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Synthesis of aromatic spiroacetals related to γ-rubromycin based on a 3*H*-spiro[1-benzofuran-2,2′-chromane] skeleton

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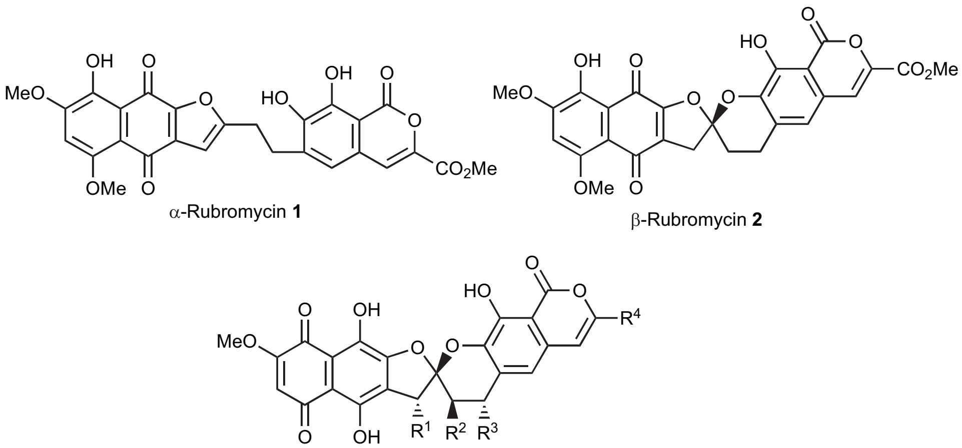
Abstract—The synthesis of a series of aromatic 5,6-benzannelated and naphthyl-benzannelated spiroacetals related to the spiroacetal unit present in the quinonoid antibiotic γ-rubromycin is reported. The key steps include the use of Sonogashira coupling to construct an aryl acetylene that is coupled to an aryl aldehyde forming a propargyl alcohol intermediate. Hydrogenation of the resultant alkynol followed by oxidation produces a masked dihydroxyketone that upon treatment with silica-supported sodium hydrogen sulfate undergoes concomitant deprotection and cyclisation to afford the desired fused aromatic spiroacetal.

1. Introduction

The rubromycins **1–3** (Fig. 1) are a family of quinonoid antibiotics isolated from cultures of *Streptomyces*[1] that exhibit activity against Gram-positive bacteria. β-Rubromycin **2** and γ-rubromycin **3** exhibit potent inhibition of human telomerase[2] (IC_{50} 3 μM) and are active against the reverse transcriptase of human immunodeficiency virus-1.[3] The presence of the unique aromatic spiroacetal ring system in these molecules in which benzannelated furan and pyran rings form a spiroacetal moiety is thought to be a key feature for the observed activity. α-Rubromycin **1**, which lacks this aryl spiroacetal moiety, exhibits substantially decreased inhibitory potency towards telomerase (IC_{50}>200 μM).



α-Rubromycin **1**

β-Rubromycin **2**

γ-Rubromycin **3**: R^1 = H, R^2 = H, R^3 = H, R^4 = CO_2Me
Purpuromycin **4**: R^1 = H, R^2 = H, R^3 = OH, R^4 = CO_2Me
Heliquinomycin **5**: R^1 = cymarose, R^2 = OH, R^3 = H, R^4 = CO_2Me
Heliquinomycinone **6**: R^1 = OH, R^2 = OH, R^3 = H, R^4 = CO_2Me
Griseorhodin C **7**: R^1 = OH, R^2 = OH, R^3 = OH, R^4 = Me
Griseorhodin G **8**: R^1 = OH, R^2 = OH, R^3 = H, R^4 = Me

Figure 1. The rubromycin family of antibiotics.

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Structurally related to the rubromycins are purpuromycin **4**,[4] a potential topical agent for vaginal infections,[5] heliquinomycin **5**,[6] an inhibitor of DNA helicase and the griseorhodins **7** and **8**.[7] Importantly, all of these compounds can also act as bioreductive alkylating agents as postulated by Moore.[8]

To date the elegant total synthesis of heliquinomycinone **6** reported by Danishefsky et al.[9] remains the only synthesis of a naturally occurring bis-benzannelated spiroacetal. Electrophilic spiroacetalization of a naphthofuran bearing a phenolic hydroxyl group as the nucleophilic partner allowed access to the key aromatic 5,6-spiroacetal ring system. Several syntheses of model bis-benzannelated and naphthyl-benzannelated spiroacetals have also been reported. de Koning et al.[10] reported the first synthesis of the bis-benzannelated spiroacetal ring system present in γ-rubromycin **3** using a Henry reaction to effect union of two aryl moieties, then a Nef reaction was used to liberate the masked carbonyl group required for generation of the spirocentre. Our research group have also communicated[11] the synthesis of several bis-benzannelated 5,6-spiroacetal analogues of the naturally occurring antibiotic γ-rubromycin **3**. We now herein report the full details of the synthesis of a larger series of bis-benzannelated and naphthyl-benzannelated 5,6-spiroacetals together highlighting some of the synthetic difficulties encountered.

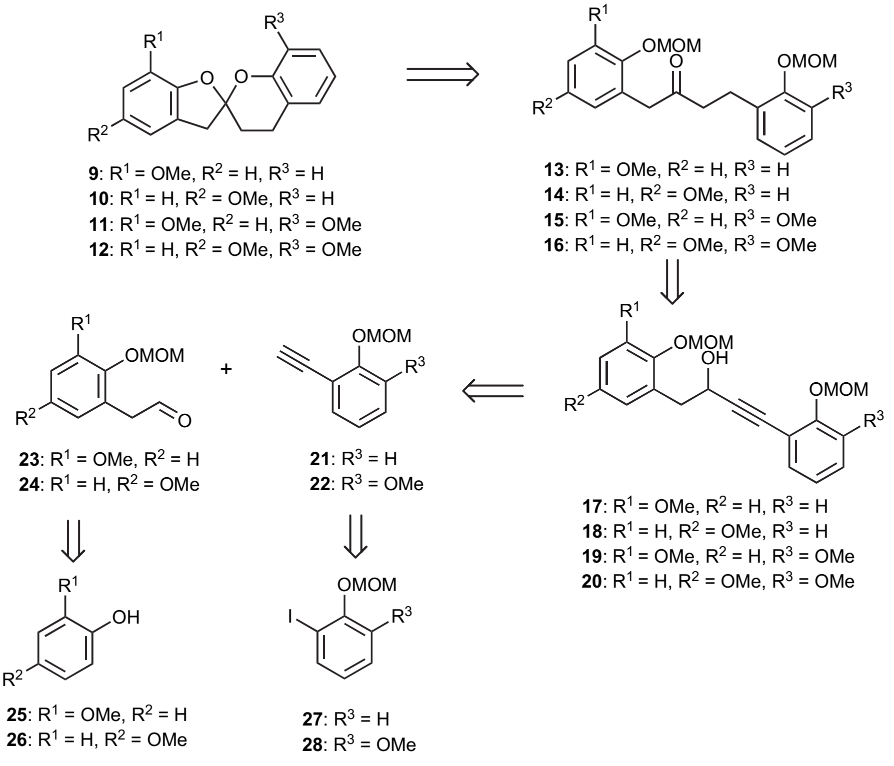
Since the time of our original communication of this work, Pettus et al.[12] have reported the synthesis of a naphthyl-benzannelated spiroacetal via [3+2] cycloaddition of an enol ether to a zwitterion. Kozlowski et al.[13] have reported the synthesis of bisphenolic spiroacetal and a naphthyl-benzannelated spiroacetal via [3+2] cycloaddition of a nitrile oxide to an olefin. The synthesis of a bis-benzannelated spiroacetal has also recently been reported by Reissig et al.[14] via addition of a lithiated methoxyallene to an aryl aldehyde followed by hydrogenation and acid catalysed spirocylisation.

2. Results and discussion

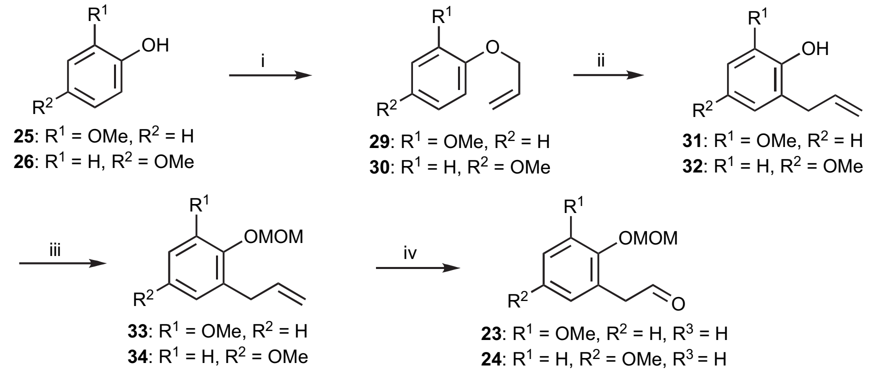
As part of our synthetic programme directed towards the synthesis of bioactive spiroacetal-containing natural products, we prepared the bis-benzannelated 5,6-spiroacetals **9–12** via acid catalysed cyclisation of MOM-protected diphenolic ketones **13–16** (Scheme 1). The required ketones **13–16** were obtained from aryl alkynols **17–20** after hydrogenation and oxidation. In turn, the required aryl alkynols **17–20** were constructed from the addition of the acetylides generated from acetylenes **21** and **22** to aryl aldehydes **23** and **24**. Aryl aldehydes **23** and **24** were readily prepared from the appropriate commercially available substituted phenols **25** and **26** whilst the acetylenes **21** and **22** were available from the corresponding MOM-protected aryl iodides **27** and **28** using the Sonogashira reaction.

Aryl aldehydes **23** and **24** were prepared from the readily available phenols **25** and **26** (Scheme 2). Allylation of phenols **25** and **26** afforded allylphenols, which then underwent Claisen rearrangement to provide allyl ethers **31** and **32** in good yield. Protection of the phenol as MOM ether followed by either ozonolysis or dihydroxylation–oxidative cleavage of the alkenes **33** and **34** furnished aldehydes **23** and **24**.

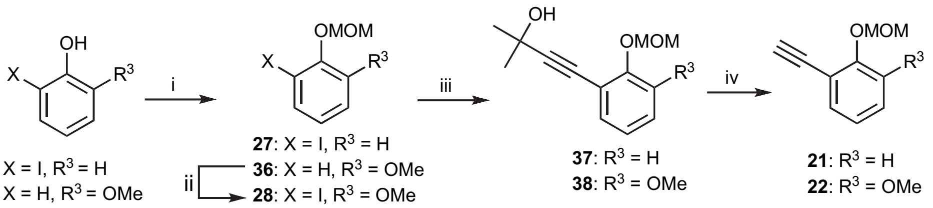
Acetylenes **21** and **22** were prepared from MOM ethers **27**[15] and **36**[16] (Scheme 3) derived from 2-iodophenol **35** and 2-methoxyphenol **25** with subsequent ortholithiation of **36**



Scheme 1.



Scheme 2. Reagents, conditions and yields: (i) allyl bromide, K_2CO_3, acetone, reflux, **29**, 87%; **30**, 89%; (ii) 180 °C, N_2, **31**, 70%; **32**, 84%; (iii) MOMCl, $^i Pr_2NEt$, CH_2Cl_2, 0 °C, **33**, 83% or NaH, DMF, MOMCl, **34**, 80%; (iv) O_3, MeOH, −50 °C, then Me_2S, **23**, 83% or cat. OsO_4, $NaIO_4$, THF–H_2O (4:1), 0 °C→rt, **24**, 51%.



Scheme 3. Reagents, conditions and yields: (i) MOMCl, $^i Pr_2EtN$, CH_2Cl_2, 0 °C→rt, **27**, 89%; **36**, 99%; (ii) ^{n}BuLi, THF, −15 °C→−45 °C, I_2, **28**, 32%; (iii) PPh_3, $PdCl_2(PPh_3)_2$, 2-methyl-3-butyn-2-ol, Et_3N, CuI, 80 °C **37**, 88%; **38**, 94%; (iv) NaOH, toluene, reflux, **21**, 70%; **22**, 78%.

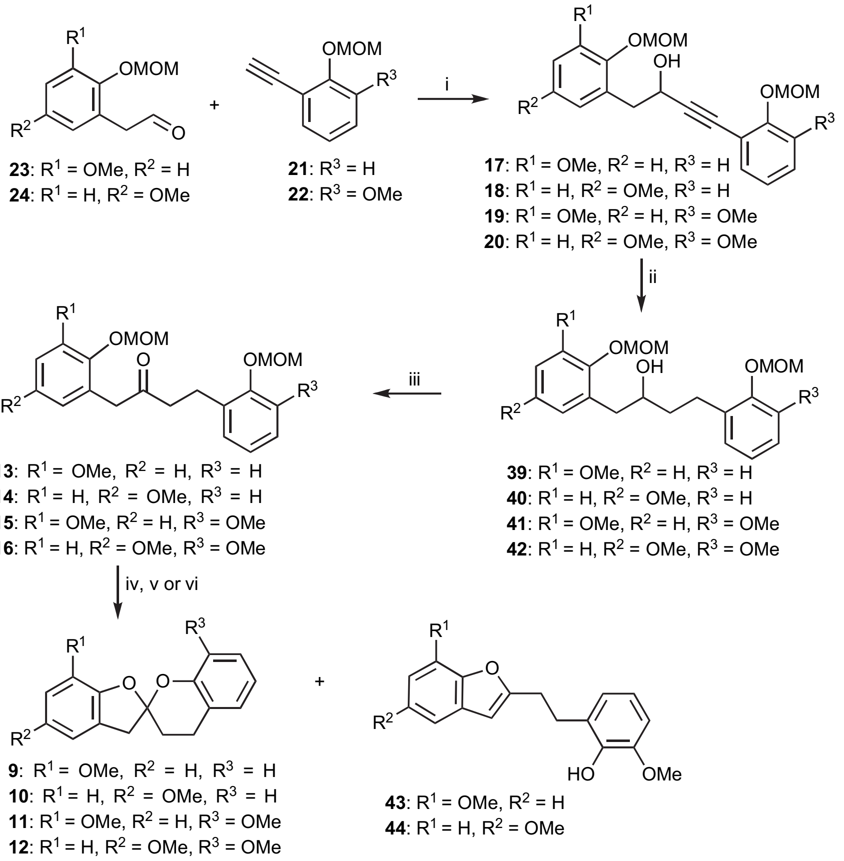
followed by iodination affording iodide **28**. Sonogashira coupling of iodides **27** and **28** with 2-methyl-3-butyn-2-ol followed by pyrolysis of the resultant tertiary acetylenic alcohols **37** and **38** under basic conditions provided acetylenes **21** and **22**.

With both acetylenes **21** and **22** and aldehydes **23** and **24** in hand, the synthesis continued with the coupling of these two subunits to construct bis-benzannelated 5,6-spiroacetals **9**–**12** (Scheme 4). The key step involved addition of the lithium acetylide generated from the appropriate acetylenes **21** and **22** using butyllithium at −78 °C, to the appropriate aldehydes **23** and **24**. Hydrogenation of the resultant alkynes **17**–**20** in ethyl acetate buffered with potassium carbonate over 10% palladium on carbon provided the saturated secondary alcohols **39**–**42** in good yield. Oxidation of the alcohols **39**–**42** using tetra-*n*-propylammonium perruthenate (TPAP), 4-methylmorpholine *N*-oxide (NMO) and 4 Å molecular sieves in dichloromethane then afforded the ketone precursors **13**–**16** en route to the spiroacetals.

With spiroacetal precursors **13**–**16** in hand, only deprotection of the MOM groups with ensuing spirocyclisation was required. Treatment of ketone **13** with a mixture of trifluoroacetic acid–water–tetrahydrohydran (4:1:1) for 30 min afforded a diol, which spontaneously cyclised to give spiroacetal **9** in 28% yield (Table 1, entry A). A similar yield was obtained when the reaction was carried out in dichloromethane (entry B). Attempts to effect deprotection and cyclisation by heating ketone **13** with concentrated hydrochloric acid in methanol resulted in a lower 13% yield of spiroacetal **9** together with unreacted ketone **13** (entry C). Heating ketone **13** in 50% acetic acid in the presence of catalytic amount of sulfuric acid at 62 °C for 5.5 h afforded a complex mixture of product (entry D). Heating ketone **13** with *p*-toluenesulfonic acid in dioxane–water (3:1) at 55 °C for 60 h afforded spiroacetal **9** in 33% yield (entry E). When the reaction was carried out at 80 °C with a prolonged reaction time of 81 h, only a complex mixture was afforded (entry F). Changing the solvent to dichloromethane resulted in a lower yield (22%) of spiroacetal **9** (entry G).

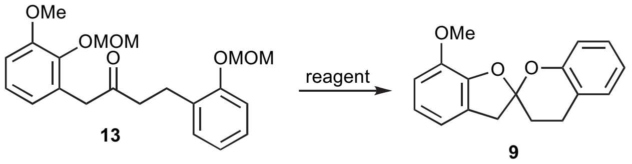
Treatment of ketone **13** with bromotrimethylsilane (4 equiv) in the presence of 4 Å molecular sieves in dichloromethane at −30 °C for 2 h followed by slowly warming the reaction mixture to room temperature and stirring for 5.5 h afforded spiroacetal **9** in 15% yield (entry H). Using a large excess of bromotrimethylsilane (8.4 equiv) the yield increased to 30% yield (entry I). This result suggests that the use of excess reagent with gradual warming of the reaction mixture was critical to the success of the reaction. Treatment of ketone **13** with bromotrimethylsilane (10 M equiv) in the presence of 4 Å molecular sieves in dichloromethane at −30 °C for 1 h followed by slowly warming to 0 °C and stirring for 4 h afforded spiroacetal **9** in 56% yield (entry J). In order to slow the sudden change in reaction temperature, the reaction was kept at −30 °C for 1 h, slowly warmed to 0 °C, stirred for 10 h, then finally warmed to room temperature for 11 h. Gratifyingly, this procedure afforded the desired spiroacetal **9** in 86% yield (entry K).

Having optimised the conditions for the cyclisation step using ketone **13**, ketone **14** was next subjected to deprotection and cyclisation using trimethylsilyl bromide (10 equiv) in dichloromethane in the presence of 4 Å molecular sieves affording spiroacetal **10** in moderate yield. Applying the same conditions to ketone **15** however, afforded a single product in 86% yield, which was identified as benzofuran



Scheme 4. Reagents, conditions and yields: (i) ^{n}BuLi, THF, −78 °C, 2–5 h, **17**, 61%; **18**, 67%; **19**, 69%; **20**, 67%; (ii) 10% Pd–C, H_2, K_2CO_3, EtOAc, 1 h–overnight, **39**, 88%; **40**, 96%; **41**, 82%; **42**, 97%; (iii) TPAP, NMO, 4 Å MS, CH_2Cl_2, 0.5–3 h, **13**, 89%; **14**, 65%; **15**, 84%; **16**, 98%; (iv) TMSBr, CH_2Cl_2, 4 Å MS, −30 °C→0 °C→rt, **9**, 86%; **10**, 51%; **43**, 86%; (v) $NaHSO_4\cdot SiO_2$, CH_2Cl_2, rt, 3 h, **11**, 43%; **44**, 50%; (vi) $NaHSO_4\cdot SiO_2$, CH_2Cl_2, rt, 5 min, **12**, 60%.

Table 1. Summary of reaction conditions used for the deprotection and cyclisation of ketone **13**



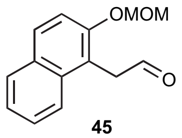
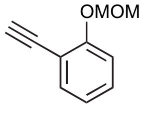
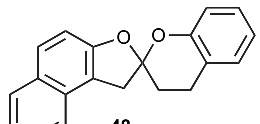
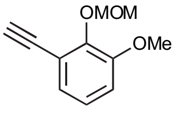
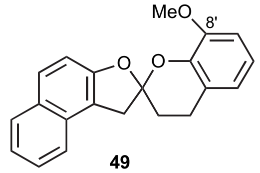
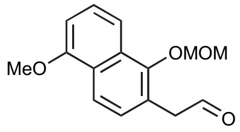
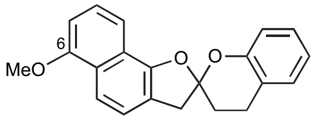
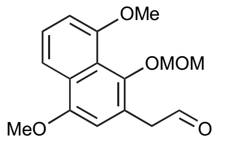
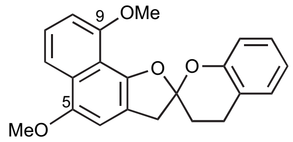
Entry	Reagents and conditions	Yield (%)
A	TFA–H_2O–THF (4:1:1), rt, 30 min	28
B	TFA, CH_2Cl_2, rt, 22 h	24
C	Concd HCl, anhydrous MeOH, 62 °C, 22 h	13
D	cat. H_2SO_4, 50% AcOH, reflux, 5.5 h	Complex mixture
E	*p*-TsOH, dioxane–H_2O (3:1), 55–60 °C, 60 h	33
F	*p*-TsOH, dioxane–H_2O (3:1), 80 °C, 81.5 h	Complex mixture
G	*p*-TsOH, CH_2Cl_2–H_2O (3:1), 50 °C, 84 h	22
H	TMSBr (4 equiv), CH_2Cl_2, 4 Å MS, −30 °C (2 h)→rt (5.5 h)	15
I	TMSBr (8.4 equiv), CH_2Cl_2, 4 Å MS, −30 °C (2 h)→5 °C (5.5 h)	30
J	TMSBr (10 equiv), CH_2Cl_2, 4 Å MS, −30 °C (1 h)→0 °C (4 h)	56
K	TMSBr (10 equiv), CH_2Cl_2, 4 Å MS, −30 °C (1 h)→0 °C (10 h)→rt (11 h)	86

43 (Scheme 4). The formation of benzofuran **43** was supported by the observation of a four proton singlet at δ_H 3.10 ppm in the ^{1}H NMR spectrum assigned to the methylene groups H-1′ and H-2′ together with a broad OH resonance at δ_H 5.75 ppm and a characteristic vinylic proton H-3″ at δ_H 6.38 ppm. It should be noted that in our earlier communication of this work deprotection of ketone **15** to spiroacetal **11** using trimethylsilyl bromide was reported to proceed in 77% yield. However, this result was not found to be reproducible despite several attempts at this reaction.

Fortunately, treatment of ketone **15** with activated silica-supported sodium hydrogen sulfate[17] in dichloromethane at room temperature for 3 h successfully afforded the desired spiroacetal **11** in 43% yield. The analogous ketone **20** was stirred in dichloromethane with activated silica-supported sodium hydrogen sulfate at room temperature for 5 min resulting in the formation of spiroacetal **12** in 60% yield. It was also observed that use of a prolonged reaction time of 3 h resulted in the formation of the undesired benzofuran **44**. This result suggests that spiroacetal **12** is the kinetic product of the reaction with shorter reaction times resulting in the formation of spiroacetal **12** rather than the thermodynamically favoured benzofuran **44**.

Having successfully synthesised the monosubstituted **9** and **10** and disubstituted bis-benzannelated spiroacetals **11** and **12**, synthesis of naphthyl-benzannelated spiroacetals

Table 2. Structures of naphthyl-benzannelated spiroacetals together with the naphthaldehydes and aryl acetylenes required for their synthesis

Naphthaldehyde	Aryl acetylene	Aryl spiroacetal
 **45**	 **21**	 **48**
45	 **22**	 **49**
 **46**	**21**	 **50**
 **47**	**21**	 **51**

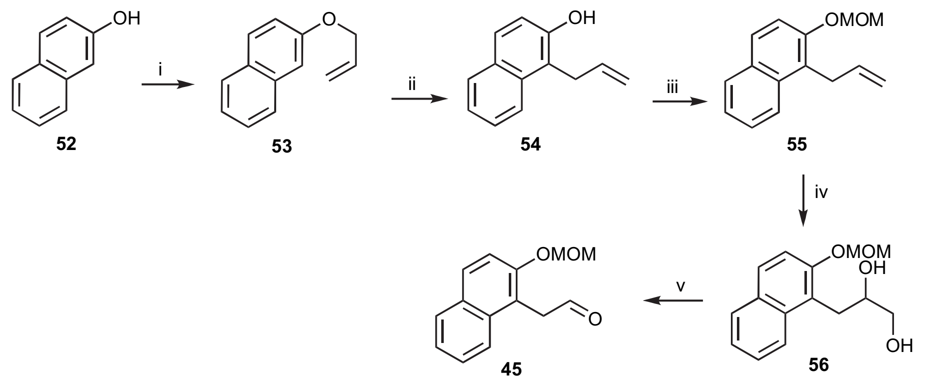
48–**51** was next investigated. The required naphthaldehydes **45**–**47**, acetylenes **21** and **22** and the corresponding spiroacetals **48**–**51** are depicted in Table 2.

