A diastereoselective cobalt-mediated synthesis of benzopyrans using a novel variation of an intramolecular Nicholas reaction in the key cyclisation step: optimisation and biological evaluation[1]

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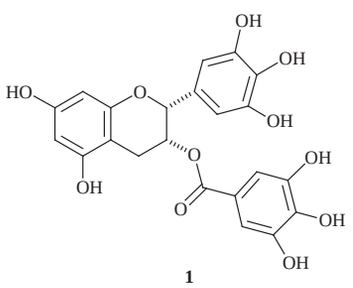
A range of novel intramolecular cyclisation reactions between an organocobalt stabilised cation and a trisubstituted alkene have been accomplished that provide a concise route for the diastereoselective synthesis of a range of functionalised benzopyrans. In addition to the usual Lewis acids employed in the Nicholas reaction our studies have identified several other reagents for effecting the cyclisation reaction. In some examples sub-stoichiometric quantities of Lewis acid were successfully employed. These studies were concluded with a biological evaluation of specific derivatives, conducted by comparing their activity with the antihypertensive agent cromakalim 2, a drug whose mode of action is known to occur *via* the modulation of potassium channel activity.

A recent disclosure[2] highlighted the anticancer activity of epigallicatechin-3 gallate **1**, isolated from green tea. This potential breakthrough into the management of cancer coupled with the potent antihypertensive activity of cromakalim **2**,[3] as well as the inhibitory activity of calanolide A **3** towards the human



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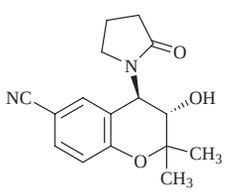

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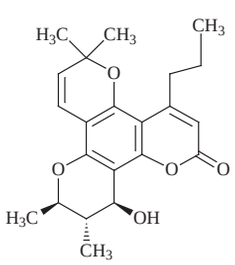

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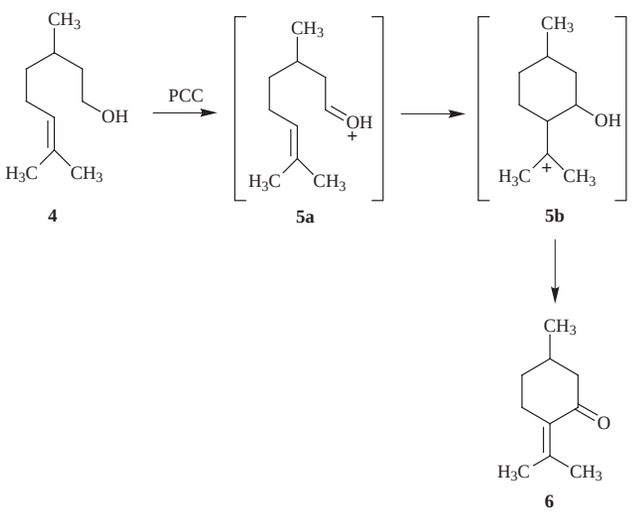
immunodefficiency virus-1 (HIV-1) reverse transcriptase,[4] has renewed interest into the development of methods for the synthesis of benzopyrans.[5]

Our contribution to the area of benzopyran synthesis was instigated by the observation that citronellol **4** underwent an intramolecular cyclisation reaction to afford pulegone **6**, during an attempted PCC oxidation to produce citronellal (Scheme 1).[6]

This transformation presumably resulted from an intramolecular attack of the alkene moiety of the protonated aldehyde **5a**, to afford a second cation **5b**, which was then oxidised to afford pulegone. What was of particular interest was that the trisubstituted alkene moiety proved sufficiently nucleophilic to quench the cation **5a** during the cyclisation reaction. Although a variety of activated carbon nucleophiles such as *O*-silyl enol ethers,[7] enamines[8] and allylsilanes[9] have been used



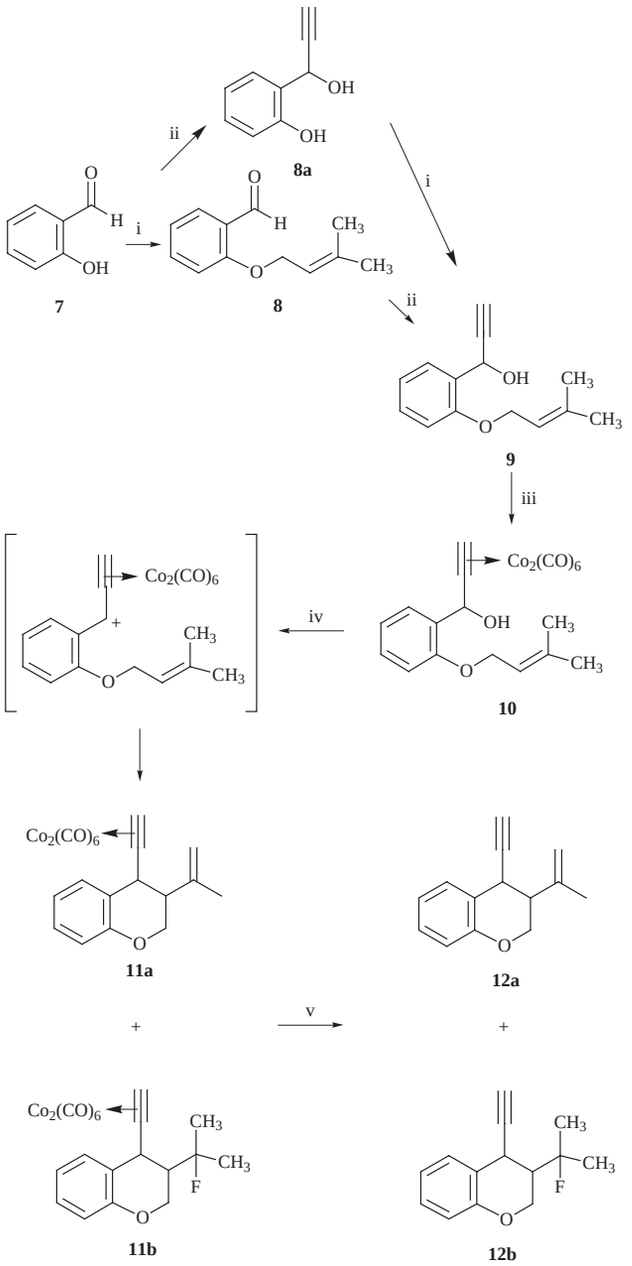
Scheme 1

to quench a hexacarbonyldicobalt stabilised cation in the Nicholas reaction,[10] the use of less activated alkenes, such as that in **5a**, has received little or no attention in the chemistry literature.[11]

In an effort to redress this imbalance an experiment was conducted upon the propynyl alcohol **9** readily obtained from salicylaldehyde **7** in two efficient steps. We reasoned, by analogy with the previous example, that formation of the hexacarbonyldicobalt stabilised cation, obtained from the treatment of the cobalt complex **10** with Lewis acid, should result in a concomitant intramolecular cyclisation reaction to afford the corresponding complexed benzopyran derivative such as **11a** which upon oxidative decomplexation would afford the benzopyran **12a** (Scheme 2).

The advantages of this strategy are firstly the availability of the starting materials and secondly the conciseness of the approach in avoiding the necessity to form an allylsilane, *O*-silyl enol ether or an enamine cyclisation precursor which are most often associated with conventional 'Nicholas' chemistry.

Thus treatment of the propynyl alcohol **9**, with octacarbonyldicobalt, led to quantitative conversion to the hexacarbonyldicobalt complex **10**. The intramolecular cyclisation reaction was conducted by the Lewis acid treatment of **10** followed by



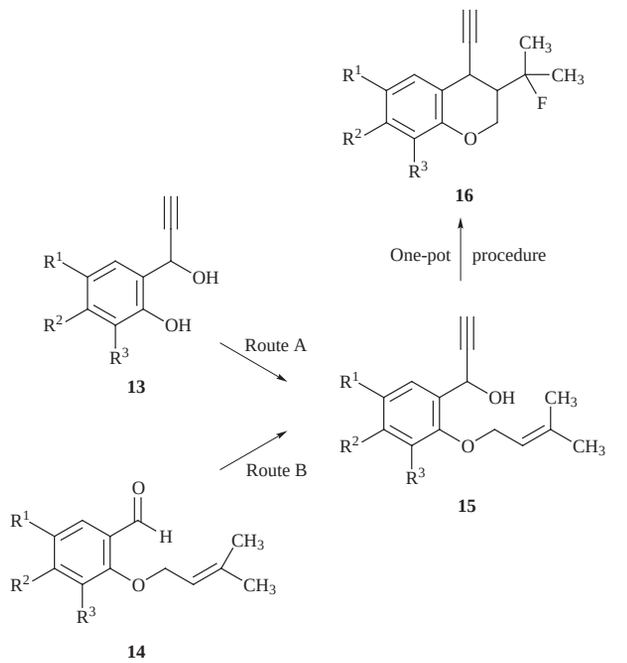
Scheme 2 *Reagents*: i, potassium carbonate, 4-bromo-2-methylbut-2-ene, ii, ethynylmagnesium bromide; iii, octacarbonyldicobalt; iv, tetrafluoroboric acid; v, ceric ammonium nitrate

decomplexation of hexacarbonyldicobalt using ceric ammonium nitrate (CAN). This novel intramolecular cyclisation reaction gave an equimolar mixture of the benzopyrans **12a** and **12b**, which were separable by chromatography, in a 25% yield from compound **9**, both as single diastereoisomers (as ascertained from extensive NMR experiments).

One advantage of working with cobalt complexes is the ease of visualising the coloured components in the reaction mixture by thin layer chromatography. This coupled with the significant R_f differences between the complexed precursor, such as **10**, and the cyclised complex such as compounds **11a** or **11b** suggested that it may be feasible to develop a one-pot, *in situ*, complexation–cyclisation–decomplexation procedure. When this newly developed one-pot procedure was carried out upon the propynyl alcohol **9**, the fluorinated benzopyran **12b** was synthesised in a yield of 45%, over three steps, from compound **9**. Thus using this one-pot procedure the overall yield of the reaction was significantly enhanced, affording a major product[12] diastereoselectively.

The stereochemical relationship of the ring methine protons

Table 1



13–16	R^1	R^2	R^3	Yield of **15** (%)[a]	Yield of **16** (%)[c]
a	Cl	H	Cl	61	59
b	H	H	OMe	90[b]	66
c	NO_2	H	H	76	66
d	Br	H	Br	66	62
e	H	OMe	H	91[b]	63
f	Cl	H	H	73	70
g	OMe	H	H	99	64
h	I	H	I	67	71
i	Br	H	H	99	66

[a] The yield was based upon two steps *i.e.* conversion of the salicylaldehyde derivative into the cyclisation precursor either *via* Route A or Route B. [b] The synthesis of the cyclisation precursors was conducted by an O-alkylation reaction followed by the propynylation step. Reversal of these steps led to a significant reduction in the yield, *i.e.* for compound **15b** the yield was 50%, for **15e** the yield was only 29%. [c] The yield is based upon the one-pot procedure, *i.e.* cobalt complexation, intramolecular cyclisation followed by decomplexation of the cobalt complex.

in compounds **12a** and **12b** were determined by extensive ^{1}H NMR experiments and shown by the magnitude of the coupling constants to be *trans*.[13]

Armed with these new methodologies the scope of both the cyclisation reaction and the one-pot procedure were extended to include the propynyl alcohols **15a**–**15i**. These were synthesised in one of two procedures involving either a propynylation step followed by an O-alkylation step (Route A) or O-alkylation followed by propynylation (Route B) from the corresponding salicylaldehyde derivatives. Thus when each of the propynyl alcohols **15a**–**15i** were subjected to our one-pot cyclisation procedure they cyclised to afford the corresponding benzopyran derivatives **16a**–**16i** in good to excellent overall yield (59–70%) and all exhibited a *trans* stereochemistry. If one invokes the formation of an intermediary benzylic cobalt stabilised cation prior to the intramolecular cyclisation step, then the effect of resonance stabilisation from the aromatic ring becomes a possibility. That being the case one might expect that the aromatic substituents should influence the stability of the cation with concomitant effects upon the yield of the cyclisation reaction. The results from Table 1 however suggest that the effects of the substituents may be insignificant and that the stability of the 'Nicholas' cation is dominated by the effects of

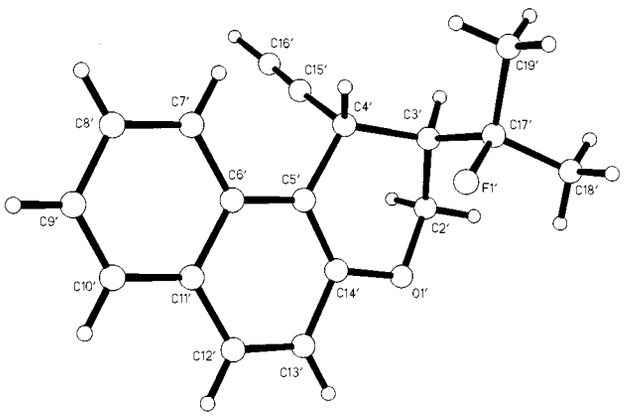
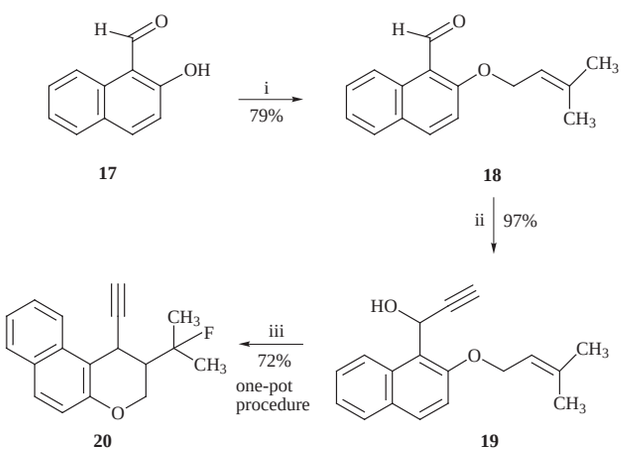


Fig. 1 X-Ray structure of compound **20** with crystallographic numbering scheme

cobalt. That being the case an attempt to effect the cyclisation reaction, in the absence of the cobalt cluster, was carried out with compound **15c**. Thus treatment of the propynyl alcohol **15c** with tetrafluoroboric acid produced a complex mixture of products including the benzopyran **16c**, as a 2:1 mixture of *cis* and *trans* isomers, in a yield of only 20% thus confirming the importance of the hexacarbonylcobalt cluster in stabilising the cation prior to the cyclisation reaction.[14]

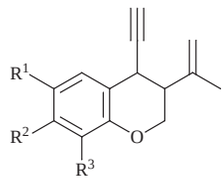
In an attempt to obtain a crystalline derivative for X-ray analysis the propynyl alcohol **19** was synthesised in two high yielding steps from 2-hydroxy-1-naphthaldehyde **17** (Scheme 3).



