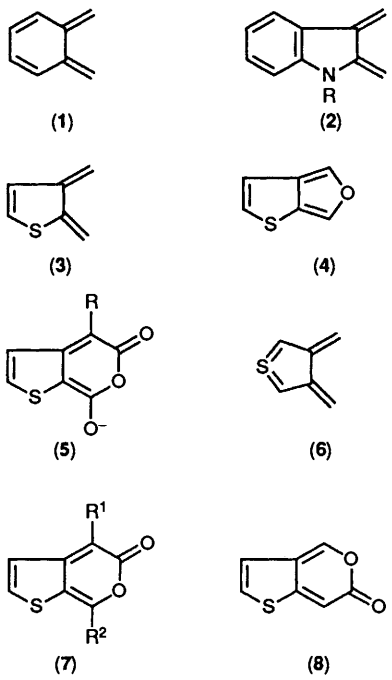
Preparation and Diels–Alder Reactivity of Thieno[2,3-*c*]-and Thieno[3,2-*c*]-pyran-3-ones, Stable 2,3-Dimethylenethiophene Derivatives; Synthesis of Benzothiophenes

P. Mark Jackson, Christopher J. Moody,*† and Pritom Shah
Department of Chemistry, Imperial College of Science, Technology, and Medicine, London SW7 2AY

The thieno[2,3-*c*]pyran-3-ones (**7**) and the isomeric [3,2-*c*]pyranones, *e.g.* (**26**) are stable derivatives of 2,3-dimethylenethiophene (**3**). When heated with alkynes they undergo Diels–Alder reaction to give, after loss of carbon dioxide, benzothiophenes. With unsymmetrical alkynes, the Diels–Alder reactions exhibit varying degrees of regioselectivity. Intramolecular Diels–Alder reactions of the thieno[2,3-*c*]pyran-3-ones (**17**) and (**21**) give cycloalka[*g*]- and cycloalka[*e*]-benzothiophenes respectively.

The heterocyclic analogues of orthoquinodimethane (*ortho*-xylylene) (**1**) are of considerable interest both from a theoretical point of view, and for their potential in synthesis. Although 2,3-dimethyleneindole (**2**) has been quite widely studied,[1] it is only recently that attention has turned to the thiophene analogue (**3**). Thus flash vacuum pyrolysis of 2-chloromethyl-3-methylthiophene yields 2,3-dimethylenethiophene (**3**) which readily



dimerises and polymerises, although it can be trapped efficiently by sulphur dioxide to give a cyclic sulphone, which also acts as a precursor to the dimethylenethiophene.[2] There is no evidence for the formation of the isomeric cyclobuta[*b*]thiophene in the gas phase.[3] Compound (**3**) can also be generated by treatment of 2,3-bis(bromomethyl)thiophene with iodide,[4] or by treatment of 3-[(trimethylammonio)methyl]-2-trimethylsilylmethyl thiophene iodide[5] or related compounds[4] with fluoride ion. In these cases the diene can be readily trapped in Diels–Alder reactions using electron-deficient dienophiles. Cyclic analogues of 2,3-dimethylenethiophene have also been studied briefly; derivatives of thieno[2,3-*c*]furan (**4**) undergo both inter- and intramolecular Diels–Alder reactions[6] as do the anionic dienes (**5**).[7] Finally, the nature of 3,4-dimethylenethiophene (**6**) and cyclic analogues has been discussed.[8]

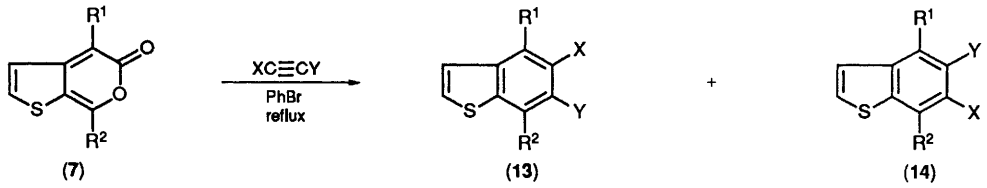
We have recently described the preparation of benzothieno[2,3-*c*]pyran-3-ones and their [3,2-*c*]-isomers, stable derivatives of 2,3-dimethylenebenzothiophene, together with their Diels–Alder reactions,[9] and we now report the full details of our work on the corresponding thiophene systems (**7**) and (**8**).[10]

