.8, 127.8, 127.4, 126.2, 47.3, 41.4, 26.2.

**HRMS-ESI (m/z) [M+H]^+** calculated for C\(_{14}\)H\(_{13}\)O\(_2\)S\(_3\) 309.0072, found 309.0066.

5-(2-(Benzylthio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (15)

![Chemical Structure](image)

White solid, 28.7 mg, 91% yield. \((R_\ell = 0.62, \text{petroleum ether/ethyl acetate} = 9/1)\)

**\(^1H\) NMR** (600 MHz, CDCl\(_3\)) \(\delta\) 7.29 (d, \(J = 5.5\) Hz, 1H), 7.28 – 7.26 (m, 2H), 7.24 (m, 1H), 7.21 – 7.17 (m, 2H), 7.04 (d, \(J = 5.5\) Hz, 1H), 6.41 (t, \(J = 3.1\) Hz, 1H), 5.56 (s, 1H), 3.86 (d, \(J = 12.3\) Hz, 1H), 3.83 (d, \(J = 12.3\) Hz, 1H), 2.62 (dd, \(J = 17.8, 2.9\) Hz, 1H), 2.57 (dd, \(J = 17.8, 3.4\) Hz, 1H), 1.54 (s, 3H).

**\(^13C\) NMR** (150 MHz, CDCl\(_3\)) \(\delta\) 206.4, 150.4, 148.5, 136.9, 129.3, 128.7, 128.5, 127.7, 127.4, 125.6, 125.5, 47.3, 43.6, 42.0, 26.1.

**HRMS-ESI (m/z) [M-H]^–** calculated for C\(_{17}\)H\(_{15}\)O\(_2\)S\(_2\) 315.0519, found 315.0515.

2-Hydroxy-5-methyl-5-(2-(propylthio)thiophen-3-yl)cyclopent-2-en-1-one (16)

![Chemical Structure](image)

Yellow oil, 26.3 mg, 98% yield. \((R_\ell = 0.65, \text{petroleum ether/ethyl acetate} = 9/1)\)

**\(^1H\) NMR** (600 MHz, CDCl\(_3\)) \(\delta\) 7.28 (d, \(J = 5.5\) Hz, 1H), 7.04 (d, \(J = 5.6\) Hz, 1H), 6.46 (t, \(J = 3.1\) Hz, 1H), 5.65 (s, 1H), \(\delta\) 2.86 (dd, \(J = 17.8, 2.9\) Hz, 1H), 2.71 – 2.60 (m, 3H), 1.66 – 1.58 (m, 2H), 1.57 (s, 3H), 0.97 (t, \(J = 7.4\) Hz, 3H).

**\(^13C\) NMR** (150 MHz, CDCl\(_3\)) \(\delta\) 206.5, 150.6, 147.2, 130.2, 127.7, 125.4, 125.2, 47.3, 41.9, 41.0, 26.1, 22.7, 13.3.

**HRMS-ESI (m/z) [M-H]^–** calculated for C\(_{17}\)H\(_{15}\)O\(_2\)S\(_2\) 267.0519, found 267.0517.

5-(2-(Hexylthio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (17)

![Chemical Structure](image)

Yellow oil, 29.5 mg, 96% yield. \((R_\ell = 0.63, \text{petroleum ether/ethyl acetate} = 9/1)\)

**\(^1H\) NMR** (600 MHz, CDCl\(_3\)) \(\delta\) 7.29 – 7.26 (m, 1H), 7.04 (d, \(J = 5.5\) Hz, 1H), 6.45 (t, \(J = 3.0\) Hz, 1H), 5.60 (s, 1H), \(\delta\) 2.86 (dd, \(J = 17.8, 2.7\) Hz, 1H), 2.73 – 2.62 (m, 3H), 1.61 – 1.54 (m, 5H), 1.39 – 1.32 (m, 2H), 1.31 – 1.22 (m, 4H), 0.88 (t, \(J = 6.9\) Hz, 3H).

**\(^13C\) NMR** (150 MHz, CDCl\(_3\)) \(\delta\) 206.4, 150.6, 147.2, 130.2, 127.7, 125.3, 125.1, 47.3, 41.9, 39.1, 31.4, 29.2, 28.3, 25.9, 22.5, 14.0.

**HRMS-ESI (m/z) [M-H]^–** calculated for C\(_{18}\)H\(_{20}\)O\(_2\)S\(_2\) 309.0988, found 309.0980.
5-(2-(Dodecylthio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (18)

White solid, 38.6 mg, 97% yield. (Rf = 0.64, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl₃) δ 7.28 (d, J = 5.5 Hz, 1H), 7.04 (d, J = 5.5 Hz, 1H), 6.45 (s, 1H), 5.57 (s, 1H), 2.86 (dd, J = 17.8, 2.8 Hz, 1H), 2.73 – 2.61 (m, 3H), 1.60 – 1.58 (m, 1H), 1.57 (s, 3H), 1.38 – 1.22 (m, 19H), 0.88 (t, J = 7.0 Hz, 3H).

^13C NMR (150 MHz, CDCl₃) δ 206.4, 150.6, 147.2, 130.3, 127.7, 127.6, 125.2, 47.3, 41.9, 39.1, 31.9, 29.6, 29.62, 29.58, 29.5, 29.34, 29.28, 29.2, 28.7, 26.0, 22.7, 14.1.

HRMS-ESI (m/z) [M-H]⁻ calculated for C₂₂H₃₃O₂S₂ 393.1927, found 393.1916.

2-Hydroxy-5-(2-(isopropylthio)thiophen-3-yl)-5-methylcyclopent-2-en-1-one (19)

Yellow oil, 25.7 mg, 96% yield. (Rf = 0.66, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl₃) δ 7.30 (d, J = 5.6 Hz, 1H), 7.07 (d, J = 5.6 Hz, 1H), 6.46 (t, J = 3.1 Hz, 1H), 5.55 (s, 1H), 3.06 – 2.95 (m, 1H), 2.88 (dd, J = 17.8, 2.8 Hz, 1H), 2.65 (dd, J = 17.8, 3.4 Hz, 1H), 1.28 (d, J = 6.7 Hz, 3H), 1.57 (s, 3H), 1.21 (d, J = 6.8 Hz, 3H).

^13C NMR (150 MHz, CDCl₃) δ 206.5, 150.5, 148.0, 129.2, 127.8, 125.4, 125.2, 47.3, 41.9, 26.1, 23.3, 22.7.

HRMS-ESI (m/z) [M-H]⁻ calculated for C₁₃H₁₄O₂S₂ 267.0519, found 267.0513.

5-(2-(Cyclohexylthio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (20)

Yellow oil, 28.3 mg, 92% yield. (Rf = 0.65, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl₃) δ 7.28 (d, J = 5.6 Hz, 1H), 7.07 (d, J = 5.6 Hz, 1H), 6.46 (t, J = 3.1 Hz, 1H), 5.63 (s, 1H), 2.88 (dd, J = 17.8, 2.8 Hz, 1H), 2.80 – 2.71 (m, 1H), 2.65 (dd, J = 17.8, 3.4 Hz, 1H), 2.08 – 1.95 (m, 1H), 1.94 – 1.82 (m, 1H), 1.80 – 1.67 (m, 2H), 1.59 (d, J = 4.4 Hz, 1H), 1.57 (s, 3H), 1.40 – 1.32 (m, 1H), 1.31 – 1.20 (m, 4H).

^13C NMR (150 MHz, CDCl₃) δ 206.5, 150.6, 147.7, 128.9, 127.7, 125.4, 50.4, 47.3, 41.9, 33.5, 33.0, 26.1, 26.1, 25.9, 25.7.

HRMS-ESI (m/z) [M-H]⁻ calculated for C₁₉H₁₉O₂S₂ 307.0832, found 307.0829.

5-(2-(((3R,5S,8R,9S,10S,13R,14S,17R)-10,13-dimethyl-17-((R)-6-methylheptan-2-yl)hexadecahydro-1H-cyclopenta(a)phenanthren-3-yl)thio)thiophen-3-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (21)
White solid, 44.1 mg, 74% yield. (Rₐ = 0.66, petroleum ether/ethyl acetate = 9/1)

¹H NMR (600 MHz, CDCl₃) δ 7.30 (d, J = 5.6 Hz, 2H), δ 7.09 (d, J = 5.6 Hz, 1H), 7.08 (d, J = 5.6 Hz, 1H), 6.49 (m, 2H), 5.68 (s, 1H), 5.62 (s, 1H), 3.25 (d, J = 10.5 Hz, 2H), 2.87 (m, 2H), 2.67 (dd, J = 17.7, 3.4 Hz, 2H), 2.00 (m, 2H), 1.92 – 1.75 (m, 7H), 1.74 – 1.63 (m, 6H), 1.59 (s, 6H), 1.52 – 1.47 (m, 8H), 1.39 – 1.32 (m, 5H), 1.30 – 1.21 (m, 10H), 1.19 – 1.10 (m, 12H), 1.08 – 0.97 (m, 8H), 0.93 – 0.88 (m, 22H), 0.78 (s, 6H), 0.67 (s, 6H).