Scheme 3 *Reagents*: i, potassium carbonate, 4-bromo-2-methylbut-2-ene; ii, ethynylmagnesium bromide; iii, octacarbonyldicobalt, tetrafluoroboric acid, ceric ammonium nitrate

Thus O-alkylation of compound **17** gave **18** in a yield of 79% which upon treatment with ethynylmagnesium bromide gave the cyclisation precursor **19** in 97% yield. When the propynyl alcohol **19** was exposed to our one-pot cyclisation procedure the crystalline benzopyran derivative **20** was isolated as a single diastereoisomer in 72% yield. Single crystal X-ray analysis of compound **20** (Fig. 1) confirmed the assigned *trans* stereochemistry for the methine protons.

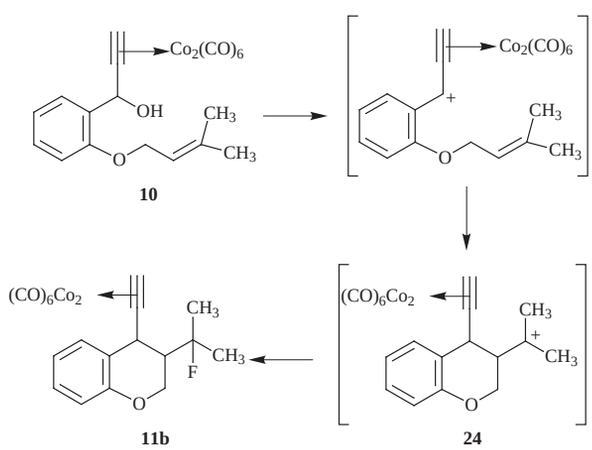
A clue to the origin of the isopropenyl derivative **12a** was obtained during NMR investigations when it was observed that for stored samples of benzopyran **12b** additional resonances, attributed to the isopropenyl derivative **12a**, began to appear on the NMR spectrum, and furthermore the intensity of the resonances increased with time suggesting that **12a** may in fact be derived from **12b** *via* a cobalt assisted elimination of HF. In order to test this hypothesis the one-pot cyclisation reaction was repeated with compounds **15a**, **15b** and **15c**. For these experiments the reaction mixture was left for a longer period[15] before the *in situ* decomplexation step was carried out. Following this procedure we were able to isolate the corresponding



21 R^1, R^3 = Cl, R^2 = H
22 R^1, R^2 = H, R^3 = OMe
23 R^1 = NO_2, R^2 = R^3 = H

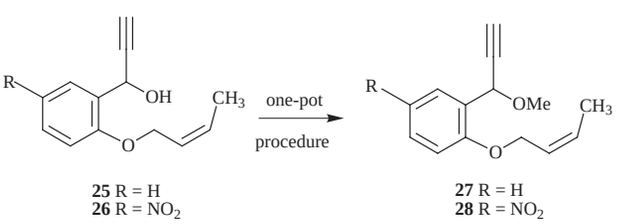
isopropenyl derivatives **21**, **22** and **23** exclusively in yields ranging from 38 to 59%. These results, therefore, do lend support to the idea that the origins of the isopropenyl derivatives such as **12a** and **30** may well be the corresponding halogenated derivatives such as compounds **12b** or **16i/29** respectively.

From this series of experiments we have concluded that at least two cations must be formed during the intramolecular cyclisation reaction (Scheme 4). Initially a cobalt stabilised cation is produced upon exposure of the propynyl alcohol **10** to a Lewis acid. Intramolecular cyclisation then takes place to afford a second cation, **24**, which is then quenched by a fluoride ion to give the hexacarbonyldicobalt complexed product **11b**.



Scheme 4

Further evidence in support of the stability of the hexacarbonyldicobalt complexed propynyl cation was observed during attempted cyclisation reactions using a range of alkenyl substituents other than the *gem*-dimethyl group. These studies were conducted in an effort to identify the minimum requirements in the alkene and hence recognise any potential limitations in our novel cyclisation reaction. Attempts to effect the cyclisation of compounds **25** and **26** (as a representative example of the compounds investigated) (Scheme 5) failed, affording only the propynyl ethers **27** and **28**.



25 R = H
26 R = NO_2

27 R = H
28 R = NO_2

Scheme 5

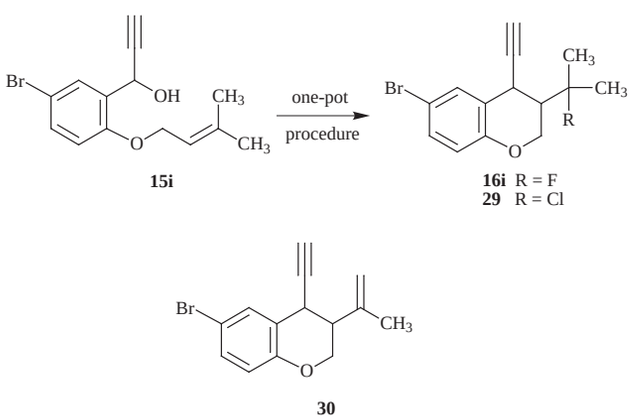
These results imply that although the cobalt stabilised propynyl cations were formed (suggested by the subsequent methanol quench during the decomplexation step) the disubstituted alkene appeared to be insufficiently nucleophilic to effect the subsequent cyclisation reaction. These results suggest that the trisubstituted alkene may be a minimum requirement for a successful cyclisation reaction using the one-pot procedure.

Table 2

Entry	Lewis acid[a]	*t*/h[b]	Yield (%)[c]	Product(s)
1	HBF_4	0.25	66	**16i**
2	$BF_3{\cdot}Et_2O$	0.25	63	**16i**
3	$AlCl_3$	1.5	56	**29** + **30** (1 : 3)
4	$TiCl_4$	5	19	**30**
5	HCl[d]	24	55	**29** + **30** (1 : 3)
6	$TiBr_4$	4.5	20	**30**
7	$SnCl_4$	0.25	69	**29** + **30** (5 : 1)
8	TiF_4	4	32	**16i** + **30** (1 : 1)
9	$ZnCl_2$[e]		—	
10	Bu_2BOTf	0.25	43	**30**

[a] 1.05 equiv. of Lewis acid was used unless otherwise stated. [b] The reaction time was based upon the loss of the hexacarbonyldicobalt complex and the appearance of the complexed cyclisation product. [c] The yield is based upon the one-pot procedure and expressed as a percentage. [d] 1.05 equiv. of a 1.0 M solution, in diethyl ether, was initially added followed after 3 h by a further 1.5 equiv. [e] Failure to cyclise possibly due to the insolubility of the Lewis acid.

As well as the use of tetrafluoroboric acid for effecting the cyclisation reaction investigations were also conducted with other Lewis acids using the cyclisation precursor **15i** (Scheme 6).



15i

16i R = F
29 R = Cl

30

Scheme 6

Depending upon the Lewis acid used this molecule underwent an intramolecular cyclisation reaction to afford either the halogenated benzopyrans **16i/29** exclusively or a mixture of the benzopyrans **16i/29** and **30**. The data obtained from these experiments are shown in Table 2.

From these data it may be concluded that in addition to the most frequently used Lewis acids for effecting the Nicholas reaction (entries 1 to 4) we have identified three additional reagents (entries 5, 7 and 10) that have proved to be effective for this particular cyclisation reaction. Tin(IV) chloride (entry 7) proved to be a most convenient reagent in terms of its handling qualities and ease of purification. Furthermore a modest improvement in the overall yield was observed with this reagent; however this was accompanied by a slight reduction in the selectivity of the reaction. In all of the examples given in Table 2 no reduction in diastereoselectivity was observed.

In considering the proposed mechanism for the cyclisation reaction we reasoned that if more than one halogen ion was displaceable from the Lewis acid then it should be feasible to effect the cyclisation reaction using sub-stoichiometric quantities of the Lewis acid. This would lend support to the proposed mechanism and may be of benefit to those engaged in this area of research that employ more sensitive substrates as well as those interested in the design of novel or chiral Lewis acids for use in analogous reactions. In a range of experiments to study this effect the cobalt complex, obtained from the exposure of propynyl alcohol **15i** with octacarbonyldicobalt was reacted with varying amounts of two different Lewis acids. In most of the examples this led to a facile cyclisation reaction which was followed by an *in situ* decomplexation reaction, with CAN, to afford the desired benzopyran(s) in good overall yields. The results from these investigations are shown in Table 3. When using tetrafluoroboric acid (entries 1–7) it can be seen that initial reductions in the amount of the Lewis acid used have little effect upon either the yield of the final product or upon the reaction time (entries 1–4). This suggests that more than one ligand may indeed be exchanged from the Lewis acid, however as the concentration of the Lewis acid is reduced further the reaction time increases (entries 5 and 6) and a reduction in the overall yield of the product is eventually observed (entry 6). For the investigations using tin(IV) chloride to effect the cyclisation (entries 8–13) a similar pattern emerges, with the time taken to complete the cyclisation reaction and the overall yield of product(s) obtained remaining constant (entries 8–11) until the amount of acid is reduced to a certain level (entry 12). As the concentration of the Lewis acid is further reduced (entries 12 and 13) there is an increase in the reaction time with a concomitant reduction in the overall yield for the reaction. Again the diastereoselectivity of the cyclisation reaction, using sub-stoichiometric quantities of these Lewis acids, does not appear to diminish and affords the benzopyrans with *trans*-stereochemistry in all of the examples studied.

As a conclusion to these studies into the synthesis of benzopyran derivatives it was decided to undertake an investigation into any biological activity that may be present. The rationale for these studies was based upon the fact that benzopyrans **16a**–**16i** possess several features found in cromakalim **2**. These include substituents at C-3 and C-4 with a *trans* disposition as well as substituents on the aromatic ring. In addition a vast range of other molecules have demonstrated similar effects to cromakalim with variable potency.[16]

The experimental procedure used in these investigations consisted of monitoring the contractions of longitudinally orientated uterine tissue upon exposure to a benzopyran derivative. The tissue, isolated from the common white rat, was connected to an isometric force transducer which in turn was linked to a chart recorder. In general uterine muscle tissue displays spontaneous contractions, however the frequency and intensity of the concentrations are often variable. To overcome this variability in contractions oxytocin was added to the incubation solution in order to ensure a more consistent and regular muscle contraction. The biological activity was then equated to a reduction in the intensity and/or irregularity in the frequency of the contractions. Of the compounds synthesised it was noted that whereas none of the alkenyl derivatives such as **30** or the chlorinated derivative **29** was able to induce a reduction in the intensity or frequency on the oxytocin regulated contraction of the uterus, some fluorinated compounds did. Of the derivatives in Table 1 all of the benzopyrans **16a** to **16i** exhibited some activity; however **16b** and **16d** displayed the highest potency. Although further evaluations will need to be undertaken in order to determine the precise mechanism of action, we found that at a concentration of 8×10^{-5} M of compound **16d**, a reduction in the intensity of uterine contraction as well as a disruption in their frequency was observed. For compound **16b** we found that at a concentration of 3.5×10^{-4} M there was a total relaxation of the smooth muscle. To put these results into perspective a concentration of 5×10^{-5} M of cromakalim[17] **2** was sufficient to eradicate any contractions. For all three of the experiments the oxytocin-related contractions were restored after washing of the uterine muscle with fresh physiological solution.

To summarise these results, we have effected a hitherto unrecorded variation of the Nicholas reaction between a hexacarbonyldicobalt stabilised cation and a trisubstituted alkene, in a one-pot procedure, to afford a range of novel benzopyrans. To the authors' knowledge these experiments illustrate the first examples in which a Lewis acid serves two functions (i) in the

Table 3 The effects of using sub-stoichiometric amounts of Lewis acid upon the one-pot cyclisation reaction

Tetrafluoroboric acid					Tin(IV) chloride					
Entry	Mole equiv.[a]	*t*/min[b]	Yield (%)[c]	Product	Entry	Mole equiv.[a]	*t*/min[b]	Yield (%)[c]	Products	Product ratio
1	1.10	15	66	**16i**	8	1.10	15	69	**29** + **30**	5:1
2	1.00	15	67	**16i**	9	1.00	15	69	**29** + **30**	4.5:1
3	0.75	15	64	**16i**	10	0.75	15	69	**29** + **30**	6:1
4	0.50	15	65	**16i**	11	0.50	15	69	**29** + **30**	5:1
5	0.35	35	64	**16i**	12	0.25	45	65	**29** + **30**	5:1
6	0.25	60	53	**16i**	13	0.10	60[d]	20	**30**	
7	0.10	60[d]	30	**16i**						

[a] This quantity represents the amount of Lewis acid in relation to 1 mole of the precursor used. [b] The reaction time is based upon the loss of the complexed propynyl alcohol (*via* TLC analysis) and the appearance of the complexed cyclisation product. [c] This is based upon the one-pot procedure. [d] The cobalt complexed propynyl alcohol was recovered from the reaction mixture.

generation of the cobalt stabilised propynylic cation and (ii) as a source of halogen that quenches the subsequent cation formed during the cyclisation reaction. In addition we have attempted to establish the minimum requirements in the alkene to effect this reaction. The diastereoselective reaction initially appears to afford the fluorinated compound but in time this undergoes an unusual HF elimination, possibly cobalt assisted, to give the alkenyl derivative with *trans*-stereochemistry. Our results have shown that extending the reaction time, prior to the *in situ* decomplexation step, affords the isopropenyl derivative exclusively thus offering a method for obtaining either benzopyran derivative selectively by simply extending the reaction time prior to removal of the cobalt complex. Furthermore we have demonstrated that the cyclisation reaction may be effected using other hitherto unused Lewis acids and for two examples sub-stoichiometric concentrations were effective for this transformation. These results show that as the concentrations of the Lewis acids used are reduced, to about 0.35 mole equivalent, there is a concomitant increase in the reaction time, a reduction in yield and with tin(IV) chloride there was a distribution of products as well. Overall these results do tend to give support to the original hypothesis concerning the lability of the ligands derived from the Lewis acid suggesting that in some examples up to three of the ligands may be displaced.