With aryl acetylenes **21** and **22** in hand, attention next focused on the synthesis of naphthaldehydes **45**–**47**. Naphthaldehyde **45** was synthesised from 2-naphthol **52** in five steps via the sequence of allylation, Claisen rearrangement, MOM protection, dihydroxylation and oxidative cleavage (Scheme 5).

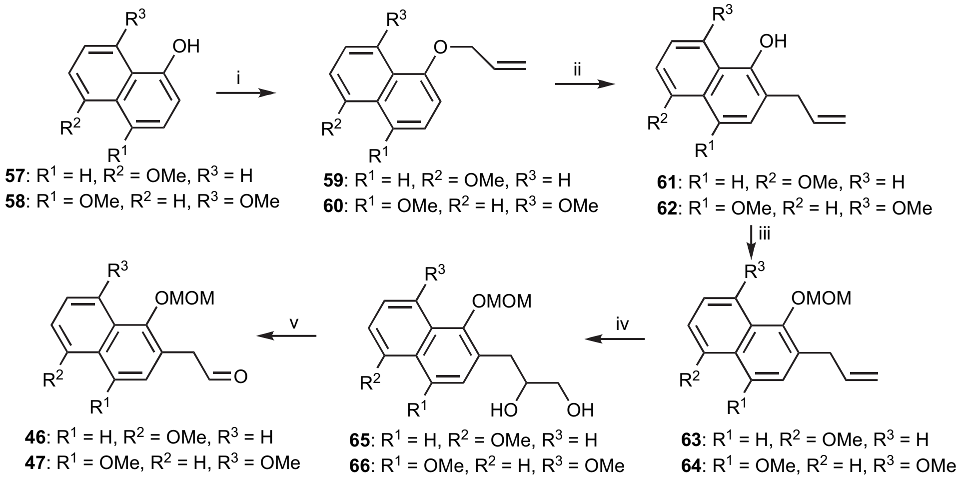
Naphthaldehydes **46** and **47** were also prepared from naphthols **57** and **58**, respectively (Scheme 6), via a sequence involving allylation, Claisen rearrangement, protection of the naphthol and finally formation of the aldehyde via dihydroxylation–oxidative cleavage. Naphthol **57**[18] was prepared according to the method reported by Giles et al. with a slight modification. Naphthol **58** was readily prepared following our reported procedure.[19]

Naphthyl-benzannelated 5,6-spiroacetals **48** and **49** (Scheme 7) and **50** (Scheme 8) were prepared by union of the appropriate aryl acetaldehyde with the appropriate acetylide followed by hydrogenation, oxidation and cyclisation using activated silica-supported sodium hydrogen sulfate.

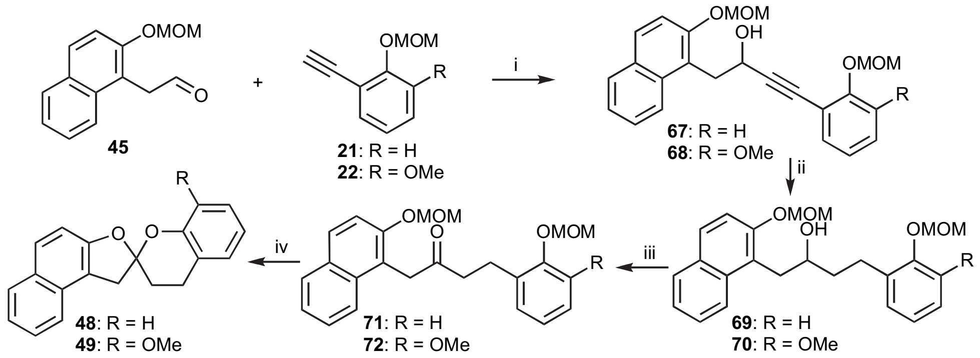
Treatment of ketones **78** with activated silica-supported sodium hydrogen sulfate in dichloromethane at room temperature for 5 min gave benzofurans **79** and **80** in 20% and 37% yield, respectively. The formation of benzofurans **79** and **80** in the cyclisation step is probably due to the steric hindrance by the methoxy group at C-9 that results in the formation of a benzofuran to alleviate unfavourable steric interactions in the initially formed spiroacetal **51**. Attempts to deprotect the MOM ethers and effect cyclisation of ketone **78** with Montmorillonite K10[20] in benzene at room temperature in the hope of obtaining the desired spiroacetal **51**, only afforded benzofuran **80** in 20% yield together with unreacted ketone **78**.



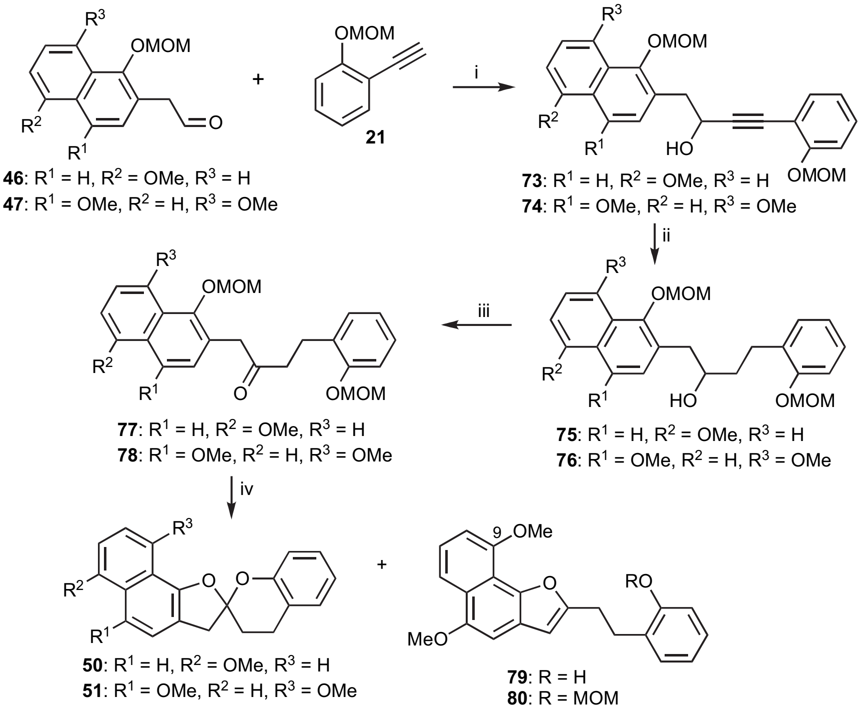
Scheme 5. Reagents, conditions and yields: (i) allyl bromide, K_2CO_3, Me_2CO, reflux, 19 h, 99%; (ii) 200 °C, N_2, 2.5 h, 70%; (iii) NaH, DMF, MOMCl, 1 h, rt, 83%; (iv) cat. OsO_4, NMO, Me_2CO–H_2O (8:1), 16 h, 72%; (v) $NaIO_4$, CH_2Cl_2–H_2O (5:3), 45 min, 62%.



Scheme 6. Reagents, conditions and yields: (i) allyl bromide, K_2CO_3, Me_2CO, reflux, 24 h, **59**, 94% or allyl bromide, NaH, DMF, 2.5 h, **60**, 72%; (ii) 210 °C, *m*-xylene, 19 h, **61**, 100%; **62**, 99%; (iii) NaH, DMF, MOMCl, 1 h, **63**, 85%; **64**, 92%; (iv) cat. OsO_4, NMO, Me_2CO–H_2O (8:1), 24 h, **65**, 89%; **66**, 90%; (v) $NaIO_4$, CH_2Cl_2–H_2O (5:3), 24 h, **46**, 88%; **47**, 40%.



Scheme 7. Reagents, conditions and yields: (i) ^{n}BuLi, THF, −78 °C, 3–4 h, **67**, 81%; **68**, 76%; (ii) Pd–C, H_2, K_2CO_3, EtOAc, 3.5–10 h, **69**, 86%; **70**, 83%; (iii) TPAP, NMO, 4 Å MS, CH_2Cl_2, 1.5–2.5 h, **71**, 91%; **72**, 83%; (iv) $NaHSO_4 \cdot SiO_2$, CH_2Cl_2, rt, 5 min, **48**, 43%; **49**, 41%.



Scheme 8. Reagents, conditions and yields: (i) ^{n}BuLi, THF, −78 °C, 3 h, **73**, 78%; **74**, 67%; (ii) 10% Pd–C, H_2, K_2CO_3, EtOAc, 1.5–2.5 h, **75**, 74%; **76**, 91%; (iii) TPAP, NMO, 4 Å MS, CH_2Cl_2, 1–4 h, **77**, 92%; **78**, 60%; (iv) $NaHSO_4 \cdot SiO_2$, CH_2Cl_2, rt, 5 min, **50**, 47%; **79**, 20% and **80**, 37%.

In summary, seven aryl 5,6-spiroacetals, analogous to the spiroacetal unit in the telomerase inhibitor γ-rubromycin **3**, have been prepared starting from appropriate aryl aldehydes and aryl acetylenes. The synthetic strategy was sufficiently flexible to allow the preparation of a series of bis-benzannelated 5,6-spiroacetals as well as naphthyl-benzannelated 5,6-spiroacetals, which differ in the orientation of the naphthalene ring. It is postulated that in the attempted spirocyclisation of ketone **78**, steric hindrance associated with the *peri*-methoxy group at C-9 in the starting ketone **78** leads to the formation of a benzofuran to alleviate unfavourable steric interactions in the initially formed spiroacetal **51**. Hence, the limitation in the method developed herein is the formation of undesired benzofurans when substituents preclude the formation of sterically congested aryl 5,6-spiroacetals.

3. Experimental

3.1. General details

Dichloromethane, toluene and triethylamine were distilled from calcium hydride prior to use. Tetrahydrofuran was dried over sodium/benzophenone and distilled before use. Glassware was oven or flame-dried under an atmosphere of nitrogen. Reactions were carried out under an atmosphere of nitrogen unless otherwise specified. Infrared spectra (IR) were obtained using Perkin–Elmer Spectrum 1000 Fourier Transform Infrared spectrometer from thin films between sodium chloride plates. Absorption peaks are expressed in wave numbers (cm^{-1}) and were measured between 450 and 4000 cm^{-1} and the absorption strengths are expressed by the following abbreviations: s=strong, m=medium, w=weak, and br=broad. NMR spectra were recorded on a Bruker DRX300 spectrometer operating at 300 MHz for ^1H nuclei and 75 MHz for ^{13}C nuclei or on a Bruker DRX400 spectrophotometer operating at 400 MHz for ^1H nuclei and 100 MHz for ^{13}C nuclei. Chemical shifts are recorded as parts per million (ppm) downfield from tetramethylsilane (TMS) as the internal standard or relative to the ^1H in $CDCl_3$. The ^{13}C values were referenced to the residual chloroform peak at δ 77.0 ppm. ^{13}C shifts are reported as chemical shift and assignment. ^1H shifts are reported as chemical shift, relative integral, multiplicity, coupling constant and assignment. ^1H NMR data are reported as s (singlet); d (doublet); dd (doublet of doublets); dt (doublet of triplets); ddd (doublet of doublets of doublets); t (triplet); q (quartet); m (multiplet); br (broad). *J* values are given in hertz. Assignments were all made with the aid of DEPT 135, COSY and HSQC experiments where required. Low-resolution mass spectra were recorded using a VG70-SE spectrometer operating at nominal accelerating voltage of 70 eV. High-resolution mass spectra were recorded using a VG70-SE spectrometer operating at nominal resolution of 5000 to 10,000 as appropriate. Fragmentation was induced using desorptive electron impact (DEI^+), electron impact (EI) or fast atom bombardment (FAB^+). Fast atom bombardment (FAB) mass spectra were obtained using 3-nitrobenzyl alcohol as the matrix. Major and significant fragments are quoted in the form *x*(*y*), where *x* is the mass to charge ratio and *y* is the percentage abundance relative to the base peak. Purification by flash chromatography was performed using Merck silica gel 0.0063–0.10 mm with the solvent systems indicated. Thin layer chromatography (TLC) was run on silica precoated aluminium plates (Merck Kieselgel F_{254}). Compounds were visualised under UV fluorescence and by staining with vanillin in methanolic acid followed by heating. Melting points were determined on a Kofler hot-stage apparatus and are uncorrected.

3.2. Standard procedures for allylation of phenols and naphthols

3.2.1. Procedure A—heating in acetone with K_2CO_3. To a stirred solution of the appropriate phenol (1 mmol) in acetone (5 mL) were added potassium carbonate (4 mmol) and allyl bromide (1 mmol). The mixture was heated under reflux for 4–24 h, cooled to room temperature, filtered and the filtrate was concentrated under reduced pressure. The residue was dissolved in dichloromethane (5 mL) and washed sequentially with 1 M aqueous sodium hydroxide (5 mL), water (5 mL) and brine (5 mL). The organic layer was dried over magnesium sulfate and concentrated under reduced pressure. The resultant residue was purified by flash column chromatography.

3.2.2. Procedure B—using sodium hydride in DMF. To a stirred solution of the appropriate naphthol (1 mmol) in anhydrous *N*,*N*-dimethylformamide (2 mL) at 0 °C, pure sodium hydride (1.05 mmol) was added portionwise. After 30 min, allyl bromide (1.3 mmol) was added dropwise and the resultant reaction mixture was warmed to room temperature and stirred for another 2 h. Water (5 mL) was added and the reaction mixture was extracted with diethyl ether (5 mL). The combined organic extracts were washed with 1 M NaOH (5 mL), 10% HCl (5 mL), brine (5 mL), dried over $MgSO_4$ and concentrated under reduced pressure. The resultant residue was purified by flash column chromatography.

3.2.3. Allyl 2-methoxyphenyl ether 29.[21] Pale yellow oil; the spectral data were in agreement with the literature value. δ_H (300 MHz, $CDCl_3$): 3.86 (3H, s, OMe), 4.60 (2H, dt, $J_{1',3'}$ 1.5 and $J_{1',2'}$ 5.1 Hz, H-1′), 5.27 (1H, dd, $J_{3'A,1'}$ 1.5 and $J_{3'A,2'}$ 10.5 Hz, H-$3'_A$), 5.39 (1H, dd, $J_{3'B,1'}$ 1.5 and $J_{3'B,2'}$ 17.3 Hz, H-$3'_B$), 6.04–6.07 (1H, m, H-2′), 6.88–6.91 (4H, m, H-3, H-4, H-5 and H-6). δ_C (75 MHz, $CDCl_3$): 55.8 (CH_3, OMe), 69.8 (CH_2, C-1′), 111.7 (CH, Ar-C), 113.5 (CH, Ar-C), 117.9 (CH_2, C-3′), 120.7 (CH, Ar-C), 121.2 (CH, Ar-C), 133.4 (CH, C-2′), 147.9 (quat., C-1 or C-2), 149.4 (quat., C-2 or C-1).

3.2.4. Allyl 4-methoxyphenyl ether 30.[22] Pale yellow oil; the spectral data were in agreement with the literature values. δ_H (300 MHz, $CDCl_3$): 3.75 (3H, s, OMe), 4.47 (2H, dt, $J_{1',3'}$ 1.5 and $J_{1',2'}$ 5.3 Hz, H-1′), 5.26 (1H, dq, $J_{3'A,1'}$ 1.5, $J_{3'A,3'B}$ 3.1 and $J_{3'A,2'}$ 10.5 Hz, H-$3'_A$), 5.39 (1H, dq, $J_{3'B,1'}$ 1.7, $J_{3'B,3'A}$ 3.1 and $J_{3'B,2'}$ 17.3 Hz, H-$3'_B$), 5.98–6.10 (1H, m, H-2′), 6.79–6.88 (4H, m, Ar-H). δ_C (75 MHz, $CDCl_3$): 55.6 (CH_3, OCH_3), 69.5 (CH_2, C-1′), 114.6 (CH, 2×Ar-C), 115.7 (CH, 2×Ar-C), 117.4 (CH_2, C-3′), 133.6 (CH, C-2′), 152.7 (quat., C-1), 153.9 (quat., C-4).

3.2.5. 2-Allyloxynaphthalene 53.[23] Yellow oil; the spectral data were in agreement with the literature.[23] δ_H (400 MHz,

$CDCl_3$): 4.62 (2H, dt, $J_{1',3'}$ 1.4 and $J_{1',2'}$ 5.4 Hz, H-1′), 5.30 (1H, dt, $J_{3'A,1'}$ 1.4, $J_{3'A,3'B}$ 2.8 and $J_{3'A,2'}$ 10.6 Hz, H-$3'_A$), 5.45 (1H, dt, $J_{3'B,1'}$ 1.5, $J_{3'B,3'A}$ 3.0 and $J_{3'B,2'}$ 17.2 Hz, H-$3'_B$), 6.02–6.15 (1H, m, H-2′), 7.11 (1H, d, $J_{1,3}$ 2.3 Hz, H-1), 7.17 (1H, dd, $J_{3,1}$ 2.3 and $J_{3,4}$ 8.9 Hz, H-3), 7.31 (1H, dt, $J_{6,8}$ 1.1 and $J_{6,7}=J_{6,5}$ 8.1 Hz, H-6), 7.41 (1H, dt, $J_{7,5}$ 1.1 and $J_{7,8}=J_{7,6}$ 8.1 Hz, H-7), 7.69–7.77 (3H, m, H-8, H-4 and H-5). δ_C (100 MHz, $CDCl_3$): 68.8 (CH_2, C-1′), 107.0 (CH, C-1), 117.7 (CH_2, C-3′), 118.9 (CH, C-3), 123.6 (CH, C-6), 126.3 (CH, C-7), 126.7 (CH, C-8 or C-5 or C-4), 127.6 (CH, C-5 or C-8 or C-4), 129.0 (quat., C-4a), 129.4 (CH, C-4 or C-8 or C-5), 133.2 (CH, C-2′), 134.5 (quat., C-8a), 156.5 (quat., C-2).

3.2.6. Allyl 5-methoxynaphthalen-1-yl ether 59. Yellow solid. Mp: 89–90 °C. HRMS (EI): Found M^+, 214.09902, $C_{14}H_{14}O_2$ requires 214.09938. ν_{max} (film)/cm^{-1}: 3053 (s, CH, aromatic), 2986 (s, CH), 1594, 1507, 1407 (s, C=C, aromatic), 1265, 1211, 1078, 1061 (s, C–O). δ_H (400 MHz, $CDCl_3$): 3.93 (3H, s, OMe), 4.65 (2H, dt, $J_{1',3'}$ 1.5 and $J_{1',2'}$ 5.1 Hz, H-1′), 5.29 (1H, dd, $J_{3A,1'}$ 1.5 and $J_{3'A,2'}$ 10.6 Hz, H-$3'_A$), 5.48 (1H, dd, $J_{3'B,1'}$ 1.5 and $J_{3'B,2'}$ 17.3 Hz, H-$3'_B$), 6.08–6.18 (1H, m, H-2′), 6.79 (2H, d, $J_{2,3}=J_{6,7}$ 7.6 Hz, H-2 and H-6), 7.30–7.37 (2H, m, H-3 and H-7), 7.84 (1H, d, $J_{8,7}$ 8.5 Hz, H-8), 7.89 (1H, d, $J_{4,3}$ 8.5 Hz, H-4). δ_C (100 MHz, $CDCl_3$): 55.4 (CH_3, OMe), 68.9 (CH_2, C-1′), 104.5 (CH, C-2), 105.8 (CH, C-6), 114.3 (2×CH, C-8 and C-4), 117.2 (CH_2, C-3′), 125.0 (2×CH, C-3 and C-7), 126.7 (2×quat., C-8a and C-4a), 133.3 (CH, C-2′), 154.1 (quat., C-1), 155.2 (quat., C-5); *m/z* (EI, %): 214 (M^+, 42), 199 (M^+-Me, 9), 185 (M^+-29, 42), 173 ($M^+-CH_2CH{=}CH_2$, 100), 145 (12), 143 (11), 115 (46).

3.2.7. Allyl 1,5-dimethoxynaphthalen-4-yl ether 60. White powder. Mp: 95–98 °C. HRMS (EI): Found M^+, 244.10972, $C_{15}H_{16}O_3$ requires 244.10994. ν_{max} (film)/cm^{-1}: 3053 (s, C–H, aromatic), 2960 (s, CH), 2252, 1597, 1459, 1409 (s, C=C, aromatic), 1272, 1076, 1048 (s, C–O), 909, 802, 732, 650. δ_H (300 MHz, $CDCl_3$): 3.93 (3H, s, OMe), 3.94 (3H, s, OMe), 4.56 (2H, dt, $J_{1',3'}$ 1.6 and $J_{1',2'}$ 4.9 Hz, H-1′), 5.31 (1H, dd, $J_{3'A,1'}$ 1.6 and $J_{3'A,2'}$ 10.7 Hz, H-$3'_A$), 5.57 (1H, dd, $J_{3'B,1'}$ 1.6 and $J_{3'B,2'}$ 17.2 Hz, H-$3'_A$), 6.11–6.24 (1H, m, H-2′), 6.83 (1H, d, $J_{2,3}$ 8.4 Hz, H-2), 6.86 (1H, d, $J_{3,2}$ 8.4 Hz, H-3), 6.90 (1H, d, $J_{6,7}$ 8.1 Hz, H-6), 7.38 (1H, t, $J_{7,8}=J_{7,6}$ 8.1 Hz, H-7), 7.85 (1H, dd, $J_{8,6}$ 0.9 and $J_{8,7}$ 8.1 Hz, H-8). δ_C (75 MHz, $CDCl_3$): 55.7 (CH_3, OMe), 56.2 (CH_3, OMe), 72.0 (CH_2, C-1′), 104.2 (CH, C-3), 107.0 (CH, C-2), 110.1 (CH, C-6), 114.6 (CH, C-8), 116.5 (CH_2, C-3′), 119.1 (quat., C-4a), 125.8 (CH, C-7), 128.8 (quat., C-8a), 134.1 (CH, C-2′), 149.5 (quat., C-4), 150.0 (quat., C-1), 156.7 (quat., C-5); *m/z* (EI, %): 244 (M^+, 57%), 203 ($M^+-CH_2CH{=}CH_2$, 100), 185 (8), 175 (28), 173 (9), 160 (22), 145 (17), 130 (11), 115 (15), 102 (9), 91 (5), 41 (11).

3.3. Standard procedure for Claisen rearrangement of allyl ethers

A mixture of allyl ether (1 mmol) in *m*-xylene (5 mL) was heated at 180 °C or 210 °C under a nitrogen atmosphere. The reaction mixture was allowed to cool and subjected to flash column chromatography.

3.3.1. 2-Methoxy-6-(prop-2-enyl)phenol 31.[10] Clear oil; the spectral data were in agreement with the literature values.[10] δ_H (300 MHz, $CDCl_3$): 3.41 (2H, dd, $J_{1',3'}$ 1.4 and $J_{1',2'}$ 6.6 Hz, H-1′), 3.87 (3H, s, OMe), 5.03–5.11 (2H, m, H-3′), 5.71 (1H, s, OH), 5.94–6.08 (1H, m, H-2′), 6.67–6.83 (2H, m, H-4 and H-6), 6.84–6.86 (1H, m, H-5). δ_C (75 MHz, $CDCl_3$): 33.8 (CH_2, C-1′), 56.0 (CH_3, OMe), 108.6 (CH, C-3 or C-5), 115.4 (CH_2, C-3′), 119.4 (CH, C-5 or C-3), 122.2 (CH, C-4), 125.8 (quat., C-6), 136.6 (CH, C-2′), 143.3 (quat., C-1 or C-2), 146.3 (quat., C-2 or C-1).

3.3.2. 2-Allyl-4-methoxyphenol 32. Clear oil. HRMS (EI): Found M^+, 206.09424 (recorded as acetate derivative), $C_{12}H_{14}O_3$ requires 206.09429. ν_{max} (film)/cm^{-1}: 3400 (br, s, OH), 3065 ($CH{=}CH_2$), 2938, 2833 (s, CH, aromatic), 1637, 1602 (C=C, aromatic), 1277, 1206 (s, C–O), 1152, 1112, 1039. δ_H (300 MHz, $CDCl_3$): 3.36 (2H, d, $J_{1',2'}$ 6.3 Hz, H-1′), 3.74 (3H, s, OMe), 5.08–5.15 (2H, m, H-3′), 5.23 (1H, br s, OH), 5.91–6.05 (1H, m, H-2′), 6.63–6.73 (3H, m, Ar-H). δ_C (75 MHz, $CDCl_3$): 34.9 (CH_2, C-1′), 55.7 (CH_3, OMe), 112.5 (CH, C-5), 115.9 (CH, C-3), 116.2 (CH_2, C-3′), 116.3 (CH, C-6), 126.8 (quat., C-2), 136.2 (CH, C-2′), 147.9 (quat., C-1), 153.5 (quat., C-4); *m/z* (EI, %): 206 (M^+, 11), 164 (100), 149 (42), 133 (5), 131 (4), 121 (7), 107 (4), 103 (6), 91 (8), 77 (7).

