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Regioselective synthesis of 1- and 4-tetralones from heteroaryl-3-cyclobutanols

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ABSTRACT

Herein we describe the first transition-metal-free ring expansion of four-membered rings to 1-tetralones from 3-substituted heteroaromatic compounds, and the first example of an oxetanol ring expansion to an oxa-tetralone. We also experimentally investigate the mechanism of the silver-mediated ring expansion and elucidate the active oxidant in these systems using electrochemical techniques.

1. Introduction

The cyclobutanol moiety has emerged as a valuable building block for the introduction of skeletal diversity [1,2]. In the last decade, a large number of distinctive protocols for the ring-opening to γ-functionalised materials and ring expansions to five-membered rings was developed using transition-metal-free or photo-/electrochemical techniques [3–9]. Protocols leading from cyclobutanols to annulated six-membered rings however remain limited, despite their clear utility [10–14].

Heterocycles annulated to six-membered ring ketones are a common motif in pharmaceutically important molecules (Fig. 1). For example, indole-based *epi*-20-dasycarpidone exhibits strong *in vitro* inhibition against multi-drug resistant K1 strains of the human malaria parasite *Plasmodium falciparum* (IC_{50} 4.5 μg/mL) [15]. Murrayafoline A, a carbazole, has been investigated as an apoptosis inducer [16]. Benzofuran-based propolisbenzofuran B, on the other hand, was found to show mild cytotoxicity toward murine colon 26-L5 carcinoma, as well as human HT-1080 fibrosarcoma cells (ED_{50} 13.7 μg/mL and 43.2 μg/mL respectively) [17]. Also, non-natural compounds with the same core structure have received significant attention in medicinal chemistry [18–22]. Of particular note are the synthetic heteroaromatic 1-tetralones **1** and **2**, which were shown to exhibit different biological activity, despite solely varying in the heteroatom [19,22]. They exhibit *in vitro* cytotoxicity against human non-small lung cancer (IC_{50} 0.0703 μM) and mild *in vitro* antibacterial activity against gram-positive bacteria respectively. The WHO essential drug ondansetron is the regioisomeric 4-tetralone, which is structurally related to **1** and acts as a serotonin 5-HT_3 receptor antagonist to prevent post-surgery nausea or vomiting. These compounds demonstrate that (1) many biologically active heteroaromatic fused 1-tetralones contain one or more substituents on the cyclohexanone ring, (2) a change in heteroatom significantly impacts and changes the molecular mechanism of action and biological target (*cf.* compounds **1** and **2**), and (3) a change in the regiochemical orientation of the tetralone moiety also leads to a variation in the therapeutic action of the product (*cf.* compound **1** and ondansetron).

The development of ring expansion protocols for the direct annulation of cyclobutanols onto aromatic rings started with Uemura's report of a palladium-mediated ring opening reaction of cyclobutanols to aryl/vinyl-substituted ketones; for substrates where β-hydride elimination was blocked, 1-tetralone products were isolated in up to 92% yield (Scheme 1, a) [13]. Over a decade later, Murakami reported a rhodium-catalysed cyclobutanol ring expansion to 1-tetralones in up to 96% yield, which hinged on the

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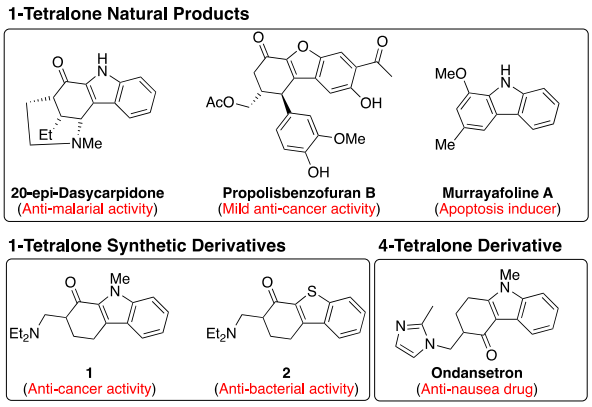
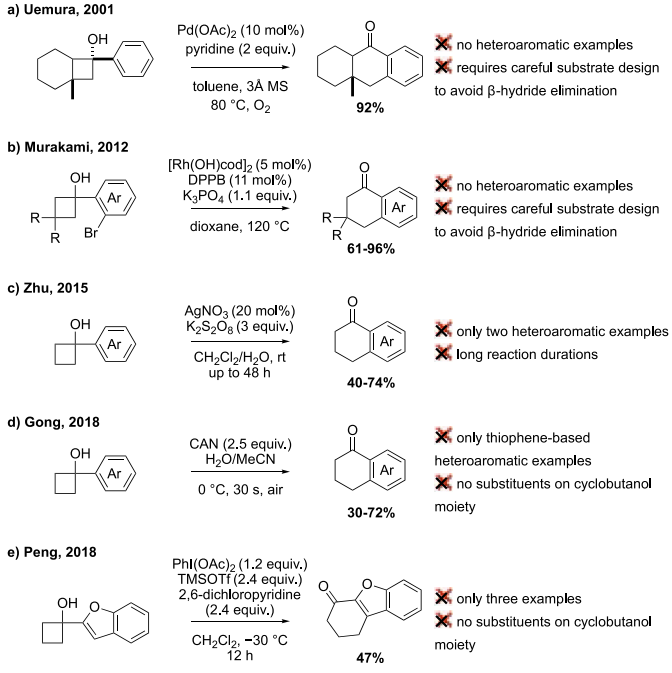


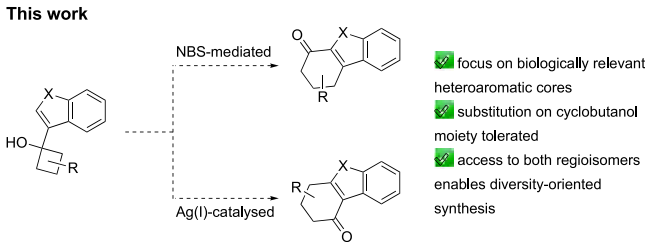
Fig. 1. Natural and synthetic biologically active 1- & 4-tetralone derivatives.



Scheme 1. Previous cyclobutanol ring expansions to 1-tetralones and their associated shortcomings (✗ = Disadvantage).

presence of an *ortho*-aryl bromine bond, and an appropriate 3,3-disubstitution pattern on the four-membered ring to block β-hydride elimination pathways (Scheme 1, b) [14]. In 2015, Zhu isolated several 1-tetralone products selectively from aryl-substituted cyclobutanols by employing silver catalysis; this report featured only two successful substrates containing heterocyclic rings, which were isolated in 40–63% yield after long reaction durations of 7–9 h (Scheme 1, c) [10]. Similarly, Gong described a synthesis of 1-tetralones from cyclobutanols using excess ceric ammonium nitrate, featuring thiophene and benzothiophene substrates (Scheme 1, d) [11]. The last two reports and a serendipitous finding reported by Peng and co-workers [12] (Scheme 1, e), however, mainly explored substrates derived from unsubstituted cyclobutanone, which lead to products of only limited biological utility (cf. Fig. 1).

We recently developed a transition-metal-free cyclobutanol ring expansion to the regioisomeric 4-tetralones [23,24]. In line with our group's interest in ring expansion protocols, and the development of diversity-oriented syntheses of pharmacophores [25], we sought to develop a protocol which enables the divergent



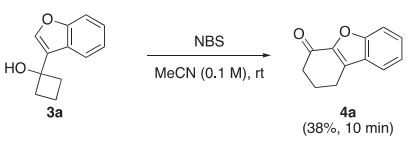
Scheme 2. Divergent cyclobutanol ring expansions to heteroaromatic-fused 1-& 4-tetralones from a common starting material (✓ = Advantage).

synthesis of heteroaromatic-fused substituted 1- & 4-tetralones from the same starting material (Scheme 2). We herein present our studies on a general *N*-bromosuccinimide (NBS) mediated cyclobutanol ring expansion to heteroaromatic-fused 1-tetralones, which allows for the instalment of the required substituents on the cyclohexanone ring and the variation of the heteroatom in the aromatic system. Further, we draw a comparison to the silver(I)-mediated ring expansion of the same starting materials to obtain the regioisomeric 4-tetralones, and we justify the inferior performance of this process in comparison to the NBS-mediated methodology through cyclic voltammetry analysis.

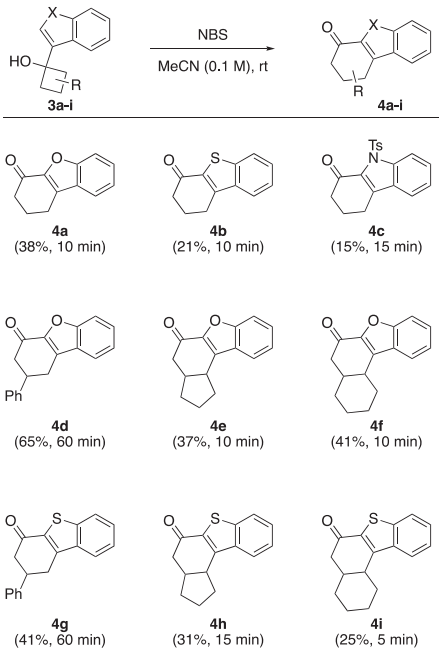
2. Results and discussion

Our investigations began with the preparation of benzofuran-substituted cyclobutanol **3a** as a model substrate for the proposed transformation. Lithium-halogen exchange of commercially available 3-bromobenzofuran in diethyl ether followed by addition of cyclobutanone provided the desired 3-substituted cyclobutanol. When cyclobutanol **3a** was treated with NBS in acetonitrile, 1-tetralone **4a** was formed in 38% yield with full conversion of the starting material achieved within 10 min (Scheme 3). The isolated yield compares favourably with the 40% yield obtained in a silver-mediated cyclobutanol ring expansion developed by Zhu et al. [10] The advantages of this NBS-mediated approach to 1-tetralones include the omission of transition metals, a significant reduction in reaction duration (from 9 h to 10 min), and simplicity of operation as evacuation/inert-fill cycles can be avoided.