¹³C NMR (151 MHz, CDCl₃) δ 206.61, 206.60, 150.58, 150.57, 147.84, 147.75, 129.99, 129.97, 127.75, 127.72, 127.71, 127.68, 125.32, 125.27, 125.26, 56.5, 56.3, 54.2, 50.3, 50.1, 47.3, 42.6, 42.03, 42.01, 40.9, 40.5, 40.0, 39.5, 36.23, 36.20, 35.8, 35.48, 35.47, 33.4, 33.2, 33.1, 32.0, 31.9, 28.4, 28.3, 28.0, 26.8, 26.4, 26.13, 26.12, 24.2, 23.9, 22.9, 22.6, 20.8, 18.7, 12.1, 11.9.

HRMS-ESI (m/z) [M+H]+ calculated for C₃₇H₅₇O₂S₂ 597.3794, found 597.3764.

2-Hydroxy-5-methyl-5-(2-(phenylthio)phenyl)cyclopent-2-en-1-one (22)

White solid, 26.9 mg, 91% yield. (Rₐ = 0.59, petroleum ether/ethyl acetate = 9/1)

¹H NMR (600 MHz, CDCl₃) δ 7.54 (dd, J = 8.0, 1.2 Hz, 1H), 7.39 (dd, J = 7.7, 1.4 Hz, 1H), 7.35 – 7.31 (m, 1H), 7.26 – 7.20 (m, 3H), 7.18 – 7.13 (m, 1H), 7.09 (m, 2H), 6.31 (t, J = 3.1 Hz, 1H), 5.61 (s, 1H), 2.76 (dd, J = 17.7, 2.6 Hz, 1H), 2.60 (dd, J = 17.7, 1H), 1.61 (s, 3H).

¹³C NMR (150 MHz, CDCl₃) δ 206.1, 150.7, 145.4, 137.4, 136.6, 133.3, 129.0, 128.8, 128.4, 128.2, 126.3, 126.4, 123.2, 50.4, 41.3, 25.3.

HRMS-ESI (m/z) [M+H]+ calculated for C₁₈H₁₇O₂S 297.0944, found 297.0939.

2-Hydroxy-5-methyl-5-(5-methyl-2-(p-tolylthio)phenyl)cyclopent-2-en-1-one (23)

White solid, 30.5 mg, 94% yield. (Rₐ = 0.60, petroleum ether/ethyl acetate = 9/1)

¹H NMR (600 MHz, CDCl₃) δ 7.35 (d, J = 1.3 Hz, 1H), 7.27 (d, J = 8.0 Hz, 1H), 7.09 – 7.04 (m, 1H), 7.03 (d, J = 8.0 Hz, 2H), 6.99 – 6.97 (m, 2H), 6.31 (t, J = 3.1 Hz, 1H), 5.61 (s, 1H), 2.75 (dd, J = 17.7, 2.6 Hz, 1H), 2.54 (dd, J = 17.7, 3.5 Hz, 1H), 2.39 (s, 3H), 2.31 (s, 3H), 1.62 (s, 3H).

¹³C NMR (150 MHz, CDCl₃) δ 206.2, 150.7, 145.1, 137.4, 136.6, 133.3, 129.0, 128.8, 128.4, 128.2, 126.3, 126.4, 123.2, 50.4, 41.3, 25.3.

HRMS-ESI (m/z) [M+H]+ calculated for C₂₀H₂₁O₂S 325.1257, found 325.1250.
5-(5-Chloro-2-((4-chlorophenyl)thio)phenyl)-2-hydroxy-5-methylcyclopent-2-en-1-one (24)

White solid, 27.4 mg, 75% yield. (R_f = 0.58, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl_3) δ 7.51 (d, J = 2.1 Hz, 1H), 7.27 (d, J = 8.2 Hz, 1H), 7.23 (dd, J = 8.3, 2.2 Hz, 1H), 7.20 (d, J = 8.6 Hz, 2H), 7.00 (d, J = 8.6 Hz, 2H), 6.33 (t, J = 3.1 Hz, 1H), 5.55 (s, 1H), 2.70 (dd, J = 17.8, 3.4 Hz, 1H), 2.57 (dd, J = 17.8, 2.4 Hz, 1H), 1.58 (s, 3H).

^13C NMR (150 MHz, CDCl_3) δ 205.4, 150.7, 147.2, 137.5, 135.3, 134.9, 132.7, 131.5, 130.1, 129.3, 129.2, 128.5, 123.4, 50.3, 41.1, 25.3.

HRMS-ESI (m/z) [M+H]^+ calculated for C_{18}H_{15}Cl_2O_2S 365.0164, found 365.0164.

2-Hydroxy-5-methyl-5-(2-(propylthio)benzofuran-3-yl)cyclopent-2-en-1-one (25)

White solid, 26.6 mg, 88% yield. (R_f = 0.61, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl_3) δ 7.40 (t, J = 7.8 Hz, 2H), 7.26 – 7.21 (m, 1H), 7.17 – 7.12 (m, 1H), 6.54 (t, J = 3.1 Hz, 1H), 5.85 (s, 1H), 2.97 – 2.88 (m, 3H), 2.72 (dd, J = 18.0, 3.3 Hz, 1H), 1.82 (s, 3H), 1.70 – 1.62 (m, 2H), 1.00 (t, J = 7.4 Hz, 3H).

^13C NMR (150 MHz, CDCl_3) δ 205.8, 155.5, 150.6, 146.9, 128.0, 126.1, 124.5, 124.1, 122.6, 120.3, 111.1, 45.4, 41.1, 37.0, 24.5, 23.2, 13.3.

HRMS-ESI (m/z) [M+H]^+ calculated for C_{17}H_{19}O_3S 303.1049, found 303.1047.

2-Hydroxy-5-methyl-5-(2-(propylthio)-1H-tosyl-1H-indol-3-yl)cyclopent-2-en-1-one (26)

White solid, 36.7 mg, 80% yield. (R_f = 0.60, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl_3) δ 8.38 (d, J = 8.6 Hz, 1H), 7.68 (d, J = 8.4 Hz, 2H), 7.61 (d, J = 8.1 Hz, 1H), 7.36 – 7.31 (m, 1H), 7.23 – 7.18 (m, 1H), 7.16 (d, J = 8.2 Hz, 2H), 6.36 (t, J = 3.0 Hz, 1H), 2.98 – 2.88 (m, 1H), 2.84 – 2.76 (m, 1H), 2.70 (dd, J = 17.6, 3.3 Hz, 1H), 2.66 (dd, J = 17.6, 2.7 Hz, 1H), 2.34 (s, 3H), 1.77 (s, 3H), 1.60 – 1.52 (m, 2H), 0.97 (t, J = 7.4 Hz, 3H).

^13C NMR (150 MHz, CDCl_3) δ 205.8, 150.6, 144.7, 138.7, 135.7, 133.3, 129.5, 129.1, 129.0, 127.1, 125.4, 123.7, 123.5, 120.6, 116.2, 47.0, 42.3, 40.6, 24., 22.04, 21.6, 13.5.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{24}H_{23}NaO_5S_2 478.1117, found 478.1104.
2-Hydroxy-5-methyl-5-(2-(propylthio)-1-tosyl-1H-pyrrol-3-yl)cyclopent-2-en-1-one (27)

White solid, 24.3 mg, 60% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.78 (d, $J$ = 8.4 Hz, 2H), 7.48 (d, $J$ = 3.7 Hz, 1H), 7.27 (d, $J$ = 7.4 Hz, 2H), 6.40 (t, $J$ = 3.1 Hz, 1H), 6.34 (d, $J$ = 3.7 Hz, 1H), 5.56 (s, 1H), 2.71 – 2.63 (m, 3H), 2.55 (dd, $J$ = 17.7, 3.4 Hz, 1H), 2.40 (s, 3H), 1.50 (m, 2H), 1.44 (s, 3H), 0.93 (t, $J$ = 7.4 Hz, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 206.2, 150.4, 145.0, 139.5, 139.8, 135.9, 129.6, 127.9, 125.2, 125.0, 119.7, 111.2, 45.1, 42.3, 29.7, 25.2, 21.9, 21.6, 13.4.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{20}$H$_{26}$NO$_2$S$_2$ 406.1141, found 406.1126.