3.3.3. 1-Allyl-2-naphthol 54.[23] Yellow oil; the spectral data were in agreement with the literature values.[23] δ_H (400 MHz, $CDCl_3$): 3.80 (2H, d, $J_{1',2'}$ 5.7 Hz, H-1′), 5.02–5.89 (2H, m, H-3′), 5.32 (1H, br s, OH), 6.00–6.08 (1H, m, H-2′), 7.04 (1H, d, $J_{3,4}$ 8.8 Hz, H-3), 7.31 (1H, t, $J_{6,5}=J_{6,7}$ 7.6 Hz, H-6), 7.45 (1H, dt, $J_{7,5}$ 0.9 and $J_{7,8}=J_{7,6}$ 7.6 Hz, H-7), 7.62 (1H, d, $J_{4,3}$ 8.8 Hz, H-4), 7.74 (1H, d, $J_{8,7}$ 7.6 Hz, H-5), 7.88 (1H, d, $J_{5,6}$ 7.6 Hz, H-8). δ_C (100 MHz, $CDCl_3$): 29.2 (CH_2, C-1′), 115.8 (CH_2, C-3′), 116.9 (quat., C-1), 117.9 (CH, C-3), 123.0 (CH, C-6), 123.1 (CH, C-8), 126.4 (CH, C-7), 128.3 (CH, C-4), 128.5 (CH, C-5), 129.4 (quat., C-4a), 133.2 (quat., C-8a), 135.8 (CH, C-2′), 151.1 (quat., C-2).

3.3.4. 5-Methoxy-(2-propen-1-yl)naphthalen-1-ol 61. Pale yellow solid. Mp: 70–72 °C. HRMS (EI): Found M^+, 214.09901, $C_{14}H_{14}O_2$ requires 214.09938. ν_{max} (film)/cm^{-1}: 3497 (s, br, OH), 3053 (s, CH, aromatic), 2985 (CH), 1600 (C=C, aromatic), 1264, 1059 (s, C–O), 925. δ_H (300 MHz, $CDCl_3$): 3.52 (2H, d, $J_{1',2'}$ 6.1 Hz, H-1′), 3.95 (3H, s, OMe), 5.18–5.22 (2H, m, H-3′), 5.51 (1H, br s, OH), 5.98–6.11 (1H, m, H-2′), 6.77 (1H, d, $J_{6,7}$ 8.1 Hz, H-6), 7.18 (1H, d, $J_{3,4}$ 8.5 Hz, H-3), 7.35 (1H, t, $J_{7,6}=J_{7,8}$ 8.1 Hz, H-7), 7.71 (1H, d, $J_{8,7}$ 8.1 Hz, H-8), 7.80 (1H, d, $J_{4,3}$ 8.5 Hz, H-4). δ_C (75 MHz, $CDCl_3$): 35.6 (CH_2, C-1′), 55.5 (CH_3, OMe), 103.8 (CH, C-6), 113.5 (CH, C-8), 114.4 (CH, C-4), 116.8 (CH_2, C-3′), 118.7 (quat., C-2), 125.3 (CH, C-7), 125.8 (quat., C-8a), 125.9 (quat., C-4a), 127.6 (CH, C-3), 136.4 (CH, C-2′), 149.3 (quat., C-1), 155.3 (quat., C-5); *m/z* (EI, %): 214 (M^+, 100), 199 (M^+-Me, 48), 171 (22), 128 (13), 115 (17), 107 (4).

3.3.5. 4,8-Dimethoxy-2-(2-propen-1-yl)naphthalen-1-ol 62. Brown powder. Mp: 56–59 °C. HRMS (EI): Found M^+, 244.10979, $C_{15}H_{16}O_3$ requires 244.10994. ν_{max} (film)/cm^{-1}: 3412 (s, br, OH), 2942 (s, C–H, aromatic), 2252, 1609, 1511, 1449, 1406 (s, C=C, aromatic), 1373, 1240, 1218, 1071 (s, C–O), 908, 803, 732. δ_H (300 MHz, CDCl$_3$): 3.52 (2H, d, $J_{1',2'}$ 6.4 Hz, H-1′), 3.87 (3H, s, OMe), 3.89 (3H, s, OMe), 5.06 (1H, dd, $J_{3'A,1'}$ 1.5 and $J_{3'A,2'}$ 10.7 Hz, H-3′$_A$), 5.10 (1H, dd, $J_{3'B,1'}$ 1.5 and $J_{3'B,2'}$ 15.2 Hz, H-3′$_B$), 6.00–6.13 (1H, m, H-2′), 6.65 (1H, s, H-3), 6.70 (1H, d, $J_{7,6}$ 7.8 Hz, H-7), 7.21 (1H, dd, $J_{6,7}$ 7.8 and $J_{6,5}$ 8.5 Hz, H-6), 7.80 (1H, dd, $J_{5,7}$ 0.8 and $J_{5,6}$ 8.5 Hz, H-5), 9.17 (1H, br s, OH). δ_C (75 MHz, CDCl$_3$): 34.3 (CH$_2$, C-1′), 55.7 (CH$_3$, OMe), 55.8 (CH$_3$, OMe), 104.9 (CH, C-3), 108.2 (CH, C-7), 115.0 (CH$_2$, C-3′), 115.3 (quat., C-8a), 115.6 (CH, C-5), 119.4 (quat., C-2), 124.3 (CH, C-6), 126.6 (quat., C-4a), 137.1 (CH, C-2′), 144.5 (quat., C-1), 147.6 (quat., C-4), 155.6 (quat., C-8); *m/z* (EI, %): 244 (M$^+$, 100), 229 (M$^+$−Me, 76), 214 (9), 197 (9), 187 (9), 158 (8), 115 (9).

3.4. Protection of allylphenols as methoxymethyl ethers

3.4.1. Procedure A—using diisopropylethylamine in dichloromethane. To a stirred solution of phenol (0.07 mol) in dichloromethane (20 mL) were added diisopropylethylamine (0.13 mol) and chloromethyl methyl ether (0.10 mol) dropwise at 0 °C under nitrogen. The mixture was warmed to room temperature and stirred overnight. Dichloromethane was removed in vacuo, the residue taken up in diethyl ether (15 mL), washed with 10% aqueous HCl solution (2×10 mL), water (2×10 mL), aqueous 10% NaOH (2×10 mL), brine (25 mL), dried over MgSO$_4$ and concentrated at reduced pressure. The residue was purified by flash column chromatography.

3.4.2. Procedure B—using sodium hydride in DMF. To a stirred solution of phenol or naphthalenol (1 mmol) in anhydrous *N*,*N*-dimethylformamide (5 mL) at 0 °C, sodium hydride (1.1 mmol) was added portionwise. After stirring at 0 °C for 30 min, MOMCl (1.2 mmol) was added dropwise. The reaction mixture was warmed to room temperature and stirred for 1 h. Water (5 mL) was added and extracted with diethyl ether (3×5 mL). The combined organic extracts were washed with 1 N NaOH (2×5 mL), then 10% HCl (2×5 mL) and brine (5 mL). The organic layer was dried over MgSO$_4$, concentrated in vacuo and subjected to flash column chromatography.

3.4.3. 1-Methoxy-2-methoxymethoxy-3-(prop-2-enyl)-benzene 33.[10] Clear oil; the spectral data were in agreement with the literature.[10] δ_H (400 MHz, CDCl$_3$): 3.48 (2H, d, $J_{1',2'}$ 6.6 Hz, H-1′), 3.59 (3H, s, OCH$_2$OC*H*$_3$), 3.77 (3H, s, OMe), 5.02–5.08 (2H, m, H-3′), 5.06 (2H, s, OCH$_2$O), 5.92–6.03 (1H, m, H-2′), 6.73–6.77 (2H, m, H-4 and H-6), 6.97–7.05 (1H, t, $J_{5,4}$=$J_{5,6}$ 7.9 Hz, H-5). δ_C (100 MHz, CDCl$_3$): 34.0 (CH$_2$, C-1′), 55.4 (CH$_3$, OMe), 57.1 (CH$_3$, OCH$_2$O*C*H$_3$), 98.7 (CH$_2$, OCH$_2$O), 110.2 (CH, C-6 or C-4), 115.3 (CH$_2$, C-3′), 121.8 (CH, C-4 or C-6), 123.9 (CH, C-5), 133.9 (quat., C-3), 136.9 (CH, C-2′), 143.9 (quat., C-2), 152.0 (quat., C-1).

3.4.4. 2-Allyl-4-methoxy-1-(methoxymethoxy)benzene 34. Clear oil. HRMS (EI): Found M$^+$, 208.10996, C$_{12}$H$_{16}$O$_3$ requires 208.10994. ν_{max} (film)/cm^{-1}: 3079 (CH=CH$_2$), 3000, 2950, 2832 (s, C–H, aromatic), 1499, 1465 (OCH$_2$O), 1280, 1223, 1195, 1150, 1077, 1008. δ_H (300 MHz, CDCl$_3$): 3.37 (2H, d, $J_{1',2'}$ 6.5 Hz, H-1′), 3.47 (3H, s, OCH$_2$OC*H*$_3$), 3.74 (3H, s, OMe), 5.03–5.10 (4H, m, H-3′ and OCH$_2$O), 5.90–6.04 (1H, m, H-2′), 6.66 (1H, d, $J_{3,5}$ 3.1 Hz, H-3), 6.71 (1H, dd, $J_{5,3}$ 3.1 and $J_{5,6}$ 8.9 Hz, H-5), 6.99 (1H, d, $J_{6,5}$ 8.7 Hz, H-6). δ_C (75 MHz, CDCl$_3$): 34.4 (CH$_2$, C-1′), 55.5 (CH$_3$, OCH$_2$O*C*H$_3$), 55.9 (CH$_3$, OMe), 95.3 (CH$_2$, OCH$_2$O), 111.6 (CH, C-5), 115.6 (CH$_2$, C-3′), 115.7 (CH, C-3 or C-6), 115.8 (CH, C-3 or C-6), 130.7 (quat., C-2), 136.7 (CH, C-2′), 149.1 (quat., C-1), 154.5 (quat., C-4); *m/z* (EI, %): 208 (M$^+$, 26), 163 (33), 131 (14), 45 (100).

3.4.5. 1-Allyl-2-methoxymethoxy-naphthalene 55. Yellow oil. HRMS (EI): Found M$^+$, 228.11483, C$_{15}$H$_{16}$O$_2$ requires 228.11503. ν_{max} (film)/cm^{-1}: 3057, 3072, 2975, 2954, 2900, 2930, 2847, 2825, 1636, 1625, 1595, 1512, 1469, 1435, 1260, 1241, 1197, 1149, 1082, 1035, 995, 919, 807. δ_H (400 MHz, CDCl$_3$): 3.49 (3H, s, OMe), 3.88 (2H, dt, $J_{1',3'}$ 1.6 and $J_{1',2'}$ 5.8 Hz, H-1′), 4.95–5.01 (2H, m, H-3′), 5.25 (2H, s, OCH$_2$O), 5.99–6.09 (1H, m, H-2′), 7.33 (1H, dt, $J_{6,8}$ 0.9 and $J_{6,7}$=$J_{6,5}$ 8.1 Hz, H-6), 7.41 (1H, d, $J_{3,4}$ 9.0 Hz, H-3), 7.45 (1H, dt, $J_{7,5}$ 1.2 and $J_{7,8}$=$J_{7,6}$ 8.1 Hz, H-7), 7.69 (1H, d, $J_{4,3}$ 9.0 Hz, H-4), 7.77 (1H, d, $J_{8,7}$ 8.1 Hz, H-5), 7.93 (1H, d, $J_{5,6}$ 8.1 Hz, H-8). δ_C (100 MHz, CDCl$_3$): 29.3 (CH$_2$, C-1′), 56.1 (CH$_3$, OMe), 95.2 (CH$_2$, OCH$_2$O), 115.1 (CH$_2$, C-3′), 116.4 (CH, C-3), 122.0 (quat., C-1), 123.7 (2×CH, C-6 and C-8), 126.2 (CH, C-7), 128.0 (CH, C-4), 128.4 (CH, C-5), 129.9 (quat., C-4a), 133.1 (quat., C-8a), 136.6 (CH, C-2′), 152.1 (quat., C-2); *m/z* (EI, %): 228 (M$^+$, 18), 183 (30), 181 (13), 168 (2), 165 (15), 152 (7), 45 (100).

3.4.6. 5-Methoxy-1-(methoxymethoxy)-2-(2-propen-1-yl)naphthalene 63. Brown oil. HRMS (EI): Found M$^+$, 258.12545, C$_{16}$H$_{18}$O$_3$ requires 258.12559. ν_{max} (film)/cm^{-1}: 3076 (s, CH, aromatic), 2929 (CH), 1637 (C=C, aromatic), 1598, 1506, 1463, 1414, 1376, 1259, 1213, 1158, 1049 (s, C–O). δ_H (400 MHz, CDCl$_3$): 3.60–3.61 (2H, m, H-1′), 3.61 (3H, s, OCH$_2$OC*H*$_3$), 3.88 (3H, s, OMe), 5.05–5.06 (1H, m, H-3′$_A$), 5.08–5.10 (1H, m, H-3′$_B$), 5.09 (2H, s, OCH$_2$O), 5.97–6.07 (1H, m, H-2′), 6.70 (1H, d, $J_{6,7}$ 7.7 Hz, H-6), 7.27 (1H, d, $J_{3,4}$ 8.6 Hz, H-3), 7.34 (1H, dd, $J_{7,6}$ 7.7 and $J_{7,8}$ 8.5 Hz, H-7), 7.65 (1H, d, $J_{8,7}$ 8.5 Hz, H-8), 8.00 (1H, d, $J_{4,3}$ 8.6 Hz, H-4). δ_C (100 MHz, CDCl$_3$): 34.2 (CH$_2$, C-1′), 55.3 (CH$_3$, OMe), 57.5 (CH$_3$, OCH$_2$O*C*H$_3$), 100.1 (CH$_2$, OCH$_2$O), 103.5 (CH, C-6), 114.3 (CH, C-8), 115.7 (CH$_2$, C-3′), 118.3 (CH, C-4), 125.8 (quat., C-2), 125.9 (CH, C-7), 127.2 (CH, C-3), 129.0 (quat., C-8a), 130.0 (quat., C-4a), 137.1 (CH, C-2′), 150.5 (quat., C-1), 155.5 (quat., C-5); *m/z* (EI, %): 258 (M$^+$, 57), 213 (37), 211 (22), 198 (14), 187 (8), 152 (12), 141 (11), 115 (17), 45 (100).

3.4.7. 4,8-Dimethoxy-1-(methoxymethoxy)-2-(2-propenyl)naphthalene 64. Tan oil. HRMS (EI): Found M$^+$, 288.13599, C$_{17}$H$_{20}$O$_4$ requires 288.13616. ν_{max} (film)/cm^{-1}: 2942 (s, C–H, aromatic), 2252, 1637, 1464 (s, C=C, aromatic), 1366, 1263, 1157, 1081 (s, C–O). δ_H (400 MHz, CDCl$_3$): 3.62 (3H, s, OCH$_2$OC*H*$_3$), 3.67 (2H, dt, $J_{1',3'}$ 1.5 and $J_{1',2'}$ 6.4 Hz, H-1′), 3.93 (3H, s, OMe), 3.94 (3H, s, OMe), 5.01 (2H, s, OCH$_2$O), 5.09 (1H, dd, $J_{3'A,1'}$ 1.5 and $J_{3'A,2'}$ 10.2 Hz, H-3′$_A$), 5.14 (1H, dd, $J_{3'B,1'}$ 1.5 and $J_{3'B,2'}$ 17.1 Hz, H-3′$_B$), 6.00–6.11 (1H, m, H-2′), 6.65 (1H, s, H-3), 6.88 (1H, d, $J_{7,6}$ 8.2 Hz, H-7), 7.31 (1H, dd, $J_{6,7}$=$J_{6,5}$ 8.2 Hz, H-6), 7.84 (1H, dd, $J_{5,7}$ 1.0 and $J_{5,6}$

8.2 Hz, H-5). δ_C (100 MHz, $CDCl_3$): 35.0 (CH_2, C-1′), 55.6 (CH_3, OMe), 56.0 (CH_3, OMe), 57.4 (CH_3, OCH_2OCH_3), 101.2 (CH_2, OCH_2O), 106.3 (CH, C-3), 106.9 (CH, C-7), 114.9 (CH, C-5), 115.6 (CH_2, C-3′), 120.4 (quat., C-2), 124.9 (CH, C-6), 127.8 (quat., C-8a), 129.5 (quat., C-4a), 137.6 (CH, C-2′), 143.5 (quat., C-1), 151.5 (quat., C-4), 155.3 (quat., C-8); *m*/*z* (EI, %): 288 (M^+, 100), 243 (M^+-CH_2OMe, 98), 228 (20), 212 (60), 197 (12), 181 (5), 168 (6), 115 (9), 45 (41).

3.5. Ozonolysis of the protected allylphenol 33

A solution of alkene **33** (143 mg, 0.7 mmol) in dry methanol (5.5 mL) was cooled to −50 °C under nitrogen. Ozone was bubbled through the solution for 10 min at a rate of 1 mL/min. The mixture was flushed with nitrogen and dimethyl sulfide (0.3 mL, 4 mmol) was added. After warming the solution to room temperature, another portion of dimethyl sulfide (0.3 mL, 4 mmol) was added and the mixture stirred for 1 h. The solvent was concentrated in vacuo to give a yellow residue, which was taken up in water (5 mL) and extracted with diethyl ether (3×10 mL). The combined organic extracts were dried over $MgSO_4$ and concentrated in vacuo to give a yellow residue, which was purified by flash column chromatography using hexane–diethyl ether (70:30) as eluent to afford (3-methoxy-2-methoxymethoxyphenyl)acetaldehyde **23** (121 mg, 83%) as a pale yellow oil for which the spectral data were in agreement with the literature.[10] δ_H (300 MHz, $CDCl_3$): 3.52 (3H, s, OCH_2O*Me*), 3.73 (2H, d, $J_{2,1}$ 2.1 Hz, H-2), 3.85 (3H, s, OMe), 5.09 (2H, s, OCH_2O), 6.78 (1H, dd, $J_{4',6'}$ 1.0 and $J_{4',5'}$ 7.8 Hz, H-4′), 6.89 (1H, dd, $J_{6',4'}$ 1.0 and $J_{6',5'}$ 7.8 Hz, H-6′), 7.04 (1H, t, $J_{5',4'}=J_{5',6'}$ 7.8 Hz, H-5′), 9.72 (1H, t, $J_{1,2}$ 2.1 Hz, H-1). δ_C (75 MHz, $CDCl_3$): 45.3 (CH_2, C-2), 55.7 (CH_3, OMe), 57.5 (CH_3, OCH_2OCH_3), 99.0 (CH_2, OCH_2O), 111.9 (CH, C-4′), 122.9 (CH, C-6′), 124.4 (CH, C-5′), 126.9 (quat., C-1′), 144.9 (quat., C-2′), 152.3 (quat., C-3′), 200.0 (CH, C-1).

3.6. One step dihydroxylation–oxidative cleavage of protected allylphenol 34

To a stirred solution of alkene **34** (1 mmol) in THF–water (5 mL, 4:1) was added osmium tetroxide (0.1 mmol). After 30 min, sodium periodate (1.82 mmol) was added portionwise. The reaction mixture was stirred at room temperature for 8 h, then quenched with water. The aqueous layer was washed with diethyl ether (4×5 mL) and the combined ethereal layer washed with brine (5 mL), dried over $MgSO_4$, concentrated in vacuo and subjected to purification by flash column chromatography.

3.6.1. (5-Methoxy-2-(methoxymethoxy)phenyl)acetaldehyde 24. Yellow oil. HRMS (EI): Found M^+, 210.08915, $C_{11}H_{14}O_4$ requires 210.08921. ν_{max} (film)/cm^{-1}: 2950, 2832 (s, C–H, aromatic), 1721 (s, C═O, aldehyde), 1504 (s, C═C, aromatic), 1475 (OCH_2O), 1226, 1077 (C–O). δ_H (300 MHz, $CDCl_3$): 3.45 (3H, s, OCH_2OCH_3), 3.65 (2H, d, $J_{2,1}$ 2.1 Hz, H-2), 3.77 (3H, s, OMe), 5.12 (2H, s, OCH_2O), 6.72 (1H, d, $J_{6',4'}$ 3.0 Hz, H-6′), 6.79 (1H, dd, $J_{4',6'}$ 3.0 and $J_{4',3'}$ 8.9 Hz, H-4′), 7.08 (1H, d, $J_{3',4'}$ 8.9 Hz, H-3′), 9.70 (1H, t, $J_{1,2}$ 2.1 Hz, H-1). δ_C (75 MHz, $CDCl_3$): 45.7 (CH_2, C-2), 55.6 (CH_3, OMe), 56.0 (CH_3, OCH_2OCH_3), 95.1 (CH_2, OCH_2O), 113.4 (CH, C-4′), 115.4 (CH, C-6′), 117.0 (CH, C-3′), 122.9 (quat., C-1′), 149.5 (quat., C-2′), 154.5 (quat., C-5′), 199.6 (CH, C-1); *m*/*z* (EI, %): 210 (M^+, 50), 178 (M^+-MeOH, 62), 151 (32), 149 (38), 137 (31), 136 (27), 121 (23), 77 (19), 45 (100).

3.7. Dihydroxylation of protected naphthols

To a solution of alkene (1 mmol) in acetone–H_2O (8:1, 9 mL) were added osmium tetroxide (2.5 wt % solution in 2-methyl-2-propanol) (0.3 mmol) and *N*-methylmorpholine-*N*-oxide (3 mmol). After stirring the mixture overnight, sodium sulfite (0.5 g) and methanol (2.5 mL) were added. After stirring for 2 h, the mixture was filtered and concentrated in vacuo. The residue was extracted with diethyl ether (3×5 mL), the combined organic extracts were washed with brine (10 mL), dried over $MgSO_4$, concentrated under vacuum and subjected to flash column chromatography.

3.7.1. 3-[(2-Methoxymethoxy)-1-naphthalenyl]-1,2-propanediol 56. Yellow powder. Mp: 110–112 °C. HRMS (EI): Found M^+, 262.12057, $C_{15}H_{18}O_4$ requires 262.12051. ν_{max} (CH_2Cl_2 solution)/cm^{-1}: 3574, 3054, 2986, 2829, 2685, 2305, 1625, 1596, 1512, 1421, 1265, 1242, 1197, 1150, 1062, 1010, 746. δ_H (300 MHz, $CDCl_3$): 3.28 (2H, d, $J_{3,2}$ 6.9 Hz, H-3), 3.34 (1H, br s, OH), 3.43 (3H, s, OMe), 3.46–3.54 (2H, m, H-1), 3.58 (1H, br s, OH), 4.01–4.08 (1H, m, H-2), 5.18 (2H, s, OCH_2O), 7.27–7.35 (2H, m, H-3′ and H-6′), 7.41 (1H, dd, $J_{7',6'}=J_{7',8'}$ 7.7 Hz, H-7′), 7.65 (1H, d, $J_{4',3'}$ 9.1 Hz, H-4′), 7.72 (1H, d, $J_{5',6'}$ 7.7 Hz, H-5′), 8.00 (1H, d, $J_{8',7'}$ 7.7 Hz, H-8′). δ_C (75 MHz, $CDCl_3$): 28.9 (CH_2, C-3), 56.1 (CH_3, OMe), 65.8 (CH_2, H-1), 72.3 (CH, H-2), 95.1 (CH_2, OCH_2O), 115.7 (CH, C-3′), 120.1 (quat., C-1′), 123.4 (CH, C-6′), 123.7 (CH, C-8′), 126.4 (CH, C-7′), 128.3 (CH×2, C-4′ and C-5′), 129.7 (quat., C-4′a), 133.2 (quat., C-8′a), 152.5 (quat., C-2′); *m*/*z* (EI, %): 262 (M^+, 18), 230 (M^+-MeOH, 12), 200 ($M^+-MOMOH$, 22), 169 (21), 157 (68), 144 (12), 141 (12), 128 (18), 45 (100).