Additionally, heteroaryl-substituted cyclobutanols **3b-i** were treated with NBS in acetonitrile at room temperature, forming 1-tetralones **4b-i** (Scheme 4). Benzothiophene and indole equivalents **3b** & **3c** showed complete conversion in less than 15 min, although the isolated yields were lower than for the benzofuran model **3a**. This observation was attributed to the more facile stabilisation of the intermediate carbocation in the 3-position of the benzofuran ring by conjugative relay. Spectroscopic analysis of the crude materials revealed the remaining mass balance consisted of inseparable brominated by-products, and a spirocyclic brominated semi-pinacol product, suggesting the potential intermediacy of this compound in the reaction mechanism. Our focus then shifted to four-membered rings containing an aryl substituent or annulated alicyclic ring, as the expansion products are more difficult to prepare by a conventional synthetic approach [26], and their



Scheme 3. Initial results for the ring expansion to 1-tetralone **4a**.

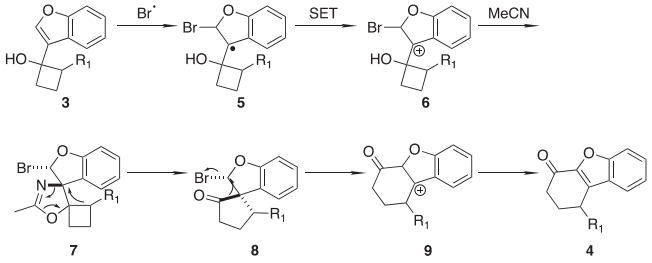


Scheme 4. Substrate scope for the NBS-mediated ring expansion to 1-tetralones.

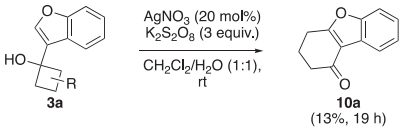
preparation has been neglected by previously reported ring expansion protocols. Expansion of phenyl-substituted four-membered rings gratifyingly nearly doubled the isolated yield for the 1-tetralones **4d** and **4g**. Satisfactory ring expansion yields were also obtained when the four-membered ring was fused to five- and six-membered rings. The cyclobutanone starting materials for these substrates were readily prepared in a single synthetic step [27]. Annulated examples **3e**, **3f**, **3h** and **3i** all expanded within 10 min and isolated yields of up to 41% were obtained. The formation of β,γ-fused products (**4e**, **4f**, **4h**, **4i**) was observed with complete regiocontrol as the most substituted carbon migrates in the initial semi-pinacol-like step.

To account for these observations, a radical-polar crossover mechanism was proposed (Scheme 5). Radical bromination of **1** forms a highly stabilised benzylic tertiary radical **5**, which is subsequently oxidised to the cation **6**. Alternatively, an electrophilic bromination of the 2-position can be invoked to obtain tertiary carbocation **6**. In line with our previous report, we propose that this cationic intermediate is stabilised by acetonitrile as the Ritter adduct **7** [24]. Rearrangement of this intermediate leads to the spirocyclic ketone **8**, which may be observed spectroscopically. Loss of bromide initiates further migration of the carbonyl group, leading to the desired 1-tetralone **4**.

As the regiochemical orientation of the ketone can significantly alter the exhibited bioactivity (cf. Fig. 1), we hypothesised that a



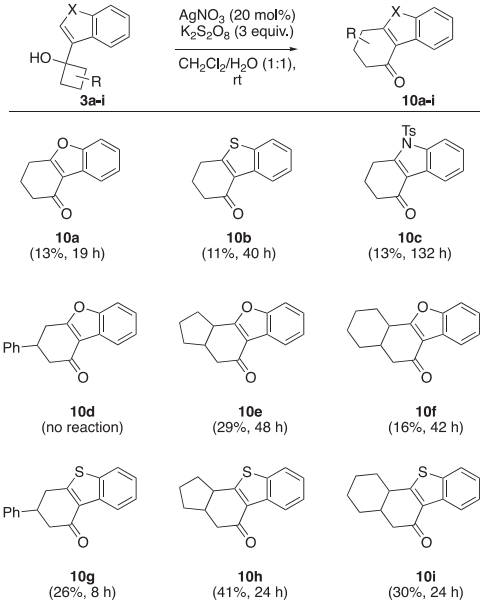
Scheme 5. Suggested mechanism for the NBS-mediated ring expansion.



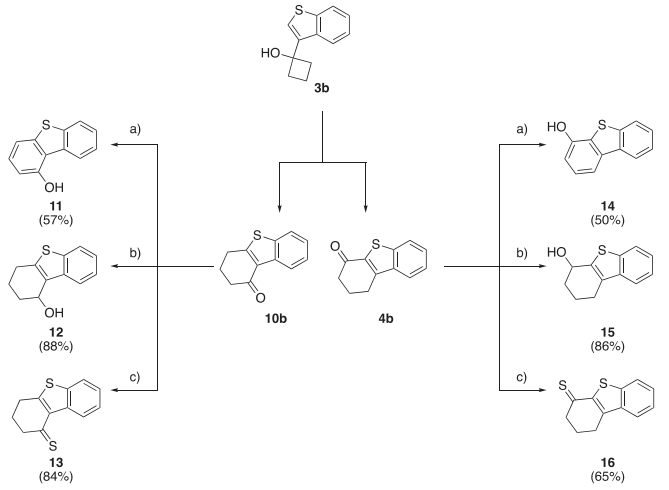
Scheme 6. Silver-mediated expansion to 4-tetralones.

silver-mediated expansion [10] of the 3-substituted benzofuran **3a** would provide the regioisomeric 4-tetralone, facilitating the preparation of both tetralone isomers from a common intermediate. To this end, cyclobutanol **3a** was treated with silver nitrate and potassium persulfate; after 19 h, the 4-tetralone **10a** was isolated in only 13% yield, despite complete conversion of the starting material (Scheme 6). This is a significant reduction in both the rate of reaction and isolated yield relative to the established NBS-mediated expansion from the isomeric heteroaryl-2-cyclobutanols, where the 4-tetralone **10a** was produced in 63% yield in under 3 h [23,24].

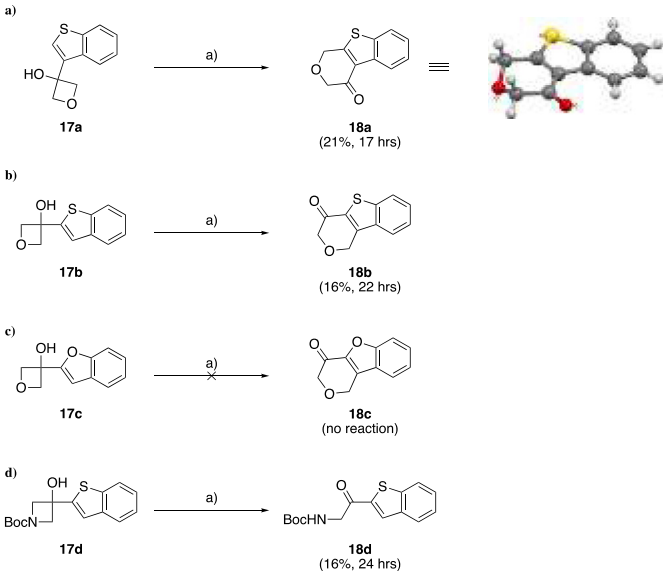
To investigate the scope of the silver-mediated transformation to 4-tetralones, heteroaryl-substituted cyclobutanols **3b-3i** were also treated with silver nitrate and potassium persulfate (Scheme 7). This substrate scope contrasts with previously developed transition-metal-catalysed methodologies that focused predominantly on aryl-substituted cyclobutanols. Similar to benzofuran **3a**, benzothiophene **3b** and indole **3c** formed 4-tetralones **10b** and **10c** in significantly lower yield than the previously published NBS-mediated rearrangement of the isomeric heteroaryl-2-cyclobutanols to 4-tetralones (11% vs. 49% and 13% vs. 52% respectively), after a significantly longer reaction duration (40 h vs. 4 h and 132 h vs. 10 min respectively) [23,24]. Additional substrates **3e** – **3i** were also successfully converted to the expected 4-tetralones in up to 41% yield, with a similar extended reaction duration. The regiochemistry of product **10g** was confirmed by X-ray crystallography (See Supporting Information). Notably, the annulated examples (**3e**, **3f**, **3h**, and **3i**) formed the β,γ-fused products (**10e, 10f, 10h, 10i)** regioselectively. Unexpectedly, no conversion was observed for alcohol **3d** after three days, and the starting material was isolated exclusively. Overall, 1- and 4-tetralones fused to heteroaromatic rings were more reliably formed using an NBS-mediated ring expansion, as higher yields can



Scheme 7. Substrate scope for the silver-mediated ring expansion to 4-tetralones.



Scheme 8. Structural diversity within two steps from a common starting material. Reaction conditions: a) $PhMe_3NBr_3$, THF, 0 °C; then Li_2CO_3, LiBr, DMF, 150 °C; b) $NaBH_4$, MeOH, rt; c) Lawesson's reagent, toluene, 110 °C.



Scheme 9. Ring expansion of heteroatom-containing four-membered rings to six-membered rings. Reaction conditions: a) $AgNO_3$ (20 mol%), $K_2S_2O_8$ (3 equiv.), CH_2Cl_2:H_2O (1:1), rt.

be obtained in significantly shorter reaction durations. Nevertheless, access to both regioisomers from a common starting material can facilitate the design of synthetic routes to diverse compound libraries of material and biological interest.

Diversification of the obtained tetralone products was also investigated (Scheme 8). The tetralones **4b** & **10b** were readily oxidised to yield fully aromatised phenols **11** & **14** by an α-bromination/elimination procedure [28]. Furthermore, the ketone can be reduced to form alcohols **12** & **15** through treatment with sodium borohydride in methanol in up to 88% yield. Treatment of ketones **4b** & **10b** with Lawesson's reagent provided thioketones **13** & **16**. Similarly derived thioketones have been used for the synthesis of molecular motors using a Barton-Kellogg reaction[29,30,31].