Results and Discussion

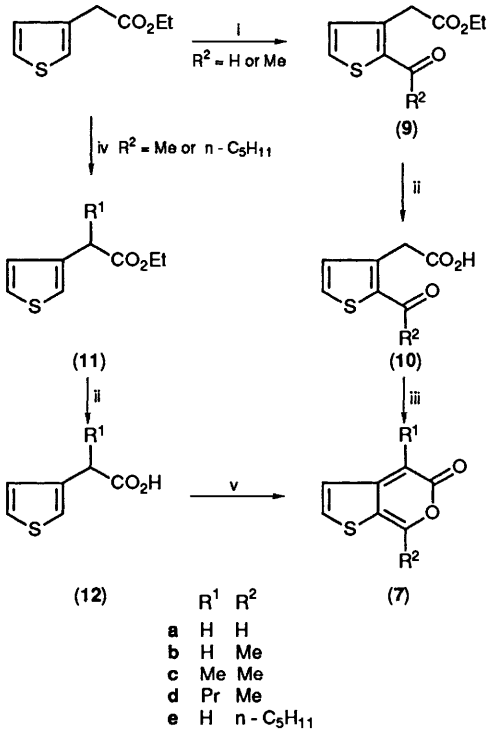
Preparation and Intermolecular Diels–Alder Reactions of Thieno[2,3-c]*pyran-3-ones.*—The thieno[2,3-*c*]pyran-3-one ring system (**7**) was prepared by two methods, either starting from ethyl 3-thienylacetate or the corresponding acid, both of which are commercially available. The first method (Scheme 1) which was needed to prepare the unsubstituted pyranone (**7a**) involved acylation of the ester with dichloromethyl methyl ether or acetyl chloride in the presence of tin(IV) chloride to give the 2-formyl (**9**; R^2 = H) or 2-acetyl (**9**; R^2 = Me) derivatives. In both cases the 2-acyl compound was accompanied by the 5-acyl isomer, which accounted for *ca.* 50% and 15% of the product in the case of formylation and acetylation respectively. Since separation of the isomers was difficult at this stage, the mixtures were used to prepare the desired thienopyranones (**7a**) and (**7b**) by hydrolysis to the acids (**10**), followed by cyclodehydration, and purification. The pyranone (**7b**), and the pentyl substituted compound (**7e**) could also be prepared directly from 3-thienylacetic acid (**12**; R^1 = H) in modest yield by reaction with the appropriate carboxylic acid anhydride in the presence of boron trifluoride–diethyl ether.[9] This approach could also be used for the preparation of the 1,4-disubstituted thienopyranones (**7c**) and (**7d**). Thus ethyl 3-thienylacetate was deprotonated using lithium isopropylcyclohexylamide (LICA) as base, and the resulting ester enolate alkylated with iodomethane or 1-iodopropane to give the substituted 3-thienylacetates (**11**; R^1 = Me or Pr). Hydrolysis to the corresponding acids (**12**) followed by reaction with acetic anhydride and BF_3·Et_2O gave the desired thienopyranones (**7c, d**) (Scheme 1).

† *Present address:* Department of Chemistry, Loughborough University of Technology, Loughborough, Leics. LE11 3TU.

Table. Diels–Alder reactions of thieno[2,3-*c*]pyran-3-ones (**7**) with alkynes.