3.7.2. 3-(5-Methoxy-1-(methoxymethoxy)naphthalen-2-yl)propane-1,2-diol 65. Yellow oil. HRMS (EI): Found M^+, 292.13031, $C_{16}H_{20}O_5$ requires 292.13107. ν_{max} (film)/cm^{-1}: 3400 (br, OH), 3071 (s, C–H, aromatic), 2934 (m, CH), 1734 (s, C–O), 1625, 1578, 1599, 1506 (C═C, aromatic), 1463, 1447, 1379 (s, C–H, alkane), 1259. δ_H (400 MHz, $CDCl_3$): 2.93 (1H, dd, $J_{3A,2}$ 5.6 and $J_{3A,3B}$ 13.7 Hz, H-3_A), 3.02 (1H, dd, $J_{3B,2}$ 7.9 and $J_{3B,3A}$ 13.7 Hz, H-3_B), 3.12 (1H, br s, OH), 3.37 (1H, br s, OH), 3.45 (1H, dd, $J_{1A,2}$ 6.2 and $J_{1A,1B}$ 11.3 Hz, H-1_A), 3.57–3.62 (1H, m, H-1_B), 3.62 (3H, s, OCH_2OCH_3), 3.94 (3H, s, OMe), 3.94–3.97 (1H, m, H-2), 5.10 (1H, d, J_{gem} 14.1 Hz, OCH_AH_BO), 5.12 (1H, d, J_{gem} 14.1 Hz, OCH_AH_BO), 6.76 (1H, d, $J_{6',7'}$ 7.7 Hz, H-6′), 7.28 (1H, d, $J_{3',4'}$ 8.5 Hz, H-3′), 7.37 (1H, dd, $J_{7',6'}$ 7.7 and $J_{7',8'}$ 8.4 Hz, H-7′), 7.55 (1H, d, $J_{8',7'}$ 8.4 Hz, H-8′), 7.99 (1H, d, $J_{4',3'}$ 8.5 Hz, H-4′). δ_C (100 MHz, $CDCl_3$): 34.0 (CH_2, C-3), 55.3 (CH_3, OMe), 57.6 (CH_3, OCH_2OCH_3), 66.0 (CH_2, C-1), 72.6 (CH, C-2), 100.3 (CH_2, OCH_2O), 103.7 (CH, C-6′), 114.1 (CH, C-8′), 118.7 (CH, C-4′), 126.0 (quat., C-2′), 126.2 (CH, C-7′), 127.6 (CH, C-3′), 129.2 (2×quat., C-8′a and C-4′a), 151.3 (quat., C-1′), 155.6 (quat., C-5′); *m*/*z* (EI, %): 292 (M^+, 23), 274 (M^+-18, 37), 260 (52), 230 (79), 212 (17), 199

(22), 187 (65), 174 (6), 171 (8), 159 (15), 129 (13), 115 (14), 45 (100).

3.7.3. 3-(4,8-Dimethoxy-1-(methoxymethoxy)naphthalen-2-yl)propane-1,2-diol 66. Yellow oil. HRMS (EI): Found M$^+$, 322.14168, $C_{17}H_{22}O_6$ requires 322.14164. ν_{max} (film)/cm^{-1}: 3430 (s, br, OH), 3156, 2938 (s, CH, aromatic), 2844, 1602, 1580, 1509, 1465 (s, OCH_2O), 1416, 1369, 1264, 1157, 1080. δ_H (300 MHz, $CDCl_3$): 2.52 (1H, br s, OH), 2.99 (1H, dd, $J_{3A,2}$ 5.3 and J_{gem} 13.7 Hz, H-3_A), 3.13 (1H, dd, $J_{3B,2}$ 8.2 and J_{gem} 13.7 Hz, H-3_B), 2.96–3.15 (1H, br, OH), 3.55 (1H, dd, $J_{1A,2}$ 6.0 and J_{gem} 11.2 Hz, H-1_A), 3.63 (3H, s, $OCH_2OC\mathit{H}_3$), 3.68 (1H, dd, $J_{1B,2}$ 3.6 and J_{gem} 11.2 Hz, H-1_B), 3.96 (6H, s, OMe), 4.02–4.08 (1H, m, H-2), 5.04 (1H, d, J_{gem} 16.6 Hz, $OC\mathit{H}_AH_BO$), 5.06 (1H, d, J_{gem} 16.6 Hz, $OCH_A\mathit{H}_BO$), 6.68 (1H, s, H-3′), 6.91 (1H, d, $J_{7',6'}$ 7.7 Hz, H-7′), 7.35 (1H, dd, $J_{6',5'}$ 8.2 and $J_{6',7'}$ 8.1 Hz, H-6′), 7.86 (1H, dd, $J_{5',7'}$ 0.9 and $J_{5',6'}$ 8.4 Hz, H-5′). δ_C (75 MHz, $CDCl_3$): 34.6 (CH_2, C-3), 55.7 (CH_3, OMe), 56.0 (CH_3, OMe), 57.4 (CH_3, OCH_2OCH_3), 66.4 (CH_2, C-1), 72.9 (CH, C-2), 101.5 (CH_2, OCH_2O), 106.6 (CH, C-3′), 107.2 (CH, C-7′), 115.0 (CH, C-5′), 120.2 (quat., C-2′), 125.2 (CH, C-6′), 127.6 (quat., C-8′a), 128.0 (quat., C-4′a), 144.5 (quat., C-1′), 151.8 (quat., C-4′), 155.1 (quat., C-8′); *m/z* (EI, %): 322 (M$^+$, 45), 304 (M$^+$− 18, 3), 290 (29), 260 (30), 229 (13), 217 (100), 189 (10), 174 (10), 45 (37).

3.8. Oxidative cleavage of diols

To a solution of diol (1 mmol) in dichloromethane (6 mL) was added sodium periodate (2 mmol) in water (5 mL) to give an immiscible mixture. The reaction mixture was stirred for 45 min at room temperature. The organic layer was separated and the aqueous layer was extracted with dichloromethane (4×5 mL). The combined organic extracts were dried over $MgSO_4$, concentrated in vacuo and subjected to flash column chromatography.

3.8.1. (2-Methoxymethoxy-naphthalen-1-yl)acetaldehyde 45. Colourless oil. Mp: 65–68 °C. HRMS (EI): Found M$^+$, 230.09444, $C_{14}H_{14}O_3$ requires 230.09429. ν_{max} (film)/cm^{-1}: 3054, 2986, 2827, 2724, 2305, 1722, 1625, 1596, 1513, 1470, 1420, 1381, 1265, 1243, 1198, 1150, 1062, 1020, 999, 743. δ_H (400 MHz, $CDCl_3$): 3.44 (3H, s, OMe), 4.12 (2H, d, $J_{2,1}$ 2.1 Hz, H-2), 5.23 (2H, s, OCH_2O), 7.33 (1H, t, $J_{6',7'}$=$J_{6',5'}$ 7.6 Hz, H-6′), 7.40–7.46 (2H, m, H-3′ and H-7′), 7.3–7.78 (3H, m, H-4′, H-5′ and H-8′), 9.66 (1H, t, $J_{1,2}$ 2.1 Hz, CHO). δ_C (100 MHz, $CDCl_3$): 40.4 (CH_2, C-2), 56.0 (CH_3, OMe), 94.8 (CH_2, OCH_2O), 114.5 (quat., C-1′), 115.5 (CH, C-3′), 122.6 (CH, C-4′ or C-5′ or C-8′), 123.9 (CH, C-6′), 126.8 (CH, C-7′), 128.5 (CH, C-5′ or C-4′ or C-8′), 129.3 (CH, C-8′ or C-4′ or C-5′), 129.6 (quat., 4′a), 133.1 (quat., C-8′a), 152.9 (quat., C-2′), 199.5 (CH, CHO); *m/z* (EI, %): 230 (M$^+$, 13), 185 (20), 169 (14), 168 (20), 141 (11), 128 (13), 115 (4), 45 (100).

3.8.2. (5-Methoxy-1-(methoxymethoxy)naphthalen-2-yl)acetaldehyde 46. Yellow oil. HRMS (EI): Found M$^+$, 260.10451, $C_{15}H_{16}O_4$ requires 260.10486. ν_{max} (film)/cm^{-1}: 3053, 2937, 2830, 2305, 1722, 1599, 1579, 1507, 1416, 1377, 1264, 1159, 1054, 965, 807, 704. δ_H (300 MHz, $CDCl_3$): 3.60 (3H, s, $OCH_2OC\mathit{H}_3$), 3.90 (2H, d, $J_{2,1}$ 1.9 Hz, H-2), 3.97 (3H, s, OMe), 5.11 (2H, s, OCH_2O), 6.82 (1H, d, $J_{6',7'}$ 7.7 Hz, H-6′), 7.24 (1H, d, $J_{3',4'}$ 8.6 Hz, H-3′), 7.42 (1H, dd, $J_{7',6'}$ 7.7 and $J_{7',8'}$ 8.4 Hz, H-7′), 7.61 (1H, d, $J_{8',7'}$ 8.4 Hz, H-8′), 8.06 (1H, d, $J_{4',3'}$ 8.6 Hz, H-4′), 9.77 (1H, t, $J_{1,2}$ 1.9 Hz, H-1). δ_C (75 MHz, $CDCl_3$): 45.6 (CH_2, C-2), 55.5 (CH_3, OMe), 57.5 (CH_3, OCH_2OCH_3), 100.3 (CH_2, OCH_2O), 104.1 (CH, C-6′), 114.1 (CH, C-8′), 119.0 (CH, C-4′), 122.3 (quat., C-2), 126.5 (CH, C-7′), 126.6 (quat., C-4′a or C-8′a), 127.4 (CH, C-3′), 129.3 (quat., C-8′a or C-4′a), 152.1 (quat., C-1′), 155.7 (quat., C-5′), 199.9 (CH, C-1); *m/z* (EI, %): 260 (M$^+$, 24), 228 (18), 201 (14), 187 (14), 155 (4), 144 (4), 128 (6), 115 (11), 45 (100).

3.8.3. (4,8-Dimethoxy-1-(methoxymethoxy)naphthalen-2-yl)acetaldehyde 47. Yellow oil. HRMS (EI): Found M$^+$, 290.11564, $C_{16}H_{18}O_5$ requires 290.11542. ν_{max} (film)/cm^{-1}: 3054, 2986 (s, C–H, aromatic), 1732 (C=O, aldehyde), 1601, 1551, 1511 (w, C=C, aromatic), 1265, 1156, 1080 (s, C–O), 738, 705. δ_H (400 MHz, $CDCl_3$): 3.55 (3H, s, $OCH_2OC\mathit{H}_3$), 3.90 (2H, d, $J_{1,2}$ 2.1 Hz, H-1), 3.91 (3H, s, OMe), 3.92 (3H, s, OMe), 5.02 (2H, s, OCH_2O), 6.57 (1H, s, H-3′), 6.89 (1H, d, $J_{7',6'}$ 8.2 Hz, H-7′), 7.34 (1H, dd, $J_{6',7'}$=$J_{6',5'}$ 8.2 Hz, H-6′), 7.86 (1H, dd, $J_{5',7'}$ 1.0 and $J_{5',6'}$ 8.2 Hz, H-5′), 9.78 (1H, t, $J_{2,1}$ 2.1 Hz, H-2). δ_C (100 MHz, $CDCl_3$): 46.1 (CH_2, C-1), 55.5 (CH_3, OMe), 55.8 (CH_3, OMe), 57.2 (CH_3, OCH_2OCH_3), 101.5 (CH_2, OCH_2O), 106.3 (CH, C-3′), 107.1 (CH, C-7′), 114.9 (CH, C-5′), 120.1 (quat., C-2′), 122.2 (quat., C-8′a), 125.5 (CH, C-6′), 128.3 (quat., C-4′a), 145.1 (quat., C-1′), 151.7 (quat., C-4′), 155.1 (quat., C-8′), 200.4 (CH, C-2); *m/z* (EI, %): 290 (M$^+$, 100), 245 (M$^+$−CH_2OCH_3, 58), 229 (M$^+$−OMOM, 29), 217 (92), 202 (27), 174 (20), 115 (22), 45 (94).

3.9. Protection of aryl phenols as MOM ethers

To a stirred solution of 2-iodophenol (4.86 mmol) in dichloromethane (5 mL) at 0 °C were added chloromethyl methyl ether (7.24 mmol) and diisopropylethylamine (9.45 mmol) under a nitrogen atmosphere and the mixture stirred for 1 h, then warmed to room temperature overnight. Water (6 mL) was added to the reaction mixture, two layers were separated and aqueous layer was extracted with diethyl ether (4×6 mL). The combined organic extracts were washed with brine (2×5 mL), dried over $MgSO_4$, concentrated in vacuo and subjected to flash column chromatography.

3.9.1. 2-(Methoxymethoxy)iodobenzene 27.[15] Orange-yellow oil. δ_H (300 MHz, $CDCl_3$): 3.51 (3H, s, OMe), 5.23 (2H, s, OCH_2O), 6.75 (1H, dt, $J_{5,3}$ 1.4 and $J_{5,4}$=$J_{5,6}$ 7.6 Hz, H-5), 7.06 (1H, dd, $J_{3,5}$ 1.4 and $J_{3,4}$ 8.3 Hz, H-3), 7.24–7.30 (1H, m, H-4), 7.77 (1H, dd, $J_{6,4}$ 1.6 and $J_{6,5}$ 7.6 Hz, H-6). δ_C (75 MHz, $CDCl_3$): 56.3 (CH_3, OCH_3), 87.1 (quat., C-1), 94.9 (CH_2, OCH_2O), 114.9 (CH, C-3), 123.6 (CH, C-5), 129.4 (CH, C-4), 139.4 (CH, C-6), 156.0 (quat., C-2).

3.9.2. 1-Methoxy-2-(methoxymethoxy)benzene 36.[16] Orange-yellow oil. δ_H (300 MHz, $CDCl_3$): 3.51 (3H, s, OMe), 3.86 (3H, s, OMe), 5.22 (2H, s, OCH_2O), 6.84–7.01 (3H, m, H-4, H-5 and H-6), 7.15 (1H, dd, $J_{3,5}$ 1.6 and $J_{3,4}$ 8.0 Hz, H-3). δ_C (75 MHz, $CDCl_3$): 55.8 (CH_3, OMe), 56.1 (CH_3, OMe), 95.5 (CH_2, OCH_2O), 111.8 (CH, C-6), 116.6

(CH, C-3), 120.8 (CH, C-4), 122.5 (CH, C-5), 146.5 (quat., C-2), 149.8 (quat., C-1).

3.10. Iodination of 36

To a solution of **36** (23.4 mmol) in THF (20 mL) at −15 °C was added *n*-butyllithium (24.0 mmol) dropwise. The mixture was warmed to room temperature and stirred for 2 h. The solution was cooled at −45 °C and a solution of iodine (23.7 mmol) in THF (10 mL) added. The reaction mixture was stirred at 20 °C for 2 h. The solution was concentrated in vacuo and the residue extracted with diethyl ether. The organic layer was washed with 20% sodium thiosulfate solution (3×35 mL), saturated sodium bicarbonate solution (3×35 mL), dried over $MgSO_4$ and concentrated in vacuo. The resultant residue was purified by flash column chromatography using hexane–ethyl acetate (90:10) as eluent to afford 3-methoxy-2-(methoxymethoxy)-1-iodobenzene **28** (1.915 g, 30%) as a tan oil. HRMS (EI): Found M^+, 293.97546, $C_9H_{11}IO_3$ requires 293.97530. ν_{max} (film)/cm^{-1}: 2960, 2938, 1569, 1580, 1464, 1434, 1290, 1259, 1157, 1030, 948, 828, 766, 735. δ_H (300 MHz, $CDCl_3$): 3.67 (3H, s, OCH_2OMe), 3.83 (3H, s, OMe), 5.16 (2H, s, OCH_2O), 6.79 (1H, t, $J_{5,4}$=$J_{5,6}$ 8.0 Hz, H-5), 6.88 (1H, dd, $J_{4,6}$ 1.3 and $J_{4,5}$ 8.2 Hz, H-4), 7.37 (1H, dd, $J_{6,4}$ 1.5 and $J_{6,5}$ 7.9 Hz, H-6). δ_C (75 MHz, $CDCl_3$): 55.9 (CH_3, OMe), 58.3 (CH_3, OCH_2OCH_3), 92.6 (quat., C-1), 98.7 (CH_2, OCH_2O), 112.8 (CH, C-4), 125.9 (CH, C-5), 131.0 (CH, C-6), 145.9 (quat., C-3), 152.4 (quat., C-2); *m/z* (EI, %): 294 (M^+, 20), 264 (M^+−30, 7), 249 (M^+−CH_2OCH_3, 7), 167 (M^+−I, 21), 107 (6), 94 (4), 51 (7), 45 (100).

3.11. Standard procedure for Sonogashira couplings

A mixture of protected iodophenol (1.2 mmol), 2-methyl-3-butyn-2-ol (1.6 mmol), triphenylphosphine (0.02 mmol) and bis(triphenylphosphine)palladium(II) dichloride (0.01 mmol) in dry triethylamine (3 mL) was heated at 80 °C for 15 min. Copper(I) iodide (0.02 mmol) was added and the reaction mixture was kept at 80 °C overnight. The reaction mixture was cooled, filtered through Celite® and concentrated in vacuo and purified by flash column chromatography.

3.11.1. 4-(2-Methoxymethoxyphenyl)-2-methyl-3-butyn-2-ol 37. Tan oil. HRMS (EI): Found M^+, 220.10958, $C_{13}H_{16}O_3$ requires 220.10994. ν_{max} (film)/cm^{-1}: 3400 (br, O–H), 2230 (C≡C), 1490 (OCH_2O), 1230 (C–O). δ_H (300 MHz, $CDCl_3$): 1.63 (6H, s, CMe_2OH), 2.47 (1H, br s, OH), 3.53 (3H, s, OMe), 5.23 (2H, s, OCH_2O), 6.94 (1H, dt, $J_{5',3'}$ 1.0 and $J_{5',4'}$=$J_{5',6'}$ 7.7 Hz, H-5′), 7.07 (1H, dd, $J_{3',5'}$ 1.0 and $J_{3',4'}$ 8.3 Hz, H-3′), 7.19–7.27 (1H, m, H-4′), 7.38 (1H, dd, $J_{6',4'}$ 1.7 and $J_{6',5'}$ 7.7 Hz, H-6′). δ_C (75 MHz, $CDCl_3$): 31.5 (CH_3, CMe_2OH), 56.2 (CH_3, OMe), 65.6 (quat., C-2), 78.3 (quat., C-4), 95.1 (quat., C-3), 97.9 (CH_2, OCH_2O), 113.5 (quat., C-1′), 115.6 (CH, C-3′), 121.9 (CH, C-5′), 129.5 (CH, C-4′), 133.5 (CH, C-6′), 157.6 (quat., C-2′); *m/z* (EI, %): 220 (M^+, 0.5), 158 (M^+−OMOM, 100), 143 (18).

3.11.2. 4-(3-Methoxy-2-(methoxymethoxy)phenyl)-2-methyl-but-3-yn-2-ol 38. Tan oil. HRMS (EI): Found M^+, 250.12083, $C_{14}H_{18}O_4$ requires 250.12051. ν_{max} (film)/cm^{-1}: 3689, 3584 (s, br, OH), 3054 (s, C–H, aromatic), 2305 (m, C≡C), 1598, 1575, 1511 (C=C, aromatic), 1469 (OCH_2O), 1265, 1208, 1160 (s, C–O). δ_H (300 MHz, $CDCl_3$): 1.60 (6H, s, CMe_2OH), 2.88 (1H, br s, OH), 3.65 (3H, s, OCH_2OMe), 3.82 (3H, s, OMe), 5.22 (2H, s, OCH_2O), 6.84–6.90 (1H, m, H-4′), 6.97–6.99 (2H, m, H-5′ and H-6′). δ_C (75 MHz, $CDCl_3$): 31.3 (6×CH_3, C-1), 55.8 (CH_3, OMe), 57.4 (CH_3, OCH_2OMe), 65.4 (quat., C-2), 84.0 (quat., C-4), 98.0 (quat., C-3), 98.3 (CH_2, OCH_2O), 112.8 (CH, C-4′), 117.8 (quat., C-1′), 124.0 (CH, C-6′), 125.2 (CH, C-5′), 146.8 (quat., C-3′), 152.4 (quat., C-2′); *m/z* (EI, %): 250 (M^+, 2), 203 (5), 188 (100), 175 (5), 173 (7), 160 (14), 145 (14), 131 (15), 115 (7), 45 (49).

3.12. Standard procedure for pyrolysis of the tertiary alcohols

A mixture of the alcohol (0.38 mmol) and solid sodium hydroxide (1.92 mmol) in dry toluene (10 mL) was heated under reflux for 3.5 h. The reaction was quenched by the addition of saturated ammonium chloride solution (4 mL) and extracted with diethyl ether (10 mL). The solvents were removed under reduced pressure and the resultant residue purified by flash column chromatography.

3.12.1. 1-Ethynyl-2-(methoxymethoxy)benzene 21. Yellow oil. HRMS (EI): Found M^+, 162.06773, $C_{10}H_{10}O_2$ requires 162.06812. ν_{max} (film)/cm^{-1}: 3282 (C–H, alkyne), 2107 (C≡C), 1488 (OCH_2O), 1238 (C–O). δ_H (300 MHz, $CDCl_3$): 3.20 (1H, s, H-2′), 3.44 (3H, s, OMe), 5.18 (2H, s, OCH_2O), 6.88 (1H, dt, $J_{5,3}$ 1.0 and $J_{5,4}$=$J_{5,6}$ 7.6 Hz, H-5), 7.04 (1H, dd, $J_{3,5}$ 1.0 and $J_{3,4}$ 8.4 Hz, H-3), 7.18–7.24 (1H, m, H-4), 7.38 (1H, $J_{6,4}$ 1.7 and $J_{6,5}$ 7.6 Hz, H-6). δ_C (75 MHz, $CDCl_3$): 56.2 (CH_3, OMe), 80.0 (CH, C-2′), 81.0 (quat., C-1′), 94.9 (CH_2, OCH_2O), 112.5 (quat., C-1), 115.0 (CH, C-3), 121.7 (CH, C-5), 130.1 (CH, C-4), 134.1 (CH, C-6), 158.3 (quat., C-2); *m/z* (EI, %): 162 (M^+, 11), 147 (1), 132 (19), 131 (34), 89 (8).

3.12.2. 1-Ethynyl-3-methoxy-2-(methoxymethoxy)benzene 22. Brown oil. HRMS (EI): Found M^+, 192.07864, $C_{11}H_{12}O_3$ requires 192.07801. ν_{max} (film)/cm^{-1}: 3075 (s, C–H, aromatic), 2999, 2961, 2936, 2901, 2839 (m, CH), 2268 (s, C≡C), 1596, 1574, 1509, 1469, 1438 (m, C=C, aromatic), 1306, 1266, 1230, 1200, 1183, 1157, 1132, 1073 (s, C–O). δ_H (300 MHz, $CDCl_3$): 3.25 (1H, s, C≡CH), 3.64 (3H, s, OCH_2OCH_3), 3.84 (3H, s, OMe), 5.23 (2H, s, OCH_2OMe), 6.91 (1H, dd, $J_{4,6}$ 1.8 and $J_{4,5}$ 7.9 Hz, H-4), 7.00 (1H, t, $J_{5,4}$=$J_{5,6}$ 7.9 Hz, H-5), 7.06 (1H, dd, $J_{6,4}$ 1.8 and $J_{6,5}$ 7.9 Hz, H-6). δ_C (75 MHz, $CDCl_3$): 55.9 (CH_3, OMe), 57.5 (CH_3, OCH_2OCH_3), 80.1 (quat., C-1′), 81.1 (CH, C-2′), 98.5 (CH_2, OCH_2O), 113.4 (CH, C-4), 117.3 (quat., C-1), 124.1 (CH, C-6), 125.7 (CH, C-5), 147.6 (quat., C-3), 152.4 (quat., C-2); *m/z* (EI, %): 192 (M^+, 5), 191 (M^+−H, 6), 162 (30), 161 (M−OMe, 22), 147 (6), 131 (M−OMOM, 11), 119 (8), 91 (7), 76 (7), 45 (100).

3.13. Standard procedure for union of acetylenes with aryl aldehydes

n-Butyllithium (1.50 mmol) was added dropwise to a stirred solution of the acetylene (1.50 mmol) in tetrahydrofuran (2 mL) at −78 °C under nitrogen. The solution was stirred at −78 °C for 30 min, then a solution of the aldehyde (1.26 mmol) in tetrahydrofuran (0.5 mL) was added dropwise and the mixture stirred for 1 h. The mixture was allowed to warm to room temperature and stirred for 2.5 h. Water (3 mL) was added and the mixture extracted with ethyl acetate (3×2 mL). The combined organic extracts were washed with brine (1 mL), dried over magnesium sulfate and concentrated in vacuo. The resultant residue was purified by flash chromatography.