Recently, a few examples of oxetanol ring expansion to five-membered rings using a photochemical or transition-metal-catalysed semi-pinacol rearrangement have been noted in the literature [32–38]. However, the expansion of an aromatic-substituted oxetanol to the corresponding six-membered ring is still unknown. To investigate this potential transformation to oxa-tetralones, thiophene-substituted oxetanols **17a** & **17b** were formed from commercially available materials. Gratifyingly, treatment of **17a** & **17b** with silver nitrate and persulfate produced the oxa-tetralones **18a** & **18b** in 21% and 16% yield respectively (Scheme 9). The structure of **18a** was confirmed by X-ray crystallography (See Supporting Information). This constitutes the first report of an oxetanol ring expansion to an oxa-tetralone.

Benzofuran-substituted oxetanol **17c** however was less successful, and no conversion to the oxa-tetralone **18c** was observed. Furthermore, when the heteroaromatic-substituted azetidinol **17d** was treated under the same reaction conditions, α-amino ketone **18d** was obtained in 16% yield through an oxidative deconstruction mechanism, which we have since optimised [39]. To our surprise, NBS-mediated oxidative ring expansion did not occur for these substrates (**17a-17d**), and instead the 3-brominated products were observed. One potential reason is, that the enthalpic benefit through release of ring-strain is reduced upon inclusion of a heteroatom, so that rearrangement is not initiated [40,41].

The yields obtained for the silver-catalysed ring expansion onto heteroaromatic rings are significantly lower than those achieved for the previously studied aryl systems [10]. We were intrigued by the low yield of this process, as well as the cessation of the reaction (**3d** and **17c**), upon small changes in the starting material. To investigate these observations experimentally, cyclic voltammetry studies were performed on a series of cyclobutanol starting materials to elucidate their oxidation potential. The lowest energy oxidation wave was irreversible, indicating significant structural and electronic rearrangement upon oxidation (See Supporting Information). As no reduction feature was observed in the return sweep of this first oxidation process, the anodic peak potential is used as an indication of the oxidation potential of each of the substrates (Fig. 2). The yield of the ring-rearranged product at complete conversion was found to inversely correlate with the measured anodic peak potential. This observation suggests that the

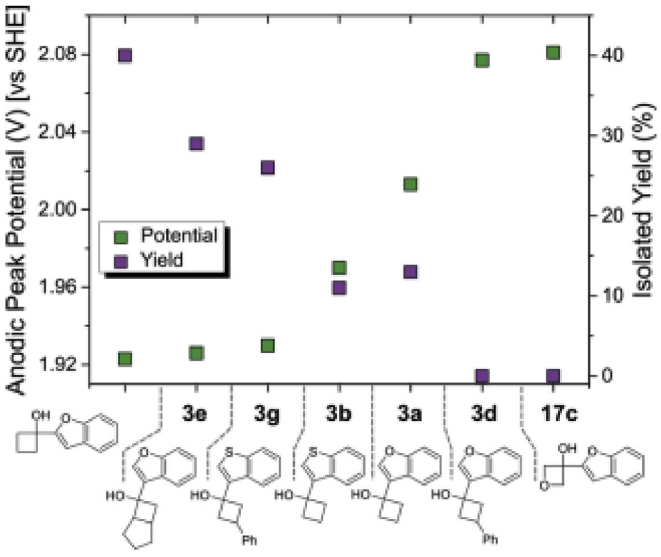


Fig. 2. Plot of the anodic peak potential for substrates **3** and **17c** and the isolated yield of the ring-expanded product. The peak potential was obtained from cyclic voltammograms using a three-electrode setup, see ESI. Measurements were performed in a 0.1 M $TBAPF_6$/MeCN electrolyte (TBA = $n Bu_4N^+$) at a scan speed of 200 mV s^{-1}. In each experiment, a ferrocene/ferrocenium redox couple (Fc/Fc^+) was measured as an internal standard and the resulting anodic peak potentials of the substrates were then referenced to the SHE using a potential value of 0.63 V [42,43].

yield of the desired product formation may be limited by the oxidation potential of the oxidising agent (Fig. 2).

The slow conversion of successful substrates and the cessation for compounds with an oxidation potential >2.08 V (**3d** & **17c**) suggests the involvement of an oxidising agent with a standard electrode potential close to 2.0 V (vs SHE). The redox couple previously suggested by Zhu and co-workers for this reaction is the Ag^{2+}/Ag^{+} couple [10]; the oxidation potential of this redox couple is 2.0 V (vs SHE), which is in agreement with the synthetic and analytical observations made within this article [44]. It is known that upon the reaction between silver nitrate and a persulfate salt, silver (I,III) oxide is formed [45]. The qualitative observation of formation of dark brown particles in the reaction mixture further confirms this suggestion. The Ag^{2+} ion, which can undergo reduction with the necessary reduction potential, is effectively formed from this intermediate only under strongly acidic conditions. The slow formation of Ag^{2+} under neutral conditions has previously been reported [46–48]. This will limit the conversion of cyclobutanols with oxidation potentials close to that of the active redox couple, and offers an explanation for the cessation of reactivity of substrates **3d** and **17c**.

3. Conclusion

In conclusion, ring expansion reactions of cyclobutanols substituted at the 3-position of a range of heteroaromatic rings were studied. It was shown that 1-tetralones could be formed under NBS-mediation, whereas 4-tetralones were obtained using silver catalysis from a common intermediate. We have further established that biologically relevant heteroaromatic-fused 1-tetralones with substitution on the cyclohexanone ring can be more efficiently obtained through the work disclosed herein compared to previously established methodologies which are limited by the oxidation potential of the oxidant. This work also includes the first examples of the expansion of oxetanols to oxatetralones. Using electrochemical techniques, we have been able to elucidate the nature of the oxidation step. This work opens up new methodology for the construction of biologically important molecules, including ondansetron and *epi*-20-dasycarpidone.

4. Experimental

4.1. General information

Chemical symbols have their usual meaning and SI units and their respective standard symbols are used. Evaporation of solvent was achieved using a Büchi B-481 rotary evaporator under reduced pressure (0–1000 mbar) with a bath temperature of 30 °C. Reaction solvents are anhydrous and purified through a Grubbs' tower solvent purification system. Dry acetonitrile (99.9%, extra dry over molecular sieves) was acquired from Acros Organics™ and used without further purification. Reagents were obtained from commercial suppliers and used as received without further purification, unless otherwise stated. Reactions were performed in oven-dried glassware (dried at 130 °C for 12 h). *n*-Butyllithium was titrated against diphenylacetic acid before use. *N*-Bromosuccinimide was recrystallised from deionised water, dried under high vacuum and stored under nitrogen at 4 °C. Thin layer chromatography (TLC) was conducted on aluminium backed silica plates precoated with fluorescent indicator (60 F254 Merck), and visualized using a Mineralight lamp Multiband UV 254/365 nm and stained with vanillin solution. Flash column chromatography was performed using silica gel (40–63 μm, VWR Chemicals) using head pressure achieved by the use of head bellows. All solvents used for chromatography were acquired from commercial suppliers and used as received. Nuclear magnetic resonance spectra (NMR) were recorded on a Bruker AV-400 (400 MHz for ^{1}H NMR and 101 MHz for ^{13}C NMR) and referenced to the non-deuterated residual solvent peaks of chloroform. Chemical shifts are reported in parts per million (ppm) and reported to two decimal places for proton shifts, and one decimal place for carbon shifts. Multiplicity of spectral peaks is assigned as follows: singlet (s), doublet (d), triplet (t), quartet (q), pentet (p) or multiplet (m), and combinations thereof. Coupling constants (*J*) are reported to the nearest 0.1 Hz. Infrared spectra were recorded using an Agilent Cary 630 Fourier Transform Infrared Spectrometer. Samples were loaded neat. Mass spectra were recorded using Micromass AutoSpec Premier or Waters LCT Premier instruments and ionised by means of electrospray ionisation (ES) or electron ionisation (EI). Melting points were measured using a Stanford Research Systems OptiMelt system and are uncorrected.

4.2. General procedure A for the synthesis of cyclobutanol starting materials

To a solution of the 3-halogenated heteroaromatic compound (3-bromobenzofuran [49], 3-bromobenzothiophene [50] or 3-iodotosylindole [51]) (1 equiv.) in diethyl ether (0.25 M) cooled to −78 °C, was added *n*-butyllithium solution (2.3 M in hexane, 1.1 equiv.) at a rate to maintain the internal temperature below −70 °C. The resulting reaction mixture was allowed to stir for 1 h at the same temperature, before a solution of the respective cyclobutanone (1.2 equiv.) in diethyl ether (0.5 M) was added as drops. The reaction mixture was allowed to stir for 1 h at −78 °C and then allowed to warm to room temperature at which it was stirred until completion of the reaction (followed by TLC). Upon completion, the reaction was diluted with ethyl acetate and quenched by the slow addition of saturated aqueous ammonium chloride solution. The aqueous phase was extracted with ethyl acetate (3x), and the combined organic layers were washed with saturated sodium chloride solution. The organic phase was dried over magnesium sulfate, filtered and concentrated under reduced pressure to yield the crude material, which was purified by flash column chromatography.

NB: The 2-substituted heteroaromatic cyclobutanols were obtained when THF was used as the reaction solvent, due to migration of the anion [52].

4.3. General procedure B for the NBS-mediated cyclobutanol ring rearrangement

To a solution of cyclobutanol starting material (1 equiv.) in acetonitrile (0.1 M) at room temperature was added *N*-bromosuccinimide (1.15 equiv.). The resulting reaction mixture was stirred at room temperature until completion was indicated by TLC. Upon completion, the reaction mixture was diluted with ethyl acetate, and quenched by addition into saturated aqueous sodium thiosulfate solution. The aqueous layer was separated and extracted with ethyl acetate (3x). The combined organic layers were washed with saturated aqueous sodium chloride solution, dried over magnesium sulfate, filtered and concentrated to yield the crude material, which was purified through flash column chromatography.