2-Hydroxy-5-methyl-5-(2-(propylthio)benzo[b]thiophen-3-yl)cyclopent-2-en-1-one (28)

White solid, 30.2 mg, 95% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.73 – 7.66 (m, 1H), 7.64 – 7.54 (m, 1H), 7.27 (m, 1H), 7.26 – 7.24 (m, 1H), 6.46 (t, $J$ = 3.1 Hz, 1H), 6.00 (s, 1H), δ 2.96 (dd, $J$ = 17.8, 2.9 Hz, 1H), 2.92 – 2.81 (m, 2H), 2.77 (dd, $J$ = 17.8, 3.3 Hz, 1H), 1.92 (s, 3H), 1.73 – 1.60 (m, 2H), 1.00 (t, $J$ = 7.4 Hz, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 206.2, 150.9, 140.8, 139.1, 138.3, 133.7, 124.5, 124.2, 124.1, 122.8, 122.0, 49.4, 41.1, 40.9, 25.4, 22.7, 13.4.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{17}$H$_{19}$O$_2$S$_2$ 319.0821, found 319.0816.

5-(3-(Dodecylthio)thiophen-2-yl)-2-hydroxy-5-methylcyclopent-2-en-1-one (29)

White solid, 31.5 mg, 80% yield, (Rf = 0.62, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (400 MHz, CDCl$_3$) δ 7.17 (d, $J$ = 5.3 Hz, 1H), 7.02 (d, $J$ = 5.3 Hz, 1H), 6.49 (t, $J$ = 3.1 Hz, 1H), 5.70 (s, 1H), 2.96 (dd, $J$ = 17.8, 2.8 Hz, 1H), 2.78 – 2.58 (m, 3H), 1.64 (s, 3H), 1.60 – 1.48 (m, 2H), 1.41 – 1.19 (m, 18H), 0.90 (t, $J$ = 6.8 Hz, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ 205.1, 150.4, 145.7, 131.9, 127.7, 125.4, 122.8, 47.4, 41.7, 36.1, 31.9, 29.67, 29.66, 29.62, 29.56, 29.5, 29.4, 29.2, 28.8, 26.5, 22.7, 14.2.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{22}$H$_{35}$O$_2$S$_2$ 395.2073, found 395.2059.

2-Hydroxy-5-methyl-5-(3-(p-tolylthio)thiophen-2-yl)cyclopent-2-en-1-one (30)

White solid, 31.0 mg, 98% yield. (Rf = 0.62, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (400 MHz, CDCl$_3$) δ 7.19 (d, $J$ = 5.3 Hz, 1H), 7.04 (d, $J$ = 8.1 Hz, 2H), 6.97 (d, $J$ = 8.2
Hz, 2H), 6.91 (d, J = 5.3 Hz, 1H), 6.42 (t, J = 3.1 Hz, 1H), 5.76 (s, 1H), 2.87 (dd, J = 17.9, 2.8 Hz, 1H), 2.69 (dd, J = 17.9, 3.4 Hz, 1H), 2.28 (s, 3H), 1.64 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ 204.7, 150.3, 148.4, 135.9, 133.7, 133.6, 129.7, 127.9, 126.0, 125.2, 123.3, 47.5, 41.5, 26.7, 21.0.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{17}$H$_{17}$O$_2$S$_2$ 317.0664, found 317.0654.

2-Hydroxy-4,5-dimethyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (31)

White solid, 23.4 mg, 74% yield. (R$_f$ = 0.60, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.48 (d, J = 5.6 Hz, 1H), 7.26 (t, J = 7.7 Hz, 2H), 7.19 – 7.14 (m, 1H), 7.11 (dd, J = 4.7, 3.2 Hz, 3H), 6.23 (d, J = 2.5 Hz, 1H), 5.54 (s, 1H), 2.95 (qd, J = 7.4, 2.6 Hz, 1H), 1.43 (s, 3H), 1.11 (d, J = 7.4 Hz, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 206.2, 150.1, 150.0, 138.0, 130.8, 130.2, 128.8, 128.5, 126.9, 126.1, 125.6, 51.0, 43.6, 20.9, 14.6.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{17}$H$_{17}$O$_2$S$_2$ 317.0664, found 317.0654.

3-Bromo-2-hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (32)

White solid, 30.5 mg, 80% yield. (R$_f$ = 0.62, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.48 (d, J = 5.6 Hz, 1H), 7.26 (m, 2H), 7.19 (d, J = 5.6 Hz, 1H), 7.16 (d, J = 7.4 Hz, 1H), 7.12 – 7.08 (m, 2H), 6.07 (s, 1H), 3.08 (d, J = 17.2 Hz, 1H), 2.87 (d, J = 17.2 Hz, 1H), 1.64 (s, 3H).

$^{13}$C NMR (151 MHz, CDCl$_3$) δ 200.8, 148.9, 148.4, 137.7, 130.3, 129.0, 128.3, 126.8, 126.2, 123.9, 49.3, 48.4, 25.7.

HRMS-ESI (m/z) [M+Na]$^+$ calculated for C$_{16}$H$_{13}$BrNaO$_2$S$_2$ 402.9433, found 402.9431.

2-Hydroxy-3-(2-(phenylthio)thiophen-3-yl)cyclohex-2-en-1-one (33)

White solid, 22.6 mg, 75% yield. (R$_f$ = 0.60, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) δ 7.45 (d, J = 5.5 Hz, 1H), 7.25 – 7.21 (m, 3H), 7.19 – 7.12 (m, 3H), 6.39 (s, 1H), 2.78 (s, J = 5.9 Hz, 2H), 2.55 (dd, J = 14.7, 7.8 Hz, 2H), 2.03 – 1.99 (m, 2H).

$^{13}$C NMR (150 MHz, CDCl$_3$) δ 195.2, 144.0, 143.1, 138.2, 129.6, 129.4, 129.0, 127.3, 126.2, 125.6, 36.1, 29.4, 22.9.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{16}$H$_{15}$O$_2$S$_2$ 303.0508, found 303.0503.
3-(2-((4-Ethylphenyl)thio)thiophen-3-yl)-2-hydroxycyclohex-2-en-1-one (34)

![Chemical Structure Image]

Colorless oil, 24.8 mg, 75% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) $\delta$ 7.44 (d, $J = 5.5$ Hz, 1H), 7.23 (d, $J = 5.5$ Hz, 1H), $\delta$ 7.15 (d, $J = 8.3$ Hz, 1H), 7.12 – 7.09 (m, 3H), 6.41 (s, 1H), 2.82 (t, $J = 5.9$ Hz, 2H), 2.65 – 2.55 (m, 4H), 2.09 – 2.01 (m, 2H), 1.22 (t, $J = 7.6$ Hz, 3H).

$^{13}$C NMR (150 MHz, CDCl$_3$) $\delta$ 195.2, 144.1, 143.8, 137.7, 132.2, 130.0, 129.6, 128.5, 125.8, 36.1, 29.4, 28.4. 15.5.

HRMS-ESI (m/z) [M+Na]$^+$ calculated for C$_{18}$H$_{18}$NaO$_2$S$_2$ 353.0640, found 353.0635.

3-(2-((4-Bromophenyl)thio)thiophen-3-yl)-2-hydroxycyclohex-2-en-1-one (35)

![Chemical Structure Image]

White solid, 22.9 mg, 60% yield. (Rf = 0.61, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.49 (d, $J = 5.5$ Hz, 1H), 7.37 – 7.32 (m, 2H), 7.22 (d, $J = 5.5$ Hz, 1H), 7.03 – 6.97 (m, 2H), 6.38 (s, 1H), 2.75 (t, $J = 5.9$ Hz, 2H), 2.60 – 2.52 (m, 2H), 2.05 – 2.01 (m, 2H).

$^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 195.1, 144.1, 143.8, 137.7, 132.2, 130.0, 129.6, 128.5, 127.7, 125.2, 119.9, 36.1, 29.5, 22.9.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{16}$H$_{14}$BrO$_2$S$_2$ 380.9613, found 380.9600.

2-Hydroxy-3-(2-(isopropylthio)thiophen-3-yl)cyclohex-2-en-1-one (36)

![Chemical Structure Image]

Yellow solid, 17.5 mg, 65% yield. (Rf = 0.60, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (600 MHz, CDCl$_3$) $\delta$ 7.35 (d, $J = 5.5$ Hz, 1H), 7.12 (d, $J = 5.5$ Hz, 1H), 6.34 (s, 1H), 3.21 – 3.17 (m, 1H), 2.86 (t, $J = 5.9$ Hz, 2H), 2.65 – 2.59 (m, 2H), 2.10 (m, 2H), 1.24 (d, $J = 6.7$ Hz, 6H).

$^{13}$C NMR (151 MHz, CDCl$_3$) $\delta$ 195.3, 144.0, 142.2, 131.4, 129.2, 128.0, 126.8, 42.5, 36.2, 29.9, 23.06, 23.00.

HRMS-ESI (m/z) [M+Na]$^+$ calculated for C$_{13}$H$_{16}$NaO$_2$S$_2$ 291.0484, found 291.0493.

2-Hydroxy-2'-(phenylthio)-5,6-dihydro-[1,1'-biphenyl]-3(4H)-one (37)

![Chemical Structure Image]

Yellow solid, 17.8 mg, 60% yield. (Rf = 0.60, petroleum ether/ethyl acetate = 9/1)
\( ^1H \text{ NMR} \) (600 MHz, CDCl\(_3\)) \( \delta \) 7.32 (m, 5H), 7.24 (m, 4H), 6.15 (s, 1H), 2.69 (t, \( J = 5.7 \) Hz, 2H), 2.64 – 2.58 (m, 2H), 2.12 (dt, \( J = 12.5, 6.2 \) Hz, 2H).