3.13.1. 1-(3-Methoxy-2-methoxymethoxyphenyl)-4-(2-methoxymethoxyphenyl)but-3-yn-2-ol 17. Pale yellow oil. HRMS (EI): Found M$^+$, 372.15690, $C_{21}H_{24}O_6$ requires 372.15729. ν_{max} (film)/cm^{-1}: 3433 (br, s, OH), 3070 (C–H, aromatic), 2937, 2837 (s, CH), 2229 (C≡C), 1597, 1585 (ArC=C), 1488 (OCH_2O), 1079, 1049 (C–O). δ_H (300 MHz, $CDCl_3$): 2.86 (1H, br s, OH), 3.21 (1H, dd, $J_{1A,2}$ 5.5 and J_{gem} 13.6 Hz, H-1$_A$), 3.29 (1H, dd, $J_{1B,2}$ 8.0 and J_{gem} 13.6 Hz, H-1$_B$), 3.51 (3H, s, 2″-OCH_2OCH_3), 3.64 (3H, s, 2′-OCH_2OCH_3), 3.87 (3H, s, OMe), 4.90–4.94 (1H, m, H-2), 5.13 (1H, d, J_{gem} 10.9 Hz, OCH_AH_BO), 5.15 (1H, d, J_{gem} 10.8 Hz, OCH_AH_BO), 5.22 (2H, s, OCH_2O), 6.84 (1H, dd, $J_{4',6'}$ 1.7 and $J_{4',5'}$ 7.9 Hz, H-4′), 6.92–6.99 (2H, m, H-5″ and H-6′), 7.05 (1H, t, $J_{5',4'}$=$J_{5',6'}$ 7.8 Hz, H-5′), 7.07–7.11 (1H, dd, $J_{3'',5''}$ 0.9 and $J_{3'',4''}$ 7.9 Hz, H-3″), 7.24 (1H, td, $J_{4'',6''}$ 1.7 and $J_{4'',3''}$=$J_{4'',5''}$ 7.9 Hz, H-4″), 7.38 (1H, dd, $J_{6'',4''}$ 1.7 and $J_{6'',5''}$ 7.6 Hz, H-6″). δ_C (75 MHz, $CDCl_3$): 38.7 (CH_2, C-1), 55.7 (CH_3, OMe), 56.2 (CH_3, 2″-OCH_2OCH_3), 57.4 (CH_3, 2′-OCH_2OCH_3), 63.2 (CH, C-2), 81.0 (quat., C-4), 94.2 (quat., C-3), 94.9 (CH_2, 2″-OCH_2O), 99.1 (CH_2, 2′-OCH_2O), 111.0 (CH, C-4′), 113.4 (quat., C-1″), 115.2 (CH, C-3″), 121.7 (CH, C-5″), 123.1 (CH, C-6′), 124.2 (CH, C-5′), 129.5 (CH, C-4″), 131.3 (quat., C-1′), 133.6 (CH, C-6″), 145.1 (quat., C-2′), 152.0 (quat., C-3′), 157.7 (quat., C-2″); *m/z* (EI, %): 372 (M$^+$, 0.1), 310 (9), 277 (9), 266 (8), 205 (8), 150 (11), 137 (18), 45 (100).

3.13.2. 1-(5-Methoxy-2-(methoxymethoxy)phenyl)-4-(2-(methoxymethoxy)phenyl)but-3-yn-2-ol 18. Yellow oil. HRMS (EI): Found M$^+$, 372.15750, $C_{21}H_{24}O_6$ requires 372.15729. ν_{max} (film)/cm^{-1}: 3432 (br, s, OH), 2955, 2934, 2830 (s, CH), 2229 (C≡C), 1596, 1575 (ArC=C), 1499 (OCH_2O), 1280, 1254, 1222 (C–O). δ_H (300 MHz, $CDCl_3$): 2.96 (1H, br s, O*H*), 3.09–3.22 (2H, m, H-1), 3.46 (6H, s, OCH_2OCH_3×2), 3.71 (3H, s, OMe), 4.91–4.93 (1H, m, H-2), 5.12 (2H, s, OCH_2O), 5.18 (2H, s, OCH_2O), 6.72 (1H, dd, $J_{4',6'}$ 3.0 and $J_{4',3'}$ 8.8 Hz, H-4′), 6.90–6.94 (2H, m, H-3′ and H-6′), 7.01–7.09 (2H, m, H-3″ and H-5″), 7.20–7.25 (1H, m, H-4″), 7.35 (1H, d, $J_{6'',5''}$ 7.6 Hz, H-6″). δ_C (75 MHz, $CDCl_3$): 39.1 (CH_2, C-1), 55.4 (CH_3, OMe), 55.9 (CH_3, OCH_2OCH_3), 56.0 (CH_3, OCH_2OCH_3), 62.8 (CH, C-2), 81.3 (quat., C-4), 94.0 (quat., C-3), 94.9 (CH_2, OCH_2O), 95.2 (CH_2, OCH_2O), 112.5 (CH, C-4′), 113.2 (quat., C-1″), 115.2 (CH, C-3″), 115.4 (CH, C-6″), 117.5 (CH, C-3′), 121.7 (CH, C-5″), 127.4 (quat., C-1′), 129.5 (CH, C-4″), 133.5 (CH, C-6″), 149.6 (quat., C-2′), 154.2 (quat., C-5′), 157.7 (quat., C-2″); *m/z* (EI, %): 372 (M$^+$, 3), 310 (M$^+$−MOMOH, 11), 278 (14), 266 (10), 166 (13), 137 (19), 131 (13), 45 (100).

3.13.3. 1,4-Bis-(3-methoxy-2-(methoxymethoxy)phenyl)-but-3-yn-2-ol 19. Yellow oil. HRMS (EI): Found M$^+$, 402.16728, $C_{22}H_{26}O_7$ requires 402.16785. ν_{max} (film)/cm^{-1}: 3435 (s, br, O–H), 2936, 2838 (s, C–H, aromatic), 2225 (C≡C), 1735, 1574 (s, C=C, aromatic), 1510, 1472 (s, OCH_2O), 1266 (s, C–O), 1157, 1075. δ_H (300 MHz, $CDCl_3$): 3.09 (1H, s, OH), 3.18 (1H, dd, $J_{1A,2}$ 5.7 and J_{gem} 13.6 Hz, H-1$_A$), 3.27 (1H, dd, $J_{1B,2}$ 7.9 and J_{gem} 13.6 Hz, H-1$_B$), 3.60 (3H, s, OCH_2OCH_3), 3.61 (3H, s, OCH_2OCH_3), 3.80 (3H, s, OMe), 3.82 (3H, s, OMe), 4.89 (1H, dd, $J_{2,1A}$ 5.7 and $J_{2,1B}$ 7.9 Hz, H-2), 5.11–5.14 (2H, m, OCH_2O), 5.15 (2H, s, OCH_2O), 6.76–6.89 (2H, m, Ar-H), 6.92–7.06 (4H, m, Ar-H). δ_C (75 MHz, $CDCl_3$): 38.6 (CH_2, CH_2CHO, C-1), 55.6 (CH_3, OMe), 55.8 (CH_3, OMe), 57.3 (CH_3 2×OCH_2OCH_3), 63.1 (CH, C-2), 81.2 (quat., C-4), 94.3 (quat., C-3), 98.5 (CH_2, OCH_2O), 99.1 (CH_2, OCH_2O), 111.0 (CH, Ar-C), 112.8 (CH, Ar-C), 117.8 (quat., C-1″), 123.1 (CH, Ar-C), 123.9 (CH, Ar-C), 124.3 (CH, Ar-C), 125.2 (CH, Ar-C), 131.1 (quat., C-1′), 145.0 (quat., C-3′ or C-3″), 147.0 (quat., C-3″ or C-3′), 151.9 (quat., C-2′ or C-2″), 152.5 (quat., C-2″ or C-2′); *m/z* (EI, %): 402 (M$^+$, 0.4), 372 (0.6), 357 (0.5), 326 (2.9), 325 (3), 308 (8), 307 (5), 296 (35), 265 (6), 161 (17), 137 (16), 45 (100).

3.13.4. 4-(3-Methoxy-2-(methoxymethoxy)phenyl)-1-(5-methoxy-2-(methoxymethoxy)phenyl)but-3-yn-2-ol 20. Yellow oil. HRMS (EI): Found M$^+$, 402.16755, $C_{22}H_{26}O_7$ requires 402.16785. ν_{max} (film)/cm^{-1}: 3450 (s, br, O–H), 2936, 2837 (s, C–H, aromatic), 2228 (s, C≡C), 1594, 1574 (s, C=C, aromatic), 1500, 1470 (s, OCH_2O), 1261 (s, C–O), 1222, 1197. δ_H (300 MHz, $CDCl_3$): 3.12 (1H, d, $J_{1A,2}$ 7.0 Hz, H-1$_A$), 3.13 (1H, d, $J_{1B,2}$ 6.5 Hz, H-1$_B$), 3.44 (3H, s, OCH_2OCH_3), 3.56 (3H, s, OCH_2OCH_3), 3.69 (1H, s, OH), 3.71 (3H, s, OMe), 3.79 (3H, s, OMe), 4.87 (1H, dd, $J_{2,1A}$ 7.0 and $J_{2,1B}$ 6.5 Hz, H-2), 5.11 (2H, s, OCH_2O), 5.15 (2H, s, OCH_2O), 6.71 (1H, dd, $J_{4'',6''}$ 3.1 and $J_{4'',3''}$ 8.9 Hz, H-4″), 6.83–6.87 (1H, m, H-5′), 6.87 (1H, $J_{6'',3''}$ 3.1 Hz, H-6″), 6.94–6.95 (2H, m, H-4′ and H-6′), 7.01 (1H, d, 1H, $J_{3'',4''}$ 8.9 Hz, H-3″). δ_C (75 MHz, $CDCl_3$): 39.0 (CH_2, C-1), 55.3 (CH_3, OMe), 55.6 (CH_3, OMe), 55.7 (CH_3, OCH_2OCH_3), 57.1 (CH_3, OCH_2OCH_3), 62.5 (CH, C-2), 81.2 (quat., C-4), 94.1 (quat., C-3), 95.1 (CH_2, OCH_2O), 98.2 (CH_2, OCH_2O), 112.7 (CH, C-4″), 112.8 (CH, C-4′), 115.3 (CH, C-6″), 117.1 (CH, C-3″), 117.6 (quat., C-1′), 123.8 (CH, C-5′), 125.0 (CH, C-6′), 127.2 (quat., C-1″), 146.8 (quat., C-3′), 149.4 (quat., C-5″), 152.3 (quat., C-2′), 154.1 (quat., C-2″); *m/z* (EI, %): 402 (M$^+$, 2), 372 (1), 340 (5), 308 (8), 296 (15), 281 (3), 267 (6), 210 (7), 178 (9), 161 (11), 137 (12), 45 (100).

3.13.5. 1-(2-Methoxymethoxy-naphthalen-1-yl)-4-(2-methoxymethoxyphenyl)but-3-yn-2-ol 67. Yellow oil. HRMS (EI): Found M$^+$, 392.16275, $C_{24}H_{24}O_5$ requires 392.16237. ν_{max} (film)/cm^{-1}: 2958, 2252, 1730, 1625, 1596, 1514, 1490, 1470, 1374, 1242, 1197, 1152, 1114, 1081, 1048, 1019, 910, 810, 738. δ_H (300 MHz, $CDCl_3$): 2.96 (1H, br s, OH), 3.40 (3H, s, OCH_2OCH_3), 3.47 (3H, s, OCH_2OCH_3), 3.64–3.77 (1H, m, H-1), 5.01–5.05 (1H, m, H-2), 5.09 (1H, s, 2′-OCH_2O), 5.25 (2H, s, 2″-OCH_2O), 6.86 (1H, dt, $J_{5'',3''}$ 1.0, $J_{5'',6''}$=$J_{5'',4''}$ 7.4 Hz, H-5″), 7.03 (1H, d, $J_{3'',4''}$ 8.0 Hz, H-3″), 7.16 (1H, d, $J_{6'',5''}$ 7.4 Hz, H-6″), 7.15–7.21 (1H, m, H-4″), 7.32 (1H, dt, $J_{6',8'}$ 1.0, $J_{6',7'}$=$J_{6',5'}$ 7.5 Hz, H-6′), 7.41 (1H, d, $J_{3',4'}$ 9.0 Hz, H-3′), 7.41–7.46 (1H, m, H-7′), 7.71 (1H, d, $J_{4',3'}$ 9.0 Hz, H-4′), 7.76 (1H, d, $J_{5',6'}$ 7.5 Hz, H-5′), 8.13 (1H, d, $J_{8',7'}$

8.5 Hz, H-8′). δ_C (75 MHz, $CDCl_3$): 33.7 (CH_2, C-1), 56.0 (CH_3, 2×OMe), 62.9 (CH, C-2), 81.0 (quat., C-4), 94.3 (quat., C-3), 94.8 (CH_2, 2″-OCH_2OCH_3), 95.1 (CH_2, 2′-OCH_2OCH_3), 113.2 (quat., C-1′), 115.2 (CH, C-3″), 115.8 (CH, C-3′), 119.4 (quat., C-1″), 121.6 (CH, C-5″), 123.6 (CH, C-5′ or C-8′), 123.7 (CH, C-8′ or C-5′), 126.2 (CH, C-6′), 128.3 (CH, C-7′), 128.6 (CH, C-6″), 129.4 (CH, C-4′), 129.8 (quat., C-4′a), 133.4 (quat., C-8′a), 133.5 (CH, C-4″), 153.2 (quat., C-2′), 157.6 (quat., C-2″); *m*/*z* (EI, %): 392 (M^+, 2), 330 (4), 315 (3), 297 (5), 285 (4), 202 (21), 171 (10), 157 (17), 131 (9), 45 (100).

3.13.6. 4-(3-Methoxy-2-methoxymethoxyphenyl)-1-(2-methoxymethoxy-naphthalen-1-yl)but-3-yn-2-ol 68. Yellow oil. HRMS (EI): Found M^+, 422.17327, $C_{25}H_{26}O_6$ requires 422.17294. ν_{max} (film)/cm^{-1}: 3454 (s, br, OH), 2936, 2840, 1736, 1625, 1595, 1574, 1470, 1438, 1373, 1261, 1242, 1261, 1185, 1151, 1047. δ_H (400 MHz, $CDCl_3$): 2.84 (1H, br s, OH), 3.50 (3H, s, 2′-OCH_2OCH_3), 3.53 (3H, s, 2″-OCH_2OCH_3), 3.64–3.74 (1H, m, H-1), 3.78 (3H, s, 3′-OMe), 5.00–5.02 (1H, m, H-2), 5.09 (2H, s, 2′-OCH_2O), 5.28 (2H, s, 2″-OCH_2O), 6.80–6.83 (2H, m, H-4′ and H-5′), 6.92 (1H, d, $J_{6',5'}$ 7.9 Hz, H-6′), 7.34 (1H, t, $J_{6'',7''}=J_{6'',5''}$ 7.8 Hz, H-6″), 7.42 (1H, d, $J_{3'',4''}$ 9.0 Hz, H-3″), 7.46 (1H, t, $J_{7'',6''}=J_{7'',8''}$ 7.8 Hz, H-7″), 7.42 (1H, d, $J_{4'',3''}$ 9.0 Hz, H-4″), 7.77 (1H, d, $J_{5'',6''}$ 7.8 Hz, H-5″), 8.10 (1H, d, $J_{8'',7''}$ 7.8 Hz, H-8″). δ_C (100 MHz, $CDCl_3$): 33.7 (CH_2, C-1), 55.7 (CH_3, 2″-OCH_2OMe), 56.1 (CH_3, 2′-OCH_2OMe), 57.3 (CH_3, OMe), 63.0 (CH, C-2), 81.2 (quat., C-4), 94.3 (quat., C-3), 95.2 (CH_2, 2′-OCH_2O), 98.4 (CH_2, 2″-OCH_2O), 112.8 (CH, C-4′), 115.8 (CH, C-3″), 117.7 (quat., C-1″), 119.3 (quat., C-1′), 123.6 (CH, C-6′), 123.7 (CH, C-8″ or C-6″), 123.9 (CH, C-6″ or C-8″), 125.1 (CH, C-5′), 126.4 (CH, C-7″), 128.4 (CH, C-4″), 128.8 (CH, C-5″), 129.8 (quat., C-4″a), 133.4 (quat., C-8″a), 146.9 (quat., C-2′), 152.4 (quat., C-3′), 153.2 (quat., C-2″); *m*/*z* (EI, %): 422 (M^+, 1), 392 (1), 360 (7), 328 (7), 316 (8), 202 (15), 157 (16), 77 (1), 45 (100).

3.13.7. 1-(5-Methoxy-1-(methoxymethoxy)naphthalen-2-yl)-4-(2-(methoxymethoxy)phenyl)but-3-yn-2-ol 73. Tan oil. HRMS (EI): Found M^+, 422.17338, $C_{25}H_{26}O_6$ requires 422.17294. ν_{max} (film)/cm^{-1}: 3428 (s, br, OH), 2997, 2956, 2934, 2850, 2247 (s, C≡C), 1598, 1577 (s, C=C, aromatic), 1506, 1490, 1449, 1415, 1378, 1258, 1155, 1051 (s, C–O). δ_H (400 MHz, $CDCl_3$): 3.18 (br s, OH), 3.34 (1H, dd, $J_{1A,2}$ 5.7 and J_{gem} 13.6 Hz, H-1_A), 3.45 (3H, s, OCH_2OCH_3), 3.47–3.52 (1H, m, H-1_B), 3.72 (3H, s, OCH_2OCH_3), 3.96 (3H, s, OMe), 5.00 (1H, m, H-2), 5.16 (2H, s, OCH_2O), 5.16–5.23 (2H, m, OCH_2O), 6.79 (1H, d, $J_{6',7'}$ 7.8 Hz, H-6′), 6.93 (1H, ddd, $J_{5'',3''}$ 0.8, $J_{5'',4''}$ 7.4 and $J_{5'',6''}$ 7.6 Hz, H-5″), 7.07 (1H, d, $J_{3'',4''}$ 7.7 Hz, H-3″), 7.20–7.26 (1H, m, H-4″), 7.37 (1H, dd, $J_{6'',4''}$ 1.6 and $J_{6'',5''}$ 7.6 Hz, H-6″), 7.39 (1H, dd, $J_{7',6'}$ 7.8 and $J_{7',8'}$ 8.4 Hz, H-7′), 7.49 (1H, d, $J_{3',4'}$ 8.7 Hz, H-3′), 7.58 (1H, d, $J_{8',7'}$ 8.4 Hz, H-8′), 8.03 (1H, d, $J_{4',3'}$ 8.7 Hz, H-4′). δ_C (100 MHz, $CDCl_3$): 38.7 (CH_2, C-1), 55.5 (CH_3, OMe), 56.1 (CH_3, OMe), 56.2 (CH_3, OCH_2OCH_3), 57.5 (CH_3, OCH_2OCH_3), 63.2 (CH, C-2), 81.2 (quat., C-4), 94.2 (quat., C-3), 94.8 (CH_2, OCH_2O), 100.3 (CH_2, OCH_2), 103.9 (CH, C-6′), 113.2 (quat., C-1″), 114.2 (CH, C-8′), 115.1 (CH, C-5″), 118.6 (CH, C-4′), 121.7 (CH, C-3″), 126.2 (CH, C-7′), 126.3 (quat., C-2′), 126.8 (quat., C-4′a), 127.8 (CH, C-3′), 129.3 (quat., C-8′a), 129.6 (CH, C-4″), 133.6 (CH, C-6″), 152.0 (quat., C-1′), 155.7 (quat., C-5′), 157.8 (quat., C-2″); *m*/*z* (EI, %): 422 (M^+, 3), 392 (3), 360 (M^+−MOMOH, 15), 328 (16), 260 (8), 228 (9), 216 (11), 199 (10), 187 (24), 131 (9), 115 (8), 45 (100).

3.13.8. 1-[4,8-Dimethoxy-1-(methoxymethoxy)naphthalen-2-yl]-4-(2-(methoxymethoxy)phenyl)but-3-yn-2-ol 74. Yellow oil. HRMS (EI): Found M^+, 452.18381, $C_{26}H_{28}O_7$ requires 452.18350. ν_{max} (film)/cm^{-1}: 3435 (s, OH), 3054, 2987 (s, C–H, aromatic), 2685, 2521, 2410, 2305 (C–H, alkane), 2126 (C≡C, alkyne), 1421 (C–H alkane), 1265 (s, C–O), 742. δ_H (400 MHz, $CDCl_3$): 3.31 (1H, dd, $J_{1A,2}$ 5.2 and J_{gem} 13.6 Hz, H-1_A), 3.44 (3H, s, OCH_2OCH_3), 3.55 (1H, dd, $J_{1B,2}$ 8.7 and J_{gem} 13.6 Hz, H-1_B), 3.63 (1H, d, *J* 6.3 Hz, OH), 3.71 (3H, s, OCH_2OCH_3), 3.89 (3H, s, OMe), 3.93 (3H, s, OMe), 5.01–5.04 (1H, m, H-2), 5.07 (1H, d, J_{gem} 16.6 Hz, OCH_AH_BO), 5.08 (1H, d, J_{gem} 16.6 Hz, OCH_AH_BO), 5.16 (2H, s, OCH_2O), 6.82 (1H, s, H-3′), 6.88 (1H, d, $J_{7',6'}$ 8.1 Hz, H-7′), 6.91 (1H, dt, $J_{5'',3''}$ 0.7, $J_{5'',6''}=J_{5'',4''}$ 7.5 Hz, H-5″), 7.07 (1H, d, $J_{3'',4''}$ 8.4 Hz, H-3″), 7.23 (1H, dt, $J_{4'',6''}$ 1.6, $J_{4'',5''}$ 7.5, $J_{4'',3''}$ 8.4 Hz, H-4″), 7.33 (1H, t, $J_{6',7'}=J_{6',5'}$ 8.1 Hz, H-6′), 7.38 (1H, dd, $J_{6'',4''}$ 1.6 and $J_{6'',5''}$ 7.6 Hz, H-6″), 7.85 (1H, d, $J_{5',6'}$ 8.1 Hz, H-5′). δ_C (100 MHz, $CDCl_3$): 39.2 (CH_2, C-1), 55.5 (CH_3, OMe), 56.0 (CH_3, OMe), 56.0 (CH_3, OCH_2OCH_3), 57.1 (CH_3, OCH_2OCH_3), 63.2 (CH, C-2), 80.8 (quat., C-4), 94.8 (quat., C-3), 94.9 (CH_2, OCH_2O), 101.4 (CH_2, OCH_2O), 106.8 (CH, C-7′), 107.0 (CH, C-5′), 113.4 (quat., C-1″), 115.0 (CH, C-3″), 115.2 (CH, C-3′), 120.1 (quat., C-2′), 121.7 (CH, C-5″), 125.1 (CH, C-6′), 126.7 (quat., C-8′a), 128.1 (quat., C-4′a), 129.5 (CH, C-4″), 133.5 (CH, C-6″), 145.1 (quat., C-8′), 151.5 (quat., C-4′), 155.1 (quat., C-1′), 157.7 (CH, C-2″); *m*/*z* (EI, %): 452 (M^+, 23), 390 (M^+−OMOM, 20), 375 (8), 358 (7), 343 (13), 217 (100), 201 (14), 69 (21), 57 (34), 45 (82).

3.14. Standard procedure for hydrogenation of acetylenes

A mixture of the acetylene (80 mg, 0.17 mmol), 10% palladium on carbon (67 mg, 0.63 mmol) and potassium bicarbonate (86 mg, 0.63 mmol) in ethyl acetate (2 mL) was stirred under an atmosphere of hydrogen at room temperature for 2 h. The resulting mixture was filtered through a plug of Celite® and the filtrate concentrated in vacuo. The resulting residue was purified by flash column chromatography.