Experimental

General details[18]

Melting points determinations were recorded on a Buchi 512 capillary tube apparatus and are uncorrected. Bulb to bulb distillations were carried out using a Buchi GKR-51 Kugelrohr apparatus. IR spectra were recorded on a Perkin-Elmer 1600 series FTIR spectrometer and were calibrated using a standard polystyrene film. The spectra were recorded either as thin films, for liquids, between sodium chloride discs or, for solids, as a Nujol mull. All infrared data are quoted in wavenumbers (cm^{-1}). Proton nuclear magnetic resonance spectra (^1H NMR) were recorded at 400 MHz using a Bruker AMX400 Fourier Transform Nuclear Magnetic spectrometer, at 300 MHz on a Bruker AC-300 FTNMR spectrometer, at 90 MHz on a Perkin-Elmer R32 spectrometer and at 60 MHz on a JEOL PMX60SI spectrometer. Peak positions are quoted using the δ scale relative to tetramethylsilane ($\delta = 0$) as an internal standard. Carbon-13 NMR spectra (^{13}C NMR) were recorded at 75.45 MHz on a Bruker AC-300 FTNMR spectrometer using deuterochloroform as the internal standard. Fluorine NMR (^{19}F NMR) were recorded at 282.40 MHz on the same spectrometer using trichlorofluoromethane as the internal standard. Peak positions are quoted in a similar manner relative to trichlorofluoromethane ($\delta = 0$). Low resolution mass spectra were recorded on a VG TRIO-2 mass spectrometer under electron impact conditions at an ionising potential of 70 eV and/or with a Hewlett Packard GC-MS,HP5890 (GC) with capillary column and HP 5971 (MS). Accurate mass analyses were performed and reported on a VG-ZAB-E under EI conditions at an ionising potential of 70 eV, by the EPSRC National Mass Spectrometry Service Centre (Swansea) using the EI Peak Match on M^+ method. Microanalyses were performed and reported by Butterworth Laboratories Ltd. on a Perkin-Elmer PE400 elemental analyser or by Medac Ltd. on a CEC 240XA instrument. The following conventions have been adopted when quoting NMR data: s = singlet, d = doublet, t = triplet, q = quartet, br = broad, m = multiplet and the coupling constants *J* are quoted in Hz.

Flash chromatography was performed using 240–360 mesh silica according to the Still[19] method, 'ether' refers to diethyl ether and 'light petroleum' refers to the fraction that boils over the range 40–60 °C. The progress of the reactions was monitored by TLC which was carried out using Merck SIL G-25 precoated plates with fluorescent indicator UV_{254} and, apart from the cobalt complexes, were visualised by short wave ultraviolet radiation, immersion in iodine vapour, or by heating after immersion in aqueous potassium permanganate or vanillin (acidified 10% methanolic solution). Organic extracts were dried over anhydrous magnesium sulfate, filtered and concentrated by evaporation under reduced pressure, *ca.* 15–20 mmHg, using a rotary evaporator.

1-(2-Hydroxyphenyl)prop-2-yn-1-ol 8a

To a solution of ethynylmagnesium bromide (250 cm^3 of a 0.5 M solution in THF, 125 mmol) at 0 °C, under a nitrogen atmosphere, was added, dropwise, salicylaldehyde **7** (6.36 g, 52.1 mmol) in THF (50 cm^3). The reaction mixture was left to stir at 0 °C and then allowed to warm to an ambient temperature. TLC analysis showed the presence of a slower moving compound (R_f 0.45, 1:1 diethyl ether:light petroleum) and the reaction mixture was quenched by the addition of saturated aqueous ammonium chloride (150 cm^3). Excess THF was removed *in vacuo* and the solution was partitioned in diethyl ether and the aqueous phase extracted with diethyl ether (4 × 50 cm^3). The organic extracts were combined, dried over anhydrous magnesium sulfate, filtered and concentrated *in vacuo* to afford a brown oil. Purification by column chromatography on silica (1:1 diethyl ether:light petroleum as eluent) gave the desired compound **8a** as a brown crystalline solid (7.72 g, 100%), mp 92.1–93.5 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3287, 2120, 1598; δ_H(300 MHz: $CDCl_3$) 7.38 (1H, dd, *J* 8 and 2, Ar*H*), 7.30 (1H, s, ArO*H*), 7.24 (1H, dt, *J* 8 and 2, Ar*H*), 6.89 (2H, m, Ar*H*), 5.66 (1H, d, *J* 2, PhC*H*), 3.48 (1H, s, O*H*), 2.73 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: $CDCl_3$) 154.63 (s), 130.06 (d), 127.79 (d), 124.79 (s), 120.41 (d), 116.72 (d), 82.00 (d), 75.85 (s), 69.68 (d); *m/z* 148 (M^+), 130, 121, 102 (100%), 91, 76, 63, 51 (Found: C, 72.93; H, 5.37. Calc. for $C_9H_8O_2$: C, 72.97; H, 5.41%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)phenoxy]but-2-ene 9

To a solution of 1-(2-hydroxyphenyl)prop-2-yn-1-ol **8a** (1.0 g, 6.8 mmol) and 4-bromo-2-methylbut-2-ene (1.10 g, 7.4 mmol)

in dry DMF (25 cm^3) was added finely divided potassium carbonate (3.72 g, 27.0 mmol) and potassium iodide (0.12 g, 0.68 mmol) and the reaction mixture was left to stir at an ambient temperature for two hours. TLC analysis showed the presence of a slower moving compound (R_f 0.35, 1:3 diethyl ether:light petroleum) and the reaction mixture was decanted into water. The mixture was partitioned in diethyl ether and the aqueous phase was extracted with diethyl ether (6 × 10 cm^3), the organic extracts were combined, washed sequentially with 10% aqueous hydrochloric acid (30 cm^3) followed by 10% aqueous potassium carbonate (30 cm^3), dried over anhydrous magnesium sulfate, filtered and concentrated *in vacuo*. Purification by column chromatography on silica (1:3 diethyl ether:light petroleum as eluent) gave the desired compound **9** (1.21 g, 82%) as a colourless oil: ν_{max}(film)/cm^{-1} 3529, 3425, 3291, 3067, 3035, 2116, 1675, 1601, 1234, 1015; δ_H(300 MHz: $CDCl_3$) 7.54 (1H, dd, *J* 8 and 2, Ar*H*), 7.27 (1H, dt, *J* 8 and 2, Ar*H*), 6.95 (1H, dt, *J* 8 and 2, Ar*H*), 6.91 (1H, d, *J* 8, Ar*H*), 5.68 (1H, dd, *J* 6 and 2, PhC*H*), 5.48 (1H, m, =C*H*), 4.60 (2H, d, *J* 6, CH_2), 3.28 (1H, d, *J* 6, O*H*), 2.61 (1H, d, *J* 2, ≡C*H*), 1.80 (3H, s, CH_3), 1.75 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 156.14 (s), 138.55 (s), 129.70 (d), 128.56 (s), 127.91 (d), 120.85 (d), 119.35 (d), 112.15 (d), 83.11 (d), 74.12 (s), 65.31 (t), 61.43 (d), 25.79 (q), 18.30 (q) (Found: M^+, 216.1150. $C_{14}H_{16}O_2$ requires M^+, 216.1150); *m/z* 216 (M^+), 198, 148, 130 (100%), 121, 102, 91, 77, 69, 53, 41.

Hexacarbonyl{2-methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-phenoxy]but-2-ene}dicobalt 10

To a solution of the propynyl alcohol **9** (2 g, 9.26 mmol) in hexane (50 cm^3) was added octacarbonyldicobalt (3.48 g, 10.1 mmol) and the reaction mixture was stirred, under an atmosphere of nitrogen, at ambient temperature. TLC analysis of the mixture after one hour showed the presence of a faster moving compound (R_f 0.75, 6:1 hexane:diethyl ether). The mixture was filtered through a plug of Florisil, the solvent removed *in situ* and the crude product **10** was isolated as a dark red oil and used without further purification (4.65 g, 100%); ν_{max}(film)/cm^{-1} 3397, 2993, 2081, 2056, 2020, 1602, 1234.

Hexacarbonyl[4-ethynyl-3-(1-methylethenyl)chromane]dicobalt 11a and hexacarbonyl[4-ethynyl-3-(1-fluoro-1-methylethyl)-chromane]dicobalt 11b

To a solution of compound **10** (3.00 g, 6.0 mmol) in DCM (15 cm^3) was added tetrafluoroboric acid diethyl ether complex (1.04 cm^3, 6.0 mmol, 85% by volume) and the reaction mixture was stirred at an ambient temperature. TLC analysis after 15 minutes showed the presence of a faster moving compound (R_f 0.90, 6:1 hexane:diethyl ether), and the reaction mixture was quenched by the addition of saturated aqueous sodium hydrogen carbonate (10 cm^3) and partitioned. The aqueous layer was extracted with DCM (3 × 15 cm^3) and the organic layers were combined, dried over anhydrous magnesium sulfate, filtered, and the solvent removed *in vacuo* to afford a red oil. Purification by column chromatography (hexane) failed to separate the two compounds and so the resultant red oil was subjected directly to a decomplexation reaction; ν_{max}(film)/cm^{-1} 3040, 2960, 2070, 2039, 2019, 1602, 1590.

4-Ethynyl-3-(1-methylethenyl)chromane 12a

To a solution of compounds **11a** and **11b** (1.52 g, 3.1 mmol) in acetone (20 cm^3) was added a solution of cerium(IV) ammonium nitrate (7.80 g, 14.0 mmol) in acetone (20 cm^3) and stirred at an ambient temperature for thirty minutes until the evolution of gas had ceased. TLC analysis of the reaction mixture indicated the presence of two products (R_f 0.55 and 0.60, 6:1 hexane:diethyl ether). The reaction was then quenched by the addition of saturated aqueous sodium hydrogen carbonate (15 cm^3) and the mixture extracted with diethyl ether (4 × 30 cm^3). The organic layers were recombined, dried over anhydrous magnesium sulfate, filtered and the solvent removed *in vacuo* to afford a brown oil. Purification by column chromatography on silica (eluted with hexane) gave compound **12a**, as an initial fraction (0.09 g, 31%) as a clear oil; ν_{max}(film)/cm^{-1} 3300, 3040, 2111, 1620, 1601, 1220; δ_H(300 MHz: $CDCl_3$) 7.51 (1H, dd, *J* 7 and 1, Ar*H*), 7.16 (1H, dt, *J* 7 and 1, Ar*H*), 6.94 (1H, t, *J* 8, Ar*H*), 6.82 (1H, d, *J* 8, Ar*H*), 5.05 (1H, d, *J* 1, =C*H*), 4.90 (1H, br s, =C*H*), 4.28 (1H, dd, *J* 12 and 4, OC*H*), 3.92 (2H, br t, *J* 12, PhC*H* and OC*H*), 2.71 (1H, dt, *J* 12 and 4, C*H*), 2.23 (1H, d, *J* 3, ≡C*H*), 1.87 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.30 (s), 142.60 (s), 128.46 (d), 128.40 (s), 120.95 (d), 120.80 (d), 116.63 (d), 113.54 (t), 84.48 (d), 70.37 (s), 66.38 (t), 45.34 (d), 32.77 (d), 21.59 (q) (Found: M^+, 198.1045. $C_{14}H_{14}O$ requires M^+, 198.1045); *m/z* 198 (M^+), 165, 130, 102 (100%), 89, 76, 67, 53, 41.

Further elution of the column gave 4-*ethynyl*-3-(1-*fluoro*-1-*methylethyl*)*chromane* **12b** (0.07 g, 22%) as a clear oil; ν_{max}(film)/cm^{-1} 3300, 2990, 2110, 1601, 1220; δ_H(300 MHz: $CDCl_3$) 7.38 (1H, br d, *J* 8, Ar*H*), 7.15 (1H, dt, *J* 8 and 1, Ar*H*), 6.94 (1H, dt, *J* 8 and 2, Ar*H*), 6.82 (1H, br t, *J* 8, Ar*H*), 4.42 (1H, dt, *J* 12 and 3, OC*H*), 4.15 (1H, dd, *J* 12 and 6, OC*H*), 3.91 (1H, br s, PhC*H*), 2.41 (1H, m, C*H*), 2.26 (1H, d, *J* 3, ≡C*H*), 1.50 (3H, d, J_{HF} 22, CH_3), 1.40 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.87 (s), 142.17 (s), 129.97 (d), 128.34 (s), 121.30 (d), 117.00 (d), 96.30 (d, J_{CF} 168, CF), 86.64 (d), 70.53 (s), 64.19 (t), 47.50 (d), 47.23 (d), 2 × 25.55 (q); *m/z* 218 (M^+), 199, 185, 171, 155, 135 (100%), 101, 89, 77, 63, 51, 41 (Found: C, 76.98; H, 6.87. Calc. for $C_{14}H_{15}FO$: C, 77.07; H, 6.88%).