\( ^13C \text{ NMR} \) (151 MHz, CDCl\(_3\)) \( \delta \) 195.2, 143.7, 139.4, 136.0, 133.8, 132.7, 130.9, 130.5, 129.1, 129.0, 128.8, 127.5, 127.0, 36.1, 30.3, 22.9.

**HRMS-ESI (m/z) [M+Na]^+** calculated for C\(_{18}\)H\(_{16}\)NaO\(_2\)S 319.0763, found 319.0768.

2-Hydroxy-4,4,6-trimethyl-6-(2-(phenylthio)thiophen-3-yl)cyclohex-2-en-1-one (38)

Green solid, 37.4 mg, 76% yield. (\( R_f = 0.40 \), petroleum ether/ethyl acetate = 9/1)

\( ^1H \text{ NMR} \) (600 MHz, CDCl\(_3\)) \( \delta \) 7.53 (d, \( J = 5.7 \) Hz, 1H), 7.28 – 7.24 (m, 2H), 7.22 (m, 1H), 7.11 (d, \( J = 5.7 \) Hz, 1H), 6.84 – 6.79 (m, 2H), 2.95 (dd, \( J = 20.2, 6.5 \) Hz, 1H), 2.64 (m, 1H), 2.51 (d, \( J = 13.4 \) Hz, 1H), 2.42 (dd, \( J = 19.4, 8.7 \) Hz, 1H), 2.23 (td, \( J = 13.6, 3.6 \) Hz, 1H), 2.13 – 2.00 (m, 2H), 1.95 – 1.84 (m, 2H), 1.76 – 1.48 (m, 7H), 1.22 – 1.11 (m, 3H), 0.99 (s, 3H), 0.87 (s, 3H).

**HRMS-ESI (m/z) [M+Na]^+** calculated for C\(_{29}\)H\(_{33}\)NaO\(_2\)S\(_2\) 515.1685, found 515.1674.

(8R,9S,10R,13S,14S)-10,13-dimethyl-2-(2-(phenylthio)thiophen-3-yl)dodecahydro-1H-cyclopenta[a]phenanthrene-3,4,17(2H)-trione (39)

2-(2-(Phenylthio)thiophen-3-yl)hexane-3,4-dione (40)

Yellow oil, 9.1 mg, 30% yield. (\( R_f = 0.75 \), petroleum ether/ethyl acetate = 9/1)

**HRMS-ESI (m/z) [M+Na]^+** calculated for C\(_{18}\)H\(_{16}\)NaO\(_2\)S\(_2\) 327.0484, found 327.0480.
III. Procedure for Multi-Step Substituted Cyclic 1.2-Diketones

TFAA (0.15 mmol, 1.5 equiv) was added to a solution of cyclic 1,2-diketones (0.15 mmol, 1.5 equiv) and sulfoxide (0.1 mmol, 1 equiv) in DCE (0.8 mL, 0.125 M) at -10 °C. After 4 hours, the reaction mixture was concentrated under reduced pressure and purified by column chromatography (eluent: petroleum ether and ethyl acetate = 9/1) to afford product.

3-(2-((4-Bromophenyl)thio)thiophen-3-yl)-2-hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (41)

Yellow solid, 40.4 mg, 70% yield. (R_f = 0.62, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl_3) δ 7.84 (d, J = 5.6 Hz, 1H), 7.48 (d, J = 5.6 Hz, 1H), 7.45 (d, J = 5.6 Hz, 1H), 7.35 – 7.30 (m, 2H), 7.19 (d, J = 5.6 Hz, 1H), 7.12 (t, J = 7.5 Hz, 2H), 7.06 (t, J = 7.3 Hz, 1H), 7.00 – 6.96 (m, 2H), 6.30 (s, 1H), 3.40 (d, J = 17.2 Hz, 1H), 1.53 (s, 3H).

^13C NMR (150 MHz, CDCl_3) δ 205.1, 149.9, 145.9, 139.4, 138.1, 138.0, 132.2, 130.9, 130.6, 130.2, 130.0, 129.0, 128.8, 128.5, 128.3, 126.7, 126.0, 125.5, 120.0, 46.5, 43.6, 26.3.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{26}H_{19}BrNaO_2S_5 592.9343, found 592.9317.

2-Hydroxy-5-methyl-3,5-bis(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one(42)

Yellow solid, 32.1 mg, 65% yield. (R_f = 0.61, petroleum ether/ethyl acetate = 9/1)

^1H NMR (400 MHz, CDCl_3) δ 7.86 (d, J = 5.6 Hz, 1H), 7.45 (d, J = 5.6 Hz, 1H), 7.44 (d, J = 5.6 Hz, 1H), 7.23 (d, J = 7.7 Hz, 2H), 7.19 (d, J = 5.6 Hz, 1H), 7.18 – 7.14 (m, 1H), 7.12 (d, J = 7.6 Hz, 2H), 7.09 – 7.03 (m, 3H), 7.03 – 6.98 (m, 2H), 6.22 (s, 1H), 3.42 (d, J = 17.3 Hz, 1H), 3.25 (d, J = 17.3 Hz, 1H), 1.52 (s, 3H).

^13C NMR (100 MHz, CDCl_3) δ 205.2, 149.9, 145.9, 138.9, 138.5, 138.1, 131.6, 130.6, 130.3, 130.1, 129.5, 129.2, 128.8, 128.6, 127.1, 126.7, 126.3, 125.9, 125.4, 46.5, 43.6, 26.2.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{26}H_{20}NaO_2S_4 515.0238, found 515.0230.
(3S,5S)-3-((4-Bromophenyl)thio)thiophen-3-yl)-5-methyl-3-(5-(phenylthio)thiophen-2-yl)-5-(2-(phenylthio)thiophen-3-yl)cyclopentane-1,2-dione (43)

Yellow solid, 50.3 mg, 66% yield. (Rf = 0.63, petroleum ether/ethyl acetate = 9/1)

\[ ^1H \text{NMR} \ (600 \text{ MHz, CDCl}_3) \delta 7.45 \ (d, J = 5.6 \text{ Hz, 1H}), 7.37 \ (d, J = 5.6 \text{ Hz, 1H}), 7.26 \ (d, J = 5.2 \text{ Hz, 1H}), 7.28 - 7.14 \ (m, 10H), 7.04 \ (d, J = 3.8 \text{ Hz, 1H}), 7.01 - 6.94 \ (m, 4H), 6.69 \ (d, J = 8.5 \text{ Hz, 2H}), 3.79 \ (d, J = 14.6 \text{ Hz, 1H}), 3.20 \ (d, J = 14.6 \text{ Hz, 1H}). \]

\[ ^13C \text{NMR} \ (150 \text{ MHz, CDCl}_3) \delta 200.8, 197.2, 152.2, 151.3, 147.8, 137.5, 137.1, 135.9, 135.4, 134.0, 131.9, 131.0, 130.9, 129.14, 129.08, 129.0, 128.6, 127.9, 127.5, 126.6, 126.4, 126.2, 125.0, 124.4, 120.3, 52.6, 49.7, 47.2, 25.8. \]

HRMS-ESI (m/z) [M+Na]^+ calculated for C₃₆H₂₅BrNaO₂S₆ 782.9254, found 782.9243.

(3R,5R)-3-((4-Bromophenyl)thio)thiophen-2-yl)-5-methyl-3,5-bis(2-(phenylthio)thiophen-3-yl)cyclopentane-1,2-dione (44)

Yellow solid, 41.9 mg, 55% yield. (Rf = 0.64, petroleum ether/ethyl acetate = 9/1)

\[ ^1H \text{NMR} \ (600 \text{ MHz, CDCl}_3) \delta 7.44 \ (d, J = 5.6 \text{ Hz, 1H}), 7.37 \ (d, J = 5.6 \text{ Hz, 1H}), 7.36 \ (d, J = 8.6 \text{ Hz, 2H}), 7.28 \ (d, J = 5.5 \text{ Hz, 1H}), 7.24 \ (t, J = 7.7 \text{ Hz, 2H}), 7.20 - 7.12 \ (m, 4H), 7.06 \ (d, J = 3.8 \text{ Hz, 1H}), 7.06 - 7.03 \ (m, 2H), 7.00 \ (d, J = 3.8 \text{ Hz, 1H}), 6.98 - 6.95 \ (m, 2H), 6.92 \ (d, J = 5.6 \text{ Hz, 1H}), 6.85 \ (m, 2H), 3.75 \ (d, J = 14.6 \text{ Hz, 1H}), 3.23 \ (d, J = 14.6 \text{ Hz, 1H}). \]

\[ ^13C \text{NMR} \ (151 \text{ MHz, CDCl}_3) \delta 200.6, 197.3, 151.8, 151.2, 148.7, 137.3, 137.0, 136.4, 136.0, 132.6, 132.1, 131.0, 130.5, 129.1, 129.1, 128.9, 128.70, 128.67, 127.6, 126.4, 126.3, 126.2, 126.1, 125.4, 124.9, 120.4, 52.6, 49.7, 47.2, 25.8. \]