Entry	Substituents R¹	R²	X	Y	Time/h	Isomers (13, 14)	Combined yield (%)	Ratio (13):(14)
1	H	H	CO_2Me	CO_2Me	4	**a**	77	—
2	H	H	H	CO_2Et	4	**b**	74	1.3:1
3	H	H	$SiMe_3$	CO_2Et	4	**c**	58	4:1
4	H	Me	CO_2Me	CO_2Me	1.5	**d**	59	—
5	H	Me	H	CO_2Et	5	**e**	64	2:1
6	H	Me	$SiMe_3$	CO_2Et	20	**f**	72	9:1
7	Me	Me	CO_2Me	CO_2Me	12	**g**	92	—
8	Me	Me	H	CO_2Et	12	**h**	96	1:1
9	Pr	Me	CO_2Me	CO_2Me	3	**i**	66	—
10	Pr	Me	H	CO_2Et	3	**j**	61	1.2:1
11	H	C_5H_{11}	CO_2Me	CO_2Me	2	**k**	69	—
12	H	C_5H_{11}	H	CO_2Et	12	**l**	62	1.8:1
13	H	C_5H_{11}	$SiMe_3$	CO_2Et	24	**m**	23	12:1

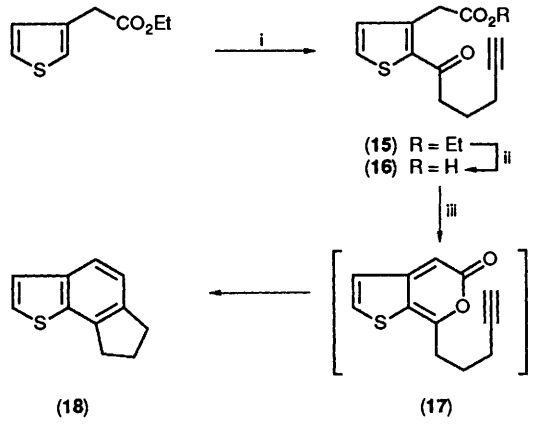


Scheme 1. *Reagents and conditions:* i, Cl_2CHOMe (or AcCl), $SnCl_4$, CH_2Cl_2; ii, KOH, H_2O, THF; iii, Ac_2O, reflux; or $ClCO_2Bu^t$, Et_3N, THF; iv, LICA, THF, −78 °C then R^1I, DMSO; v, $(R^2CO)_2O$, $BF_3{\cdot}Et_2O$.

The thieno[2,3-*c*]pyran-3-ones (**7**) are yellow crystalline solids with the exception of (**7e**) which is a viscous oil, and exhibit the expected spectroscopic properties. When heated with alkynes in boiling bromobenzene they undergo Diels–Alder reaction to give, after loss of carbon dioxide, benzothiophenes (Table). Compared with the analogous benzothieno[2,3-*c*]pyran-3-ones,[9] the thiophene derivatives (**7**) are more reactive dienes, and react relatively rapidly with a range of electron deficient alkynes. Thus reaction with dimethyl acetylenedicarboxylate (DMAD) (Entries 1, 4, 7, 9, and 11) gave the benzothiophene-5,6-diesters (**13a**, **d**, **g**, **i**, **k**) in good to excellent yield. With the unsymmetrical alkyne ethyl propiolate, the Diels–Alder reactions exhibit little regioselectivity (Entries, 2, 5, 8, 10, and 12) and give essentially equal amounts of the benzothiophene-6-esters (**13**) and 5-esters (**14**), with the 6-ester predominating slightly. This lack of regioselectivity with ethyl propiolate as dienophile is in line with our earlier results on similar systems.[9,11,12] However, ethyl trimethylsilylpropynoate in which the bulky trimethylsilyl group replaces the acetylenic hydrogen, is regioselective in its Diels–Alder reactions with the thienopyranones (**7**), and gives the 5-trimethylsilyl benzothiophene-6-carboxylates (**13c**, **f**, **m**) as the major products (Entries 3, 6, and 13). The structures of the benzothiophenes (**13**) and (**14**) were assigned on the basis of their ^1H NMR spectra. In the case of the 6- and 5-esters (**13b**) and (**14b**), the peaks in the aromatic region associated with the minor isomer (**14b**) were in excellent agreement with the reported values for the known methyl benzothiophene-5-carboxylate.[13] The 7-methyl substituted benzothiophene 6- and 5-esters (**13e**) and (**14e**) were easily distinguishable; in the 6-isomer, 4-H and 5-H occurred as 2 doublets (J 8 Hz), whereas in the 5-isomer, 4-H and 6-H were broad singlets. Also, in general, the 7-methyl group in the 6-esters resonated downfield relative to that in the 5-esters. In the case of the benzothiophene (**13f**), treatment with aqueous trifluoroacetic acid resulted in protodesilylation and formation of ethyl 7-methylbenzothiophene-6-carboxylate (**13e**), isolated pure after chromatography, thus confirming the structure.