3.14.1. 1-(3-Methoxy-2-methoxymethoxyphenyl)-4-(2-methoxymethoxyphenyl)butan-2-ol 39. Colourless solid. Mp: 41–42 °C. HRMS (EI): Found M^+, 376.18842, $C_{21}H_{28}O_6$ requires 376.18859. ν_{max} (film)/cm^{-1}: 3460 (br, s, OH), 3064 (C–H, aromatic), 2998, 2836 (s, CH), 1600, 1585 (ArC=C), 1493 (OCH_2O), 1070, 1049 (C–O), 753 (ArC–H). δ_H (400 MHz, $CDCl_3$): 1.77–1.84 (2H, m, H-3), 2.58 (1H, br s, OH), 2.71–2.93 (4H, m, H-4 and H-1), 3.42 (3H, s, 2″-OCH_2OCH_3), 3.53 (3H, s, 2′-OCH_2OCH_3), 3.78 (3H, s, OMe), 5.07 (2H, m, 2′-OCH_AH_BO), 5.15 (2H, s, 2″-OCH2O), 6.75–6.80 (2H, m, H-4′ and H-6′), 6.90 (1H, t, $J_{5'',6''}=J_{5'',4''}$ 7.2 Hz, H-5″), 6.97 (1H, t, $J_{5',4'}=J_{5',6'}$ 7.9 Hz, H-5′), 7.03 (1H, dd, $J_{3'',4''}$ 8.1 Hz, H-3″), 7.10–7.14 (1H, m, H-4″), 7.15 (1H, d, $J_{6'',5''}$ 7.2 Hz, H-6″). δ_C (100 MHz, $CDCl_3$): 26.5 (CH_2, C-4), 37.6 (CH_2, C-3), 38.1 (CH_2, C-1), 55.5 (CH_3, OMe), 55.8 (CH_3, 2″-OCH_2OCH_3), 57.2 (CH_3, 2′-OCH_2OCH_3), 71.4 (CH, C-2), 94.2 (CH_2, 2″-OCH_2O), 98.9 (CH_2, 2′-OCH_2O), 110.4 (CH, C-4′ or C-6′), 113.7 (CH, C-3″), 121.5 (CH, C-5″), 122.8 (CH, C-6′ or C-4′), 124.0 (CH, C-5′), 126.8 (CH, C-4″), 130.0 (CH, C-6″), 131.0 (quat., C-1″), 132.8 (quat., C-1′), 144.6 (quat., C-2′), 151.9 (quat., C-3′), 154.9 (quat., C-2″); *m*/*z* (EI, %): 376 (M^+, 2), 344 (M^+−MeOH, 9), 314 (M^+−MOMOH, 9), 300 (2), 282 (10), 270 (4), 150 (28), 133 (22), 45 (100).

3.14.2. 1-(5-Methoxy-2-(methoxymethoxy)phenyl)-4-(2-(methoxymethoxy)phenyl)butan-2-ol 40. Pale yellow oil. HRMS (EI): Found M^+, 376.18807, $C_{21}H_{28}O_6$ requires 376.18859. ν_{max} (film)/cm^{-1}: 3452 (br, s, OH), 3062 (C–H, aromatic), 2932, 2829, 2788 (s, CH), 1601, 1587 (ArC=C), 1495 (OCH_2O), 1283, 1221, 1150, 1113, 1006 (C–O). δ_H (300 MHz, $CDCl_3$): 1.76–1.84 (2H, m, H-3), 2.35 (1H, br s, OH), 2.71–2.89 (4H, m, H-4 and H-1), 3.39 (3H, s, $OCH_2OC\mathit{H}_3$), 3.43 (3H, s, $OCH_2OC\mathit{H}_3$), 3.73 (3H, s, OMe), 3.83–3.88 (1H, m, H-2), 5.07 (2H, s, OCH_2O), 5.17 (2H, s, OCH_2O), 6.69 (1H, dd, $J_{4',6'}$ 3.0 and $J_{4',3'}$ 8.8 Hz, H-4′), 6.74 (1H, d, $J_{6',4'}$ 3.0 Hz, H-6′), 6.89–6.94 (1H, m, H-3′), 6.98–7.05 (2H, m, H-3″ and H-5″), 7.10–7.24 (2H, m, H-4″ and H-6″). δ_C (75 MHz, $CDCl_3$): 26.4 (CH_2, C-4), 37.2 (CH_2, C-3), 38.7 (CH_2, C-1), 55.5 (CH_3, OMe), 55.9 (CH_3, OCH_2OCH_3), 57.4 (CH_3, OCH_2OCH_3), 71.1 (CH, C-2), 94.3 (CH_2, OCH_2O), 95.1 (CH_2, OCH_2O), 111.9 (CH, C-4′), 113.9 (CH, C-3″), 115.4 (CH, C-6′), 117.1 (CH, C-3′), 121.7 (CH, C-5″), 127.0 (CH, C-4″), 129.2 (quat., C-1″), 130.1 (CH, C-6″), 131.0 (quat., C-1′), 149.4 (quat., C-2′), 154.3 (quat., C-5′), 155.0 (quat., C-2″); *m*/*z* (EI, %): 376 (M^+, 6), 344 (11), 314 (17), 282 (8), 270 (5), 175 (11), 163 (18), 137 (18), 13 (18), 107 (12), 45 (100).

3.14.3. 1,4-Bis-(3-methoxy-2-methoxymethoxyphenyl)-butan-2-ol 41. Colourless oil. HRMS (EI): Found M^+, 406.19883, $C_{22}H_{30}O_7$ requires 406.19915. ν_{max} (film)/cm^{-1}: 3470 (br, s, OH), 2936, 2838 (C–H, aromatic), 1599, 1584 (s, C=C, aromatic), 1475 (s, OCH_2O), 1439, 1402, 1307, 1267 (s, C–O). δ_H (300 MHz, $CDCl_3$): 1.74–1.88 (2H, m, H-3), 2.78–2.94 (4H, m, H-4 and H-1), 3.41–3.50 (1H, m, H-2), 3.53 (3H, s, $OCH_2OC\mathit{H}_3$), 3.55 (3H, s, $OCH_2OC\mathit{H}_3$), 3.77 (3H, s, OMe), 3.78 (3H, s, OMe), 3.86 (1H, br s, OH), 5.02–5.06 (2H, m, OCH_2O), 5.06 (2H, s, OCH_2O), 6.71–6.84 (4H, m, Ar-H), 6.95 (1H, t, $J_{5',4'}$=$J_{5',6'}$ 7.9 Hz, H-5′), 6.97 (1H, t, $J_{5'',4''}$=$J_{5'',6''}$ 7.9 Hz, H-5″). δ_C (75 MHz, $CDCl_3$): 26.3 (CH_2, C-4), 38.2 (CH_2, C-3), 38.3 (CH_2, C-1), 55.6 (CH_3, OMe), 55.6 (CH_3, OMe), 57.4 (CH_3, OCH_2OCH_3), 57.4 (CH_3, OCH_2OCH_3), 71.5 (CH, C-2), 99.0 (CH_2, OCH_2O), 99.1 (CH_2, OCH_2O), 110.0 (CH, Ar-C), 110.6 (CH, Ar-C), 118.7 (quat., C-1″), 122.1 (CH, Ar-C), 122.9 (CH, Ar-C), 124.1 (CH, Ar-C), 124.2 (CH, Ar-C), 133.0 (quat., Ar-C), 136.3 (quat., Ar-C), 144.2 (quat., Ar-C), 144.7 (quat., Ar-C), 152.1 (quat., Ar-C); *m*/*z* (EI, %): 406 (M^+, 0.1), 374 (M^+−MeOH, 4), 342 (5), 330 (8), 312 (12), 300 (14), 175 (19), 163 (47), 137 (35), 45 (100).

3.14.4. 4-(3-Methoxy-2-(methoxymethoxy)phenyl)-1-(5-methoxy-2-(methoxymethoxy)phenyl)butan-2-ol 42. Pale yellow oil. HRMS (EI): Found M^+, 406.19948, $C_{22}H_{30}O_7$ requires 406.19915. ν_{max} (film)/cm^{-1}: 3466 (s, br, O–H), 3061, 2995, 2936, 2836 (s, C–H, aromatic), 1736, 1601, 1585 (s, C=C, aromatic), 1499, 1475 (s, OCH_2O), 1439, 1403, 1372, 1305, 1266 (s, C–O), 1221, 1196, 1152, 1119, 1073, 1045, 1005. δ_H (300 MHz, $CDCl_3$): 1.72–1.89 (2H, m, H-3), 2.46 (1H, br s, OH), 2.68–2.94 (4H, m, H-4 and H-1), 3.39 (3H, s, $OCH_2OC\mathit{H}_3$), 3.44–3.53 (1H, m, H-2), 3.57 (3H, s, $OCH_2OC\mathit{H}_3$), 3.73 (3H, s, OMe), 3.81 (3H, s, OMe), 5.06 (2H, s, OCH_2O), 5.08 (2H, s, OCH_2O), 6.69 (1H, dd, $J_{4'',6''}$ 3.1 and $J_{4'',3''}$ 8.8 Hz, H-4″), 6.73 (1H, d, $J_{6'',4''}$ 3.1 Hz, H-6″), 6.74–6.80 (2H, m, H-4′ and H-5′), 6.96 (1H, d, $J_{6',5'}$ 7.9 Hz, H-6′), 6.98 (1H, d, $J_{3'',4''}$ 8.5 Hz, H-3″). δ_C (75 MHz, $CDCl_3$): 26.1 (CH_2, C-4), 37.9 (CH_2, C-3), 38.7 (CH_2, C-1), 55.5 (CH_3, OMe), 55.6 (CH_3, OMe), 55.8 (CH_3, OCH_2OCH_3), 57.4 (CH_3, OCH_2OCH_3), 70.9 (CH, C-2), 95.1 (CH_2, OCH_2O), 99.0 (CH_2, OCH_2O), 109.9 (CH, C-4′), 112.0 (CH, C-4″), 115.4 (CH, C-6″), 117.0 (CH, C-3″), 122.0 (CH, C-5′), 124.1 (CH, C-6′), 129.3 (quat., C-1″), 136.1 (quat., C-1′), 144.2 (quat., C-3′), 149.4 (quat., C-5″), 152.0 (quat., C-2′), 154.3 (quat., C-2″); *m*/*z* (EI, %): 402 (M^+, 2), 374 (7), 344 (4), 342 (3), 330 (5), 300 (12), 298 (3), 175 (20), 163 (38), 150 (31), 137 (34), 57 (21), 45 (100).

3.14.5. 1-(2-Methoxymethoxy-naphthalen-1-yl)-4-(2-methoxymethoxyphenyl)butan-2-ol 69. Pale yellow oil. HRMS (EI): Found M^+, 396.19360, $C_{24}H_{28}O_5$ requires 396.19367. ν_{max} (film)/cm^{-1}: 2933, 2354, 2251, 1730, 1624, 1595, 1513, 1491, 1469, 1374, 1240, 1197, 1151, 1061, 1010, 909, 808, 649. δ_H (400 MHz, $CDCl_3$): 1.88–1.93 (2H, m, H-3), 2.35 (1H, br s, OH), 2.72–2.91 (2H, m, H-4), 3.31–3.32 (2H, m, H-1), 3.32 (3H, s, OMe), 3.38 (3H, s, OMe), 3.99 (1H, m, H-2), 5.07 (2H, s, 2′-OCH_2O), 5.17 (1H, d, J_{gem} 9.6 Hz, 2″-$OC\mathit{H}_A H_B O$), 5.19 (1H, d, J_{gem} 9.6 Hz, 2″-$OCH_A \mathit{H}_B O$), 6.87 (1H, dt, $J_{5'',3''}$ 0.9 Hz, $J_{5'',6''}$=$J_{5'',4''}$ 7.4 Hz, H-5″), 6.99 (1H, d, $J_{3'',4''}$ 7.5 Hz, H-3″), 7.06–7.13 (2H, m, H-4″ and H-6″), 7.30 (1H, t, $J_{6',7'}$=$J_{6',5'}$ 7.8 Hz, H-6′), 7.35 (1H, d, $J_{3',4'}$ 9.0 Hz, H-3′), 7.42 (1H, dt, $J_{7',5'}$ 1.1, $J_{7',6'}$=$J_{7',8'}$ 7.8 Hz, H-7′), 7.65 (1H, d, $J_{4',3'}$ 9.0 Hz, H-4′), 7.73 (1H, d, $J_{5',6'}$ 7.8 Hz, H-5′), 7.98 (1H, d, $J_{8',7'}$ 7.8 Hz, H-8′). δ_C (100 MHz, $CDCl_3$): 26.6 (CH_2, C-4), 33.2 (CH_2, C-3), 37.5 (CH_2, C-1), 56.0 (2×CH_3, OMe), 71.6 (CH, C-2), 94.1 (CH_2, 2″-OCH_2O), 94.8 (CH_2, 2′-OCH_2O), 113.7 (CH, C-3″), 115.6 (CH, C-3′), 121.1 (quat., C-1′), 121.5 (CH, C-5″), 123.5 (CH, C-5′ or C-8′), 123.6 (CH, C-8′ or C-5′), 126.2 (CH, C-6′), 126.8 (CH, C-7′), 128.0 (CH, C-6″), 128.3 (CH, C-4′), 129.7 (quat., C-1″), 130.0 (CH, C-4″), 131.0 (quat., C-4′a), 133.4 (quat., C-8′a), 152.6 (quat., C-2′), 154.9 (quat., C-2″); *m*/*z* (EI, %): 396 (M^+, 6), 364 (6), 334 (8), 289 (4), 202 (20), 195 (9), 183 (5), 181 (6), 170 (38), 157 (34), 133 (26), 129 (8), 121 (9), 45 (100).

3.14.6. 4-(3-Methoxy-2-methoxymethoxyphenyl)-1-(2-methoxymethoxy-naphthalen-1-yl)butan-2-ol 70. Pale yellow oil. HRMS (EI): Found M^+, 426.20424, $C_{25}H_{30}O_6$ requires 426.20424. ν_{max} (film)/cm^{-1}: 3435 (s, br, OH), 2935, 2840, 2251, 1730, 1625, 1585, 1475, 1438, 1401, 1382, 1265, 1241, 1197, 1151, 1063, 1018, 909, 733. δ_H (400 MHz, $CDCl_3$): 1.90–1.96 (2H, m, H-3), 2.41 (1H, br s, OH), 2.83–2.91 (2H, m, H-4), 3.30–3.33 (2H, m, H-1), 3.41 (3H, s, 2′-$OCH_2O\mathit{Me}$), 3.52 (3H, s, 2″-$OCH_2O\mathit{Me}$), 3.77 (3H, s, OMe), 3.96–3.99 (1H, m, H-2), 5.05 (2H, s, 2′-OCH_2O), 5.20 (1H, d, J_{gem} 9.8 Hz, 2″-$OC\mathit{H}_A H_B O$), 5.22

(1H, d, J_{gem} 9.8 Hz, $2''$-OCH$_A$$H_B$O), 6.71–6.76 (2H, m, H-$4'$ and H-$6'$), 6.93 (1H, t, $J_{5',4'}$=$J_{5',6'}$ 7.6 Hz, H-$5'$), 7.32 (1H, t, $J_{6'',7''}$=$J_{6'',5''}$ 7.6 Hz, H-$6''$), 7.37 (1H, d, $J_{3'',4''}$ 9.0 Hz, H-$3''$), 7.43 (1H, dt, $J_{7'',5''}$ 1.0 and $J_{7'',6''}$=$J_{7'',8''}$ 7.6 Hz, H-$7''$), 7.68 (1H, d, $J_{4'',3''}$ 9.0 Hz, H-$4''$), 7.74 (1H, d, $J_{5'',6''}$ 7.6 Hz, H-$5''$), 8.00 (1H, d, $J_{8'',7''}$ 7.6 Hz, H-$8''$). δ_C (100 MHz, CDCl$_3$): 26.3 (CH$_2$, C-4), 33.2 (CH$_2$, C-1), 38.2 (CH$_2$, C-3), 55.5 (CH$_3$, $2''$-OCH$_2$O*Me*), 56.0 (CH$_3$, $2'$-OCH$_2$O*Me*), 57.3 (CH$_3$, OMe), 71.6 (CH, C-2), 94.9 (CH$_2$, $2'$-OCH$_2$O), 98.9 (CH$_2$, $2''$-OCH$_2$O), 109.9 (CH, C-$4'$ or C-$6'$), 115.7 (CH, C-$3''$), 121.2 (quat., C-$1''$), 121.9 (CH, C-$6'$ or C-$4'$), 123.6 (2×CH, C-$8''$ and C-$6''$), 124.0 (CH, C-$5'$), 126.2 (CH, C-$7''$), 128.1 (CH, C-$4''$), 128.3 (CH, C-$5''$), 129.8 (quat., C-$4''$a), 133.4 (quat., C-$8''$a), 136.1 (quat., C-$1'$), 144.1 (quat., C-$2'$), 152.0 (quat., C-$3'$), 152.7 (quat., C-$2''$); *m*/*z* (EI, %): 426 (M$^+$, 3), 394 (10), 364 (9), 322 (5), 320 (8), 246 (7), 201 (17), 181 (9), 170 (44), 163 (34), 157 (23), 151 (16), 137 (12), 128 (4), 45 (100).

3.14.7. 1-(5-Methoxy-1-(methoxymethoxy)naphthalen-2-yl)-4-(2-(methoxymethoxy)phenyl)butan-2-ol 75. Pale yellow oil. HRMS (EI): Found M$^+$, 426.20403, C$_{25}$H$_{30}$O$_6$ requires 426.20424. ν_{max} (film)/cm^{-1}: 3435 (s, br, OH), 3054, 2986 (CH, aromatic), 1637, 1601, 1420, 1333, 1265, 1154, 1079, 1006 (s, C–O), 896, 739, 705. δ_H (400 MHz, CDCl$_3$): 1.78–1.90 (2H, m, H-3), 2.60 (1H, br s, OH), 2.74–2.90 (2H, m, H-4), 2.99–3.09 (2H, m, H-1), 3.39 (3H, s, OCH$_2$OC*H*$_3$), 3.64 (3H, s, OCH$_2$OC*H*$_3$), 3.95 (3H, s, OMe), 3.95–3.98 (1H, m, H-2), 5.11–5.15 (4H, m, 2×OCH$_2$O), 6.77 (1H, d, $J_{6',7'}$ 7.7 Hz, H-$6'$), 6.92 (1H, dt, $J_{5'',3''}$ 0.9, $J_{5'',4''}$=$J_{5'',6''}$ 7.3 Hz, H-$5''$), 7.04 (1H, d, $J_{3'',4''}$ 7.6 Hz, H-$3''$), 7.11–7.17 (2H, m, H-$4''$ and H-$6''$), 7.31 (1H, d, $J_{3',4'}$ 8.6 Hz, H-$3'$), 7.38 (1H, dd, $J_{7',6'}$ 7.7 and $J_{7',8'}$ 8.5 Hz, H-$7'$), 7.58 (1H, d, $J_{8',7'}$ 8.5 Hz, H-$8'$), 7.99 (1H, d, $J_{4',3'}$ 8.6 Hz, H-$4'$). δ_C (100 MHz, CDCl$_3$): 26.6 (CH$_2$, C-4), 37.9 (CH$_2$, C-3), 38.2 (CH$_2$, C-1), 55.5 (CH$_3$, OMe), 55.9 (CH$_3$, OCH$_2$O*C*H$_3$), 57.5 (CH$_3$, OCH$_2$O*C*H$_3$), 71.7 (CH, C-2), 94.3 (CH$_2$, OCH$_2$O), 100.3 (CH$_2$, OCH$_2$O), 103.7 (CH, C-$6'$), 113.9 (CH, C-$8'$), 114.3 (CH, C-$5''$), 118.6 (CH, C-$4'$), 121.7 (CH, C-$3''$), 126.0 (quat., C-$2'$), 126.2 (CH, C-$7'$), 127.0 (CH, C-$3'$), 127.8 (CH, C-$4''$), 128.4 (quat., C-$4'$a), 129.4 (quat., C-$8'$a), 130.1 (CH, C-$6''$), 131.1 (quat., C-$1''$), 151.5 (quat., C-$1'$), 155.0 (quat., C-$5'$), 155.7 (quat., C-$2''$); *m*/*z* (EI, %): 426 (M$^+$, 9), 394 (21), 364 (38), 332 (12), 225 (24), 213 (31), 211 (30), 187 (43), 133 (13), 107 (13), 45 (100).

3.14.8. 1-[4,8-Dimethoxy-1-(methoxymethoxy)naphthalen-2-yl]-4-[(2-methoxymethoxy)phenyl]butan-2-ol 76. Pale yellow oil. HRMS (EI): Found M$^+$, 456.21485, C$_{26}$H$_{32}$O$_7$ requires 456.21480. ν_{max} (film)/cm^{-1}: 3435 (s, br, OH), 3054, 2986 (CH, aromatic), 1637, 1601, 1420, 1333, 1265, 1154, 1079, 1006 (s, C–O), 896, 739, 705. δ_H (400 MHz, CDCl$_3$): 1.83–1.94 (2H, m, H-3), 2.76–2.94 (3H, m, H-2 and H-4), 3.01–3.12 (2H, m, H-1), 3.41 (3H, s, OCH$_2$OC*H*$_3$), 3.60 (3H, s, OCH$_2$OC*H*$_3$), 3.91 (3H, s, OMe), 3.92 (3H, s, OMe), 4.02 (1H, br s, OH), 5.01 (1H, d, J_{gem} 17.7 Hz, OC*H*$_A$H$_B$O), 5.03 (1H, d, J_{gem} 17.7 Hz, OCH$_A$*H*$_B$O), 5.16 (2H, s, OCH$_2$O), 6.67 (1H, s, H-$3'$), 6.87 (1H, d, $J_{7',6'}$ 8.0 Hz, H-$7'$), 6.92 (1H, dd, $J_{5'',6''}$=$J_{5'',4''}$ 7.4 Hz, H-$5''$), 7.05 (1H, d, $J_{3'',4''}$ 8.0 Hz, H-$3''$), 7.13 (1H, ddd, $J_{4'',6''}$ 1.5, $J_{4'',5''}$ 7.4 and $J_{4'',3''}$ 8.0 Hz, H-$4''$), 7.18 (1H, d, $J_{6'',5''}$ 7.4 Hz, H-$6''$), 7.31 (1H, t, $J_{6',7'}$=$J_{6',5'}$ 8.0 Hz, H-$6'$), 7.85 (1H, d, $J_{5',6'}$ 8.0 Hz, H-$5'$). δ_C (100 MHz, CDCl$_3$): 26.6 (CH$_2$, C-4), 38.2 (CH$_2$, C-3), 38.7 (CH$_2$, C-1), 55.6 (CH$_3$, OMe), 55.9 (CH$_3$, OMe), 56.0 (CH$_3$, OCH$_2$O*C*H$_3$), 57.2 (CH$_3$, OCH$_2$O*C*H$_3$), 71.9 (CH, C-2), 94.3 (CH$_2$, O*C*H$_2$OCH$_3$), 101.4 (CH$_2$, O*C*H$_2$OCH$_3$), 106.8 (CH, C-$7'$), 107.0 (CH, C-$5'$), 113.8 (CH, C-$3''$), 114.9 (CH, C-$3'$), 120.2 (quat., C-$2'$), 121.6 (CH, C-$5''$), 124.9 (CH, C-$6'$), 126.9 (CH, C-$4''$), 127.8 (quat., C-$8'$a), 128.5 (quat., C-$4'$a), 130.1 (CH, C-$6''$), 131.2 (quat., C-$1''$), 144.6 (quat., C-$8'$), 151.5 (quat., C-$4'$), 155.0 (quat., C-$1'$), 155.1 (CH, C-$2''$); *m*/*z* (EI, %): 456 (M$^+$, 24), 424 (14), 394 (51), 350 (8), 243 (31), 217 (100), 45 (67).

3.15. Standard procedure for oxidation of secondary alcohols to ketones

Tetra-*n*-propylammonium perruthenate (0.3 mg, 0.008 mmol) was added to a stirred mixture of the secondary alcohol (74 mg, 0.16 mmol), 4-methylmorpholine *N*-oxide (3 mg, 0.24 mmol) and 4 Å molecular sieves (45 mg) in dichloromethane (1 mL). The reaction was stirred at room temperature for 1.5 h, then filtered through a plug of silica gel and the filtrate concentrated in vacuo. The resultant residue was purified by flash column chromatography.