1-(2-Hydroxy-3,5-dichlorophenyl)prop-2-yn-1-ol 13a

To a solution of ethynylmagnesium bromide (91.50 cm^3 of a 0.5 M solution in THF, 45.7 mmol) at 0 °C, under a nitrogen atmosphere, was added, dropwise, 3,5-dichlorosalicylaldehyde (3.64 g, 19.1 mmol) in THF (15 cm^3). The reaction mixture was left to stir at 0 °C and then allowed to warm to an ambient temperature. TLC analysis showed the presence of a slower moving compound (R_f 0.43, 1:1 diethyl ether:light petroleum) and the reaction mixture was quenched by the addition of saturated aqueous ammonium chloride (50 cm^3). Excess THF was removed *in vacuo* and the solution was partitioned in diethyl ether and the aqueous phase extracted with diethyl ether (4 × 20 cm^3). The organic extracts were combined, dried over anhydrous magnesium sulfate, filtered and concentrated *in vacuo* to afford a white semi-solid. Recrystallisation from ethanol gave the desired compound **13a** as a white crystalline solid (2.76 g, 67%), mp 91.5–92.2 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3296, 2119, 1580, 1051; δ_H(300 MHz: $CDCl_3$) 7.43 (1H, d, *J* 2, Ar*H*), 7.34 (1H, d, *J* 2, Ar*H*), 7.26 (1H, s, ArO*H*), 6.89 (2H, m, Ar*H*), 5.69 (1H, d, *J* 2, PhC*H*), 2.74 (1H, d, *J* 2, ≡C*H*), 1.61 (1H, s, O*H*); δ_C(75.45 MHz: $CDCl_3$) 156.55 (s), 153.65 (s), 129.12 (d), 126.59 (d), 124.92 (s), 118.82 (s), 81.89 (d), 75.35 (s), 62.75 (d); *m/z* 218 ($M^+ + 1$), 216 ($M^+ - 1$), 198 (100%), 189, 170, 135, 99, 74, 63, 53.

1-(2-Hydroxy-3-methoxyphenyl)prop-2-yn-1-ol 13b. The method used was similar to that used for the synthesis of **13a** using the following reagents: ethynylmagnesium bromide (100 cm^3 of a 0.5 M solution in THF, 50.5 mmol) 3-methoxysalicylaldehyde (3.2 g, 21 mmol) in THF (15 cm^3) to afford a brown solid. Recrystallisation from ethanol gave the desired compound **13b** as a brown crystalline solid (2.15 g, 57%), mp 90.5–92.1 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3531, 3286, 3206, 2128, 1613, 1070; δ_H(300 MHz: $CDCl_3$) 7.13 (1H, dd, *J* 6 and 2, Ar*H*), 6.87 (2H, m, Ar*H*), 6.14 (1H, s, ArO*H*), 5.73 (1H, s, PhC*H*), 3.89 (3H, s, *Me*), 3.06 (1H, s, O*H*), 2.65 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: $CDCl_3$) 146.63 (s), 143.14 (s), 125.77 (s), 120.04 (d), 119.70 (d), 111.05 (d), 82.82 (d), 74.32 (s), 60.91 (d), 56.18 (q); *m/z* 178 (M^+), 160 (100%), 130, 118, 102, 89, 77, 63, 53, 41 (Found: C, 67.63; H, 5.61. Calc. for $C_{10}H_{10}O_3$: C, 67.42; H, 5.62%).

1-(2-Hydroxy-5-nitrophenyl)prop-2-yn-1-ol 13c. The method

used was similar to that used for the synthesis of **13a** using the following reagents: ethynylmagnesium bromide (86.2 cm^3 of a 0.5 M solution in THF, 43.1 mmol), 5-nitrosalicylaldehyde (3.00 g, 17.9 mmol) in THF (15 cm^3) to afford a yellow solid. Recrystallisation from ethanol gave the desired compound **13c** as a yellow solid (3.10 g, 89%), mp 60 °C (decomp.) (from ethanol); ν_{max}(Nujol)/cm^{-1} 3441, 3288, 3076, 2124, 1615, 1594, 1289, 1086; δ_H(300 MHz: DMSO) 8.27 (1H, d, *J* 3, Ar*H*), 7.98 (1H, dd, *J* 9 and 3, Ar*H*), 6.74 (1H, d, *J* 9, Ar*H*), 5.55 (1H, d, *J* 2, PhC*H*), 5.41 (2H, br s, O*H* and ArO*H*), 3.44 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: DMSO) 158.78 (s), 146.34 (s), 129.17 (d), 125.43 (s), 123.28 (d), 116.67 (d), 84.68 (d), 75.11 (s), 66.90 (d); *m*/*z* 193 (M^+), 175 (100%), 146, 129, 89, 76, 57, 41.

1-(2-Hydroxy-3,5-dibromophenyl)prop-2-yn-1-ol 13d. The method used was similar to that used for the synthesis of **13a** using the following reagents: ethynylmagnesium bromide (62.00 cm^3 of a 0.5 M solution in THF, 31.0 mmol), 3,5-dibromosalicylaldehyde (3.62 g, 12.9 mmol) in THF (15 cm^3) to afford a pale yellow crystalline compound. Recrystallisation from ethanol gave the desired compound **13d** as a pale yellow solid (2.87 g, 73%), mp 99.9–102.1 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3374, 3288, 3274, 3076, 2123, 1195, 1014; δ_H(300 MHz: DMSO) 7.59 (2H, dd, *J* 8 and 2, Ar*H*), 6.65 (1H, br s, ArO*H*), 5.69 (1H, s, PhC*H*), 2.93 (1H, br s, O*H*), 2.74 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: $CDCl_3$) 141.73 (s), 134.66 (d), 131.94 (s), 130.13 (d), 123.47 (s), 115.64 (s), 83.74 (d), 74.86 (s), 61.44 (d); *m*/*z* 305 ($M^+ - 1$), 287 (100%), 259, 179, 143, 100, 74, 53.

1-(2-Hydroxy-4-methoxyphenyl)prop-2-yn-1-ol 13e. The method used was similar to that used for the synthesis of **13a** using the following reagents: ethynylmagnesium bromide (63.10 cm^3 of a 0.5 M solution in THF, 31.5 mmol), 4-methoxysalicylaldehyde (2.0 g, 13.3 mmol) in THF (10 cm^3) to afford an oil. Purification by chromatography on silica gave the desired compound **13e** as a pale yellow oil (1.65 g, 71%); ν_{max}(Nujol)/cm^{-1} 3402, 3287, 2119, 1620, 1518, 1164, 1035; δ_H(300 MHz: $CDCl_3$) 7.35 (1H, d, *J* 2, Ar*H*), 7.13 (2H, m, Ar*H*), 6.27 (1H, s, ArO*H*), 5.52 (1H, s, PhC*H*), 3.78 (3H, s, *Me*), 3.32 (1H, s, O*H*), 2.54 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: $CDCl_3$) 144.83 (s), 141.90 (s), 126.72 (s), 120.28 (d), 116.84 (d), 112.35 (d), 83.24 (d), 73.96 (s), 61.28 (d), 54.71 (q); *m*/*z* 178 (M^+), 160 (100%), 130, 118, 102, 89, 77, 63, 54 (Found: C, 67.51; H, 5.60. Calc. for $C_{10}H_{10}O_3$: C, 67.42; H, 5.62%).

1-(2-Hydroxy-5-chlorophenyl)prop-2-yn-1-ol 13f. The method used was similar to that used for the synthesis of **13a** using the following reagents: ethynylmagnesium bromide (76.60 cm^3 of a 0.5 M solution in THF, 38.3 mmol), 5-chlorosalicylaldehyde which was purified by recrystallisation from ethanol (2.50 g, 16.0 mmol) in THF (10 cm^3) to afford an oil. Purification by chromatography on silica gave the desired compound **13f** as a colourless oil (2.71 g, 93%); ν_{max}(Nujol)/cm^{-1} 3393, 3294, 2122, 1604, 1273, 1064; δ_H(300 MHz: $CDCl_3$) 7.37 (1H, d, *J* 3, Ar*H*), 7.17 (1H, dd, *J* 9 and 3, Ar*H*), 7.01 (1H, d, *J* 9, Ar*H*), 6.74 (1H, s, ArO*H*), 5.64 (1H, d, *J* 2, PhC*H*), 3.43 (1H, s, O*H*), 2.78 (1H, d, *J* 2, ≡C*H*); δ_C(75.45 MHz: $CDCl_3$) 153.60 (s), 129.94 (d), 127.44 (d), 126.62 (s), 125.08 (s), 118.34 (d), 80.93 (d), 74.11 (s), 62.89 (d); *m*/*z* 183 ($M^+ + 1$), 146, 138 (100%), 108, 88, 75, 63, 41.

2-Methyl-4-[(2-formyl-6-methoxy)phenoxy]but-2-ene 14b

The method used was similar to that used for the synthesis of **9** using the following reagents: 3-methoxysalicylaldehyde (2.00 g, 13.2 mmol) and 4-bromo-2-methylbut-2-ene (2.16 g, 14.5 mmol) in dry DMF (40 cm^3). To the mixture was added finely divided potassium carbonate (7.27 g, 52.6 mmol) and potassium iodide (0.22 g, 1.30 mmol) to give the desired compound **14b** (2.80 g, 98%) as a colourless oil; ν_{max}(film)/cm^{-1} 3045, 2744, 1691, 1594, 1248, 1067; δ_H(300 MHz: $CDCl_3$) 10.36 (1H, s, *H*C=O), 7.34 (1H, dd, *J* 9 and 3, Ar*H*), 7.06 (2H, m, Ar*H*), 5.44 (1H, m, =C*H*), 4.60 (2H, d, *J* 8, CH_2), 3.87 (3H, s, O*Me*), 1.70 (3H, s, *Me*), 1.57 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 190.53 (d), 153.23 (s), 151.30 (s), 140.27 (s), 130.56 (s), 124.04 (d), 119.28 (d), 118.74 (d), 117.74 (d), 70.45 (t), 55.98 (q), 25.74 (q), 17.82 (q); *m*/*z* 220 (M^+), 202, 165, 152 (100%), 136, 122, 106, 79, 69, 53, 41 (Found: C, 71.02; H, 7.26. Calc. for $C_{13}H_{16}O_3$: C, 70.91; H, 7.27%).

2-Methyl-4-[(2-formyl-5-methoxy)phenoxy]but-2-ene 14e. The method used was similar to that used for the synthesis of **9** using the following reagents: 4-methoxysalicylaldehyde (1.5 g, 9.9 mmol) and 4-bromo-2-methylbut-2-ene (1.62 g, 10.9 mmol) in dry DMF (30 cm^3). To the mixture was added finely divided potassium carbonate (5.45 g, 39.5 mmol) and potassium iodide (0.16 g, 1.00 mmol) to give the desired compound **14e** (2.13 g, 97%) as a white crystalline solid, mp 41.7–43.1 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3038, 2736, 1666, 1608, 1262, 1018; δ_H(300 MHz: $CDCl_3$) 10.31 (1H, s, *H*C=O), 7.87 (1H, d, *J* 9, Ar*H*), 6.51 (1H, dd, *J* 8 and 2, Ar*H*), 6.44 (1H, d, *J* 2, Ar*H*), 5.46 (1H, m, =C*H*), 4.59 (2H, d, *J* 8, CH_2), 3.86 (3H, s, O*Me*), 1.80 (3H, s, *Me*), 1.75 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 188.51 (d), 166.01 (s), 163.09 (s), 138.73 (s), 130.32 (d), 119.28 (s), 118.86 (d), 105.83 (d), 98.98 (d), 65.46 (t), 55.59 (q), 25.79 (q), 18.31 (q) (Found: M^+, 220.1099. $C_{13}H_{16}O_3$ requires *M*, 220.1099); *m*/*z* 220 (M^+), 202, 187, 165, 151 (100%), 135, 95, 79, 69, 53, 41.

2-Methyl-4-[(2-formyl-4-methoxy)phenoxy]but-2-ene 14g. The method used was similar to that used for the synthesis of **9** using the following reagents: 5-methoxysalicylaldehyde (2.00 g, 13.2 mmol) and 4-bromo-2-methylbut-2-ene (2.16 g, 14.5 mmol) in dry DMF (40 cm^3). To the mixture was added finely divided potassium carbonate (7.27 g, 52.6 mmol) and potassium iodide (0.22 g, 1.30 mmol) to give the desired compound **14g** (2.91 g, 99%) as pale yellow needles, mp 24.1–25.8 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3042, 2750, 1683, 1615, 1585, 1195, 1040; δ_H(300 MHz: $CDCl_3$) 10.42 (1H, s, *H*C=O), 7.28 (1H, d, *J* 3, Ar*H*), 7.06 (1H, dd, *J* 9 and 3, Ar*H*), 6.91 (1H, d, *J* 9, Ar*H*), 5.44 (1H, tt, *J* 7 and 2, =C*H*), 4.55 (2H, d, *J* 7, CH_2), 3.76 (3H, s, O*Me*), 1.76 (3H, s, *Me*), 1.71 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 189.68 (d), 156.13 (s), 153.59 (s), 138.59 (s), 125.44 (s), 123.42 (d), 119.19 (d), 115.13 (d), 110.01 (d), 66.23 (t), 55.71 (q), 25.74 (q), 18.23 (q); *m*/*z* 220 (M^+), 202, 165, 152 (100%), 137, 123, 109, 81, 69, 53, 41.

2-Methyl-4-[(2-formyl-4,6-diiodo)phenoxy]but-2-ene 14h. The method used was similar to that used for the synthesis of **9** using the following reagents: 3,5-diiodosalicylaldehyde (1.5 g, 4.0 mmol) and 4-bromo-2-methylbut-2-ene (0.66 g, 4.4 mmol) in dry DMF (30 cm^3). To the mixture was added finely divided potassium carbonate (2.22 g, 16.0 mmol) and potassium iodide (0.07 g, 0.40 mmol) to give the desired compound **14h** (1.55 g, 87%) as white needles, mp 116.3–118.1 °C (from ethanol); ν_{max}(film)/cm^{-1} 3051, 2732, 1684, 1617, 1560, 1220, 1133; δ_H(300 MHz: $CDCl_3$) 10.13 (1H, s, *H*C=O), 8.33 (1H, d, *J* 2, Ar*H*), 8.07 (1H, d, *J* 2, Ar*H*), 5.51 (1H, m, =C*H*), 4.46 (2H, d, *J* 7, CH_2), 1.77 (3H, s, *Me*), 1.58 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 188.01 (d), 162.57 (s), 152.42 (d), 142.29 (s), 137.32 (d), 132.20 (s), 117.93 (d), 91.26 (s), 89.03 (s), 72.85 (t), 25.81 (q), 18.16 (q); *m*/*z* 440 ($M^+ - 1$), 424, 382, 373 (100%), 355, 316, 297, 272, 260, 231, 174, 146, 118, 91, 63, 43 (Found: C, 32.33; H, 2.80. Calc. for $C_{12}H_{12}I_2O_2$: C, 32.65; H, 2.72%).