4.4. General procedure C for the silver nitrate-mediated cyclobutanol ring rearrangement

A reaction tube was filled with the cyclobutanol starting material (0.3 mmol, 1 equiv.), silver nitrate (10 mg, 0.06 mmol, 0.2 equiv.) and potassium persulfate (243 mg, 0.9 mmol, 3 equiv.). The reaction tube was evacuated and backfilled with nitrogen three times,

before degassed dichloromethane (0.5 mL) and degassed deionised water (0.5 mL) were added simultaneously. The reaction tube was sealed, and the reaction mixture stirred at room temperature. Upon completion, the reaction mixture was diluted with dichloromethane (10 mL) and water (10 mL). The aqueous layer was separated and extracted with dichloromethane (3x15 mL). The combined organic layers were washed with saturated aqueous sodium chloride solution (20 mL), dried over magnesium sulfate, filtered and concentrated to yield the crude material, which was purified using flash column chromatography.

4.5. Characterisation of compounds

4.5.1. 1-(Benzofuran-3-yl)cyclobutan-1-ol; (**3a**)

Prepared following general procedure A. Purified by flash column chromatography (10% EtOAc/pentane). White solid; 138 mg, 0.73 mmol, 47%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.74 (1H, ddd, J = 7.7, 1.5, 0.7 Hz), 7.60 (1H, s), 7.49 (1H, dt, J = 8.2, 0.9 Hz), 7.32 (1H, ddd, J = 8.3, 7.2, 1.4 Hz), 7.26 (1H, m), 2.57 (2H, m), 2.46 (2H, m), 2.15 (1H, s), 1.94 (1H, dtt, J = 11.2, 9.6, 3.9 Hz), 1.70 (1H, dp, J = 11.2, 8.7 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 156.1, 140.8, 126.0, 125.2, 124.6, 122.6, 121.2, 111.6, 72.1, 36.5, 13.1. IR (neat, ν cm^{-1}): 3282, 2987, 2950, 1448, 1124, 1093. HRMS (FTMS + p) m/z calculated for $C_{11}H_{11}O$ $(M - OH)^+$ 171.0804, found 171.0799. Melting point: 93.8–98.9 °C.

4.5.2. 1-(Benzo[b]thiophen-3-yl)cyclobutan-1-ol; (**3b**)

Prepared following general procedure A. Purified by flash column chromatography (20% Et_2O/pentane). White solid; 397 mg, 1.94 mmol, 82%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.01 (1H, m), 7.87 (1H, m), 7.45–7.29 (3H, m), 2.68 (2H, m), 2.51 (2H, m), 2.18 (1H, br. s), 1.98 (1H, dtt, J = 11.2, 9.5, 4.1 Hz), 1.67 (1H, dp, J = 11.1, 8.6 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 141.3, 140.0, 137.2, 124.4, 124.0, 123.9, 122.9, 122.0, 74.7, 36.3, 13.5. IR (neat, ν cm^{-1}): 3255, 2970, 2938, 2864, 1456, 1427, 1247, 1118. HRMS (FTMS + p) m/z calculated for $C_{12}H_{12}OS$ $(M)^+$ 204.0603, found 204.0608. Melting point: 94.6–100.4 °C.

4.5.3. 1-(1-Tosyl-1H-indol-3-yl)cyclobutan-1-ol; (**3c**)

Prepared following general procedure A. Purified by flash column chromatography (40% Et_2O/pentane). Off-white solid; 2.21 g, 6.47 mmol, 65%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.98 (1H, dt, J = 8.3, 0.9 Hz), 7.78 (2H, m), 7.70 (1H, dt, J = 7.8, 1.0 Hz), 7.53 (1H, s), 7.32 (1H, ddd, J = 8.4, 7.2, 1.3 Hz), 7.23 (3H, m), 2.56 (2H, dddd, J = 12.5, 8.6, 3.9, 2.7 Hz), 2.43 (2H, m), 2.35 (3H, s), 2.09 (1H, s), 1.93 (1H, dtt, J = 11.2, 9.6, 3.9 Hz), 1.66 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 145.0, 136.0, 135.3, 129.9, 128.8, 126.9, 126.7, 124.9, 123.1, 122.2, 121.4, 113.7, 72.8, 36.5, 21.6, 13.2. IR (neat, ν cm^{-1}): 3535, 2983, 2925, 2853, 1595, 1446, 1364, 1170, 1128. HRMS (MS ES+) m/z calculated for $C_{19}H_{18}NO_2S$ $(M - OH)^+$ 324.1058, found 324.1053. Melting point: 122.8–136.7 °C.

4.5.4. 1-(Benzofuran-3-yl)-3-phenylcyclobutan-1-ol; (**3d**)

Prepared following general procedure A. Purified by flash column chromatography (20% Et_2O/pentane). White solid; 480 mg, 1.82 mmol, 20%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.79 (1H, ddd, J = 7.7, 1.5, 0.7 Hz), 7.72 (1H, s), 7.53 (1H, dt, J = 8.2, 0.9 Hz), 7.31 (6H, m), 7.23 (1H, m), 3.14 (1H, m), 3.04 (2H, m), 2.63 (2H, m), 2.23 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 156.2, 144.3, 141.1, 128.4, 126.7, 126.2, 126.0, 124.8, 122.8, 121.2, 111.8, 67.9, 43.9, 31.0. IR (neat, ν cm^{-1}): 3338, 3056, 3025, 2973, 2961, 2933, 1451, 1424, 1373, 1234, 1229. HRMS (MS ES+) m/z calculated for $C_{18}H_{15}O$ $(M - OH)^+$ 247.1123, found 247.1122. Melting point: 93.4–96.5 °C.

4.5.5. 6-(Benzofuran-3-yl)bicyclo[3.2.0]heptan-6-ol; (**3e**)

Prepared following general procedure A. Purified by flash column chromatography (2% EtOAc/pentane). Yellow solid; 518 mg, 2.27 mmol, 31%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.73 (1H, m), 7.59 (1H, s), 7.49 (1H, dt, J = 8.3, 0.9 Hz), 7.31 (1H, ddd, J = 8.3, 7.2, 1.5 Hz), 7.25 (1H, m), 3.09 (1H, m), 2.74 (1H, ddd, J = 13.0, 8.7, 3.0 Hz), 2.62 (1H, m), 2.21 (1H, m), 2.00 (1H, dq, J = 18.5, 6.4 Hz), 1.90 (1H, m), 1.84 (1H, s), 1.68–1.47 (4H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 156.2, 140.4, 127.7, 125.9, 124.5, 122.5, 121.2, 111.6, 68.7, 49.3, 40.0, 32.7, 31.4, 26.3, 26.0. IR (neat, ν cm^{-1}): 3553, 3411, 2947, 2851, 1452, 1096. HRMS (MS ES+) m/z calculated for $C_{15}H_{15}O$ $(M - OH)^+$ 211.1123, found 211.1126. Melting point: 68.2–77.0 °C.

4.5.6. 7-(Benzofuran-3-yl)bicyclo[4.2.0]octan-7-ol; (**3f**)

Prepared following general procedure A. Purified by flash column chromatography (5% EtOAc/pentane). Yellow solid; 430 mg, 1.77 mmol, 51%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.71 (1H, ddd, J = 7.7, 1.4, 0.7 Hz), 7.61 (1H, s), 7.49 (1H, dt, J = 8.2, 0.9 Hz), 7.31 (1H, ddd, J = 8.3, 7.2, 1.4 Hz), 7.25 (1H, m), 2.66 (1H, m), 2.41 (2H, dd, J = 9.2, 1.8 Hz), 2.11 (1H, m), 1.99 (1H, s), 1.89 (2H, m), 1.76 (1H, m), 1.63–1.41 (4H, m), 1.15 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 156.0, 140.9, 126.4, 125.7, 124.5, 122.5, 121.3, 111.6, 70.0, 42.8, 37.2, 25.8, 24.7, 22.7, 21.8. IR (neat, ν cm^{-1}): 3546, 3383, 2918, 2846, 1577, 1450, 1224. HRMS (MS ES+) m/z calculated for $C_{16}H_{17}O$ $(M - OH)^+$ 225.1279, found 228.1282. Melting point: 45.5–53.9 °C.

4.5.7. 1-(Benzo[b]thiophen-3-yl)-3-phenylcyclobutan-1-ol; (**3g**)

Prepared following general procedure A. Purified by flash column chromatography (10%–20% Et_2O/pentane). Off-white solid; 370 mg, 1.32 mmol, 44%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.08 (1H, m), 7.92 (1H, m), 7.49 (1H, s), 7.46–7.21 (7H, m), 3.23–3.01 (3H, m), 2.66 (2H, ddt, J = 9.4, 8.2, 1.7 Hz), 2.46 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 144.4, 141.4, 139.3, 137.3, 128.5, 126.7, 126.2, 124.6, 124.2, 124.1, 123.1, 122.5, 70.4, 43.9, 31.2. IR (neat, ν cm^{-1}): 3547, 3349, 3023, 3056, 3023, 2973, 2933, 1601, 1494, 1456, 1427, 1237. HRMS (MS ES+) m/z calculated for $C_{18}H_{15}S$ $(M - OH)^+$ 263.0894, found 263.0897. Melting point: 74.6–82.8 °C.