Intramolecular Diels–Alder Reactions.—In continuation of our interest in the intramolecular Diels–Alder (IMDA) reactions of heterocyclic fused pyrones,[14] we have also studied IMDA reactions of thieno[2,3-*c*]pyran-3-ones as a route to cycloalkabenzothiophenes. The substrates for the IMDA

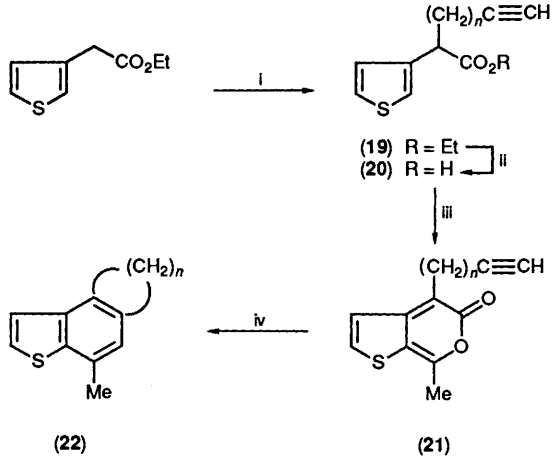
reactions were the thienopyranones (**17**) and (**21**). The 1-substituted derivative (**17**) was prepared by acylation of ethyl 3-thienylacetate with hex-5-ynoyl chloride in the presence of zinc chloride (Scheme 2). The resulting 2-acylthiophene (**15**), which,



Scheme 2. *Reagents and conditions:* i, $HC{\equiv}C(CH_2)_3COCl$, $ZnCl_2$, CH_2Cl_2; ii, KOH, H_2O, THF, MeOH; iii, Ac_2O, reflux.

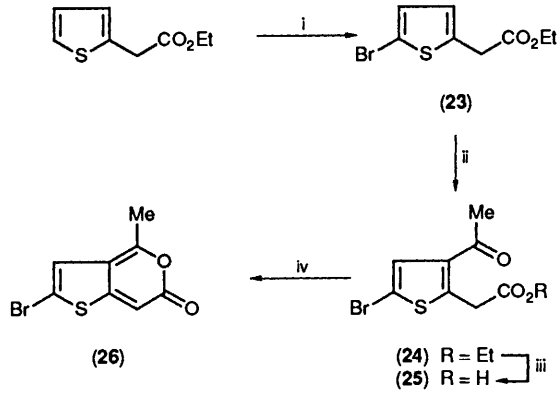
in common with earlier results, was contaminated with *ca.* 15% of the unwanted 5-acyl isomer, was hydrolysed, and the resulting acid (**16**) purified by recrystallisation. Since the pyranone (**17**) proved difficult to isolate, the IMDA reaction was simply effected by heating the acid (**16**) in acetic anhydride for 5 h, and gave 7,8-dihydroindeno[4,5-*b*]thiophene (**18**) directly in 77% yield (Scheme 2).