2-Methyl-4-[(2-formyl-4-bromo)phenoxy]but-2-ene 14i. The method used was similar to that used for the synthesis of **9** using the following reagents: 5-bromosalicylaldehyde (8.60 g, 42.7 mmol) and 4-bromo-2-methylbut-2-ene (7.00 g, 47.0 mmol) in dry DMF (110 cm^3). To the mixture was added finely divided potassium carbonate (23.61 g, 170.8 mmol) and potassium iodide (0.69 g, 4.30 mmol) to give the desired compound **14i** (11.40 g, 99%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 3067, 3030, 2753, 1682, 1590, 1270, 1232, 1122; δ_H(300 MHz: $CDCl_3$) 10.35 (1H, s, *H*C=O), 7.84 (1H, d, *J* 3, Ar*H*), 7.52 (1H, dd, *J* 9 and 3, Ar*H*), 6.84 (1H, d, *J* 9, Ar*H*), 5.41 (1H, m, =C*H*), 4.57 (2H, d, *J* 6, CH_2), 1.77 (3H, s, *Me*), 1.72 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 188.44 (d), 160.18 (s), 139.21 (s), 138.11 (d), 130.70 (d),

126.30 (s), 118.53 (d), 115.05 (d), 113.24 (s), 65.81 (t), 25.76 (q), 18.31 (q); *m/z* 268 ($M^+ - 1$), 251, 237, 225, 200 (100%), 184, 172, 156, 145, 102, 69, 53, 41 (Found: C, 53.49; H, 4.80. Calc. for $C_{12}H_{13}BrO_2$: C, 53.53; H, 4.83%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4,6-dichlorophenoxy]-but-2-ene 15a

The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13a** (0.70 g, 3.3 mmol), 4-bromo-2-methylbut-2-ene (0.53 g, 3.6 mmol), in DMF (15 cm^3), potassium carbonate (1.78 g, 13.0 mmol) and potassium iodide (0.06 g, 0.3 mmol) to afford the desired compound **15a** (0.83 g, 91%) as a yellow powder, mp 49.2–51.3 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3396, 3301, 3076, 2119, 1672, 1566, 1162, 1027; δ_H(300 MHz: $CDCl_3$) 7.51 (1H, d, *J* 3, Ar*H*), 7.32 (1H, d, *J* 3, Ar*H*), 5.67 (1H, dd, *J* 6 and 2, PhC*H*), 5.54 (1H, m, =C*H*), 4.55 (2H, *J* 8 and 4, CH_2), 3.11 (1H, d, *J* 6, O*H*), 2.65 (1H, d, *J* 2, ≡C*H*), 1.79 (3H, s, CH_3), 1.71 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 151.14 (s), 140.46 (s), 136.99 (s), 130.35 (d), 129.96 (s), 128.86 (s), 126.71 (d), 119.09 (d), 82.69 (d), 75.16 (s), 70.83 (t), 59.79 (d), 25.87 (q), 18.14 (q); *m/z* 285 (M^+), 216, 198, 170, 123, 100, 85, 70 (100%), 53, 41 (Found: C, 59.12; H, 4.95. Calc. for $C_{14}H_{14}Cl_2O_2$: C, 58.98; H, 4.95%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-6-methoxyphenoxy]-but-2-ene 15b. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13b** (0.70 g, 3.9 mmol), 4-bromo-2-methylbut-2-ene (0.65 g, 4.3 mmol), in DMF (15 cm^3), potassium carbonate (2.17 g, 15.7 mmol) and potassium iodide (0.07 g, 0.4 mmol) to afford the desired compound **15b** (0.82 g, 87%) as a yellow oil. Alternatively compound **15b** was synthesised *via* propynylation of compound **14b** (1.4 equiv. of the Grignard reagent) to afford compound **15b** in 92% yield; ν_{max}(film)/cm^{-1} 3432, 3287, 2115, 1676, 1591, 1210, 1039; δ_H(300 MHz: $CDCl_3$) 7.21 (1H, dd, *J* 8 and 3, Ar*H*), 7.02 (1H, t, *J* 8, Ar*H*), 6.87 (1H, dd, *J* 8 and 2, Ar*H*), 5.65 (1H, dd, *J* 6 and 2, PhC*H*), 5.55 (1H, m, =C*H*), 4.62 (2H, d, *J* 8, CH_2), 3.85 (3H, s, O*Me*), 3.22 (1H, d, *J* 6, O*H*), 2.59 (1H, d, *J* 2, ≡C*H*), 1.78 (3H, s, CH_3), 1.70 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 152.70 (s), 145.39 (s), 139.05 (s), 134.49 (s), 124.20 (d), 120.27 (d), 119.50 (d), 112.74 (d), 83.92 (d), 74.01 (s), 69.70 (t), 60.95 (d), 55.87 (q), 25.84 (q), 18.02 (q); *m/z* 246 (M^+), 228, 192, 178, 160 (100%), 151, 130, 118, 102, 89, 69, 53, 41 (Found: C, 72.79; H, 7.36. Calc. for $C_{15}H_{18}O_3$: C, 73.17; H, 7.32%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4-nitrophenoxy]-but-2-ene 15c. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13c** (1.00 g, 5.2 mmol), 4-bromo-2-methylbut-2-ene (0.85 g, 5.7 mmol), in DMF (15 cm^3), potassium carbonate (2.86 g, 20.7 mmol) and potassium iodide (0.09 g, 0.52 mmol) to afford the desired compound **15c** (1.15 g, 85%) as a yellow granular solid, mp 65.5–66.8 °C (from methylated spirit); ν_{max}(Nujol)/cm^{-1} 3409, 3292, 3092, 3035, 2120, 1664, 1593, 1269, 1087; δ_H(300 MHz: $CDCl_3$) 8.48 (1H, d, *J* 3, Ar*H*), 8.17 (1H, dd, *J* 9 and 3, Ar*H*), 6.94 (1H, d, *J* 9, Ar*H*), 5.71 (1H, dd, *J* 6 and 2, PhC*H*), 5.44 (1H, m, =C*H*), 4.68 (2H, d, *J* 6, CH_2), 3.12 (1H, d, *J* 6, O*H*), 2.59 (1H, d, *J* 2, ≡C*H*), 1.79 (3H, s, CH_3), 1.76 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 160.86 (s), 141.18 (s), 140.01 (s), 129.65 (s), 125.86 (d), 123.74 (d), 118.06 (d), 111.64 (d), 81.97 (d), 74.94 (s), 65.85 (t), 59.79 (d), 25.77 (q), 18.37 (q); *m/z* 261 (M^+), 231, 193, 175, 159, 129, 89, 77, 69 (100%), 53, 41 (Found: C, 64.60; H, 5.59; N, 5.75. Calc. for $C_{14}H_{15}NO_3$: C, 64.38; H, 5.76; N, 5.39%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4,6-dibromophenoxy]but-2-ene 15d. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13d** (1.50 g, 4.9 mmol), 4-bromo-2-methylbut-2-ene (0.80 g, 5.4 mmol), in DMF (20 cm^3), potassium carbonate (2.71 g, 19.6 mmol) and potassium iodide (0.08 g, 0.50 mmol) to afford the desired compound **15d** (1.65 g, 90%) as off-white needles, mp 47.2–48.5 °C (from methylated spirit); ν_{max}(Nujol)/cm^{-1} 3418, 3298, 3072, 3023, 2120, 1674, 1557, 1145, 1026; δ_H(300 MHz: $CDCl_3$) 7.68 (2H, dd, *J* 8 and 3, Ar*H*), 5.69 (1H, dd, *J* 6 and 2, PhC*H*), 5.54 (1H, m, =C*H*), 4.60 (2H, m, CH_2), 2.83 (1H, d, *J* 6, O*H*), 2.67 (1H, d, *J* 2, ≡C*H*), 1.81 (3H, s, CH_3), 1.73 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 152.86 (s), 140.49 (s), 137.38 (s), 136.07 (s), 130.40 (d), 119.06 (d), 118.43 (s), 117.44 (d), 82.64 (d), 75.37 (s), 71.07 (t), 59.99 (d), 25.89 (q), 18.24 (q); *m/z* 332 ($M^+ - 42$), 306, 288, 277, 260, 223, 205, 153, 136, 108, 90, 78 (100%), 70, 52, 42 (Found: C, 45.17; H, 3.76. Calc. for $C_{14}H_{14}Br_2O_2$: C, 44.96; H, 3.77%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-5-methoxyphenoxy]but-2-ene 15e. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13e** (1.25 g, 7.0 mmol), 4-bromo-2-methylbut-2-ene (1.15 g, 7.7 mmol), in DMF (30 cm^3), potassium carbonate (3.89 g, 28.1 mmol) and potassium iodide (0.12 g, 0.7 mmol) to afford the desired compound **15e** (0.71 g, 41%) as a pale yellow oil. Alternatively compound **15e** was synthesised *via* propynylation of compound **14e** (1.4 equiv. of the Grignard reagent) to afford compound **15e** in 94% yield; ν_{max}(film)/cm^{-1} 3438, 3302, 2116, 1675, 1583, 1204, 1036; δ_H(300 MHz: $CDCl_3$) 7.45 (1H, t, *J* 4, Ar*H*), 6.46 (2H, dt, *J* 8 and 2, Ar*H*), 5.63 (1H, dd, *J* 6 and 2, PhC*H*), 5.46 (1H, m, =C*H*), 4.56 (2H, d, *J* 6, CH_2), 3.81 (3H, s, O*Me*), 3.03 (1H, d, *J* 6, O*H*), 2.60 (1H, d, *J* 2, ≡C*H*), 1.79 (3H, s, CH_3), 1.74 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 161.04 (s), 157.17 (s), 138.55 (s), 128.66 (d), 121.39 (s), 119.22 (d), 104.29 (d), 99.99 (d), 83.34 (d), 73.85 (s), 65.32 (t), 60.88 (d), 55.42 (q), 25.76 (q), 18.28 (q); *m/z* 246 (M^+), 228, 192, 178, 160 (100%), 145, 132, 117, 102, 89, 69, 53, 41 (Found: C, 72.19; H, 7.30. Calc. for $C_{15}H_{18}O_3$: C, 73.17; H, 7.32%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4-chlorophenoxy]-but-2-ene 15f. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8a**, using the following reagents: **13f** (1.33 g, 7.3 mmol), 4-bromo-2-methylbut-2-ene (1.20 g, 8.0 mmol), in DMF (20 cm^3), potassium carbonate (4.02 g, 29.2 mmol) and potassium iodide (0.12 g, 0.7 mmol) to afford the desired compound **15f** (1.4 g, 78%) as a yellow oil; ν_{max}(film)/cm^{-1} 3416, 3298, 3074, 3021, 2119, 1674, 1567, 1244, 1016; δ_H(300 MHz: $CDCl_3$) 7.54 (1H, d, *J* 3, Ar*H*), 7.21 (1H, dd, *J* 9 and 3, Ar*H*), 6.81 (1H, d, *J* 9, Ar*H*), 5.65 (1H, d, *J* 2, PhC*H*), 5.44 (1H, m, =C*H*), 4.56 (2H, d, *J* 7, CH_2), 3.22 (1H, br s, O*H*), 2.61 (1H, d, *J* 2, ≡C*H*), 1.79 (3H, s, CH_3), 1.79 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 154.61 (s), 138.94 (s), 130.23 (s), 129.24 (d), 127.86 (d), 125.74 (s), 118.98 (d), 113.42 (d), 82.44 (d), 74.62 (s), 65.71 (t), 60.53 (d), 25.77 (q), 18.31 (q); *m/z* 250 (M^+), 233, 217, 182, 164 (100%), 137, 111, 89, 69, 53, 41 (Found: C, 66.59; H, 5.92; Cl, 14.26. Calc. for $C_{14}H_{15}ClO_2$: C, 67.05; H, 6.03; Cl, 14.15%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4-methoxyphenoxy]but-2-ene 15g. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8**, using the following reagents: **14g** (2.00 g, 9.1 mmol), ethynylmagnesium bromide (25.40 cm^3, 12.7 mmol of 0.5 M solution in THF), in THF (15 cm^3) to afford the desired compound **15g** (2.24 g, 100%) as a pale yellow oil; ν_{max}(film)/cm^{-1} 3421, 3288, 2116, 1673, 1587, 1274, 1025; δ_H(300 MHz: $CDCl_3$) 7.13 (1H, d, *J* 2, Ar*H*), 6.81 (2H, m, Ar*H*), 5.63 (1H, dd, *J* 6 and 2, PhC*H*), 5.47 (1H, m, =C*H*), 4.53 (2H, d, *J* 6, CH_2), 3.77 (3H, s, O*Me*), 3.32 (1H, d, *J* 6, O*H*), 2.60 (1H, d, *J* 2, ≡C*H*), 1.78 (3H, s, CH_3), 1.72 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.72 (s), 138.34 (s), 129.73 (s), 119.62 (d), 114.18 (d), 113.76 (d), 113.66 (d), 83.02 (d), 74.20 (s), 68.56 (t), 61.30 (d), 55.75 (q), 25.77 (q), 18.25 (q); *m/z* 246 (M^+), 228, 213, 198, 178,

160 (100%), 145, 132, 117, 102, 89, 69, 53, 41 (Found: C, 72.92; H, 7.28. Calc. for $C_{15}H_{18}O_3$: C, 73.17; H, 7.32%).

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4,6-diiodophenoxy]-but-2-ene 15h. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8**, using the following reagents: **14h** (1.00 g, 2.3 mmol), ethynylmagnesium bromide (5.50 cm^3, 2.7 mmol of 0.5 M solution in THF), in THF (10 cm^3) to afford the desired compound **15h** (0.81 g, 77%) as a viscous orange oil; ν_{max}(neat)/cm^{-1} 3454, 3279, 2116, 1669, 1594, 1221, 1032; δ_H(300 MHz: $CDCl_3$) 8.09 (1H, d, *J* 2, Ar*H*), 7.90 (1H, d, *J* 2, PhC*H*), 5.68 (1H, dd, *J* 6 and 2, PhC*H*), 5.60 (1H, m, =C*H*), 4.51 (2H, dq, *J* 11 and 7, CH_2), 2.73 (1H, d, *J* 6, O*H*), 2.68 (1H, d, *J* 2, ≡C*H*), 1.83 (3H, s, CH_3), 1.75 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 151.96 (s), 149.35 (s), 147.49 (d), 145.86 (s), 142.35 (s), 137.42 (d), 136.86 (s), 119.06 (d), 87.21 (d), 75.47 (s), 71.54 (t), 59.94 (d), 25.90 (q), 18.38 (q); *m*/*z* 429 (M$^+$ − 39), 409, 398, 382 (100%), 357, 307, 283, 255, 226, 196, 181, 152, 127, 100, 63, 44.