HRMS-ESI (m/z) [M+Na]^+ calculated for C₃₆H₂₅BrNaO₂S₆ 784.9260, found 784.9260.
(3S,5S)-3-(2-((4-Bromophenyl)thio)thiophen-3-yl)-3-(5-((4-chlorophenyl)thio)thiophen-2-yl)-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopentane-1,2-dione (45)

Yellow solid, 55.7 mg, 70% yield. \( (R_f = 0.64, \text{petroleum ether/ethyl acetate} = 9/1) \)

\( ^1H \text{ NMR} \) (600 MHz, CDCl\(_3\)) \( \delta 7.46 \) (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.37 (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.26 – 7.17 (m, 7H), 7.15 (t, \( J = 7.3 \text{ Hz}, 1\text{H} \)), 7.11 (d, \( J = 8.6 \text{ Hz}, 2\text{H} \)), 7.02 (d, \( J = 3.8 \text{ Hz}, 1\text{H} \)), 6.95 (m, 4H), 6.66 (d, \( J = 8.6 \text{ Hz}, 2\text{H} \)), 3.76 (d, \( J = 14.6 \text{ Hz}, 1\text{H} \)), 3.20 (d, \( J = 14.6 \text{ Hz}, 1\text{H} \)), 1.50 (s, 3H).

\( ^13C \text{ NMR} \) (151 MHz, CDCl\(_3\)) \( \delta 200.6, 197.2, 152.0, 148.3, 137.1, 136.0, 135.9, 135.6, 133.3, 132.7, 131.9, 131.1, 131.0, 129.3, 129.2, 129.1, 128.9, 128.7, 127.6, 127.5, 126.5, 126.1, 124.9, 124.4, 120.3, 52.6, 49.7, 47.2, 25.8.

HRMS-ESI \( (m/z) [M+Na]^+ \) calculated for C\(_{36}\)H\(_{24}\)BrClNaO\(_2\)S\(_8\) 818.8865, found 818.8879.

3-(2-(Cyclohexylthio)thiophen-3-yl)-2-hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (46)

Yellow oil, 34.9 mg, 70% yield. \( (R_f = 0.64, \text{petroleum ether/ethyl acetate} = 9/1) \)

\( ^1H \text{ NMR} \) (600 MHz, CDCl\(_3\)) \( \delta 7.54 \) (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.46 (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.33 (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.25 (d, \( J = 5.6 \text{ Hz}, 1\text{H} \)), 7.10 – 7.03 (m, 3H), 6.44 (s, 1H), 3.41 (d, \( J = 17.2 \text{ Hz}, 1\text{H} \)), 3.33 (d, \( J = 17.2 \text{ Hz}, 1\text{H} \)), 2.96 – 2.84 (m, 1H), 1.90 (m, 2H), 1.76 – 1.66 (m, 2H), 1.64 (s, 3H), 1.58 (m, 1H), 1.34 – 1.28 (m, 2H), 1.25 – 1.18 (m, 3H).

\( ^13C \text{ NMR} \) (150 MHz, CDCl\(_3\)) \( \delta 204.9, 149.9, 145.4, 138.2, 138.1, 132.9, 132.2, 130.0, 129.8, 128.8, 128.6, 128.0, 126.8, 126.0, 125.7, 51.6, 46.7, 44.7, 33.0, 26.4, 26.0, 25.5.

HRMS-ESI \( (m/z) [M+Na]^+ \) calculated for C\(_{26}\)H\(_{26}\)NaO\(_2\)S\(_4\) 521.0708, found 521.0695.

3-(2-(Hexylthio)thiophen-3-yl)-2-hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one (47)

Yellow oil, 32.5 mg, 65% yield. \( (R_f = 0.63, \text{petroleum ether/ethyl acetate} = 9/1) \)
\[1^1\text{H} \text{NMR} \ (600 \text{ MHz, CDCl}_3) \delta \ 7.68 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.46 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.29 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.26 \ (m, \ 1\text{H}), \ 7.18 - 7.10 \ (m, \ 2\text{H}), \ 7.10 - 7.01 \ (m, \ 3\text{H}), \ 6.71 \ (s, \ 1\text{H}), \ 3.45 \ (d, \ J = 17.2 \text{ Hz, } 1\text{H}), \ 3.36 \ (d, \ J = 17.2 \text{ Hz, } 1\text{H}), \ 2.79 - 2.69 \ (m, \ 2\text{H}), \ 1.66 \ (s, \ 3\text{H}), \ 1.60 - 1.52 \ (m, \ 2\text{H}), \ 1.40 - 1.32 \ (m, \ 2\text{H}), \ 1.31 - 1.21 \ (m, \ 4\text{H}), \ 0.89 \ (t, \ J = 7.1 \text{ Hz, } 3\text{H}).
\]

\[1^3\text{C} \text{NMR} \ (150 \text{ MHz, CDCl}_3) \delta \ 205.1, \ 150.0, \ 145.5, \ 138.3, \ 136.4, \ 135.5, \ 132.6, \ 130.08, \ 130.07, \ 128.8, \ 128.7, \ 126.78, \ 126.76, \ 125.9, \ 125.6, \ 46.7, \ 44.5, \ 39.5, \ 31.4, \ 29.2, \ 28.4, \ 26.5, \ 22.6, \ 14.1.
\]

HRMS-ESI (m/z) [M+Na]+ calculated for C_{26}H_{26}NaO_{2}S_{4} 523.0864, found 523.1041.

(\text{3R,5R}-3-Methyl-5-(5-(phenylthio)thiophen-2-yl)-3,5-bis(2-(phenylthio)thiophen-3-y1)cyclopentane-1,2-dione (48)

Yellow solid, 44.4 mg, 65% yield. (Rf = 0.64, petroleum ether/ethyl acetate = 9/1)

\[1^1\text{H} \text{NMR} \ (600 \text{ MHz, CDCl}_3) \delta \ 7.43 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.35 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.27 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.26 - 7.20 \ (m, \ 4\text{H}), \ 7.19 - 7.10 \ (m, \ 7\text{H}), \ 7.05 \ (d, \ J = 3.8 \text{ Hz, } 1\text{H}), \ 6.97 \ (d, \ J = 3.8 \text{ Hz, } 1\text{H}), \ 6.95 \ (d, \ J = 7.7 \text{ Hz, } 2\text{H}), \ 6.91 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 6.83 \ (d, \ J = 7.4 \text{ Hz, } 2\text{H}), \ 3.78 \ (d, \ J = 14.6 \text{ Hz, } 1\text{H}), \ 3.19 \ (d, \ J = 14.6 \text{ Hz, } 1\text{H}), \ 1.51 \ (s, \ 3\text{H}).
\]

\[1^3\text{C} \text{NMR} \ (150 \text{ MHz, CDCl}_3) \delta \ 200.1, \ 197.3, \ 152.2, \ 151.2, \ 148.0, \ 137.7, \ 137.7, \ 136.5, \ 135.7, \ 133.4, \ 131.0, \ 130.6, \ 129.1, \ 129.1, \ 128.9, \ 128.8, \ 128.7, \ 127.8, \ 127.6, \ 126.5, \ 126.4, \ 126.3, \ 126.12, \ 126.05, \ 125.1, \ 124.9, \ 52.6, \ 49.7, \ 47.3, \ 25.8.
\]

HRMS-ESI (m/z) [M+Na]+ calculated for C_{26}H_{26}NaO_{2}S_{4} 705.0149, found 705.0141.