The thienopyranones (**21**) in which the side chain bearing the triple bond is attached at the 4-position, were also prepared from ethyl 3-thienylacetate by alkylation of the ester enolate with 5-iodopentyne and 6-iodohexyne to give the esters (**19a**) and (**19b**) respectively in good yield. Hydrolysis (94%), followed by reaction with acetic anhydride and boron trifluoride–diethyl ether gave the required pyranones (**21**) albeit in poor yield. When heated in boiling bromobenzene, the pyranones (**21**) underwent facile IMDA reaction to give, after loss of carbon dioxide, the indenothiophene (**22a**) (81%) and the naphthothiophene (**22b**) (71%) (Scheme 3).



Scheme 3. (**a**, n = 3; **b**, n = 4) *Reagents and conditions:* i, LICA, THF, −78 °C, then $I(CH_2)_nC{\equiv}CH$; ii, KOH, H_2O, MeOH, THF; iii, Ac_2O, $BF_3{\cdot}Et_2O$; iv, bromobenzene, reflux.

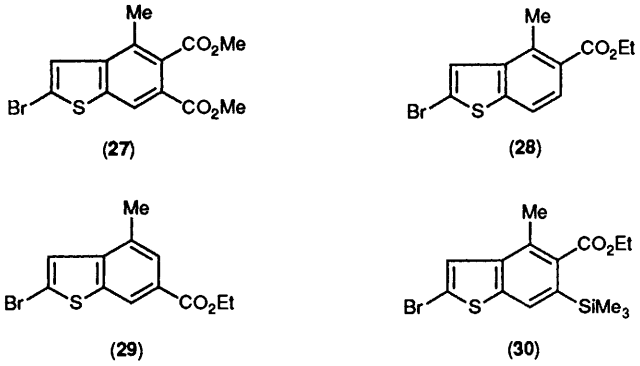
Preparation and Diels–Alder Reactions of Thieno[3,2-c]*pyran-3-ones.*—The isomeric thieno[3,2-*c*]pyran-3-one ring system was prepared from ethyl 2-thienylacetate, although blocking of the 5-position with a bromine atom was necessary (Scheme 4).



Scheme 4. *Reagents and conditions:* i, NBS, $CHCl_3$, AcOH; ii, AcCl, $SnCl_4$, $ClCH_2CH_2Cl$; iii, KOH, H_2O, MeOH; iv, Ac_2O, reflux.

Thus, although acetylation (AcCl, $SnCl_4$) of ethyl 3-thienylacetate give the 5-acetyl derivative (49%), acetylation of ethyl 5-bromo-2-thienylacetate (**23**), prepared by bromination with *N*-bromosuccinimide (NBS), gave the 3-acetyl compound (**24**). Hydrolysis gave the corresponding acid (**25**), which, without purification, was cyclodehydrated to the required pyranone (**26**).

Assuming that the additional bromine atom does not have a dramatic effect, the thienopyranone system (**26**; H replacing Br) is less reactive in Diels–Alder reactions with alkynes than its [2,3-*c*]-isomer (**7b**). Thus its reaction with DMAD takes 24 h, and gives a 70% yield of the benzothiophene diester (**27**). Likewise the reactions of pyranone (**26**) with ethyl propiolate and ethyl trimethylsilylpropynoate are slower than the corresponding reactions of the isomeric pyranone (**7b**), and proceed to give a 1.4:1 mixture of the benzothiophene-5-ester (**28**) and 6-ester (**29**) (easily distinguishable by NMR), and the 6-trimethylsilylbenzothiophene-5-ester (**30**) as the only product, respectively. The structure of (**30**) was confirmed by NOE difference



spectroscopy in which pre-irradiation of the singlet at δ 0.32 (Me_3Si) resulted in enhancement of the singlet at δ 7.77 (7-H) and *vice versa*. Also pre-irradiation of the singlet at δ 2.53 (4-Me) resulted in enhancement of the singlet at 7.42 (3-H). Hence the direction of addition of the thieno[3,2-*c*]pyran-3-one (**26**) to unsymmetrical alkynes is, perhaps not surprisingly, opposite to that of the isomeric diene (**7b**), a feature which parallels the chemistry of the closely related indole and benzothiophene derived dienes.[9,11,12]