2-Methyl-4-[2-(1-hydroxyprop-2-yn-1-yl)-4-bromophenoxy]-but-2-ene 15i. The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8**, using the following reagents: **14i** (9.00 g, 33.4 mmol), ethynylmagnesium bromide (93.63 cm^3, 46.8 mmol, 0.5 M in THF), in THF (30 cm^3), to afford the desired compound **15i** (9.9 g, 100%) as a yellow oil; ν_{max}(film)/cm^{-1} 3403, 3296, 2118, 1676, 1592, 1242, 1018; δ_H(300 MHz: $CDCl_3$) 7.66 (1H, d, *J* 2, Ar*H*), 7.33 (1H, dd, *J* 8 and 2, Ar*H*), 6.74 (1H, d, *J* 8, Ar*H*), 5.63 (1H, dd, *J* 6 and 2, PhC*H*), 5.42 (1H, m, =C*H*), 4.53 (2H, d, *J* 6, CH_2), 3.33 (1H, br s, O*H*), 2.60 (1H, d, *J* 2, ≡C*H*), 1.77 (3H, s, CH_3), 1.72 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 155.05 (s), 138.85 (s), 132.18 (d), 130.75 (d), 130.64 (s), 119.02 (d), 113.90 (d), 113.02 (s), 82.58 (d), 74.53 (s), 65.65 (t), 60.19 (d), 25.77 (q), 18.32 (q); *m*/*z* 294 (M$^+$), 279, 251, 240, 226, 208 (100%), 182, 171, 155, 129, 118, 69, 53, 41.

Typical one-pot cyclisation reaction

6,8-Dichloro-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16a. To a solution of the propynyl alcohol **15a** (0.40 g, 1.4 mmol) in anhydrous DCM (12 cm^3), under an atmosphere of nitrogen, was added octacarbonyldicobalt (0.53 g, 1.5 mmol) and the reaction was stirred at ambient temperature. The progress of the reaction was monitored by observing the evolution of carbon monoxide from the reaction mixture. TLC analysis, after fifteen minutes, showed the presence of a faster moving compound (R_f 0.45, 2:1 hexane:diethyl ether). The reaction mixture was then cooled to −10 °C whereupon tetrafluoroboric acid diethyl ether complex (0.27 cm^3, 1.5 mmol, 85% by volume) was added and the mixture left to stir. TLC analysis, after five minutes, showed the presence of a new compound (R_f 0.65, 2:1 hexane:diethyl ether). To the reaction mixture, maintained at −10 °C, was added dropwise methanolic ceric ammonium nitrate (CAN) (3.45 g, 6.3 mmol, 30 cm^3) until the evolution of carbon dioxide ceased and the yellow colour of CAN persisted (about fifteen minutes). TLC analysis of the reaction mixture revealed the presence of a new compound (R_f 0.40, 3:1 hexane:diethyl ether). Residual methanol was removed *in vacuo* and the residue was partitioned between diethyl ether (25 cm^3) and water (25 cm^3). The aqueous phase was extracted with diethyl ether (3 × 20 cm^3) and the combined organic extracts were dried over anhydrous magnesium sulfate, filtered, and the solvent removed *in vacuo* to afford an oil. Purification was effected by column chromatography on silica (3:1 hexane:diethyl ether) to afford the desired compound **16a** as a pale yellow oil (0.22 g, 59%); ν_{max}(film)/cm^{-1} 3298, 3080, 2116, 1573, 1244; δ_H(300 MHz: $CDCl_3$) 7.10 (1H, d, *J* 2, Ar*H*), 7.04 (1H, d, *J* 2, Ar*H*), 4.27 (1H, dt, *J* 12 and 2, OC*H*), 4.03 (1H, dd, *J* 12 and 5, OC*H*), 3.70 (1H, br s, PhC*H*), 2.17 (1H, m, C*H*), 2.13 (1H, d, *J* 2, ≡C*H*), 1.25 (3H, d, J_{HF} 22, CH_3), 1.14 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 148.54 (s), 128.70 (d), 128.19 (d), 125.62 (s), 124.17 (s), 122.55 (s), 94.71 (d, J_{CF} 169, *C*F), 85.16 (d), 71.75 (s), 64.93 (t), 46.67 (d), 27.87 (d), 2 × 25.33 (q); δ_F(282.40 MHz: $CDCl_3$) −137.04 [1F, d of septets, *J* 22 and 11, $(CH_3)_2CF$]; *m*/*z* 286 (M$^+$ − 1), 267, 251, 223 (100%), 198, 191, 170, 155, 126, 109, 99, 73, 61, 41 (Found: C, 58.15; H, 4.51. Calc. for $C_{14}H_{13}Cl_2FO$ requires C, 58.54; H, 4.53%).

By repeating the experiment and extending the reaction before decomplexation to seven hours the corresponding isopropenyl derivative was isolated.

6,8-Dichloro-4-ethynyl-3-(1-methylethenyl)chromane 21. This was prepared using propynyl alcohol **15a** (0.20 g, 0.7 mmol) in anhydrous DCM (5 cm^3), octacarbonyldicobalt (0.26 g, 0.8 mmol), tetrafluoroboric acid diethyl ether complex (0.12 cm^3, 0.8 mmol, 85% by volume). After seven hours methanolic CAN (1.73 g, 3.20 mmol, 10 cm^3) was added to afford the desired compound **21** as a pale yellow oil (0.11 g, 59%); ν_{max}(film)/cm^{-1} 3276, 3069, 2118, 1637, 1595, 1239; δ_H(300 MHz: $CDCl_3$) 7.40 (1H, dd, *J* 3 and 1, Ar*H*), 7.24 (1H, dd, *J* 3 and 1, Ar*H*), 5.06 (1H, 7, *J* 1, =C*H*), 4.88 (1H, d, *J* 1, =C*H*), 4.39 (1H, dd, *J* 11 and 3, OC*H*), 3.94 (1H, dd, *J* 11 and 2, PhC*H*), 3.83 (1H, td, *J* 10 and 1, OC*H*), 2.64 (1H, dt, *J* 10 and 3, C*H*), 2.27 (1H, d, *J* 2, ≡C*H*), 1.85 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 141.58 (s), 132.11 (d), 128.74 (d), 127.72 (s), 125.95 (s), 123.86 (s), 122.18 (s), 114.16 (t), 82.95 (d), 71.61 (s), 69.07 (t), 44.62 (d), 32.75 (d), 21.49 (q) (Found: M$^+$, 266.0265; $C_{14}H_{12}Cl_2O$ requires 266.0265 for $^{35}Cl_2$. Found: M$^+$, 268.0236; $C_{14}H_{12}Cl_2O$ requires 268.0236 for $^{35}Cl^{37}Cl$); *m*/*z* 266 (M$^+$) (100%), 251, 237, 223, 214, 198, 181, 170, 151, 135, 125, 98, 67, 53, 41.

8-Methoxy-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16b. The one-pot procedure was used for the synthesis of compound **16b** using propynyl alcohol **15b** (0.80 g, 3.3 mmol) in anhydrous DCM (12 cm^3), octacarbonyldicobalt (1.22 g, 3.6 mmol), tetrafluoroboric acid diethyl ether complex (0.62 cm^3, 3.6 mmol, 85% by volume) and methanolic CAN (8.00 g, 15.00 mmol, 40 cm^3) to afford the desired compound **16b** as a pale yellow oil (0.53 g, 66%); ν_{max}(film)/cm^{-1} 3292, 3068, 2116, 1589, 1265; δ_H(300 MHz: $CDCl_3$) 6.96 (1H, d, *J* 8, Ar*H*), 6.84 (1H, t, *J* 8, Ar*H*), 6.72 (1H, d, *J* 8, Ar*H*), 4.41 (1H, dt, *J* 12 and 3, OC*H*), 4.22 (1H, dd, *J* 12 and 5, OC*H*), 3.89 (1H, br s, PhC*H*), 3.83 (3H, s, OMe), 2.34 (1H, m, C*H*), 2.24 (1H, d, *J* 2, ≡C*H*), 1.43 (3H, d, J_{HF} 22, CH_3), 1.30 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 148.30 (s), 143.42 (s), 122.06 (s), 121.62 (d), 120.79 (d), 109.83 (d), 95.17 (d, J_{CF} 168, *C*F), 86.55 (d), 70.52 (s), 64.34 (t), 50.9 (q), 47.21 (d), 27.39 (d), 25.48 (q), 25.16 (q); *m*/*z* 248 (M$^+$, 100%), 213, 185, 175, 159, 144, 130, 115, 102, 89, 61, 41 (Found: C, 72.52; H, 6.78. Calc. for $C_{15}H_{17}FO_2$: C, 72.58; H, 6.85%).

8-Methoxy-4-ethynyl-3-(1-methylethynyl)chromane 22. This was prepared using propynyl alcohol **15b** (0.30 g, 1.2 mmol) in anhydrous DCM (5 cm^3), octacarbonyldicobalt (0.46 g, 1.3 mmol), tetrafluoroboric acid diethyl ether complex (0.23 cm^3, 1.3 mmol, 85% by volume). After 26 hours methanolic CAN (3.00 g, 5.50 mmol, 20 cm^3) was added to afford the desired compound **22** as a pale yellow oil (0.11 g, 38%), ν_{max}(film)/cm^{-1} 3257, 3067, 2112, 1646, 1586, 1268; δ_H(300 MHz: $CDCl_3$) 7.11 (1H, d, *J* 8, Ar*H*), 6.86 (1H, t, *J* 8, Ar*H*), 6.76 (1H, d, *J* 8, Ar*H*), 5.04 (1H, d, *J* 1, =C*H*), 4.88 (1H, br s, =C*H*), 4.37 (1H, dd, *J* 10 and 3, OC*H*), 3.92 (2H, br t, *J* 10, PhC*H* and OC*H*), 3.87 (3H, s, O*Me*), 2.67 (1H, dt, *J* 10 and 3, C*H*), 2.21 (1H, d, *J* 2, ≡C*H*), 1.86 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 148.19 (s), 143.67 (s), 142.50 (s), 121.71 (d), 121.18 (s), 120.31 (d), 113.61 (d), 110.02 (t), 84.50 (d), 70.38 (s), 68.69 (t), 55.98 (q), 45.22 (d), 32.58 (d), 21.65 (q) (Found: M$^+$, 288.1150. $C_{15}H_{16}O_2$ requires *M*, 228.1150); *m*/*z* 228 (M$^+$, 100%), 213, 198, 185, 172, 159, 152, 130, 115, 102, 89, 77, 63, 51, 41.

6-Nitro-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16c. The one-pot procedure was used for the synthesis of compound **16c** using propynyl alcohol **15c** (0.50 g, 1.9 mmol) in anhydrous DCM (12 cm^3), octacarbonyldicobalt (0.72 g, 2.1 mmol), tetrafluoroboric acid diethyl ether complex (0.37 cm^3, 2.1

mmol, 85% by volume) and methanolic CAN (4.68 g, 8.50 mmol, 30 cm^3) to afford the desired compound **16c** as a pale yellow oil (0.34 g, 66%); ν_{max}(film)/cm^{-1} 3296, 3074, 2118, 1587, 1266, 1092; δ_H(300 MHz: $CDCl_3$) 8.31 (1H, d, *J* 3, Ar*H*), 7.98 (1H, dd, *J* 9 and 3, Ar*H*), 6.85 (1H, d, *J* 9, Ar*H*), 4.46 (1H, dt, *J* 12 and 2, OC*H*), 4.21 (1H, dd, *J* 12 and 5, OC*H*), 3.95 (1H, br s, PhC*H*), 2.39 (1H, m, C*H*), 2.36 (1H, d, *J* 2, ≡C*H*), 1.45 (3H, d, J_{HF} 22, CH_3), 1.37 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 159.13 (s), 141.64 (s), 126.30 (d), 124.29 (d), 122.03 (s), 117.59 (d), 94.60 (d, J_{CF} 169, *C*F), 84.72 (d), 72.34 (s), 65.00 (t), 46.07 (d), 28.02 (d), 2 × 25.55 (q); δ_F(282.40 MHz: $CDCl_3$) −137.53 [1F, d of septets, *J* 21 and 9, $(CH_3)_2CF$] (Found: M^+, 263.0958. $C_{14}H_{14}FNO_3$ requires *M*, 263.0958); *m*/*z* 263 (M^+), 247, 228, 200 (100%), 186, 176, 154, 129, 101, 89, 75, 61, 41.

6-Nitro-4-ethynyl-3-(1-methylethenyl)chromane 23. This was prepared using propynyl alcohol **15c** (0.15 g, 0.6 mmol) in anhydrous DCM (5 cm^3), octacarbonyldicobalt (0.22 g, 0.6 mmol), tetrafluoroboric acid diethyl ether complex (0.12 cm^3, 0.6 mmol, 85% by volume). After nineteen hours methanolic CAN (1.42 g, 2.6 mmol, 20 cm^3) was added to afford the desired compound **23** (0.06 g, 42%) as a pale yellow oil, ν_{max}(film)/cm^{-1} 3293, 3066, 2114, 1639, 1589, 1239; δ_H(300 MHz: $CDCl_3$) 8.46 (1H, dd, *J* 3 and 1, Ar*H*), 8.04 (1H, dd, *J* 8 and 3, Ar*H*), 6.87 (1H, d, *J* 8, Ar*H*), 5.09 (1H, t, *J* 1, =C*H*), 4.91 (1H, br s, =C*H*), 4.38 (1H, dd, *J* 11 and 3, OC*H*), 3.93 (2H, m, PhC*H* and OC*H*), 2.71 (1H, dt, *J* 11 and 3, C*H*), 2.33 (1H, d, *J* 2, ≡C*H*), 1.88 (3H, s, CH_3) (Found: M^+, 243.0895. $C_{14}H_{13}NO_3$ requires *M*, 243.0895); *m*/*z* 243 (M^+), 219, 200, 182, 168, 152, 130, 115, 101, 91, 76, 69 (100%), 58, 52, 42.