(\text{3R,5R}-3-(5-Hexylthio)thiophen-2-yl)-5-methyl-3,5-bis(2-(phenylthio)thiophen-3-y1)cyclopentane-1,2-dione (49)

Yellow oil, 36.6 mg, 53% yield. (Rf = 0.63, petroleum ether/ethyl acetate = 9/1)

\[1^1\text{H} \text{NMR} \ (600 \text{ MHz, CDCl}_3) \delta \ 7.42 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.33 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.27 \ (d, \ J = 5.6 \text{ Hz, } 1\text{H}), \ 7.22 \ (t, \ J = 7.8 \text{ Hz, } 2\text{H}), \ 7.18 - 7.09 \ (m, \ 4\text{H}), \ 6.99 - 6.94 \ (m, \ 2\text{H}), \ 6.88 \ (d, \ J = 5.8 \text{ Hz, } 1\text{H}), \ 6.88 \ (d, \ J = 3.6 \text{ Hz, } 1\text{H}), \ 6.86 \ (d, \ J = 3.7 \text{ Hz, } 1\text{H}), \ 6.83 \ (d, \ J = 7.3 \text{ Hz, } 2\text{H}), \ 3.83 \ (d, \ J = 14.5 \text{ Hz, } 1\text{H}), \ 3.18 \ (d, \ J = 14.5 \text{ Hz, } 1\text{H}), \ 2.77 \ (t, \ J = 7.3 \text{ Hz, } 2\text{H}), \ 1.65 - 1.55 \ (m, \ 3\text{H}), \ 1.52 \ (s, \ 3\text{H}), \ 1.42 - 1.35 \ (m, \ 2\text{H}), \ 1.34 - 1.31 \ (m, \ 1\text{H}), \ 1.25 \ (m, \ 2\text{H}), \ 0.89 \ (t, \ J = 7.0 \text{ Hz, } 3\text{H}).
\]

\[1^3\text{C} \text{NMR} \ (150 \text{ MHz, CDCl}_3) \delta \ 201.0, \ 197.3, \ 152.6, \ 151.1, \ 145.2, \ 137.5, \ 137.4, \ 136.6, \ 132.7, \ 130.8, \ 130.4, \ 129.04, \ 128.99, \ 128.9, \ 128.4, \ 127.7, \ 126.34, \ 126.26, \ 126.11, \ 126.08, \ 125.0, \ 124.9, \ 52.6, \ 49.6, \ 47.2, \ 38.7, \ 31.3, \ 29.3, \ 28.1, \ 25.9, \ 22.5, \ 14.0.
\]

HRMS-ESI (m/z) [M+Na]+ calculated for C_{36}H_{36}NaO_{5}S_{6} 713.0775, found 713.0759.
2-Hydroxy-5-methyl-3-(5-methyl-2-(p-tolylthio)phenyl)-5-(2-(phenylthio)phenyl)cyclopent-2-en-1-one (S-X)

Yellow solid, 35.6 mg, 70% yield. (R_f = 0.65, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl_3) δ 7.60 (dd, J = 8.0, 1.0 Hz, 1H), 7.45 (dd, J = 7.7, 1.3 Hz, 1H), 7.38 (m, 1H), 7.34 – 7.29 (m, 1H), 7.28 – 7.22 (m, 3H), 7.18 (m, 1H), 7.16 – 7.11 (m, 4H), 7.09 (m, 3H), 6.94 (d, J = 1.3 Hz, 1H), 5.95 (s, 1H), 3.19 (d, J = 17.0 Hz, 1H), 2.93 (d, J = 17.0 Hz, 1H), 2.33 (s, 3H), 2.32 (s, 3H), 1.62 (s, 3H).

^13C NMR (151 MHz, CDCl_3) δ 205.1, 146.9, 145.6, 137.9, 137.5, 136.8, 136.64, 136.62, 136.0, 133.2, 132.9, 130.9, 130.3, 130.1, 130.0, 129.9, 129.6, 129.0, 128.7, 128.53, 128.46, 128.2, 126.1, 50.4, 45.7, 25.0, 21.1, 21.0.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{32}H_{28}NO_2S_2 531.1423, found 531.1428.

3-(5-(4-Methoxyphenyl)thiophen-2-yl)-5-methyl-3-(5-methyl-2-(p-tolylthio)phenyl)-5-(2-(phenylthio)phenyl)cyclopentane-1,2-dione (50)

Yellow oil, 52.3 mg, 75% yield. (R_f = 0.60, petroleum ether/ethyl acetate = 15/1)

^1H NMR (600 MHz, CDCl_3) δ 7.70 (dd, J = 8.1, 1.1 Hz, 1H), 7.34 – 7.26 (m, 3H), 7.26 – 7.24 (m, 1H), 7.24 – 7.14 (m, 4H), 7.13 – 7.05 (m, 3H), 7.03 – 6.90 (m, 6H), 6.82 – 6.77 (m, 2H), 6.74 (d, J = 8.2 Hz, 2H), 4.17 (d, J = 14.9 Hz, 1H), 3.77 (s, 3H), 2.88 (d, J = 14.9 Hz, 1H), 2.28 (s, 3H), 2.27 (s, 3H), 1.73 (s, 3H).

^13C NMR (151 MHz, CDCl_3) δ 199.1, 195.7, 159.1, 147.5, 147.3, 138.2, 136.9, 136.5, 136.2, 136.1, 135.7, 135.6, 133.8, 132.1, 131.8, 131.7, 131.2, 129.8, 129.7, 129.6, 129.3, 129.1, 128.7, 128.4, 128.2, 127.9, 127.63, 127.55, 126.8, 114.8, 55.4, 55.2, 50.7, 49.3, 25.5, 21.5, 21.1.

HRMS-ESI (m/z) [M+H]^+ calculated for C_{46}H_{37}O_3S_4 729.1620, found 729.1621.
(3R,5R)-3-(5-(Benzylthio)thiophen-2-yl)-3-(2-(hexylthio)thiophen-3-yl)-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopentane-1,2-dione (51)

Yellow oil, 40.9 mg, 58% yield. (R_f = 0.65, petroleum ether/ethyl acetate = 15/1)

^1H NMR (600 MHz, CDCl_3) δ 7.47 (d, J = 5.6 Hz, 1H), 7.39 (d, J = 5.6 Hz, 1H), 7.24 (m, 2H), 7.19 (t, J = 7.1 Hz, 2H), 7.14 (m, 5H), 7.10 – 7.05 (m, 2H), 6.90 (d, J = 3.8 Hz, 1H), 6.83 (d, J = 3.7 Hz, 1H), 6.35 (d, J = 5.5 Hz, 1H), 3.96 (s, 2H), 3.78 (d, J = 14.4 Hz, 1H), 3.02 (d, J = 14.5 Hz, 1H), 2.47 – 2.36 (m, 2H), 1.52 – 1.46 (m, 2H), 1.44 (s, 3H), 1.33 – 1.25 (m, 6H), 0.90 (t, J = 7.1 Hz, 3H).

^13C NMR (151 MHz, CDCl_3) δ 200.0, 198.8, 154.4, 149.6, 146.7, 138.4, 137.2, 135.0, 134.7, 130.5, 129.10, 129.02, 128.70, 128.67, 128.4, 128.2, 127.9, 127.6, 127.3, 126.3, 126.1, 125.9, 52.2, 50.6, 48.0, 43.4, 38.2, 31.3, 28.6, 28.4, 26.1, 22.5, 14.1.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{37}H_{36}NaO_{2}S_{6} 727.0932, found 727.0957.

(3R,5R)-3-(5-((4-Ethylphenyl)thio)thiophen-2-yl)-3-(2-(hexylthio)thiophen-3-yl)-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopentane-1,2-dione (52)

Yellow oil, 55.1 mg, 60% yield. (R_f = 0.66, petroleum ether/ethyl acetate = 15/1)

^1H NMR (600 MHz, CDCl_3) δ 7.46 (d, J = 5.6 Hz, 1H), 7.38 (d, J = 5.6 Hz, 1H), 7.21 (m, 2H), 7.19 – 7.16 (m, 2H), 7.14 (m, 2H), 7.11 (m, 3H), 7.05 (m, 3H), 6.50 (d, J = 5.6 Hz, 1H), 3.82 (d, J = 14.5 Hz, 1H), 3.10 (d, J = 14.5 Hz, 1H), 2.60 (q, J = 7.6 Hz, 2H), 2.45 – 2.36 (m, 2H), 1.52 (s, 3H), 1.33 – 1.23 (m, 8H), 1.20 (t, J = 7.6 Hz, 3H), 0.90 (t, J = 7.1 Hz, 3H).

^13C NMR (151 MHz, CDCl_3) δ 200.2, 198.8, 153.9, 149.8, 147.6, 143.1, 138.2, 135.0, 134.5, 134.1, 130.5, 129.1, 128.8, 128.7, 128.5, 128.4, 128.40, 128.40, 127.91, 127.89, 127.89, 126.3, 126.1, 125.8, 52.4, 50.4, 47.9, 38.2, 31.3, 28.6, 28.40, 28.39, 26.0, 22.5, 15.5, 14.1.

HRMS-ESI (m/z) [M+Na]^+ calculated for C_{38}H_{38}NaO_{2}S_{6} 741.1088, found 741.1103.
2-Hydroxy-6-(5-(isopropylthio)thiophen-2-yl)-6-(2-(phenylthio)thiophen-3-yl)cyclohex-2-en-1-one (53)

Yellow oil, 22.5 mg, 49% yield. (R_f = 0.62, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl₃) δ 7.32 (d, J = 5.6 Hz, 1H), 7.25 (t, J = 7.6 Hz, 2H), 7.19 – 7.13 (m, 3H), 7.02 (d, J = 3.7 Hz, 1H), 6.79 (d, J = 3.7 Hz, 1H), 6.45 (d, J = 5.6 Hz, 1H), 6.05 – 5.99 (m, 2H), 3.19 – 3.11 (m, 1H), 3.07 – 3.00 (m, 1H), 2.60 – 2.47 (m, 2H), 2.34 – 2.24 (m, 1H), 1.28 (d, J = 6.7 Hz, 6H).