3.15.1. 1-(3-Methoxy-2-methoxymethoxyphenyl)-4-(2-methoxymethoxyphenyl)butan-2-one 13. Colourless solid. Mp: 65–68 °C. HRMS (EI): Found M$^+$, 374.17320, C$_{21}$H$_{26}$O$_6$ requires 374.17294. ν_{max} (film)/cm^{-1}: 3054 (C–H, aromatic), 2905, 2840 (s, CH), 1711 (C=O), 1601, 1585 (ArC=C), 1492 (OCH$_2$O), 1077 (C–O). δ_H (300 MHz, CDCl$_3$): 2.72–2.79 (2H, m, H-4), 2.85–2.91 (2H, m, H-3), 3.42 (3H, s, $2''$-OCH$_2$OC*H*$_3$), 3.51 (3H, s, $2'$-OCH$_2$OC*H*$_3$), 3.76 (2H, s, H-1), 3.83 (3H, s, OMe), 5.06 (2H, s, $2'$-OCH$_2$O), 5.15 (2H, s, $2''$-OCH$_2$O), 6.72 (1H, dd, $J_{4',6'}$ 1.4 and $J_{4',5'}$ 7.6 Hz, H-$4'$), 6.83 (1H, dd, $J_{6',4'}$ 1.4, $J_{6',5'}$ 8.2 Hz, H-$6'$), 6.89 (1H, dt, $J_{5'',3''}$ 1.4 and $J_{5'',6''}$=$J_{5'',4''}$ 7.3 Hz, H-$5''$), 6.97–7.03 (2H, m, H-$3''$ and H-$5'$), 7.06–7.19 (2H, m, H-$4''$ and H-$6''$). δ_C (75 MHz, CDCl$_3$): 24.9 (CH$_2$, C-4), 41.8 (CH$_2$, C-1), 44.9 (CH$_2$, C-3), 55.7 (CH$_3$, OMe), 55.9 (CH$_3$, $2''$-OCH$_2$O*C*H$_3$), 57.5 (CH$_3$, $2'$-OCH$_2$O*C*H$_3$), 94.2 (CH$_2$, $2''$-OCH$_2$O), 98.9 (CH$_2$, $2'$-OCH$_2$O), 111.4 (CH, C-$4'$), 113.7 (CH, C-$3''$), 121.6 (CH, C-$5''$), 122.9 (CH, C-$6'$), 124.3 (CH, C-$5'$), 127.3 (CH, C-$4''$), 129.1 (quat., C-$1''$), 130.0 (quat., C-$1'$), 130.2 (CH, C-$6''$), 144.5 (quat., C-$2'$), 152.2 (quat., C-$3'$), 155.1 (quat., C-$2''$), 208.1 (quat., C-2); *m*/*z* (EI, %): 374 (M$^+$, 0.2), 342 (M$^+$−MeOH, 4), 297 (6), 280 (5), 268 (31), 161 (34), 150 (14), 107 (9), 45 (100).

3.15.2. 1-(5-Methoxy-2-(methoxymethoxy)phenyl)-4-(2-(methoxymethoxy)phenyl)butan-2-one 14. Yellow oil. HRMS (EI): Found M$^+$, 374.17355, C$_{21}$H$_{26}$O$_6$ requires 374.17294. ν_{max} (film)/cm^{-1}: 2949, 2826 (s, CH), 1712 (C=O), 1588 (C=C, aromatic), 1496, 1455 (OCH$_2$O), 1080 (C–O). δ_H (300 MHz, CDCl$_3$): 2.76 (2H, t, $J_{4,3}$ 5.9 Hz, H-4), 2.90 (2H, t, $J_{3,4}$ 5.9 Hz, H-3), 3.39 (3H, s, OCH$_2$OC*H*$_3$), 3.41 (3H, s, OCH$_2$OC*H*$_3$), 3.65 (2H, s, H-1), 3.72 (3H, s, OMe), 5.03 (2H, s, OCH$_2$O), 5.14 (2H, s, OCH$_2$O), 6.67 (1H, d, $J_{6',4'}$ 3.0 Hz, H-$6'$), 6.72 (1H, dd, $J_{4',6'}$ 3.0 and $J_{4',3'}$ 8.2 Hz, H-$4'$), 6.89 (1H, td, $J_{3',6'}$ 0.9 and $J_{3',4'}$ 8.2 Hz, H-$3'$), 7.01 (1H, d, $J_{3'',4''}$ 8.9 Hz, H-$3''$), 7.02 (1H, d, $J_{5'',4''}$=$J_{5'',6''}$ 7.8 Hz, H-$5''$), 7.10–7.15 (2H, m, H-4″ and H-6″). δ_C (75 MHz, $CDCl_3$): 24.9 (CH_2, C-4), 41.8 (CH_2, C-1), 45.0 (CH_2, C-3), 55.5 (CH_3, OMe), 55.8 (CH_3, OCH_2OCH_3), 55.9 (CH_3, OCH_2OCH_3), 94.1 (CH_2, OCH_2O), 95.0 (CH_2, OCH_2O), 112.8 (CH, C-4′), 113.7 (CH, C-3″), 115.3 (CH, C-6′), 116.9 (CH, C-3′), 121.5 (CH, C-5″), 125.4 (quat., C-1′), 127.3 (CH, C-4″), 129.9 (quat., C-1′), 130.0 (CH, C-6″), 149.2 (quat., C-2′), 154.3 (quat., C-5′), 155.0 (quat., C-2″), 207.8 (quat., C-2); *m/z* (EI, %): 374 (M^+, 2), 342 (M^+-MeOH, 3), 280 (9), 268 (19), 161 (38), 150 (14), 45 (100).

3.15.3. 1,4-Bis-(3-methoxy-2-(methoxymethoxy)phenyl)-butan-2-one 15. Yellow oil. HRMS (EI): Found M^+, 404.18331, $C_{22}H_{28}O_7$ requires 404.18350. ν_{max} (film)/cm^{-1}: 2937, 2902, 2839 (C–H, aromatic), 1712, 1599, 1585, 1476, 1439, 1403, 1361, 1306, 1266, 1223, 1157, 1069, 968, 781, 750. δ_H (300 MHz, $CDCl_3$): 2.78 (2H, t, $J_{4,3}$ 7.5 Hz, H-4), 2.94 (2H, t, $J_{3,4}$ 7.5 Hz, H-3), 3.51 (3H, br s, OCH_2OCH_3), 3.52 (3H, br s, OCH_2OCH_3), 3.76 (2H, s, H-1), 3.80 (3H, br s, OMe), 3.81 (3H, br s, OMe), 5.05 (4H, s, OCH_2O), 6.72–6.76 (3H, m, Ar-H), 6.82 (1H, dd, $J_{4',6'}$ 1.2 and $J_{4',5'}$ 8.2 Hz, H-4′ or H-4″), 6.92–7.02 (2H, m, Ar-H). δ_C (75 MHz, $CDCl_3$): 24.5 (CH_2, C-4), 42.4 (CH_2, C-1), 44.7 (CH_2, C-3), 55.6 (CH_3, OMe), 55.6 (CH_3, OMe), 57.3 (CH_3, OCH_2OCH_3), 57.4 (CH_3, OCH_2OCH_3), 98.8 (CH_2, OCH_2O), 98.8 (CH_2, OCH_2O), 110.2 (CH, Ar-C), 111.3 (CH, Ar-C), 121.9 (CH, Ar-C), 122.9 (CH, Ar-C), 124.0 (CH, Ar-C), 124.2 (CH, Ar-C), 129.0 (quat., C-1′), 135.3 (quat., C-1″), 144.2 (quat., C-3′ or C-3″), 144.4 (quat., C-3″ or C-3′), 152.0 (quat., C-2′ or C-2″), 152.1 (quat., C-2″ or C-2′), 207.7 (quat., C-2); *m/z* (EI, %): 404 (M^+, 0.1), 372 (M^+-MeOH, 1), 354 (0.2), 342 (2), 328 (2), 310 (9), 298 (52), 284 (8), 191 (7), 161 (30), 150 (12), 137 (48), 45 (100).

3.15.4. 4-(3-Methoxy-2-(methoxymethoxy)phenyl)-1-(5-methoxy-2-(methoxymethoxy)phenyl)butan-2-one 16. Yellow oil. HRMS (EI): Found M^+, 404.18337, $C_{22}H_{28}O_7$ requires 404.18350. ν_{max} (film)/cm^{-1}: 2995, 2937, 2836 (s, C–H, aromatic), 1715, 1666, 1599, 1585, 1499, 1476, 1439, 1404, 1361, 1266 (s, C–O), 1223, 1196, 1152, 1196, 1073, 1041, 977, 924. δ_H (300 MHz, $CDCl_3$): 2.80 (2H, t, $J_{4,3}$ 7.7 Hz, H-4), 2.93 (2H, t, $J_{3,4}$ 7.7 Hz, H-3), 3.40 (3H, s, OCH_2OCH_3), 3.53 (3H, s, OCH_2OCH_3), 3.66 (2H, s, H-1), 3.74 (3H, s, OMe), 3.82 (3H, s, OMe), 5.06 (4H, s, $2\times OCH_2O$), 6.67–6.78 (4H, m, H-4′, H-4″, H-6′ and H-6″), 6.96 (1H, t, $J_{5',4'}=J_{5',6'}$ 7.9 Hz, H-5′), 7.02 (1H, d, $J_{3'',4''}$ 8.9 Hz, H-3″). δ_C (75 MHz, $CDCl_3$): 24.7 (CH_2, C-4), 42.6 (CH_2, C-1), 45.0 (CH_2, C-3), 55.6 (CH_3, OMe), 55.7 (CH_3, OMe), 56.0 (CH_3, OCH_2OCH_3), 57.4 (CH_3, OCH_2OCH_3), 95.1 (CH_2, OCH_2O), 98.9 (CH_2, OCH_2O), 110.4 (CH, C-4″), 113.0 (CH, C-4′), 115.4 (CH, C-6″), 116.9 (CH, C-3″), 122.0 (CH, C-5′), 124.1 (CH, C-6′), 125.3 (quat., C-1″), 135.3 (quat., C-1′), 144.3 (quat., C-3′), 149.3 (quat., C-5″), 152.1 (quat., C-2′), 154.3 (quat., C-2″), 207.7 (quat., C-2); *m/z* (EI, %): 404 (M^+, 2%), 372 (2), 342 (2), 328 (2), 310 (7), 298 (38), 195 (7), 161 (42), 150 (13), 137 (33), 45 (100).

3.15.5. 1-(2-Methoxymethoxy-naphthalen-1-yl)-4-(2-methoxymethoxyphenyl)butan-2-one 71. Yellow oil. HRMS (EI): Found M^+, 394.17795, $C_{24}H_{26}O_5$ requires 394.17802. ν_{max} (film)/cm^{-1}: 2929, 2320, 1710, 1625, 1596, 1512, 1492, 1470, 1404, 1235, 1198, 1151, 1079, 1037, 1013, 922, 810, 752. δ_H (400 MHz, $CDCl_3$): 2.72 (2H, t, $J_{4,3}$ 7.6 Hz, H-4), 2.86 (2H, t, $J_{3,4}$ 7.6 Hz, H-3), 3.26 (3H, s, OMe), 3.44 (3H, s, OMe), 4.17 (2H, s, H-1), 5.02 (2H, s, 2′-OCH_2O), 5.23 (2H, s, 2″-OCH_2O), 6.83 (1H, t, $J_{5'',6''}=J_{5'',4''}$ 7.3 Hz, H-5″), 6.96 (1H, d, $J_{3'',4''}$ 8.0 Hz, H-3″), 7.04 (1H, dt, $J_{4'',6''}$ 1.5 and $J_{4'',3''}=J_{4'',5''}$ 7.3 Hz, H-4″), 7.06–7.11 (1H, m, H-6″), 7.34 (1H, t, $J_{6',7'}=J_{6',5'}$ 7.4 Hz, H-6′), 7.41 (1H, d, $J_{3',4'}$ 9.1 Hz, H-3′), 7.44 (1H, t, $J_{7',8'}=J_{7',6'}$ 7.8 Hz, H-7′), 7.73 (1H, $J_{4',3'}$ 9.1 Hz, H-4′), 7.72–7.77 (2H, m, H-8′ and H-5′). δ_C (100 MHz, $CDCl_3$): 24.9 (CH_2, C-4), 40.5 (CH_2, C-1), 41.3 (CH_2, C-3), 55.8 (CH_3, OMe), 56.1 (CH_3, OMe), 94.0 (CH_2, 2″-OCH_2O), 94.9 (CH_2, 2′-OCH_2O), 113.6 (CH, C-3″), 115.7 (CH, C-3′), 117.3 (quat., C-1′), 121.5 (CH, C-5″), 123.1 (CH, C-8′ or C-4′ or C-5′), 123.8 (CH, C-6′), 126.8 (CH, C-7′), 127.2 (CH, C-6″), 128.4 (CH, C-5′ or C-8′ or C-4′), 128.9 (CH, C-4′ or C-5′ or C-8′), 129.6 (quat., C-4′a or C-1″), 129.9 (quat., C-1″ or C-4′a), 130.0 (CH, C-4″), 133.2 (quat., C-8′a), 152.6 (quat., C-2′), 154.9 (quat., C-2″), 208.7 (quat., C=O); *m/z* (EI, %): 394 (M^+, 4), 300 (5), 288 (5), 201 (10), 181 (18), 170 (25), 45 (100).

3.15.6. 4-(3-Methoxy-2-methoxymethoxyphenyl)-1-(2-methoxymethoxy-naphthalen-1-yl)butan-2-one 72. Yellow oil. HRMS (EI): Found M^+, 424.18843, $C_{25}H_{28}O_6$ requires 424.18859. ν_{max} (film)/cm^{-1}: 3067, 2934, 2842, 2252, 1708, 1625, 1597, 1585, 1475, 1438, 1264, 1243, 1198, 1155, 1067, 1039, 1018, 908, 731. δ_H (400 MHz, $CDCl_3$): 2.79 (2H, t, $J_{4,3}$ 7.6 Hz, H-4), 2.92 (2H, t, $J_{3,4}$ 7.6 Hz, H-3), 3.43 (3H, s, 2′-OCH_2OCH_3), 3.44 (3H, s, 2″-OCH_2OCH_3), 3.75 (3H, s, OMe), 4.18 (2H, s, C-1), 5.00 (2H, s, 2″-OCH_2O), 5.24 (2H, s, 2′-OCH_2O), 6.66 (1H, d, $J_{4',5'}$ 7.8 Hz, H-4′), 6.71 (1H, d, $J_{6',5'}$ 7.8 Hz, H-6′), 6.89 (1H, t, $J_{5',4'}=J_{5',6'}$ 7.8 Hz, H-5′), 7.33 (1H, t, $J_{6'',7''}=J_{6'',5''}$ 7.5 Hz, H-6″), 7.40–7.46 (2H, m, H-3″ and H-7″), 7.72–7.78 (3H, m, H-4″, H-5″ and H-8″). δ_C (100 MHz, $CDCl_3$): 24.6 (CH_2, C-4), 40.4 (CH_2, C-1), 42.0 (CH_2, C-3), 55.5 (CH_3, 2″-OCH_2OMe), 56.0 (CH_3, 2′-OCH_2OMe), 57.1 (CH_3, OMe), 94.9 (CH_2, 2′-OCH_2O), 98.7 (CH_2, 2″-OCH_2O), 110.2 (CH, C-4′), 115.6 (CH, C-3″), 117.1 (quat., C-1″), 121.8 (CH, C-6′), 123.1 (CH, C-8″ or C-6″), 123.8 (CH, C-6″ or C-8″), 124.0 (CH, C-5′), 126.7 (CH, C-7″), 128.4 (CH, C-4″), 128.9 (CH, C-5″), 129.6 (quat., C-4″a), 133.2 (quat., C-8″a), 135.2 (CH, C-1′), 144.2 (quat., C-2′), 152.0 (quat., C-), 152.5 (quat., C-3′), 208.7 (quat., C-2″); *m/z* (EI, %): 424 (M^+, 1.0), 318 (8), 246 (14), 223 (6), 181 (36), 170 (29), 137 (6), 45 (100).

3.15.7. 1-(5-Methoxy-1-(methoxymethoxy)naphthalen-2-yl)-4-(2-(methoxymethoxy)phenyl)butan-2-one 77. Tan oil. HRMS (EI): Found M^+, 424.18921, $C_{25}H_{28}O_6$ requires 424.18859. ν_{max} (film)/cm^{-1}: 3376, 3053, 2978, 1707, 1602, 1402, 1420, 1265, 1069 (s, C–O), 737, 705. δ_H (400 MHz, $CDCl_3$): 2.74–2.78 (2H, m, H-4), 2.88–2.91 (2H, m, H-3), 3.32 (3H, s, OCH_2OCH_3), 3.59 (3H, s, OCH_2OCH_3), 3.93 (2H, s, H-1), 3.98 (3H, s, OMe), 5.08 (4H, m, $2\times OCH_2O$), 6.81 (1H, d, $J_{6',7'}$ 7.7 Hz, H-6′), 6.87 (1H, t, $J_{5'',4''}=J_{5'',6''}$ 7.4 Hz, H-5″), 6.99 (1H, d, $J_{3'',4''}$ 7.4 Hz, H-3″), 7.09–7.11 (2H, m, H-4″ and H-6″), 7.21 (1H, d, $J_{3',4'}$ 8.6 Hz, H-3′), 7.40 (1H, d, $J_{7',6'}$ 7.7 and $J_{7',8'}$ 8.3 Hz, H-7′), 7.61 (1H, d, $J_{8',7'}$ 8.3 Hz, H-8′), 8.00 (1H, d,

$J_{4',3'}$ 8.6 Hz, H-4′). δ_C (100 MHz, CDCl$_3$): 25.1 (CH$_2$, C-4), 41.9 (CH$_2$, C-1), 45.3 (CH$_2$, C-3), 55.6 (CH$_3$, OMe), 55.8 (CH$_3$, OCH$_2$O*C*H$_3$), 57.6 (CH$_3$, OCH$_2$O*C*H$_3$), 94.1 (CH$_2$, O*C*H$_2$O), 100.4 (CH$_2$, O*C*H$_2$O), 104.0 (CH, C-6′), 113.6 (CH, C-8′), 114.4 (CH, C-5″), 118.8 (CH, C-4′), 121.6 (CH, C-3″), 124.6 (quat., C-2′), 126.3 (CH, C-7′), 126.5 (quat., C-1″), 127.3 (CH, C-3′), 127.6 (CH, C-4″), 129.4 (quat., C-4′a), 129.9 (quat., C-8′a), 130.1 (CH, C-6″), 151.6 (quat., C-1′), 155.0 (quat., C-2″), 155.7 (quat., C-5′), 208.2 (quat., C-2); *m/z* (EI, %): 424 (M$^+$, 4), 392 (3), 362 (3), 348 (6), 330 (21), 318 (16), 211 (49), 200 (18), 187 (10), 45 (100).

3.15.8. 1-[4,8-Dimethoxy-1-(methoxymethoxy)naphthalen-2-yl]-4-[(2-methoxymethoxy)phenyl]butan-2-one 78. Yellow oil. HRMS (EI): Found M$^+$, 454.19894, C$_{26}$H$_{30}$O$_7$ requires 454.19915. ν_{max} (film)/cm^{-1}: 3054, 2987 (s, C–H, aromatic), 2685, 2521, 2411, 2305 (C–H alkane), 1710 (C=O, ketone), 1601, 1580, 1551, 1511, 1492 (s, C=C, aromatic), 1265 (s, C–O), 1155, 1079, 739, 705. δ_H (400 MHz, CDCl$_3$): 2.78–2.83 (2H, m, H-4), 2.88–2.92 (2H, m, H-3), 3.32 (3H, s, 2′-OCH$_2$O*Me*), 3.54 (3H, s, 1′-OCH$_2$O*Me*), 3.91 (3H, s, 8′-OMe), 3.95 (3H, s, 4′-OMe), 3.97 (2H, s, H-1), 4.99 (2H, s, OCH$_2$O), 5.07 (2H, s, OCH$_2$O), 6.54 (1H, s, H-3′), 6.86 (1H, dt, $J_{5'',3''}$ 0.7, $J_{5'',6''}$=$J_{5'',4''}$ 7.4 Hz, H-5″), 6.90 (1H, d, $J_{7',6'}$ 8.0 Hz, H-7′), 6.97–6.99 (1H, m, H-3″), 7.09–7.12 (2H, m, H-4″ and H-6″), 7.35 (1H, t, $J_{6',7'}$=$J_{6',5'}$ 8.0 Hz, H-6′), 7.86 (1H, d, $J_{5',6'}$ 8.0 Hz, H-5′). δ_C (100 MHz, CDCl$_3$): 24.9 (CH$_2$, C-4), 41.7 (CH$_2$, C-1), 45.5 (CH$_2$, C-3), 55.6 (CH$_3$, OMe), 55.7 (CH$_3$, OMe), 55.9 (CH$_3$, OCH$_2$O*C*H$_3$), 57.4 (CH$_3$, OCH$_2$O*C*H$_3$), 94.0 (CH$_2$, O*C*H$_2$O), 101.5 (CH$_2$, O*C*H$_2$O), 106.5 (CH, C-7′), 107.0 (CH, C-5′), 113.5 (CH, C-3″), 115.0 (CH, C-3′), 120.3 (quat., C-2′), 121.4 (CH, C-5″), 124.5 (quat., C-8′a), 125.3 (CH, C-6′), 127.2 (CH, C-4″), 128.2 (quat., C-4′a), 130.0 (quat., C-1″), 130.1 (CH, C-6″), 144.6 (quat., C-8′), 151.5 (quat., C-4′), 155.0 (quat., C-1′), 155.1 (CH, C-2″), 208.6 (quat., C-2); *m/z* (EI, %): 454 (M$^+$, 18), 422 (6), 410 (2), 392 (26), 378 (7), 360 (9), 348 (10), 241 (100), 229 (29), 226 (11), 217 (16), 45 (66).

3.16. Standard procedure for cyclisation of ketones to a 5,6-spiroacetal or a benzofuran

3.16.1. Procedure A—using bromotrimethylsilane in dichloromethane. A solution of ketone (0.17 mmol) in dichloromethane (1 mL) containing 4 Å molecular sieves was treated with bromotrimethylsilane (1.70 mmol) at −30 °C under nitrogen and the mixture stirred for 1 h at this temperature. The reaction mixture was warmed to 0 °C and stirred for 10 h, then warmed to room temperature and stirred for a further 11 h. The reaction mixture was poured into a solution of saturated sodium bicarbonate (2 mL), then extracted with ether (4×2 mL). The combined organic extracts were washed with brine (5 mL), dried over MgSO$_4$ and concentrated in vacuo to give a yellow residue, which was purified by flash column chromatography.

3.16.2. Procedure B—using silica-supported sodium hydrogen sulfate in dichloromethane. To a stirred solution of ketone (0.34 mmol) in dichloromethane (5 mL) was added NaHSO$_4$·SiO$_2$ (804 mg) that had been heated at 120 °C for 48 h. The reaction mixture was stirred at room temperature for 3 h, the catalyst was removed by filtration, washed successively with dichloromethane (50 mL) then concentrated and subjected to flash column chromatography.

3.16.3. 7-Methoxy-3*H*-spiro[1-benzofuran-2,2′-chromane] 9. Yellow powder. Mp: 115–118 °C. HRMS (EI): Found M$^+$, 268.11020, C$_{17}$H$_{16}$O$_3$ requires 268.10994. ν_{max} (film)/cm^{-1}: 3053 (CH, aromatic), 1584 (ArC=C), 1093 and 1049 (C–O). δ_H (300 MHz, CDCl$_3$): 2.13–2.24 (1H, m, H-3′$_{ax}$), 2.37 (1H, ddd, $J_{3'eq,4'eq}$ 3.3, $J_{3'eq,4'ax}$ 5.9 and J_{gem} 13.4 Hz, H-3′$_{eq}$), 2.82 (1H, ddd, $J_{4'eq,3'eq}$ 3.3, $J_{4'eq,3'ax}$ 5.8 and J_{gem} 16.7 Hz, H-4′$_{eq}$), 3.30 (1H, d, J_{gem} 16.4 Hz, H-3$_{ax}$), 3.32 (1H, ddd, $J_{4'ax,3'eq}$ 5.9, $J_{4'ax,3'ax}$ 12.0, J_{gem} 16.7 Hz, H-4′$_{ax}$), 3.45 (1H, d, J_{gem} 16.4 Hz, H-3$_{eq}$), 3.81 (3H, s, OMe), 6.76–6.79 (2H, m, H-4, H-8′), 6.84–6.92 (3H, m, H-4, H-5, H-6′), 7.07–7.17 (2H, m, H-5′ and H-7′). δ_C (75 MHz, CDCl$_3$): 22.0 (CH$_2$, C-3′), 30.5 (CH$_2$, C-4′), 42.3 (CH$_2$, C-3), 56.0 (CH$_3$, OMe), 109.6 (quat., C-2), 111.8 (CH, C-4 or C-8′), 117.0 (CH, Ar-C), 117.1 (CH, Ar-C), 121.0 (CH, C-4 or C-5 or C-6′), 121.4 (quat., C-4′a), 121.7 (CH, C-5 or C-6′ or C-4), 126.5 (quat., C-3a or C-7a), 127.4 (CH, C-7′ or C-5′), 129.1 (CH, C-5′ or C-7′), 144.4 (quat., C-7), 146.3 (quat., C-7a or C-3a), 152.3 (quat., C-8′a); *m/z* (EI, %): 268 (M$^+$, 41), 267 (9), 167 (3), 161 (100), 149 (12), 131 (12), 107 (21), 97 (10), 77 (8), 57 (26).