4.5.8. 6-(Benzo[b]thiophen-3-yl)bicyclo[3.2.0]heptan-6-ol; (**3h**)

Prepared following general procedure A. Purified by flash column chromatography (10% EtOAc/pentane). Off-white solid; 465 mg, 1.90 mmol, 63%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.97 (1H, m), 7.87 (1H, m), 7.43–7.33 (3H, m), 3.19 (1H, tt, J = 8.7, 7.0, 2.9 Hz), 2.89 (1H, ddd, J = 13.2, 8.8, 3.1 Hz), 2.54 (1H, m), 2.29 (1H, dd, J = 13.4, 6.9 Hz), 2.10–1.82 (4H, m), 1.75–1.46 (3H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 142.2, 141.5, 137.2, 124.4, 124.2, 123.9, 123.0, 121.5, 70.9, 49.0, 39.6, 32.8, 31.6, 26.5, 26.0. IR (neat, ν cm^{-1}): 3314, 2944, 2845, 1425, 1107. HRMS (MS ES+) m/z calculated for $C_{15}H_{15}S$ $(M - OH)^+$ 227.0889, found 227.0890. Melting point: 77.2–83.0 °C.

4.5.9. 7-(Benzo[b]thiophen-3-yl)bicyclo[4.2.0]octan-7-ol; (**3i**)

Prepared following general procedure A. Purified by flash column chromatography (10% Et_2O/pentane). Off-white solid; 120 mg, 0.46 mmol, 20%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.96 (1H, m), 7.86 (1H, m), 7.40 (1H, s), 7.40–7.31 (2H, m), 2.75 (1H, qd, J = 8.9, 4.4 Hz), 2.56 (1H, ddd, J = 11.1, 7.9, 4.5 Hz), 2.45 (1H, t, J = 11.0 Hz), 2.03 (2H, m), 2.00–1.89 (2H, m), 1.77 (1H, dtt, J = 12.8, 3.1 Hz), 1.62–1.57 (2H, m), 1.50–1.41 (2H, m), 1.14 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 141.3, 140.4, 137.6, 124.4, 124.0, 123.9, 122.9, 121.9, 72.5, 42.8, 37.1, 25.8, 24.8, 22.8, 22.0, 21.8. IR (neat, ν cm^{-1}) 3537, 3425, 3264, 2922, 2847, 1456, 1428, 1229, 1061. HRMS (MS ES+) m/z calculated for $C_{16}H_{17}S$ $(M - OH)^+$ 241.1040, found 241.1045.

4.5.10. 3-(Benzo[b]thiophen-3-yl)oxetan-3-ol; (**17a**)

Prepared following general procedure A. Purified by flash column chromatography (30% Et_2O/pentane). Yellow solid; 290 mg, 1.41 mmol, 30%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.94–7.85 (2H, m),

7.45 (1H, s), 7.43–7.38 (2H, m), 5.11 (2H, dd, J = 6.8, 0.8 Hz), 5.01 (2H, dd, J = 6.9, 0.8 Hz), 2.80 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 141.2, 136.6, 136.4, 124.8, 124.6, 123.4, 123.2, 122.7, 83.8, 74.2. IR (neat, ν cm^{-1}) 3843, 2947, 2872, 1457, 1428. HRMS (MS ES+) *m/z* calculated for $C_{11}H_9OS$ (M − OH)$^+$ 189.0374, found 189.0368. Melting point: 80.2–84.1 °C.

*4.5.11. 3-(Benzo[b]thiophen-2-yl)oxetan-3-ol; (**17b**)*

To a solution of benzothiophene (500 mg, 3.73 mmol) in THF (15 mL) cooled to −78 °C was added *n*-butyllithium solution (1.9 M in hexane, 2.2 mL, 4.1 mmol) as drops. The reaction mixture was allowed to stir at −78 °C for 2 h before a solution of 3-oxetanone (0.24 mL, 4.1 mmol) in THF (3 mL) was added as drops. The resulting solution was allowed to warm to room temperature and stirred for a further 1.5 h. Upon completion, the reaction was diluted with ethyl acetate and quenched by the slow addition of saturated aqueous ammonium chloride solution. The aqueous phase was extracted with ethyl acetate (3x), and the combined organic layers were washed with saturated sodium chloride solution. The organic phase was dried over magnesium sulfate, filtered and concentrated under reduced pressure to yield the title compound (693 mg, 3.36 mmol, 90%) as an off-white solid which was used without further purification. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.83 (1H, ddd, J = 7.4, 1.7, 0.7 Hz), 7.76 (1H, m), 7.40 (1H, d, J = 0.7 Hz), 7.40–7.31 (2H, m), 4.96 (4H, m), 3.01 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 147.0, 139.6, 139.5, 124.7, 123.8, 122.5, 120.2, 85.3, 74.8. IR (neat, ν cm^{-1}) 3232, 2940, 2871, 1419, 1456, 1433, 1237, 1140. HRMS (FTMS + p) *m/z* calculated for $C_{11}H_9OS$ (M − OH)$^+$ 189.0369, found 189.0364. Melting point: 104.8–112.9 °C.

*4.5.12. 3-(Benzofuran-2-yl)oxetan-3-ol; (**17c**)*

To a solution of benzofuran (1.60 mL, 14.5 mmol) in diethyl ether (30 mL) cooled to −78 °C was added *n*-butyllithium solution (2.3 M in hexane, 6.3 mL, 14.5 mmol) as drops. The reaction mixture was allowed to stir at −78 °C for 1 h, before it was warmed to room temperature and stirred for further 3 h. The reaction mixture was then cooled to −78 °C before a solution of 3-oxetanone (0.64 mL, 11 mmol) in THF (3 mL) was added as drops. The resulting solution was allowed to warm to room temperature and stirred for a further 1.5 h. Upon completion, the reaction was diluted with ethyl acetate and quenched by the slow addition of saturated aqueous ammonium chloride solution. The aqueous phase was extracted with ethyl acetate (3x), and the combined organic layers were washed with saturated sodium chloride solution. The organic phase was dried over magnesium sulfate, filtered and concentrated under reduced pressure to yield the crude material, which was purified through flash column chromatography (50% Et_2O/pentane) to yield the title compound (1.66 g, 8.73 mmol, 79%) as an off-white solid. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.58 (1H, ddd, J = 7.6, 1.5, 0.7 Hz), 7.50 (1H, dq, J = 8.2, 0.9 Hz), 7.32 (1H, m), 7.26 (1H, m), 6.78 (1H, d, J = 1.0 Hz), 5.05 (2H, dd, J = 6.9, 0.9 Hz), 4.89 (2H, m), 3.04 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 156.6, 155.0, 127.9, 124.8, 123.2, 121.3, 111.4, 102.9, 82.8, 72.6. IR (neat, ν cm^{-1}) 3279, 3127, 2954, 2878, 1451, 1407, 1253, 1174. HRMS (FTMS + p) *m/z* calculated for $C_{11}H_9O_2$ (M − OH)$^+$ 173.0597, found 173.0601.

*4.5.13. 2,3-Dihydrodibenzo[b,d]furan-4(1H)-one; (**4a**)*

Prepared following general procedure B from alcohol **3a** (93 mg, 0.5 mmol). Purified by flash column chromatography (15% EtOAc/pentane). White solid; 35 mg, 0.19 mmol, 38%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.64 (1H, dt, J = 7.8, 1.0 Hz), 7.55 (1H, dt, J = 8.4, 1.0 Hz), 7.48 (1H, ddd, J = 8.4, 7.1, 1.3 Hz), 7.31 (1H, ddd, J = 8.0, 7.1, 1.1 Hz), 2.99 (2H, t, J = 6.0 Hz), 2.69 (2H, m), 2.28 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 188.4, 155.8, 147.7, 134.7, 129.1, 126.4, 123.6, 121.8, 112.8, 38.6, 24.1, 21.4. IR (neat, ν cm^{-1}) 3056, 2947, 2884, 1661, 1588, 1394, 1079. HRMS (MS ES+) *m/z* calculated for $C_{12}H_{11}O_2$ (M)$^+$ 187.0759, found 187.0762. The data obtained are in agreement with those previously reported [10].

*4.5.14. 2,3-Dihydrodibenzo[b,d]thiophen-4(1H)-one; (**4b**)*

Prepared following general procedure B from alcohol **3b** (3.99 g, 19.3 mmol). Purified by flash column chromatography (20% Et_2O/pentane). White solid; 820 mg, 4.05 mmol, 21%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.88 (1H, dt, J = 8.1, 1.0 Hz), 7.82 (1H, dt, J = 7.8, 1.0 Hz), 7.49 (1H, ddd, J = 8.2, 7.1, 1.4 Hz), 7.43 (1H, ddd, J = 8.2, 7.1, 1.2 Hz), 3.07 (2H, t, J = 6.1 Hz), 2.74 (2H, dd, J = 7.3, 5.8 Hz), 2.32 (2H, p, J = 6.3 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 193.7, 147.9, 142.5, 138.3, 136.2, 128.1, 124.8, 123.9, 123.5, 38.6, 24.1, 24.0. IR (neat, ν cm^{-1}) 3057, 2947, 2887, 1662, 1523, 1380, 1282. HRMS (MS ES+) *m/z* calculated for $C_{12}H_{11}OS$ (M)$^+$ 203.0525, found 203.0523. Melting point: 106.7–111.3 °C. The data obtained are in agreement with those previously reported [12].

*4.5.15. 9-Tosyl-2,3,4,9-tetrahydro-1H-carbazol-1-one; (**4c**)*

Prepared following general procedure B from alcohol **3c** (153 mg, 0.45 mmol). Purified by flash column chromatography (40% Et_2O/pentane). Pale brown solid; 23 mg, 0.068 mmol, 15%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.37 (1H, dt, J = 8.7, 0.9 Hz), 8.04 (2H, m), 7.63 (1H, dt, J = 7.9, 1.0 Hz), 7.55 (1H, ddd, J = 8.6, 7.2, 1.3 Hz), 7.34 (1H, ddd, J = 8.0, 7.1, 0.9 Hz), 7.31 (2H, m), 2.95 (2H, t, J = 6.1 Hz), 2.61 (2H, m), 2.40 (3H, s), 2.19 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 187.7, 144.4, 139.7, 137.7, 137.3, 132.3, 129.3, 129.2, 127.7, 127.1, 123.6, 121.3, 116.0, 39.5, 23.5, 21.8, 21.7. IR (neat, ν cm^{-1}) 3052, 2924, 2866, 1675, 1596, 1551, 1366. HRMS (MS ES+) *m/z* calculated for $C_{19}H_{18}NO_3S$ (M)$^+$ 340.1007, found 340.0999. The data obtained are in agreement with those previously reported [53].