^13C NMR (150 MHz, CDCl₃) δ 193.5, 149.1, 146.7, 146.0, 138.0, 134.9, 133.8, 130.7, 129.7, 129.3, 128.9, 127.2, 127.2, 126.3, 117.1, 55.0, 41.7, 36.4, 23.1, 21.4.

HRMS-ESI (m/z) [M+Na]^+ calculated for C₂₃H₂₂NaO₂S₄ 481.0395, found 481.0385.

6-(2-((4-Bromophenyl)thio)thiophen-3-yl)-2-hydroxy-6-(5-(isopropylthio)thiophen-2-yl)-3-(2-(isopropylthio)thiophen-3-yl)cyclohex-2-en-1-one (54)

Yellow oil, 45.1 mg, 65% yield. (R_f = 0.63, petroleum ether/ethyl acetate = 9/1)

^1H NMR (600 MHz, CDCl₃) δ 7.40 – 7.34 (m, 3H), 7.32 (d, J = 5.5 Hz, 1H), 7.13 (d, J = 5.5 Hz, 1H), 7.02 (d, J = 3.6 Hz, 1H), 7.01 (d, J = 8.5 Hz, 2H), 6.84 (d, J = 3.7 Hz, 1H), 6.58 (d, J = 5.6 Hz, 1H), 6.35 (s, 1H), 3.19 – 3.08 (m, 2H), 3.08 – 2.95 (m, 2H), 2.77 (m, 1H), 2.64 (m 1H), 1.29 (d, J = 6.7 Hz, 6H), 1.11 (m, 6H).

^13C NMR (150 MHz, CDCl₃) δ 193.1, 149.3, 146.2, 143.7, 141.9, 137.3, 134.7, 134.1, 131.9, 131.6, 120.0, 129.6, 129.3, 128.7, 128.0, 127.2, 126.4, 125.4, 120.2, 54.5, 42.4, 41.6, 36.4, 26.7, 23.1, 23.1, 22.90, 22.89.

HRMS-ESI (m/z) [M+Na]^+ calculated for C₃₀H₂₉BrNaO₅S₇ 714.9567, found 714.9562.
IV. Gram-Scale Reaction and Derivatization of Compound 11

1. Gram-scale reaction

\[
\begin{align*}
&\text{TFAA (7.5 mmol, 1.0655 mL) was added to a solution of cyclic 1,2-diketones 1 (7.5 mmol, 855 mg) and sulfoxide 2b (5 mmol, 1.050 g) in DCE (40 mL, 0.125 M) at -10 °C. After 4 hours, the reaction mixture was concentrated under reduced pressure and purified by column chromatography (eluent: petroleum ether/ethyl acetate = 9/1) to afford product 11 (1.420 g, 94%) as a white solid.}
\end{align*}
\]

2. Synthesis for 1-methyl-1-(2-(phenylthio)thiophen-3-yl)-2,3-dihydro-1H-cyclopenta[b]quinoxaline (55)

A 25 mL round-bottomed flask was charged with a solution of the appropriate 1,2-dicarbonyl compound 11 (0.1 mmol) in H$_2$O (3 mL). To this solution was added the respective 1,2-diphenylamine (0.888 mmol) and the mixture was stirred at 45 °C. After 12h, the crude mixture was extracted with CH$_2$Cl$_2$ (3 × 10 mL). The combined organic layers were dried (MgSO$_4$) and after filtration, the solvent was removed to give the desired product.

Yellow solid, 35.2 mg, 94% yield. (R$_f$ = 0.64, petroleum ether/ethyl acetate = 9/1)

$^1$H NMR (400 MHz, CDCl$_3$) δ 7.95 (dd, J = 8.3, 1.2 Hz, 1H), 7.80 (dd, J = 8.3, 1.2 Hz, 1H), 7.59 (ddd, J = 8.3, 7.0, 1.5 Hz, 1H), 7.55 – 7.49 (m, 1H), 7.47 (d, J = 5.6 Hz, 1H), 7.25 (d, J = 5.6 Hz, 1H), 6.97 (t, J = 7.6 Hz, 2H), 6.90 – 6.83 (m, 1H), 6.82 – 6.77 (m, 2H), 3.35 – 3.12 (m, 2H), 2.82 (ddd, J = 13.2, 9.4, 7.6 Hz, 1H), 2.46 – 2.31 (m, 1H), 1.83 (s, 3H).

$^{13}$C NMR (100 MHz, CDCl$_3$) δ 165.1, 159.9, 153.6, 141.7, 141.5, 137.9, 123.0, 129.2, 129.0, 128.9, 128.5, 128.42, 128.39, 125.8, 125.7, 125.1, 48.6, 38.8, 30.0, 27.6.

HRMS-ESI (m/z) [M+H]$^+$ calculated for C$_{22}$H$_{19}$N$_2$S$_3$ 375.0984, found 375.0973.

3. Synthesis for 5-methyl-5-(2-(phenylthio)thiophen-3-yl)-2-(pyridin-2-ylamino)cyclopent-2-en-1-one (56)

In a 38 mL round bottom flask, equipped with a condenser, 2-hydroxy-5-methyl-5-(2-(phenylthio)thiophen-3-yl)cyclopent-2-en-1-one 11 (60 mg, 0.2 mmol), 2-aminopyridine (18.8 mg, 0.2 mmol), alumina (0.2 g) and toluene (4 mL) was stirred and heated to reflux for 36 h. Upon reaction completion, alumina was removed by filtration and washed with EtOAc (2 x 10 mL). The
organic phases were combined and concentrated under vacuum and the residue was purified by flash chromatography eluting with hexane/EtOAc (10:1 v/v) to give S6 (41.6 mg, 55%) as an oil.

Yellow oil, 41.6 mg, 55% yield. (Rf = 0.65, petroleum ether/ethyl acetate = 9/1)

1H NMR (600 MHz, CDCl3) δ 8.26 (dd, J = 5.0, 1.2 Hz, 1H), 7.58 (t, J = 3.2 Hz, 1H), 7.49 (ddd, J = 8.9, 7.3, 1.9 Hz, 1H), 7.45 (d, J = 5.6 Hz, 1H), 7.22 (d, J = 5.6 Hz, 1H), 7.18 (t, J = 7.6 Hz, 2H), 7.11 (t, J = 7.3 Hz, 1H), 7.05 (dd, J = 5.2, 3.3 Hz, 2H), 6.88 (s, 1H), 6.79 – 6.74 (m, 1H), 6.69 (d, J = 8.3 Hz, 1H), 2.96 (dd, J = 18.1, 3.0 Hz, 1H), 2.80 (dd, J = 18.1, 3.4 Hz, 1H), 1.62 (s, 3H).

13C NMR (150 MHz, CDCl3) δ 206.4, 154.5, 150.2, 147.8, 138.4, 137.4, 136.0, 130.0, 129.7, 128.8, 128.7, 126.8, 125.9, 125.5, 115.4, 110.8, 47.5, 44.0, 26.4.

HRMS-ESI (m/z) [M+H]+ calculated for C21H19N2O2S3 379.0933, found 379.0924.

4. Synthesis for 2-hydroxy-5-methyl-5-(2-(phenylsulfinyl)thiophen-3-yl)cyclopent-2-en-1-one (57)

A solution of 11 (0.1 mmol, 1.0 equiv) in dichloromethane (0.5 mL, 0.2 M) was cooled to 0 °C. After addition of m-CPBA (0.98 equiv) the solution was stirred for overnight The reaction mixture was washed with saturated NaHCO3 solution, dried over anhydrous magnesium sulfate and the solvent was removed under reduced pressure. The crude product was purified by flash chromatography on silica gel using a mixture of petroleum ether and ethyl acetate to afford the product 57 (dr = 1.32:1).

White solid, 29.3 mg, 92% yield. (Rf = 0.2, petroleum ether/ethyl acetate = 1/1)

1H NMR (600 MHz, CDCl3) δ 7.68 (dd, J = 6.5, 3.0 Hz, 2H), 7.61 (dd, J = 6.5, 3.0 Hz, 2H), 7.52 (d, J = 5.2 Hz, 1H), 7.50 – 7.47 (m, 4H), 7.46 – 7.41 (m, 3H), 7.10 (d, J = 5.2 Hz, 1H), 7.02 (d, J = 5.3 Hz, 1H), 6.60 (t, J = 3.1 Hz, 1H), 6.51 (t, J = 3.1 Hz, 1H), 3.12 (dd, J = 18.5, 2.6 Hz, 1H), 3.09 (dd, J = 19.2, 2.7 Hz, 1H), 2.94 (dd, J = 18.1, 3.3 Hz, 1H), 2.77 (dd, J = 18.3, 3.4 Hz, 1H), 1.71 (s, 3H), 1.66 (s, 3H).