6,8-Dibromo-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16d. The one-pot procedure was used for the synthesis of compound **16d** using propynyl alcohol **15d** (1.00 g, 2.7 mmol) in anhydrous DCM (20 cm^3), octacarbonyldicobalt (1.00 g, 2.9 mmol), tetrafluoroboric acid diethyl ether complex (0.50 cm^3, 2.9 mmol, 85% by volume) and methanolic CAN (6.62 g, 12.1 mmol, 40 cm^3) to afford the desired compound **16d** (0.61 g, 62%) as a yellow oil; ν_{max}(film)/cm^{-1} 3295, 3074, 2117, 1562, 1243; δ_H(300 MHz: $CDCl_3$) 7.33 (1H, d, *J* 2, Ar*H*), 7.24 (1H, d, *J* 2, Ar*H*), 4.25 (1H, dt, *J* 12 and 2, OC*H*), 4.02 (1H, dd, *J* 12 and 5, OC*H*), 3.70 (1H, br s, PhC*H*), 2.15 (1H, m, C*H*), 2.11 (1H, d, *J* 3, ≡C*H*), 1.24 (3H, d, J_{HF} 22, CH_3), 1.13 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 149.90 (s), 134.21 (d), 131.83 (d), 124.60 (s), 113.02 (s), 111.77 (s), 94.68 (d, J_{CF} 169, *C*F), 85.19 (d), 71.84 (s), 65.06 (t), 45.71 (d), 27.92 (d), 25.68 (q), 25.36 (q); δ_F(282.40 MHz: $CDCl_3$) −136.71 [1F, d of septets, *J* 22 and 12, $(CH_3)_2CF$] [Found: M^+, 375.9297. $C_{14}H_{13}Br_2FO$ ($^{79}Br^{81}Br$) requires *M*, 375.9297]; *m*/*z* 376 (M^+), 341, 313 (100%), 288, 260, 234, 207, 181, 155, 126, 99, 61, 41 (Found: C, 43.67; H, 3.76. Calc. for $C_{14}H_{13}Br_2FO$: C, 44.71; H, 3.48%).

7-Methoxy-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16e. The one-pot procedure was used for the synthesis of compound **16e** using propynyl alcohol **15e** (0.75 g, 3.1 mmol) in anhydrous DCM (15 cm^3), octacarbonyldicobalt (0.95 g, 3.2 mmol), tetrafluoroboric acid diethyl ether complex (0.55 cm^3, 3.2 mmol, 85% by volume) and methanolic CAN (7.52 g, 13.7 mmol, 40 cm^3) to afford the desired compound **16e** (0.48 g, 63%) as a yellow oil; ν_{max}(film)/cm^{-1} 3293, 3071, 2115, 1589, 1251, 1036; δ_H(300 MHz: $CDCl_3$) 7.25 (1H, d, *J* 2, Ar*H*), 6.53 (1H, dd, *J* 8 and 2, Ar*H*), 6.36 (1H, d, *J* 2H, Ar*H*), 4.37 (1H, ddd, *J* 12, 3 and 2, OC*H*), 4.11 (1H, dd, *J* 12 and 5, OC*H*), 3.83 (1H, br s, PhC*H*), 3.76 (3H, s, O*Me*), 2.33 (1H, m, C*H*), 2.25 (1H, d, *J* 2, ≡C*H*), 1.45 (3H, d, J_{HF} 22, CH_3), 1.36 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 159.70 (s), 154.65 (s), 130.50 (d), 113.41 (s), 108.46 (d), 101.47 (d), 95.21 (d, J_{CF} 168, *C*F), 86.84 (d), 70.34 (s), 64.15 (t), 55.28 (q), 47.19 (d), 27.25 (d), 25.71 (q), 25.18 (q); δ_F(282.40 MHz: $CDCl_3$) −135.76 [1F, d of septets, *J* 22 and 12, $(CH_3)_2CF$] (Found: M^+, 248.1213. $C_{15}H_{17}FO_2$ requires *M*, 248.1213]; *m*/*z* 248 (M^+), 227, 213, 187 (100%), 171, 160, 145, 132, 117, 102, 89, 63, 53, 41.

6-Chloro-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16f. The one-pot procedure was used for the synthesis of compound **16f** using propynyl alcohol **15f** (1.02 g, 4.1 mmol) in anhydrous DCM (20 cm^3), octacarbonyldicobalt (1.53 g, 4.5 mmol), tetrafluoroboric acid diethyl ether complex (0.82 cm^3, 4.5 mmol, 85% by volume) and methanolic CAN (10.03 g, 18.33 mmol, 40 cm^3) to afford the desired compound **16f** (0.72 g, 70%) as a yellow oil; ν_{max}(film)/cm^{-1} 3298, 3069, 2117, 1581, 1239; δ_H(300 MHz: $CDCl_3$) 7.36 (1H, d, *J* 2, Ar*H*), 7.08 (1H, dd, *J* 8 and 2, Ar*H*), 6.73 (1H, d, *J* 8, Ar*H*), 4.36 (1H, dt, *J* 12 and 2, OC*H*), 4.11 (1H, dd, *J* 12 and 5, OC*H*), 3.86 (1H, br s, PhC*H*), 2.32 (1H, m, C*H*), 2.29 (1H, d, *J* 3, ≡C*H*), 1.43 (3H, d, J_{HF} 22, CH_3), 1.35 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.49 (s), 129.55 (d), 128.45 (d), 127.03 (s), 122.86 (s), 118.37 (d), 92.59 (d, J_{CF} 169, *C*F), 85.61 (d), 71.16 (s), 64.35 (t), 47.15 (d), 27.80 (d), 25.81 (q), 25.22 (q); δ_F(282.40 MHz: $CDCl_3$) −136.38 [1F, d of septets, *J* 22 and 12, $(CH_3)_2CF$] (Found: M^+, 252.0717. $C_{14}H_{13}ClFO$ requires *M*, 252.0717); *m*/*z* 252 (M^+), 231, 217, 189 (100%), 182, 157, 136, 113, 101, 87, 75, 61, 53, 41 (Found: C, 66.31; H, 5.55. Calc. for $C_{14}H_{13}ClFO$: C, 66.64; H, 5.58%).

6-Methoxy-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16g. The one-pot procedure was used for the synthesis of compound **16g** using propynyl alcohol **15g** (0.75 g, 3.1 mmol) in anhydrous DCM (12 cm^3), octacarbonyldicobalt (0.95 g, 3.2 mmol), tetrafluoroboric acid diethyl ether complex (0.55 cm^3, 3.2 mmol, 85% by volume) and methanolic CAN (7.52 g, 13.70 mmol, 40 cm^3) to afford the desired compound **16g** as a pale yellow oil (0.50 g, 64%); ν_{max}(film)/cm^{-1} 3291, 3072, 2116, 1589, 1258, 1029; δ_H(300 MHz: $CDCl_3$) 7.05 (1H, d, *J* 2, Ar*H*), 6.89 (1H, dd, *J* 8 and 2, Ar*H*), 6.64 (1H, d, *J* 2, Ar*H*), 4.39 (1H, ddd, *J* 12, 3 and 2, OC*H*), 4.18 (1H, dd, *J* 12 and 5, OC*H*), 3.87 (1H, br s, PhC*H*), 3.69 (3H, s, OMe), 2.34 (1H, m, C*H*), 2.26 (1H, d, *J* 2, ≡C*H*), 1.44 (3H, d, J_{HF} 22, CH_3), 1.28 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 156.70 (s), 154.10 (s), 132.59 (d), 112.16 (s), 106.71 (d), 100.42 (d), 95.36 (d, J_{CF} 168, *C*F), 87.04 (d), 71.65 (s), 65.90 (t), 55.92 (q), 47.26 (d), 26.62 (d), 24.17 (q), 24.03 (q); *m*/*z* 248 (M^+), 227, 213, 185, 171 (100%), 162, 145, 116, 102, 89, 63, 51, 41 (Found: C, 72.49; H, 6.84. Calc. for $C_{15}H_{17}FO_2$: C, 72.58; H, 6.85%).

6,8-Diiodo-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16h. The one-pot procedure was used for the synthesis of compound **16h** using propynyl alcohol **15h** (0.50 g, 1.1 mmol) in anhydrous DCM (15 cm^3), octacarbonyldicobalt (0.41 g, 1.2 mmol), tetrafluoroboric acid diethyl ether complex (0.21 cm^3, 1.2 mmol, 85% by volume) and methanolic CAN (2.64 g, 4.8 mmol, 20 cm^3) to afford the desired compound **16h** (0.36 g, 71%) as a yellow oil; ν_{max}(film)/cm^{-1} 3294, 3062, 2116, 1574, 1238; δ_H(300 MHz: $CDCl_3$) 7.90 (1H, d, *J* 2, Ar*H*), 7.64 (1H, *J* 2, Ar*H*), 4.44 (1H, ddd, *J* 12, 3 and 2, OC*H*), 4.20 (1H, dd, *J* 12 and 5, OC*H*), 3.84 (1H, br s, PhC*H*), 2.35 (1H, m, C*H*), 2.31 (1H, d, *J* 3, ≡C*H*), 1.43 (3H, d, J_{HF} 22, CH_3), 1.31 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 152.78 (s), 145.36 (d), 138.76 (d), 124.28 (s), 115.02 (s), 118.77 (s), 94.69 (d, J_{CF} 169, *C*F), 85.28 (d), 71.83 (s), 65.23 (t), 46.83 (d), 27.90 (d), 25.73 (q), 25.40 (q); δ_F(282.40 MHz: $CDCl_3$) −136.81 [1F, d of septets, *J* 22 and 12, $(CH_3)_2CF$]; *m*/*z* 421 (M^+ − 49), 407 (100%), 382, 354, 308, 282, 255, 227, 201, 181, 155, 127, 100, 61, 52, 41 (Found: C, 35.65; H, 2.69. Calc. for $C_{14}H_{13}I_2FO$: C, 35.78; H, 2.79%).

6-Bromo-4-ethynyl-3-(1-fluoro-1-methylethyl)chromane 16i. The one-pot procedure was used for the synthesis of compound **16i** using propynyl alcohol **15i** (0.80 g, 2.7 mmol), octacarbonyldicobalt (1.02 g, 3.0 mmol), tetrafluoroboric acid diethyl ether complex (0.52 cm^3, 3.0 mmol, 85% by volume) and methanolic CAN (6.67 g, 12.20 mmol, 30 cm^3) to afford the desired compound **16i** (0.53 g, 66%) as a yellow oil; ν_{max}(film)/cm^{-1} 3295, 3071, 2117, 1591, 1242; δ_H(300 MHz: $CDCl_3$) 7.50 (1H, br s, Ar*H*), 7.20 (1H, br d, *J* 8, Ar*H*), 6.67 (1H, d, *J* 8, Ar*H*), 4.35 (1H, dd, *J* 12 and 3, OC*H*), 4.09 (1H, dd, *J* 12 and 5, OC*H*), 3.86 (1H, br s, PhC*H*), 2.33 (1H, m, C*H*), 2.29 (1H, d, *J* 3,

≡C*H*), 1.42 (3H, d, J_{HF} 22, CH_3), 1.34 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.04 (s), 132.49 (d), 131.31 (d), 123.44 (s), 118.84 (d), 113.19 (s), 94.93 (d, J_{CF} 169, *C*F), 85.76 (d), 71.30 (s), 64.18 (t), 46.81 (d), 27.66 (d), 25.54 (q), 25.22 (q) (Found: M^+, 296.0212. $C_{14}H_{14}BrFO$ requires 296.0212); *m*/*z* 296 (M^+), 277, 261, 235 (100%), 210, 182, 169, 157, 128, 113, 101, 75, 61, 53, 41.

2-Methyl-4-(1-formyl-2-naphthyloxy)but-2-ene 18

The method used for the synthesis of compound **18** was similar to that used for the synthesis of compound **8** from compound **7** using the following reagents: 2-hydroxy-1-naphthaldehyde **17** (recrystallised from ethanol) (1.50 g, 8.7 mmol) and 4-bromo-2-methylbut-2-ene (1.43 g, 9.6 mmol) in dry DMF (30 cm^3). To the mixture was added finely divided potassium carbonate (4.82 g, 34.9 mmol) and potassium iodide (0.15 g, 0.90 mmol) to give the desired compound **18** (1.65 g, 79%) as a white crystalline solid, mp 64.4–65.7 °C (from ethanol); ν_{max}(Nujol)/cm^{-1} 3040, 2723, 1665, 1609, 1565, 1245, 1049; δ_H(300 MHz: $CDCl_3$) 10.91 (1H, s, *H*C=O), 9.28 (1H, d, *J* 8, Ar*H*), 8.02 (1H, d, *J* 9, Ar*H*), 7.76 (1H, d, *J* 8, Ar*H*), 7.59 (1H, m, Ar*H*), 7.39 (1H, m, Ar*H*), 7.26 (1H, d, *J* 3, Ar*H*), 5.51 (1H, m, =C*H*), 4.77 (2H, d, *J* 7, CH_2), 1.81 (3H, s, *Me*), 1.78 (3H, s, *Me*); δ_C(75.45 MHz: $CDCl_3$) 192.35 (d), 164.71 (s), 153.93 (s), 139.29 (s), 137.34 (d), 134.37 (s), 132.41 (d), 129.77 (d), 128.52 (d), 124.74 (d), 118.89 (d), 117.21 (s), 114.22 (d), 66.53 (t), 25.79 (q), 18.36 (q); *m*/*z* 240 (M^+), 221, 207, 194, 181, 172 (100%), 152, 144, 115, 88, 44 (Found: C, 81.05; H, 6.59. Calc. for $C_{16}H_{16}O_2$: C, 80.00; H, 6.67%).