*4.5.16. 2-Phenyl-2,3-dihydrodibenzo[b,d]furan-4(1H)-one; (**4d**)*

Prepared following general procedure B from alcohol **3d** (78 mg, 0.30 mmol). Purified by flash column chromatography (10% EtOAc/pentane). White solid; 51 mg, 0.19 mmol, 65%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.62 (2H, ddt, J = 15.3, 8.4, 1.0 Hz), 7.52 (1H, ddd, J = 8.4, 7.1, 1.3 Hz), 7.42–7.29 (6H, m), 3.68 (1H, ddt, J = 12.2, 11.0, 4.7 Hz), 3.33 (1H, ddd, J = 16.9, 4.7, 1.1 Hz), 3.16 (1H, dd, J = 16.9, 11.0 Hz), 2.98 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 187.1, 156.3, 147.6, 142.7, 133.9, 129.3, 128.9, 127.3, 126.8, 126.2, 123.8, 121.8, 113.0, 45.5, 42.8, 29.4. IR (neat, ν cm^{-1}) 3060, 3028, 2954, 2941, 2906, 1669, 1396, 1306, 1128, 1109, 1072. HRMS (MS ES+) *m/z* calculated for $C_{18}H_{15}O_2$ (M)$^+$ 263.1072, found 263.1073.

*4.5.17. 1,2,3,3a,4,10c-hexahydro-5H-indeno[5,4-b]benzofuran-5-one; (**4e**)*

Prepared following general procedure B from alcohol **3e** (67 mg, 0.3 mmol). Purified by flash column chromatography (10% EtOAc/pentane). Yellow solid; 25 mg, 0.11 mmol, 37%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.70 (1H, dt, J = 7.9, 1.0 Hz), 7.57 (1H, dt, J = 8.4, 0.9 Hz), 7.49 (1H, ddd, J = 8.4, 7.1, 1.3 Hz), 7.32 (1H, ddd, J = 8.0, 7.1, 1.0 Hz), 3.54 (1H, dt, J = 8.0, 6.0 Hz), 2.85 (1H, m), 2.81–2.68 (2H, m), 2.28 (1H, dtd, J = 13.0, 8.3, 6.8 Hz), 2.10 (1H, ddt, J = 12.7, 8.5, 6.0 Hz), 1.96 (1H, dtd, J = 12.8, 8.0, 6.2 Hz), 1.77 (2H, ddt, J = 15.0, 8.4, 6.5 Hz), 1.55 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 187.9, 156.3, 146.4, 136.0, 128.9, 126.4, 123.5, 122.2, 113.0, 41.3, 40.3, 37.0, 31.3, 30.4, 24.6. IR (neat, ν cm^{-1}) 2943, 2868, 1670, 1586, 1577, 1444, 1394, 1113, 1079. HRMS (MS ES+) *m/z* calculated for $C_{15}H_{15}O_2$ (M)$^+$ 227.1072, found 227.1065. Melting point: 42.4–46.6 °C.

*4.5.18. 1,3,4,4a,5,11c-Hexahydronaphtho[2,1-b]benzofuran-6(2H)-one; (**4f**)*

Prepared following general procedure B from alcohol **3f** (71 mg, 0.30 mmol). Purified by flash column chromatography (5% EtOAc/

pentane). Faint yellow solid; 29 mg, 0.12 mmol, 41%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.70 (1H, dt, J = 7.9, 1.0 Hz), 7.57 (1H, dt, J = 8.5, 0.9 Hz), 7.48 (1H, ddd, J = 8.4, 7.2, 1.3 Hz), 7.31 (1H, ddd, J = 8.1, 7.1, 1.0 Hz), 3.22 (1H, dt, J = 10.7, 4.4 Hz), 2.92 (1H, dd, J = 16.9, 12.2 Hz), 2.64 (1H, dp, J = 13.0, 4.3 Hz), 2.48 (1H, dd, J = 16.9, 4.2 Hz), 2.03 (1H, dq, J = 12.1, 3.8 Hz), 1.80–1.65 (4H, m), 1.62 (1H, m), 1.50 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 188.8, 156.2, 147.1, 138.6, 128.9, 125.9, 123.6, 121.9, 113.0, 40.5, 35.9, 34.6, 29.9, 28.4, 24.9, 21.4. IR (neat, ν cm^{-1}) 3058, 2923, 2851, 1673, 1588, 1576, 1444, 1395, 1309, 1142, 1070. HRMS (MS ES+) *m/z* calculated for $C_{16}H_{17}O_2$ $(M)^+$ 241.1229, found 241.1240. Melting point: 96.1–100.4 °C.

*4.5.19. 2-Phenyl-2,3-dihydrodibenzo[b,d]thiophen-4(1H)-one; (**4g**)*

Prepared following general procedure B from alcohol **3g** (105 mg, 0.37 mmol). Purified by flash column chromatography (5% EtOAc/pentane). White solid; 43 mg, 0.15 mmol, 41%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.91 (1H, dt, J = 8.2, 0.9 Hz), 7.80 (1H, dt, J = 7.9, 1.0 Hz), 7.51 (1H, ddd, J = 8.2, 7.1, 1.3 Hz), 7.46–7.28 (6H, m), 3.67 (1H, m), 3.47 (1H, m), 3.14 (1H, dd, J = 16.9, 11.3 Hz), 3.01 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 192.7, 146.8, 142.9, 142.8, 138.0, 136.1, 128.9, 128.2, 127.3, 126.9, 124.9, 123.8, 123.6, 45.4, 42.5, 32.2. IR (neat, ν cm^{-1}) 3056, 3027, 2919, 2891, 2949, 1661, 1523, 1381, 1288. HRMS (MS ES+) *m/z* calculated for $C_{18}H_{15}OS$ $(M)^+$ 279.0844, found 279.0836. Melting point: 91.1–108.4 °C.

*4.5.20. 1,2,3,3a,4,10c-hexahydro-5H-benzo[b]indeno[4,5-d] thiophen-5-one; (**4h**)*

Prepared following general procedure B from alcohol **3h** (121 mg, 0.50 mmol). Purified by flash column chromatography (10% Et_2O/pentane). Pink solid; 37 mg, 0.15 mmol, 31%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.86 (2H, ddt, J = 13.6, 7.8, 0.9 Hz), 7.45 (2H, m), 3.52 (1H, td, J = 8.5, 6.5 Hz), 2.96 (1H, dtd, J = 13.5, 6.6, 3.9 Hz), 2.69 (1H, d, J = 1.4 Hz), 2.67 (1H, d, J = 4.2 Hz), 2.41 (1H, dddd, J = 12.1, 9.7, 7.1, 2.5 Hz), 2.07–1.78 (4H, m), 1.63 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 193.5, 149.8, 143.0, 138.6, 134.7, 127.8, 124.7, 124.3, 123.6, 41.2, 40.8, 39.2, 31.1, 31.0, 24.6. IR (neat, ν cm^{-1}) 2943, 2869, 1659, 1523, 1384, 1329, 1287, 1240. HRMS (FTMS + p) *m/z* calculated for $C_{15}H_{15}OS$ $(M + H)^+$ 243.0838, found 243.0832. Melting point: 79.4–89.0 °C.

*4.5.21. 1,3,4,4a,5,11c-Hexahydrobenzo[b]naphtho[1,2-d]thiophen-6(2H)-one; (**4i**)*

Prepared following general procedure B from alcohol **3i** (80 mg, 0.33 mmol). Purified by flash column chromatography (10% Et_2O/pentane). Light pink film; 20 mg, 0.083 mmol, 25%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.86 (2H, ddt, J = 16.5, 7.8, 0.9 Hz), 7.45 (2H, dddd, J = 21.7, 8.1, 7.1, 1.3 Hz), 3.25 (1H, dt, J = 12.0, 4.4 Hz), 3.02 (1H, dd, J = 17.0, 14.3 Hz), 2.69 (1H, dt, J = 14.4, 3.8 Hz), 2.46 (1H, dd, J = 17.0, 4.2 Hz), 2.03 (1H, m), 1.82 (3H, m), 1.68 (1H, m), 1.52 (3H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 194.4, 152.8, 143.0, 137.6, 135.6, 127.9, 124.7, 123.9, 123.7, 39.1, 36.8, 35.3, 30.6, 28.1, 25.8, 20.4. IR (neat, ν cm^{-1}) 3056, 2922, 2851, 1654, 1521, 1448, 1380, 1290, 1280. HRMS (FTMS + p) *m/z* calculated for $C_{16}H_{17}OS$ $(M + H)^+$ 257.0995, found 257.0998.

*4.5.22. 3,4-Dihydrodibenzo[b,d]furan-1(2H)-one; (**10a**)*

Prepared following general procedure C from alcohol **3a** (61 mg, 0.30 mmol). Purified by flash column chromatography (15% EtOAc/pentane). White solid; 8 mg, 0.04 mmol, 13%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.05 (1H, m), 7.47 (1H, m), 7.32 (2H, m), 3.04 (2H, t, J = 6.3 Hz), 2.61 (2H, m), 2.28 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 194.8, 170.8, 154.5, 125.0, 124.5, 123.7, 121.8, 116.5, 111.1, 37.9, 23.8, 22.5. The data obtained are in agreement with those previously reported [23].

*4.5.23. 3,4-Dihydrodibenzo[b,d]thiophen-1(2H)-one; (**10b**)*

Prepared following general procedure C from alcohol **3b** (100 mg, 0.45 mmol). Purified by flash column chromatography (12% EtOAc/pentane). Brown solid; 11 mg, 0.05 mmol, 11%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.67 (1H, dt, J = 8.1, 1.0 Hz), 7.77 (1H, dt, J = 8.0, 1.0 Hz), 7.45 (1H, ddd, J = 8.2, 7.2, 1.2 Hz), 7.36 (1H, ddd, J = 8.3, 7.1, 1.3 Hz), 3.15 (2H, t, J = 6.1 Hz), 2.67 (2H, m), 2.29 (2H, tt, J = 7.5, 5.8 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 193.6, 160.1, 137.3, 136.5, 130.0, 125.8, 125.1, 125.0, 121.7, 38.8, 26.6, 24.3. The data obtained are in agreement with those previously reported [23].