13C NMR (150 MHz, CDCl3) δ 206.3, 204.8, 151.0, 150.9, 150.1, 149.0, 144.5, 144.0, 143.3, 142.3, 132.3, 131.9, 131.3, 131.1, 129.2, 129.1, 127.67, 127.66, 127.6, 127.5, 124.9, 124.8, 47.8, 47.7, 42.7, 41.9, 28.1, 26.4.

HRMS-ESI (m/z) [M+Na]+ calculated for C16H13NaO3S 341.0277, found 341.0269.

5. Synthesis for 2-hydroxy-5-methyl-5-(2-(phenylsulfonyl)thiophen-3-yl)cyclopent-2-en-1-one (58)

A solution of 11 (0.1 mmol, 1.0 equiv) in dichloromethane (0.5 mL, 0.2 M) was cooled to 0 °C. After addition of m-CPBA (2.1 equiv) the solution was stirred for overnight. The reaction mixture
was washed with saturated NaHCO$_3$ solution, dried over anhydrous magnesium sulfate and the solvent was removed under reduced pressure. The crude product was purified by flash chromatography on silica gel using a mixture of petroleum ether and ethyl acetate to afford the product.

White solid, 30 mg, 90% yield. ($R_f = 0.25$, petroleum ether/ethyl acetate = 1/1)

$^1$H NMR (600 MHz, DMSO) $\delta$ 9.57 (s, 1H), 8.07 (d, $J = 5.3$ Hz, 1H), 7.86 (d, $J = 7.4$ Hz, 2H), 7.72 (t, $J = 7.4$ Hz, 1H), 7.65 (t, $J = 7.8$ Hz, 2H), 7.23 (d, $J = 5.3$ Hz, 1H), 6.34 (t, $J = 3.1$ Hz, 1H), 2.63 (dd, $J = 17.6$, 2.7 Hz, 1H), 2.55 (dd, $J = 17.6$, 3.4 Hz, 1H), 1.48 (s, 3H).

$^{13}$C NMR (151 MHz, DMSO) $\delta$ 204.7, 151.8, 149.2, 142.3, 136.5, 134.2, 134.1, 131.0, 130.0, 127.6, 126.4, 47.8, 41.3, 27.4.

HRMS-ESI ($m/z$) [M+Na]$^+$ calculated for C$_{16}$H$_{14}$NaO$_3$S$_2$ 357.0226, found 357.0234.
V. X-Ray Crystal Data of 13, 39, 45.

CCDC 1938311
X-ray structure and CCDC number of compound 13.

Crystal data and structure refinement for 13
Identification code 13
Empirical formula C_{18}H_{16}O_{3}S_{2}
Formula weight 344.43
Temperature 290(2) K
Wavelength 0.71073 Å
Crystal system, space group ?
Unit cell dimensions a = 7.2857(4) Å  alpha = 90 deg.
                          b = 11.4124(6) Å  beta = 94.519(2) deg.
                          c = 20.6457(11) Å  gamma = 90 deg.
Volume 1711.30(16) Å^3
Z, Calculated density 4, 1.337 Mg/m^3
Absorption coefficient 0.322 mm^-1
F(000) 720
Crystal size ? x ? x ? mm
Theta range for data collection 2.67 to 27.55 deg.
Limiting indices -9<=h<=9, -14<=k<=14, -26<=l<=26
Reflections collected / unique 23912 / 3953 [R(int) = 0.0369]
<table>
<thead>
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<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
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<tr>
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<td>99.8 %</td>
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<tr>
<td>Refinement method</td>
<td>Full-matrix least-squares on $F^2$</td>
</tr>
<tr>
<td>Data / restraints / parameters</td>
<td>$3953 / 0 / 208$</td>
</tr>
<tr>
<td>Goodness-of-fit on $F^2$</td>
<td>1.042</td>
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<tr>
<td>Final R indices [$I&gt;2\sigma(I)$]</td>
<td>$R_1 = 0.0696$, $wR_2 = 0.1676$</td>
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<tr>
<td>R indices (all data)</td>
<td>$R_1 = 0.1090$, $wR_2 = 0.1974$</td>
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<tr>
<td>Largest diff. peak and hole</td>
<td>0.406 and -0.434 e.A$^{-3}$</td>
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CCDC 1938322
X-ray structure and CCDC number of compound 39.

Crystal data and structure refinement for 39
Identification code 39
Empirical formula C_{29}H_{32}O_{3}S_{2}
Formula weight 492.66
Temperature/K 283.47
Crystal system orthorhombic
Space group P2_1_2_1_2_1
a/Å 9.2472(8)
b/Å 13.6858(14)
c/Å 19.2652(15)
α/° 90
β/° 90
γ/° 90
Volume/Å^3 2438.1(4)
Z 4
ρ_{calc} g/cm^3 1.342
μ/mm^{-1} 0.249
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<th>Description</th>
<th>Value</th>
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<tr>
<td>F(000)</td>
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<tr>
<td>Crystal size/mm³</td>
<td>0.12 × 0.10 × 0.09</td>
</tr>
<tr>
<td>Radiation</td>
<td>MoKα (λ = 0.71073)</td>
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<tr>
<td>2θ range for data collection/°</td>
<td>4.886 to 55.01</td>
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<tr>
<td>Index ranges</td>
<td>-12 ≤ h ≤ 9, -16 ≤ k ≤ 17, -20 ≤ l ≤ 24</td>
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<tr>
<td>Reflections collected</td>
<td>12728</td>
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<tr>
<td>Independent reflections</td>
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<tr>
<td>Data/restraints/parameters</td>
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<tr>
<td>Goodness-of-fit on F²</td>
<td>1.047</td>
</tr>
<tr>
<td>Final R indexes [I&gt;=2σ (I)]</td>
<td>R₁ = 0.0638, wR₂ = 0.1100</td>
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<tr>
<td>Final R indexes [all data]</td>
<td>R₁ = 0.1475, wR₂ = 0.1418</td>
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<tr>
<td>Largest diff. peak/hole / e Å⁻³</td>
<td>0.41/-0.55</td>
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<td>Flack parameter</td>
<td>0.00(5)</td>
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</table>
**CCDC 1938323**

X-ray structure and CCDC number of compound 45.

Crystal data and structure refinement for 45

**Identification code**: 45  
**Empirical formula**: C_{36}H_{24}BrClO_{2}S_{6}  
**Formula weight**: 796.27  
**Temperature/K**: 100.00(10)  
**Crystal system**: monoclinic  
**Space group**: P2\(_1\)/c  
**a/A**: 18.920(3)  
**b/A**: 6.6165(9)  
**c/A**: 29.427(4)  
**\(\alpha/\degree\)**: 90  
**\(\beta/\degree\)**: 91.184(14)  
**\(\gamma/\degree\)**: 90  
**Volume/Å\(^3\)**: 3682.9(9)  
**Z**: 4  
**\(\rho_{calc}/\text{g/cm}^3\)**: 1.436
\[ \mu/\text{mm}^{-1} \quad 1.560 \\
F(000) \quad 1616.0 \\
\text{Crystal size/mm}^3 \quad 0.12 \times 0.11 \times 0.1 \\
\text{Radiation} \quad \text{MoK}\alpha (\lambda = 0.71073) \\
2\Theta \text{ range for data collection}/^\circ \quad 4.306 \text{ to } 50 \\
\text{Index ranges} \quad -21 \leq h \leq 22, -7 \leq k \leq 6, -34 \leq l \leq 34 \\
\text{Reflections collected} \quad 14585 \\
\text{Independent reflections} \quad 6482 \ [R_{\text{int}} = 0.0832, R_{\text{sigma}} = 0.1180] \\
\text{Data/restraints/parameters} \quad 6482/38/416 \\
\text{Goodness-of-fit on } F^2 \quad 1.042 \\
\text{Final R indexes } [I\geq 2\sigma (I)] \quad R_1 = 0.0851, wR_2 = 0.2035 \\
\text{Final R indexes } [\text{all data}] \quad R_1 = 0.1201, wR_2 = 0.2325 \\
\text{Largest diff. peak/hole } / e \text{ Å}^3 \quad 1.51/-1.50
VI. References

VII. NMR Spectra
6
**Diagram of Compound 48**

The diagram shows a molecular structure with labels indicating key features. The compound appears to be a complex organic molecule with sulfur (S) atoms and other functional groups.

**NMR Spectrum**

The NMR spectrum is displayed with peaks at various chemical shifts (ppm values). Peak assignments are marked with values such as 3.09, 1.94, 0.96, 2.94, 0.98, 6.93, 4.16, 1.08, 1.02, 0.96, and others.

**Chemical Shifts**

- 3.09 ppm
- 1.94 ppm
- 0.96 ppm
- 2.94 ppm
- 0.98 ppm
- 6.93 ppm
- 4.16 ppm
- 1.08 ppm
- 1.02 ppm
- 0.96 ppm

These values are indicative of different functional groups and atomic environments within the molecule, providing insight into the molecular structure and its properties.
$\text{S140}$
58