2-Methyl-4-[1-(1-hydroxyprop-2-yn-1-yl)-2-naphthyloxy]but-2-ene 19

The method used for the synthesis of this compound was similar to the procedure used for the formation of compound **9** from compound **8**. Using the following quantities of reagents: **18** (0.50 g, 1.9 mmol), ethylmagnesium bromide (4.20 cm^3, 2.1 mmol, 0.5 M in THF), in THF (10 cm^3), to afford the desired compound **19** (0.55 g, 97%) as a colourless oil: ν_{max}(film)/cm^{-1} 3432, 3292, 3055, 2114, 1673, 1625, 1596, 1237, 1016; δ_H(300 MHz: $CDCl_3$) 8.33 (1H, d, *J* 9, Ar*H*), 7.80 (2H, d, *J* 9, Ar*H*), 7.52 (1H, dt, *J* 9 and 1, Ar*H*), 7.37 (1H, dt, *J* 9 and 1, Ar*H*), 7.25 (1H, d, *J* 9, Ar*H*), 6.45 (1H, br s, PhC*H*), 5.55 (1H, m, =C*H*), 4.73 (2H, d, *J* 6, CH_2), 3.94 (1H, br s, O*H*), 2.57 (1H, d, *J* 2, ≡C*H*), 1.82 (3H, s, CH_3), 1.78 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.91 (s), 138.92 (s), 131.22 (d), 130.48 (d), 129.66 (s), 128.64 (s), 126.94 (d), 123.99 (s), 123.51 (d), 121.85 (d), 119.48 (d), 115.31 (d), 84.59 (d), 73.08 (s), 66.96 (t), 53.93 (d), 25.86 (q), 18.34 (q); *m*/*z* 266 (M^+), 248, 212, 198, 180 (100%), 169, 152, 139, 115, 88, 69, 53, 41.

1-Ethynyl-2-(1-fluoro-1-methylethyl)-2,3-dihydro-1*H*-benzo[*f*]-chromene 20

The one-pot procedure was used for the synthesis of compound **20** using propynyl alcohol **19** (0.43 g, 1.5 mmol), octacarbonyldicobalt (0.58 g, 1.7 mmol), tetrafluoroboric acid diethyl ether complex (0.35 cm^3, 1.7 mmol, 85% by volume) and methanolic CAN (4.00 g, 6.8 mmol, 30 cm^3) to afford the desired compound **20** (0.31 g, 72%) as an off-white crystalline solid mp 103.3–104.1 °C (from methylated spirit); ν_{max}(Nujol)/cm^{-1} 3284, 3058, 2107, 1627, 1601, 1236, 1100; δ_H(300 MHz: $CDCl_3$) 8.09 (1H, d, *J* 8, Ar*H*), 7.76 (1H, d, *J* 8, Ar*H*), 7.64 (1H, d, *J* 8, Ar*H*), 7.54 (1H, dt, *J* 8 and 1, Ar*H*), 7.36 (1H, dt, *J* 8 and 1, Ar*H*), 6.98 (1H, d, *J* 8, Ar*H*), 4.51 (1H, dt, *J* 12 and 3, OC*H*), 4.40 (1H, d, *J* 12, OC*H*), 4.30 (1H, br s, PhC*H*), 2.53 (1H, br d, *J* 12, C*H*), 2.23 (1H, d, *J* 2, ≡C*H*), 1.45 (3H, d, J_{HF} 22, CH_3), 1.18 (3H, d, J_{HF} 22, CH_3); δ_C(75.45 MHz: $CDCl_3$) 151.76 (s), 132.35 (s), 129.73 (s), 129.38 (d), 128.76 (d), 126.99 (d), 123.85 (d), 122.64 (d), 118.89 (d), 112.57 (s), 95.51 (d, J_{CF} 168, *C*F), 86.67 (d), 70.51 (s), 63.14 (t), 47.60 (d), 25.98 (q), 25.75 (q), 24.06 (d); δ_F(282.40 MHz: $CDCl_3$) −133.49 [1F, d of septets, *J* 22 and 9, $(CH_3)_2$C*F*] (Found: M^+, 268.1263. $C_{18}H_{17}FO$ requires *M*, 268.1263); *m*/*z* 268 (M^+), 247, 233, 218, 205, 179, 163, 152 (100%), 139, 126, 102, 88, 76, 61, 41 (Found: C, 80.58; H, 6.39. Calc. for $C_{18}H_{17}FO$: C, 80.57; H, 6.39%).

4-[2-(1-Hydroxyprop-2-yn-1-yl)-4-nitrophenoxy]but-2-ene 26

Using **13c** (1.00 g, 5.2 mmol), 4-bromobut-2-ene (0.77 g, 5.7 mmol) in DMF (20 cm^3), potassium carbonate (2.86 g, 20.7 mmol) and potassium iodide (0.09 g, 0.5 mmol) afforded the desired compound **26** (1.12 g, 88%) as a fine white powder, mp 76.9–77.1 °C (from methylated spirit); ν_{max}(Nujol)/cm^{-1} 3357, 3291, 3085, 3028, 2118, 1664, 1610, 1593, 1268, 1088; δ_H(300 MHz: $CDCl_3$) 8.49 (1H, d, *J* 3, Ar*H*), 8.17 (1H, td, *J* 9 and 3, Ar*H*), 6.94 (1H, dd, *J* 9 and 3, Ar*H*), 6.82 (1H, m, *H*C=), 5.73 (1H, dd, *J* 6 and 2, PhC*H*), 5.66 (1H, m, =C*H*), 4.64 (2H, d, *J* 5, CH_2), 3.00 (1H, d, *J* 6, O*H*), 2.65 (1H, d, *J* 2, ≡C*H*), 1.76 (3H, d, *J* 2, CH_3); δ_C(75.45 MHz: $CDCl_3$) 160.67 (s), 141.26 (s), 132.10 (d), 130.45 (s), 125.88 (d), 124.34 (d), 123.77 (d), 111.73 (d), 81.90 (d), 75.04 (s), 69.98 (t), 59.80 (d), 17.90 (q); *m*/*z* 247 (M^+), 229, 218, 204, 193, 175 (100%), 161, 146, 129, 112, 91, 76, 64, 53, 41 (Found: C, 63.14; H, 5.24; N, 6.15. Calc. for $C_{13}H_{13}NO_3$: C, 63.15; H, 5.30; N, 5.67%).

4-[2-(1-Methoxyprop-2-yn-1-yl)-4-nitrophenoxy]but-2-ene 28

The one-pot method used was identical to that used for the synthesis of **16a**, however the reaction time was extended to 48 hours before the *in situ* decomplexation step was carried out. Using the following quantities: compound **26** (0.45 g, 1.8 mmol), octacarbonyldicobalt (0.68 g, 2.0 mmol) in DCM (15 cm^3), tetrafluoroboric acid diethyl ether complex (0.35 cm^3, 2.0 mmol) and ceric ammonium nitrate (4.5 g, 8.2 mmol) gave compound **28** (0.42 g, 88%) as a yellow oil; ν_{max}(neat)/cm^{-1} 3290, 3086, 3027, 2115, 1675, 1594, 1269, 1079; δ_H(300 MHz: $CDCl_3$) 8.49 (1H, d, *J* 2, Ar*H*), 8.15 (1H, td, *J* 9 and 2, Ar*H*), 6.95 (1H, dd, *J* 9 and 5, Ar*H*), 5.85 (1H, m, *H*C=), 5.68 (1H, m, =C*H*), 5.40 (1H, br s, PhC*H*), 4.62 (2H, d, *J* 5, CH_2), 3.51 (3H, s, O*Me*), 2.68 (1H, d, *J* 2, ≡C*H*), 1.76 (3H, d, *J* 5, CH_3); δ_C(75.45 MHz: $CDCl_3$) 160.64 (s), 141.19 (s), 131.37 (d), 129.98 (s), 125.79 (d), 124.18 (d), 124.09 (d), 111.62 (d), 80.55 (s), 75.51 (d), 69.86 (t), 66.47 (d), 56.70 (q), 17.87 (q); *m*/*z* 261 (M^+), 245, 230 (100%), 213, 199, 184, 175, 156, 141, 128, 115, 102, 91, 77, 65, 55, 41.

The use of tin(IV) chloride: 6-bromo-4-ethynyl-3-(1-chloro-1-methylethyl)chromane 29

The one-pot procedure was used for the synthesis of compound **27** using propynyl alcohol **15i** (0.38 g, 1.3 mmol), octacarbonyldicobalt (0.48 g, 1.4 mmol), in DCM (10 cm^3), tin(IV) chloride (0.17 cm^3, 1.40 mmol) and methanolic ceric ammonium nitrate (3.17 g, 5.8 mmol, 20 cm^3) to afford compounds **29** and **30** in a ratio of (5:1). Compound **29** (0.27 g, 59%) was a yellow oil; ν_{max}(film)/cm^{-1} 3289, 3057, 2112, 1589, 1252; δ_H(300 MHz: $CDCl_3$) 7.50 (1H, d, *J* 2, Ar*H*), 7.20 (1H, dd, *J* 8 and 2, Ar*H*), 6.69 (1H, d, *J* 8, Ar*H*), 4.37 (1H, dd, *J* 12 and 3, OC*H*), 4.24 (1H, dd, *J* 12 and 5, OC*H*), 4.05 (1H, br s, PhC*H*), 2.24 (1H, dd, *J* 4 and 2, C*H*), 2.30 (1H, d, *J* 3, ≡C*H*), 1.75 (3H, s, CH_3), 1.58 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 153.14 (s), 132.66 (d), 131.28 (d), 123.87 (s), 118.89 (d), 113.45 (s), 86.26 (d), 85.77 (d), 72.18 (s), 71.31 (s), 65.15 (t), 50.09 (d), 31.50 (q), 31.18 (q) (Found: M^+, 311.9917. $C_{14}H_{14}BrClO$ requires *M*, 311.9917); *m*/*z* 314 (M^+ + 1), 299, 277, 261, 233 (100%), 209, 182, 155, 128, 101, 75, 51, 41. Compound **29** was also synthesised using Lewis acids other than tin(IV) chloride such as aluminium chloride (in 20% yield) and hydrogen chloride (in 15% yield).

Further elution of the column gave compound **30** as a yellow oil (0.015 g, 10%); ν_{max}(film)/cm^{-1} 3293, 3045, 2112, 1646, 1591; δ_H(300 MHz: $CDCl_3$) 7.60 (1H, dd, *J* 3 and 1, Ar*H*), 7.21 (1H, td, *J* 8 and 2, Ar*H*), 6.68 (1H, d, *J* 8, Ar*H*), 5.04 (1H, t, *J* 1, =C*H*), 4.88 (1H, d, *J* 1, =C*H*), 4.25 (1H, dd, *J* 11 and 3, OC*H*), 3.82 (2H, m, PhC*H* and OC*H*), 2.62 (1H, dt, *J* 10 and 3, C*H*),

2.25 (1H, d, J 2, ≡CH), 1.86 (3H, s, CH_3); δ_C(75.45 MHz: $CDCl_3$) 152.47 (s), 142.11 (s), 131.96 (d), 131.32 (d), 128.80 (s), 123.11 (s), 118.45 (d), 113.82 (t), 83.57 (d), 71.13 (s), 68.14 (t), 44.87 (d), 32.55 (d), 22.63 (q); m/z 378 (M^+ + 1), 261, 235, 208 (100%), 182, 142, 129, 101, 75, 51, 41. Compound **30** was also synthesised using Lewis acids other than tin(IV) chloride such as aluminium chloride (in 36% yield), hydrogen chloride (in 32% yield), dibutylboron triflate (43%), titanium(IV) chloride (19%) and titanium(IV) fluoride (16%).

X-Ray crystallographic determination for compound 20

Crystal data. $C_{18}H_{17}FO$, $M = 268.32$, monoclinic, space group $P2_1/c$, $a = 13.950(5)$, $b = 15.126(8)$, $c = 13.168(7)$ Å, $\beta = 102.73(3)°$, $U = 2710(2)$ Å^3, $T = 190$ K, $Z = 8$, $D_c = 1.283$ g cm^{-3}, Mo-Kα radiation, $\lambda = 0.710\ 73$ Å, μ(Mo-Kα) = 0.087 mm^{-1}, $F(000) = 1136$. All crystals of the sample examined showed split diffraction peaks, the simplest example found used for data collection was a colourless plate with the approximate dimensions 0.36 × 0.26 × 0.08 mm.

Accurate unit cell dimensions were determined by least squares refinement of ω angles for 18 centred reflections with $4.5 < \theta < 12.5°$. Data were measured on a Siemens P4 diffractometer using ω scans. 5249 reflections were measured over the range $2.5 < \theta < 24°$ and the reflections were corrected for Lorentz and polarisation effects to yield 3924 independent reflections ($R_{int} = 0.0928$).

The structure was solved by direct methods using the program SHELXTL-PC[20] and refined by full-matrix least squares on F^2 using the program SHELXL96.[21] The molecular structure has two unique molecules in the asymmetric unit with only minor differences in conformation. All hydrogen atoms were included in calculated positions (C–H = 0.96 Å) with fixed isotropic displacement parameters. The number of atoms refined with anisotropic displacement parameters was restricted by the data : parameter ratio. Final cycles of refinement gave $R_1 = 0.098$, $wR_2 = 0.282$ for all data, $w = 1/[\sigma^2(F_o^2) + (0.0922P)^2]$ and $P = [\max(F_o^2,0) + 2F_c^2]/3$. The R factors are comparable to those from a preliminary data set collected to $2\theta_{max}$ of 42° (3591 unique reflections) at 293 K ($R_1 = 0.094$, $wR_2 = 0.262$) indicating that the quality of the crystals was the limiting factor. The maximum and minimum residual electron densities in the final ΔF map were 0.340 and −0.272 e Å^{-3} respectively. The mean and maximum shift/error in the final refinement cycle were 0.001 and 0.003.

Full crystallographic details, excluding structure factor tables, have been deposited at the Cambridge Crystallographic Data Centre (CCDC). For details of the deposition scheme, see 'Instructions for Authors', *J. Chem. Soc.*, *Perkin Trans. 1*, available *via* the RSC Web page (http://www.rsc.org/authors). Any request to the CCDC for this material should quote the full literature citation and the reference number 207/196.

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