*4.5.24. 9-Tosyl-1,2,3,9-tetrahydro-4H-carbazol-4-one; (**10c**)*

Prepared following general procedure C from alcohol **3c** (100 mg, 0.30 mmol). Purified by flash column chromatography (15% EtOAc/pentane). Colourless oil; 13 mg, 0.038 mmol, 13%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.24 (1H, m), 8.16 (1H, m), 7.76 (2H, m), 7.34 (2H, m), 7.27 (2H, m), 3.33 (2H, t, J = 6.2 Hz), 2.56 (2H, m), 2.37 (3H, s), 2.22 (2H, dq, J = 7.8, 6.3 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 195.0, 150.9, 145.8, 136.0, 135.6, 130.3, 126.6, 125.8, 125.3, 124.9, 121.9, 118.0, 113.9, 37.9, 24.5, 23.2, 21.7. The data obtained are in agreement with those previously reported [23].

*4.5.25. 1,2,3,3a,4,10b-hexahydro-5H-indeno[4,5-b]benzofuran-5-one; (**10e**)*

Prepared following general procedure C from alcohol **3e** (69 mg, 0.30 mmol). Purified by flash column chromatography (5% EtOAc/pentane). Yellow oil; 20 mg, 0.088 mmol, 29%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.06 (1H, m), 7.47 (1H, m), 7.32 (2H, m), 3.48 (1H, td, J = 7.0, 5.7 Hz), 2.81 (2H, m), 2.64 (1H, dd, J = 16.7, 5.1 Hz), 2.20 (2H, m), 1.95 (1H, m), 1.74 (2H, m), 1.53 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 194.4, 172.1, 154.9, 124.9, 124.4, 123.8, 121.9, 115.4, 111.1, 41.0, 39.4, 38.3, 30.6, 30.0, 24.3. The data obtained are in agreement with those previously reported [23].

*4.5.26. 1,3,4,4a,5,11b-Hexahydronaphtho[1,2-b]benzofuran-6(2H)-one; (**10f**)*

Prepared following general procedure C from alcohol **3f** (71 mg, 0.30 mmol). Purified by flash column chromatography (10% Et_2O/pentane). Colourless film; 12 mg, 0.050 mmol, 17%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.06 (1H, m), 7.48 (1H, m), 7.32 (2H, m), 3.28 (1H, dt, J = 7.5, 4.7 Hz), 2.69 (1H, dd, J = 17.4, 9.2 Hz), 2.56 (2H, dt, J = 11.4, 4.3 Hz), 2.09 (1H, br. s), 1.92 (1H, ddt, J = 13.4, 8.8, 4.8 Hz), 1.72–1.39 (6H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 194.9, 173.4, 154.8, 124.8, 124.4, 123.9, 121.8, 115.4, 111.2, 35.9, 35.5, 28.8, 26.9, 23.6, 22.9. The data obtained are in agreement with those previously reported [24].

*4.5.27. 3-Phenyl-3,4-dihydrodibenzo[b,d]thiophen-1(2H)-one; (**10g**)*

Prepared following general procedure C from **3g** (81 mg, 0.30 mmol). Purified by flash column chromatography (10% Et_2O/pentane). Crystals suitable for X-ray diffraction analysis were obtained through slow evaporation from $CDCl_3$. White solid; 13 mg, 0.047 mmol, 16%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.70 (1H, d, J = 8.0 Hz), 7.79 (1H, d, J = 8.0 Hz), 7.48 (1H, t, J = 7.6 Hz), 7.42–7.28 (6H, m), 3.67 (1H, dtd, J = 12.3, 8.1, 4.5 Hz), 3.43 (1H, dd, J = 17.1, 4.6 Hz), 3.32 (1H, dd, J = 17.1, 11.2 Hz), 2.94 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 192.6, 159.1, 142.5, 137.6, 136.3, 129.8, 128.9, 127.3, 126.8, 126.0, 125.3, 125.0, 121.8, 45.8, 42.5, 34.1. The data obtained are in agreement with those previously reported [23].

*4.5.28. 1,2,3,3a,4,10b-hexahydro-5H-benzo[b]indeno[5,4-d] thiophen-5-one; (**10h**)*

Prepared following general procedure C from alcohol **3h** (74 mg, 0.30 mmol). Purified by flash column chromatography (5% EtOAc/

pentane). White solid; 30 mg, 0.12 mmol, 41%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.66 (1H, ddd, J = 8.1, 1.3, 0.7 Hz), 7.78 (1H, dt, J = 8.0, 0.9 Hz), 7.44 (1H, ddd, J = 8.2, 7.2, 1.2, Hz), 7.35 (1H, ddd, J = 8.4, 7.2, 1.3 Hz), 3.58 (1H, dt, J = 7.5, 5.8 Hz), 2.82 (2H, m), 2.66 (1H, dd, J = 16.4, 6.6 Hz), 2.24 (1H, ddt, J = 13.0, 8.7, 7.6 Hz), 2.07 (1H, m), 1.97 (1H, m), 1.78 (2H, m), 1.55 (1H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 193.3, 163.7, 137.7, 136.5, 129.0, 125.7, 125.0, 121.8, 41.4, 41.2, 40.2, 34.5, 30.1, 23.9. The data obtained are in agreement with those previously reported [23].

*4.5.29. 1,3,4,4a,5,11b-Hexahydrobenzo[b]naphtho[2,1-d]thiophen-6(2H)-one; (**10i**)*

Prepared following general procedure C from alcohol **3i** (77 mg, 0.30 mmol). Purified by flash column chromatography (5% EtOAc/pentane). Colourless oil; 23 mg, 0.090 mmol, 30%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.68 (1H, dt, J = 8.2, 0.9 Hz), 7.79 (1H, dt, J = 8.0, 0.9 Hz), 7.45 (1H, ddd, J = 8.2, 7.1, 1.2 Hz), 7.36 (1H, m), 3.40 (1H, dt, J = 7.1, 4.8 Hz), 2.73 (1H, dd, J = 16.7, 7.9 Hz), 2.63 (1H, dd, J = 16.8, 4.5 Hz), 2.54 (1H, m), 2.15–1.87 (2H, m), 1.74–1.39 (6H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 193.8, 164.8, 137.5, 136.8, 129.1, 125.7, 125.0, 124.9, 121.8, 42.8, 38.2, 36.6, 31.0, 28.6, 23.4, 23.0. The data obtained are in agreement with those previously reported [24].

*4.5.30. 1H-Benzo[4,5]thieno[2,3-c]pyran-4(3H)-one; (**18a**)*

Prepared following general procedure C from alcohol **17a** (62 mg, 0.30 mmol). Purified by flash column chromatography (10% EtOAc/pentane). Red solid; 13 mg, 0.063 mmol, 21%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.59 (1H, dt, J = 8.1, 1.0 Hz), 7.84 (1H, dt, J = 8.0, 1.0 Hz), 7.50 (1H, ddd, J = 8.2, 7.2, 1.1 Hz), 7.42 (1H, ddd, J = 8.3, 7.2, 1.3 Hz), 5.11 (2H, d, J = 0.8 Hz), 4.36 (2H, d, J = 0.9 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 189.0, 156.6, 137.4, 135.4, 128.2, 126.3, 125.8, 125.0, 122.1, 72.6, 65.3. IR (neat, ν cm^{-1}) 3062, 2967, 2840, 1671, 1466, 1392, 1198, 1088. HRMS (FTMS + p) m/z calculated for $C_{11}H_9O_2S$ $(M + H)^+$ 205.0318, found 205.0318. Melting point: 113.6–116.4 °C.

*4.5.31. 1H-Benzo[4,5]thieno[3,2-c]pyran-4(3H)-one; (**18b**)*

Prepared following general procedure C from alcohol **17b** (63 mg, 0.30 mmol). Purified by flash column chromatography (10% EtOAc/pentane). Light-red solid; 10 mg, 0.049 mmol, 16%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.94 (1H, dt, J = 8.2, 0.9 Hz), 7.73 (1H, ddd, J = 8.0, 1.3, 0.8 Hz), 7.54 (1H, ddd, J = 8.2, 7.1, 1.3 Hz), 7.46 (1H, ddd, J = 8.1, 7.1, 1.1 Hz), 5.13 (2H, d, J = 1.0 Hz), 4.43 (2H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 189.3, 146.3, 143.0, 135.4, 132.7, 128.6, 125.3, 123.8, 123.6, 72.8, 64.6. IR (neat, ν cm^{-1}) 3053, 2848, 2818, 1670, 1525, 1343, 1327, 1293. HRMS (FTMS + p) m/z calculated for $C_{11}H_9O_2S$ $(M + H)^+$ 205.0318, found 205.0319.

*4.5.32. 1,2,3,4-Tetrahydrodibenzo[b,d]thiophen-1-ol; (**12**)*

To a suspension of ketone (50 mg, 0.25 mmol) in methanol (1 mL) at room temperature was added sodium borohydride (12 mg, 0.31 mmol, 1.25 equiv.). The resulting solution was allowed to stir for 20 min, before it was cooled to 0 °C and quenched by the addition of deionised water (1 mL) and stirred for 10 further minutes. The methanol was removed under reduced pressure and the aqueous layer extracted with ethyl acetate (3 x 10 mL). The combined organic layers were washed with saturated aqueous sodium chloride solution (10 mL), dried over magnesium sulfate, filtered and concentrated to obtain the crude product, which was purified through flash column chromatography (25% Et_2O/pentane). White solid; 44 mg, 0.22 mmol, 88%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.86 (1H, dt, J = 8.0, 0.9 Hz), 7.77 (1H, dt, J = 7.9, 0.9 Hz), 7.37 (1H, ddd, J = 8.0, 7.1, 1.2 Hz), 7.29 (1H, ddd, J = 8.3, 7.2, 1.3 Hz), 5.07 (1H, dt, J = 6.8, 3.8 Hz), 2.93 (1H, m), 2.80 (1H, m), 2.17-1-87 (4H, m), 1.78 (1H, d, J = 6.2 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 141.4, 138.7, 138.6, 131.2, 124.3, 124.0, 122.3, 121.4, 63.6, 31.9, 25.9, 19.0. IR (neat, ν cm^{-1}) 3305, 2935, 2902, 2878, 2861, 2831, 1465, 1434, 1272, 1257, 1072. HRMS (FTMS + p) m/z calculated for $C_{12}H_{11}S$ $(M - OH)^+$ 187.0576, found 187.0577. Melting point: 97.5–102.4 °C.