3.16.4. 5-Methoxy-3*H*-spiro[1-benzofuran-2,2′-chromane] 10. Colourless needles. Mp: 90–92 °C. HRMS (EI): Found M$^+$, 268.10970, C$_{17}$H$_{16}$O$_3$ requires 268.10994. ν_{max} (CH$_2$Cl$_2$ solution)/cm^{-1}: 3054, 2986, 2959, 2930, 2305, 1584, 1488, 1457, 1466, 1433, 1422, 1265, 1222, 1209, 1177, 736, 705. δ_H (300 MHz, CDCl$_3$): 2.17 (1H, ddd, $J_{3'ax,4'eq}$ 6.0, $J_{3'ax,4'ax}$ 13.3 and J_{gem} 13.3 Hz, H-3′$_{ax}$), 2.31 (1H, ddd, $J_{3'eq,4'eq}$ 2.8, $J_{3'eq,4'ax}$ 6.0 and J_{gem} 13.3 Hz, H-3′$_{eq}$), 2.81 (1H, ddd, $J_{4'eq,3'eq}$ 2.8, $J_{4'eq,3'ax}$ 6.0 and J_{gem} 16.4 Hz, H-4′$_{eq}$), 3.17–3.27 (1H, m, H-4′$_{ax}$), 3.26 (1H, J_{gem} 16.6 Hz, H-3$_A$), 3.41 (1H, J_{gem} 16.6 Hz, H-3$_B$), 3.76 (3H, s, OMe), 6.69 (2H, m, H-4 and H-6), 6.77–6.82 (2H, m, H-7 and H-8′), 6.90 (1H, dt, $J_{6',8'}$ 1.1 and $J_{6',5'}$=$J_{6',7'}$ 7.9 Hz, H-6′), 7.07–7.13 (2H, m, H-5′ and H-7′). δ_C (75 MHz, CDCl$_3$): 21.9 (CH$_2$, C-4′), 30.4 (CH$_2$, C-3′), 42.3 (CH$_2$, C-3), 56.0 (CH$_3$, OMe), 109.2 (quat., C-2), 109.8 (CH, C-6), 111.2 (CH, C-8′), 113.0 (CH, C-4), 117.1 (CH, C-7), 121.1 (CH, C-6′), 121.4 (quat., C-4′a), 126.3 (quat., C-3a), 127.4 (CH, C-7′), 129.1 (CH, C-5′), 152.0 (quat., C-7a), 152.3 (quat., C-8′a), 154.6 (quat., C-5); *m/z* (EI, %): 268 (M$^+$, 32), 161 (100), 131 (6), 107 (12), 77 (6), 65 (3), 45 (3).

3.16.5. 2-Methoxy-6-(2-(7-methoxybenzofuran-2-yl)-ethyl)phenol 43. White solid. Mp: 82–84 °C. HRMS (EI): Found M$^+$, 298.12025, C$_{18}$H$_{18}$O$_4$ requires 298.12051. ν_{max} (CH$_2$Cl$_2$ solution)/cm^{-1}: 3534 (s, br, O–H), 3053, 2985 (s, aromatic, CH), 1732, 1620, 1479, 1373, 1265 (C–O), 1096, 1079, 1046. δ_H (300 MHz, CDCl$_3$): 3.10 (4H, s, H-1′ and H-2′), 3.85 (3H, s, OMe), 3.99 (3H, s, OMe), 5.75 (1H, br s, OH), 6.38 (1H, s, H-3″), 6.69–6.77 (4H, m, Ar-H), 7.06–7.11 (2H, m, Ar-H). δ_C (75 MHz, CDCl$_3$): 28.2 (CH$_2$, C-1′ or C-2′), 28.3 (CH$_2$, C-2′ or C-1′), 55.9 (CH$_3$, 2×OMe), 102.4 (CH, C-3″), 105.5 (CH, Ar-C), 108.7 (CH, Ar-C), 110.0 (CH, Ar-C), 112.8 (CH, Ar-C), 119.3 (CH, Ar-C), 122.2 (CH, Ar-C), 122.9 (CH, Ar-C), 126.6 (quat., Ar-C), 130.7 (quat., Ar-C), 143.6 (quat., Ar-C), 143.7 (quat., Ar-C), 144.9 (quat., C-7$''$ or C-2), 146.3 (quat., C-2 or C-7$''$), 159.2 (quat., Ar-C); *m/z* (EI, %): 298 (M^+, 64), 161 (100), 146 (5), 137 (96), 118 (11), 77 (6).

3.16.6. 7-Methoxy-3*H*-spiro[1-benzofuran-2,2$'$-(8-methoxychromane)] 11. Off-white powder. Mp: 185–188 °C. HRMS (EI): Found M^+, 298.11990, $C_{18}H_{18}O_4$ requires 298.12051. ν_{max} (CH_2Cl_2 solution)/cm^{-1}: 3054, 2986, 2959, 2923, 2305, 1584, 1482, 1457, 1466, 1433, 1422, 1264, 1225, 1180, 1082, 903, 747. δ_H (300 MHz, $CDCl_3$): 2.15 (1H, ddd, $J_{3'ax,4'eq}$ 5.7, $J_{3'ax,4'ax}$ 13.0 and J_{gem} 13.0 Hz, H-3$'_{ax}$), 2.33 (1H, $J_{3'eq,4'eq}$ 2.7, $J_{3'eq,4'ax}$ 5.7 and J_{gem} 13.4 Hz, H-3$'_{eq}$), 2.78 (1H, ddd, $J_{4'eq,3'eq}$ 2.5, $J_{4'eq,3'ax}$ 5.6, J_{gem} 16.4 Hz, H-4$'_{eq}$), 3.31 (1H, d, J_{gem} 16.6 Hz, H-3$_A$), 3.26–3.33 (1H, m, H-4$'_{ax}$), 3.60 (1H, d, J_{gem} 16.6 Hz, H-3$_B$), 3.75 (3H, s, OMe), 3.79 (3H, s, OMe), 6.70–6.75 (3H, m, Ar-H), 6.82–6.87 (3H, m, Ar-H). δ_C (75 MHz, $CDCl_3$): 21.8 (CH_2, C-4$'$), 30.6 (CH_2, C-3$'$), 42.4 (CH_2, C-3), 55.9 (CH_3, OMe), 56.0 (CH_3, OMe), 109.5 (quat., C-2), 110.0 (CH, Ar-C), 111.6 (CH, Ar-C), 117.1 (CH, Ar-C), 120.6 (CH, Ar-C), 121.1 (CH, Ar-C), 121.5 (CH, Ar-C), 122.4 (quat., C-4$'$a), 126.5 (quat., C-3a), 141.9 (quat., C-8$'$a), 144.3 (quat., C-7 or C-8$'$), 146.3 (quat., C-7a), 148.4 (quat., C-8$'$ or C-7); *m/z* (EI, %): 298 (M^+, 62), 167 (8), 161 (100), 146 (7), 137 (96), 118 (8), 91 (9), 77 (8), 71 (14), 57 (23), 43 (16).

3.16.7. 2-Methoxy-6-(2-(5-methoxybenzofuran-2-yl)-ethyl)phenol 44. Colourless oil. HRMS (EI): Found M^+, 298.12072, $C_{18}H_{18}O_4$ requires 298.12051. δ_H (300 MHz, $CDCl_3$): 3.07 (4H, s, H-1$'$ and H-2$'$), 3.82 (3H, s, OMe), 3.87 (3H, s, OMe), 5.76 (1H, br s, OH), 6.33 (1H, s, H-3$''$), 6.75–6.79 (5H, m, Ar-H), 7.06–7.11 (1H, d, $J_{4'',6''}$ 2.48 Hz, H-4$''$); *m/z* (EI, %): 298 (M^+, 43), 161 (100), 137 (44), 118 (8), 77 (6).

3.16.8. 5-Methoxy-3*H*-spiro[1-benzofuran-2,2$'$-(8-methoxychromane)] 12. Colourless needles. Mp: 139–141 °C. HRMS (EI): Found M^+, 298.12017, $C_{18}H_{18}O_4$ requires 298.12051. ν_{max} (film)/cm^{-1}: 3053, 2986 (CH, s, aromatic), 1586, 1482 (C=C, aromatic), 1421, 1265 (C–O), 1180, 1080, 1030, 1004, 896. δ_H (400 MHz, $CDCl_3$): 2.15–2.19 (1H, m, H-3$'_{ax}$), 2.29 (1H, $J_{3'eq,4'eq}$ 2.6, $J_{3'eq,4'ax}$ 6.0 and J_{gem} 13.3 Hz, H-3$'_{eq}$), 2.81 (1H, ddd, $J_{4'eq,3'eq}$ 2.5, $J_{4'eq,3'ax}$ 5.8, J_{gem} 16.4 Hz, H-4$'_{eq}$), 3.20–3.30 (1H, m, H-4$'_{ax}$), 3.28 (1H, d, J_{gem} 16.5 Hz, H-3$_A$), 3.55 (1H, d, J_{gem} 16.6 Hz, H-3$_B$), 3.75 (6H, s, 2×OMe), 6.62–6.74 (4H, m, H-6, H-7, H-5$'$ and H-7$'$), 6.78 (1H, s, H-4), 6.84 (1H, t, $J_{6',5'}=J_{6',7'}$ 7.84 Hz, H-6$'$). δ_C (75 MHz, $CDCl_3$): 21.9 (CH_2, C-4$'$), 30.5 (CH_2, C-3$'$), 42.3 (CH_2, C-3), 55.9 (CH_3, OMe), 56.0 (CH_3, OMe), 109.2 (quat., C-2), 109.7 (CH, Ar-C), 110.1 (CH, Ar-C), 111.0 (CH, Ar-C), 113.0 (CH, Ar-C), 120.7 (CH, Ar-C), 121.1 (CH, Ar-C), 122.4 (quat., C-4$'$a), 126.3 (quat., C-3a), 142.0 (quat., C-7a), 148.5 (quat., C-8$'$a), 152.1 (quat., C-8$'$), 154.5 (quat., C-5); *m/z* (EI, %): 298 (M^+, 43), 209 (9), 161 (100), 137 (47), 135 (14), 118 (6), 91 (3), 77 (4).

3.16.9. 3*H*-Spiro[1-naphthofuran-2,2$'$-chromane] 48. White powder. Mp: 153–156 °C. HRMS (EI): Found M^+, 288.11484, $C_{20}H_{16}O_2$ requires 288.11503. ν_{max} (CH_2Cl_2 solution)/cm^{-1}: 3053, 2971, 2905, 1627, 1577, 1486, 1454, 1421, 1265, 739. δ_H (400 MHz, $CDCl_3$): 2.26 (1H, ddd, $J_{3'ax,4'eq}$ 5.9, $J_{3'ax,4'ax}$ 13.0 and J_{gem} 13.0 Hz, H-3$'_{ax}$), 2.39 (1H, ddd, $J_{3'eq,4'eq}$ 2.6, $J_{3'eq,4'ax}$ 6.0, J_{gem} 13.4 Hz, H-3$'_{eq}$), 2.84 (1H, ddd, $J_{4'eq,3'eq}$ 2.6, $J_{4'eq,3'ax}$ 6.0, J_{gem} 13.4 Hz, H-4$'_{eq}$), 2.39 (1H, ddd, $J_{4'ax,3'eq}$ 6.0, $J_{4'ax,3'ax}$ 12.6, J_{gem} 16.4 Hz, H-4$'_{ax}$), 3.51 (1H, d, J_{gem} 16.4 Hz, H-3$_A$), 3.73 (1H, d, J_{gem} 16.4 Hz, H-3$_B$), 6.80 (1H, d, $J_{8',7'}$ 8.1 Hz, H-8$'$), 6.93 (1H, t, $J_{6',7'}=J_{6',5'}$ 7.6 Hz, H-6$'$), 7.09 (1H, d, $J_{9,8}$ 8.8 Hz, H-9), 7.08–7.13 (1H, m, H-7$'$), 7.14 (1H, d, $J_{5',6'}$ 7.6 Hz, H-5$'$), 7.32 (1H, t, $J_{6,5}$ 7.7 and $J_{6,7}$ 8.2 Hz, H-6), 7.47 (1H, t, $J_{5,6}$ 7.7 and $J_{5,4}$ 8.2 Hz, H-5), 7.60 (1H, d, $J_{4,5}$ 8.2 Hz, H-4), 7.69 (1H, d, $J_{8,9}$ 8.8 Hz, H-8), 7.80 (1H, d, $J_{7,6}$ 8.2 Hz, H-7). δ_C (100 MHz, $CDCl_3$): 21.9 (CH_2, C-4$'$), 30.6 (CH_2, C-3$'$), 40.8 (CH_2, C-3), 109.8 (quat., C-2), 112.2 (CH, C-9), 117.1 (CH, C-8$'$), 117.1 (quat., C-3a), 121.2 (CH, C-6$'$), 121.4 (quat., C-4$'$a), 122.7 (CH, C-4), 123.1 (CH, C-6), 126.7 (CH, C-5), 127.5 (CH, C-7$'$), 128.8 (CH, C-7), 129.1 (2×CH, C-5$'$ and C-8), 129.5 (quat., C-7a), 130.6 (quat., C-4a), 152.3 (quat., C-8$'$a), 155.3 (quat., C-9a); *m/z* (EI, %): 288 (M^+, 23), 181 (100), 152 (10), 149 (4), 115 (1), 107 (2), 91 (2), 77 (3), 57 (6).

3.16.10. 8$'$-Methoxy-3*H*-spiro[1-naphthofuran-2,2$'$-chromane] 49. Colourless needles. Mp: 162–164 °C. HRMS (EI): Found M^+, 318.12535, $C_{21}H_{18}O_3$ requires 318.12559. ν_{max} (film)/cm^{-1}: 3053, 2978, 2840 (CH, aromatic), 2681, 2311, 1739, 1627, 1580, 1476, 1461, 1418, 1265, 1215, 738. δ_H (400 MHz, $CDCl_3$): 2.27 (1H, ddd, $J_{3'ax,4'eq}$ 5.8, $J_{3'ax,4'ax}$ 12.8 and J_{gem} 13.2 Hz, H-3$'_{ax}$), 2.39 (1H, ddd, $J_{3'eq,4'eq}$ 2.4, $J_{3'eq,4'ax}$ 5.9 and J_{gem} 13.2 Hz, H-3$'_{eq}$), 2.85 (1H, ddd, $J_{4'eq,3'eq}$ 2.4, $J_{4'eq,3'ax}$ 5.8 and J_{gem} 16.5 Hz, H-4$'_{eq}$), 3.31 (1H, ddd, $J_{4'ax,3'eq}$ 6.0, $J_{4'ax,3'ax}$ 12.8 and J_{gem} 16.5 Hz, H-4$'_{ax}$), 3.56 (1H, d, J_{gem} 16.6 Hz, H-3$_A$), 3.75 (3H, s, OMe), 3.89 (1H, d, J_{gem} 16.6 Hz, H-3$_B$), 6.73–6.78 (2H, m, H-5$'$ and H-7$'$), 6.88 (1H, t, $J_{6',7'}=J_{6',5'}$=7.8 Hz, H-6$'$), 7.09 (1H, d, $J_{9,8}$ 8.8 Hz, H-9), 7.32 (1H, dd, $J_{6,5}$ 8.1 and $J_{6,7}$ 8.2 Hz, H-6), 7.47 (1H, dd, $J_{5,6}$ 8.1 and $J_{5,4}$ 8.2 Hz, H-5), 7.60 (1H, d, $J_{4,5}$ 8.2 Hz, H-4), 7.68 (1H, d, $J_{8,9}$ 8.8 Hz, H-8), 7.80 (1H, d, $J_{7,6}$ 8.2 Hz, H-7). δ_C (100 MHz, $CDCl_3$): 30.7 (CH_2, C-4$'$), 30.8 (CH_2, C-3$'$), 40.9 (CH_2, C-3), 55.8 (CH_3, OMe), 109.9 (quat., C-2), 109.9 (CH, C-5$'$ or C-7$'$), 112.1 (CH, C-9), 117.1 (quat., C-3a), 120.7 (CH, C-6$'$), 121.0 (CH, C-5$'$ or C-7$'$), 122.3 (quat., C-4$'$a), 122.7 (CH, C-5), 123.0 (CH, C-6), 126.6 (CH, C-5), 128.6 (CH, C-7), 128.9 (CH, C-8), 129.4 (quat., C-7a), 130.5 (quat., C-4a), 141.9 (quat., C-8$'$a), 148.4 (quat., C-8$'$), 155.2 (quat., C-9a); *m/z* (EI, %): 318 (M^+, 23), 181 (100), 152 (8), 149 (37), 137 (7), 129 (27), 69 (4), 57 (46), 43 (33).

3.16.11. 6-Methoxy-3*H*-spiro[1-naphthofuran-2,2$'$-chromane] 50. Colourless solid. Mp: 166–168 °C. HRMS (EI): Found M^+, 318.12535, $C_{21}H_{18}O_3$ requires 318.12559. ν_{max} (CH_2Cl_2 solution)/cm^{-1}: 2980 (CH, aromatic), 1793, 1644, 1601, 1469, 1403, 1381, 1298, 1261, 1224, 1166, 1096, 1044, 1003, 907, 733, 650. δ_H (400 MHz, $CDCl_3$): 2.20–2.28 (1H, m, H-3$'_{ax}$), 2.44 (1H, ddd, $J_{3'eq,4'eq}$ 2.7, $J_{3'eq,4'ax}$ 5.8 and J_{gem} 13.4 Hz, H-3$'_{eq}$), 2.86 (1H, ddd, $J_{4'eq,3'eq}$ 2.7, $J_{4'eq,3'ax}$ 5.8 and J_{gem} 16.3 Hz, H-4$'_{eq}$), 3.34–3.42 (1H, m, H-4$'_{ax}$), 3.46 (1H, d, J_{gem} 16.4 Hz, H-3$_A$), 3.62 (1H, d, J_{gem} 16.4 Hz, H-3$_B$), 3.98 (3H, s, OMe), 6.75

(1H, d, $J_{7,8}$ 7.8 Hz, H-7), 6.79 (1H, d, $J_{8',7'}$ 7.8 Hz, H-8′), 6.94 (1H, t, $J_{6',7'}=J_{6',5'}$ 7.8 Hz, H-6′), 7.12 (1H, t, $J_{7',6'}=J_{7',8'}$ 7.8 Hz, H-7′), 7.17 (1H, $J_{5',6'}$ 7.8 Hz, H-5′), 7.29 (1H, t, $J_{8,7}=J_{8,9}$ 7.8 Hz, H-8), 7.35 (1H, d, $J_{4,5}$ 8.5 Hz, H-4), 7.47 (1H, d, $J_{9,8}$ 7.8 Hz, H-9), 7.84 (1H, d, $J_{5,4}$ 8.5 Hz, H-5). δ_C (100 MHz, $CDCl_3$): 21.8 (CH_2, C-4′), 30.6 (CH_2, C-3′), 42.7 (CH_2, C-3), 55.4 (CH_3, OMe), 103.7 (CH, C-7), 109.7 (quat., C-2), 113.9 (CH, C-9), 114.9 (CH, C-5), 117.0 (CH, C-8′), 119.0 (quat., C-3a), 121.0 (CH, C-6′), 121.3 (quat., C-9a), 121.5 (quat., C-4′a), 121.6 (CH, C-4), 125.4 (CH, C-8), 126.0 (quat., C-5a), 127.4 (CH, C-7′), 129.0 (CH, C-5′), 152.3 (quat., C-8′a), 153.0 (quat., C-9b), 155.4 (quat., C-6); *m*/*z* (EI, %): 318 (M^+, 19), 255 (6), 230 (4), 211 (100), 196 (5), 168 (8), 45 (8).

3.16.12. 2-[2-(5,9-Dimethoxynaphtho[1,2-*b*]furan-2-yl)-ethyl]phenol 79. White powder. Mp: 107–108 °C. HRMS (EI): Found M^+, 348.13687, $C_{22}H_{20}O_4$ requires 348.13616. ν_{max} (film)/cm^{-1}: 3054, 2898 (s, C–H, aromatic), 1822, 1786, 1600, 1463, 1382, 1265, 1155, 1079, 730. δ_H (400 MHz, $CDCl_3$): 3.15–3.19 (2H, m, H-2′ or H-1′), 3.21–3.25 (2H, m, H-1′ or H-2′), 3.99 (3H, s, OMe), 4.12 (3H, s, OMe), 5.53 (1H, s, OH), 6.44 (1H, s, H-3), 6.74 (1H, d, $J_{6'',5''}$ 8.0 Hz, H-6″), 6.85 (1H, t, $J_{4'',3''}=J_{4'',5''}$ 7.4 Hz, H-4″), 6.91 (1H, s, H-4), 7.01 (1H, d, $J_{8,7}$ 8.1 Hz, H-8), 7.06 (1H, ddd, $J_{5'',3''}$ 1.4, $J_{5'',4''}$ 7.4 and $J_{5'',6''}$ 8.0 Hz, H-5″), 7.17 (1H, dd, $J_{3'',5''}$ 1.4 and $J_{3'',4''}$ 7.4 Hz, H-3″), 7.37 (1H, t, $J_{7,6}=J_{7,8}$ 8.1 Hz, H-7), 7.91 (1H, d, $J_{6,7}$ 8.1 Hz, H-6). δ_C (100 MHz, $CDCl_3$): 27.9 (CH_2, C-1′ or C-2′), 29.2 (CH_2, C-2′ or C-1′), 55.9 (CH_3, OMe), 56.0 (CH_3, OMe), 97.8 (CH, C-4), 103.4 (CH, C-3), 106.4 (CH, C-8), 115.0 (quat.,C-9a), 115.2 (CH, C-6), 116.1 (CH, C-6″), 120.8 (CH, C-4″), 124.1 (CH, C-7), 124.6 (quat., C-5a), 127.2 (quat., C-2″), 127.6 (CH, C-5″), 129.0 (quat., C-3a), 130.3 (CH, C-3″), 143.6 (quat., C-9b), 151.6 (quat., C-5), 153.8 (quat., C-9), 154.1 (quat., C-1″), 157.3 (quat., C-2); *m*/*z* (EI, %): 348 (M^+, 30), 346 (27), 331 (12), 257 (10), 241 (100), 231 (27), 226 (14), 97 (10), 81 (12), 69 (27), 55 (19).

3.16.13. 5,9-Dimethoxy-2-(2-(methoxymethoxy)phenethyl)naphtho[1,2-*b*]furan 80. Yellow solid. Mp: 145–147 °C. HRMS (EI): Found M^+, 392.16283, $C_{24}H_{24}O_5$ requires 392.16237. ν_{max} (film)/cm^{-1}: 2930, 2853, 2253, 1793, 1575, 1456, 1413, 1381, 1261, 1234, 1215, 1075, 907. δ_H (400 MHz, $CDCl_3$): 3.14–3.24 (2H, m, H-1′ and H-2′), 3.49 (3H, s, OCH_2O*Me*), 4.00 (3H, s, 5-OMe), 4.08 (3H, s, 9-OMe), 5.20 (2H, s, OCH_2O), 5.28 (1H, s, OH), 6.46 (1H, s, H-3), 6.91–6.95 (1H, m, H-5″), 6.94 (1H, s, H-4), 6.99 (1H, d, $J_{8,7}$ 8.1 Hz, H-8), 7.09 (1H, d, $J_{3'',4''}$ 8.1 Hz, H-3″), 7.16–7.22 (2H, m, H-4″ and H-6″), 7.36 (1H, t, $J_{7,8}=J_{7,6}$ 8.1 Hz, H-7), 7.91 (1H, dd, $J_{6,8}$ 0.6 and $J_{6,7}$ 8.1 Hz, H-6). δ_C (100 MHz, $CDCl_3$): 28.8 (CH_2, C-1′ or C-2′), 29.0 (CH_2, C-2′ or C-1′), 55.8 (CH_3, OMe), 56.0 (CH_3, 2×OMe), 94.4 (CH_2, OCH_2O), 97.8 (CH, C-4 or C-5″), 102.7 (CH, C-3), 106.5 (CH, C-8), 113.9 (CH, C-3″), 114.1 (quat., C-9a), 115.2 (CH, C-6), 121.7 (CH, C-4 or C-5″), 123.9 (CH, C-7), 124.7 (quat., C-3a), 125.1 (quat., C-5a), 127.4 (CH, C-4″ or C-6″), 130.1 (CH, C-6″ or C-4″), 130.2 (quat., C-1″), 143.6 (quat., C-9b), 151.5 (quat., C-5), 154.2 (quat., C-9), 155.2 (quat., C-2″), 158.3 (quat., C-2); *m*/*z* (EI, %): 241 (M^+, 27), 226 (12), 45 (13).

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