*4.5.33. 1,2,3,4-Tetrahydrodibenzo[b,d]thiophen-4-ol; (**15**)*

To a suspension of ketone (50 mg, 0.25 mmol) in methanol (1 mL) at room temperature was added sodium borohydride (12 mg, 0.31 mmol, 1.25 equiv.). The resulting solution was allowed to stir for 20 min, before it was cooled to 0 °C and quenched by the addition of deionised water (1 mL) and stirred for 10 further minutes. The methanol was removed under reduced pressure and the aqueous layer extracted with ethyl acetate (3 x 10 mL). The combined organic layers were washed with saturated aqueous sodium chloride solution (10 mL), dried over magnesium sulfate, filtered and concentrated to obtain the crude product, which was purified through flash column chromatography (30% Et_2O/pentane). White solid; 43 mg, 0.21 mmol, 84%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.82 (1H, m), 7.62 (1H, m), 7.35 (2H, m), 4.98 (1H, q, J = 5.5 Hz), 2.81 (1H, m), 2.72 (1H, m), 2.20 (1H, m), 2.08 (1H, m), 2.03–1.83 (3H, m). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 139.4, 139.0, 132.0, 124.6, 124.1, 122.7, 121.5, 66.1, 33.5, 23.7, 19.2. IR (neat, ν cm^{-1}) 3351, 2945, 2916, 2877, 2851, 1435, 1292, 1169, 1045. HRMS (FTMS + p) m/z calculated for $C_{11}H_{11}S$ $(M - OH)^+$ 187.0576, found 187.0580. Melting point: 90.6–100.6 °C.

*4.5.34. Dibenzo[b,d]thiophen-1-ol; (**11**)*

To a solution of ketone (100 mg, 0.5 mmol) in THF (3 mL) cooled to 0 °C, was added trimethylphenylammonium tribromide (207 mg, 0.55 mmol) and the solution stirred at 0 °C for 1 h, before it was allowed to warm to room temperature and stirred for further 4.5 h. At that point, the reaction mixture was diluted with ethyl acetate (10 mL) and deionised water (10 mL). The aqueous layer was separated and extracted with ethyl acetate (3x15 mL). The combined organic layers were washed with saturated aqueous sodium chloride solution (15 mL), dried over magnesium sulfate, filtered and concentrated to yield the crude material as a dark grey solid. This was immediately dissolved in DMF (4 mL) and to the solution was added lithium carbonate (164 mg, 2.22 mmol, 4.5 equiv.) and lithium bromide (193 mg, 2.22 mmol, 4.5 equiv.). The reaction mixture was heated to 150 °C and stirred at the same temperature for 4 h, before it was allowed to cool down to room temperature and quenched by the addition into deionised water (20 mL). The aqueous layer was extracted with ethyl acetate (3 x 20 mL), and the combined organic layers were subsequently washed with deionised water (2x20 mL) and saturated aqueous sodium chloride solution (20 mL), dried over magnesium sulfate, filtered and concentrated to yield the crude material, which was purified through flash column chromatography (10% Et_2O/pentane). White solid; 57 mg, 0.28 mmol, 57%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.66 (1H, m), 7.84 (1H, m), 7.52–7.41 (3H, m), 7.29 (1H, t, J = 7.9 Hz), 6.77 (1H, dd, J = 7.8, 0.8 Hz), 5.48 (1H, d, J = 1.3 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 153.0, 141.4, 138.6, 135.0, 127.1, 125.9, 125.8, 124.5, 123.7, 122.1, 115.3, 110.5. IR (neat, ν cm^{-1}) 3283, 3055, 1565, 1423, 1229. HRMS (FTMS-p) m/z calculated for $C_{12}H_7OS$ $(M - H)^-$ 199.0212, found 199.0218. Melting point: 136.4–141.8 °C.

*4.5.35. Dibenzo[b,d]thiophen-4-ol; (**14**)*

To a solution of ketone (100 mg, 0.5 mmol) in THF (3 mL) cooled to 0 °C, was added trimethylphenylammonium tribromide (207 mg, 0.55 mmol) and the solution stirred at 0 °C for 1 h, before it was allowed to warm to room temperature and stirred for further 4.5 h. At that point, the reaction mixture was diluted with ethyl acetate (10 mL) and deionised water (10 mL). The aqueous layer was separated and extracted with ethyl acetate (3x15 mL). The

combined organic layers were washed with saturated aqueous sodium chloride solution (15 mL), dried over magnesium sulfate, filtered and concentrated to yield the crude material as a dark grey solid. This was immediately dissolved in DMF (4 mL) and to the solution was added lithium carbonate (164 mg, 2.22 mmol, 4.5 equiv.) and lithium bromide (193 mg, 2.22 mmol, 4.5 equiv.). The reaction mixture was heated to 150 °C and stirred at the same temperature for 4 h, before it was allowed to cool down to room temperature and quenched by the addition into deionised water (20 mL). The aqueous layer was extracted with ethyl acetate (3 x 20 mL), and the combined organic layers were subsequently washed with deionised water (2x20 mL) and saturated aqueous sodium chloride solution (20 mL), dried over magnesium sulfate, filtered and concentrated to yield the crude material, which was purified through flash column chromatography (10% EtOAc/pentane). Grey solid; 50 mg, 0.25 mmol, 50%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 8.14 (1H, m), 7.89 (1H, m), 7.79 (1H, dd, J = 7.9, 0.9 Hz), 7.47 (2H, m), 7.35 (1H, t, J = 7.8 Hz), 6.89 (1H, dd, J = 7.8, 0.9 Hz), 5.24 (1H, s). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 150.4, 139.6, 138.0, 135.9, 126.9, 126.6, 125.8, 124.4, 123.1, 122.0, 114.5, 111.8. IR (neat, ν cm^{-1}) 3231, 3060, 1567, 1442, 1249, 1047. HRMS (FTMS + p) m/z calculated for $C_{12}H_9OS$ $(M + H)^+$ 201.0369, found 201.0368. The data obtained are in agreement with those previously reported [54].

4.5.36. 3,4-Dihydrodibenzo[b,d]thiophene-1(2H)-thione; (**13**)

To a solution of ketone (47 mg, 0.23 mmol, 1 equiv.) in toluene (8 mL) was added Lawesson's reagent (202 mg, 0.5 mmol, 2 equiv.) and the solution heated to reflux for 4 h. The reaction mixture was allowed to cool to room temperature and concentrated to yield the crude material, which was purified by flash column chromatography (10% Et_2O/pentane). Purple oil; 42 mg, 0.19 mmol, 84%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 9.32 (1H, d, J = 8.3 Hz), 7.77 (1H, d, J = 7.9 Hz), 7.49 (1H, t, J = 7.7 Hz), 7.39 (1H, t, J = 7.7 Hz), 3.28–3.15 (4H, m), 2.25 (2H, p, J = 5.7 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 229.3, 156.9, 137.4, 137.4, 126.5, 126.4, 125.6, 125.0, 121.8, 50.8, 27.9, 25.1. IR (neat, ν cm^{-1}) 3056, 2931, 2861, 1482, 1454, 1420, 1361, 1339. HRMS (FTMS + p) m/z calculated for $C_{12}H_{11}S_2$ $(M + H)^+$ 219.0297, found 219.0298.

4.5.37. 2,3-Dihydrodibenzo[b,d]thiophene-4(1H)-thione; (**16**)

To a solution of ketone (47 mg, 0.23 mmol, 1 equiv.) in toluene (8 mL) was added Lawesson's reagent (202 mg, 0.5 mmol, 2 equiv.) and the solution heated to reflux for 4 h. The reaction mixture was allowed to cool to room temperature and concentrated to yield the crude material, which was purified by flash column chromatography (5% Et_2O/pentane). Green solid; 32 mg, 0.15 mmol, 59%. ^{1}H NMR (400 MHz, $CDCl_3$): δ_H 7.81 (2H, td, J = 7.7, 1.0 Hz), 7.49 (1H, ddd, J = 8.1, 7.1, 1.3 Hz), 7.39 (1H, ddd, J = 8.2, 7.1, 1.1 Hz), 3.19 (2H, m), 3.02 (2H, t, J = 6.2 Hz), 2.29 (2H, p, J = 6.3 Hz). ^{13}C NMR (101 MHz, $CDCl_3$): δ_C 227.9, 147.6, 144.4, 140.3, 139.1, 128.5, 125.1, 125.0, 123.1, 47.5, 24.9, 24.6. IR (neat, ν cm^{-1}) 3055, 2924, 2861, 1653, 1499, 1423, 1333, 1293, 1150. HRMS (FTMS + p) m/z calculated for $C_{12}H_{11}S_2$ $(M + H)^+$ 219.0297, found 219.0297.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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This paper is a contribution to the memory of a very dear friend who was a true scholar in his field of synthetic chemistry. Jon Williams was appointed to the chair of organic chemistry at 31 years of age and he was a creative and highly productive scientist before and during his 24 years as Professor of Organic Chemistry at the University of Bath. He was kind and gracious and he will be sorely missed by all those fortunate enough to have worked with him. We condole with his family and we know that his memory will live on.

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Appendix A. Supplementary data

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