Conclusion

The thieno[2,3-*c*]pyran-3-ones (**7**), readily prepared from

commercially available thiophenes, are stable 2,3-dimethylenethiophene-type dienes which react with alkynes to give benzothiophenes. Given the variation in substitution patterns available, this is a versatile route to benzothiophenes, especially when the reaction is extended by incorporating a trimethylsilyl group from the commercially available alkyne, ethyl trimethylsilylpropynoate. The fact that IMDA reactions can be easily carried out adds to the versatility of the reaction.

Experimental

For general points, see ref. 11. Light petroleum refers to the fraction boiling at 40–60 °C.

Preparation of Thieno[2,3-c]pyran-3-ones

Formylation of Ethyl 3-Thienylacetate.—To a solution of ethyl 3-thienylacetate (2.146 g, 12.61 mmol) and tin(IV) chloride (7.38 ml, 63.03 mmol) in dry dichloromethane (40 ml) at 0 °C under nitrogen was added dichloromethyl methyl ether (1.37 ml, 15.13 mmol), dropwise with stirring. The mixture was stirred overnight, acidified with dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (3:1)] to give an oily mixture of ethyl 2-formyl-3-thienylacetate (**9**; R^2 = H) and ethyl 2-formyl-4-thienylacetate (2.27 g, 91%) in the ratio 1:1, characterised as a mixture (Found: C, 54.4; H, 5.1. $C_9H_{10}O_3S$ requires C, 54.5; H, 5.1%); ν_{max}(film) 3 094, 1 734, 1 669, and 1 190 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 10.02 (1 H, d, *J* 0.7 Hz), 9.89 (1 H, d, *J* 1.2 Hz), 7.73 (1 H, d, *J* 1.5 Hz, 2,4-isomer), 7.69 (1 H, d, *J* 4.9 Hz, 2,3-isomer), 7.59 (1 H, d, *J* 0.7 Hz, 2,4-isomer), 7.13 (1 H, d, *J* 4.9 Hz, 2,3-isomer), 4.19 (2 H, q, *J* 7 Hz), 4.18 (2 H, q, *J* 7 Hz), 4.00 (2 H, s, 2,3-isomer), 3.67 (2 H, s, 2,4-isomer), 1.28 (3 H, t, *J* 7 Hz), and 1.27 (3 H, t, *J* 7 Hz); *m/z* 198 (M^+, 23%), 170 (20), 153 (11), 152 (7), 125 (100), and 97 (42).

2-Formyl-3-thienylacetic Acid and 2-Formyl-4-thienylacetic Acid.—A 1:1 mixture of ethyl 2-formyl-3-thienylacetate and ethyl 2-formyl-4-thienylacetate (1.98 g, 9.98 mmol) and aqueous potassium hydroxide (2M; 25 ml) in tetrahydrofuran (THF) (27 ml) and methanol (3 ml) was stirred at room temperature for 2 h. The mixture was diluted with water (50 ml) and extracted with ether. The ether extract was discarded and the aqueous layer acidified and extracted with ether. These ether extracts were washed with water and brine, dried ($MgSO_4$), and evaporated to give an oily mixture of 2-formyl-3-thienylacetic acid (**10**; R^2 = H) and 2-formyl-4-thienylacetic acid in the ratio 1:1 (1.54 g, 91%), characterised as a mixture (Found: M^+, 170.0021. $C_7H_6O_3S$ requires 170.0038); ν_{max}(film) 3 200–2 400, 1 713, and 1 654 cm^{-1}; δ_H(270 MHz; [$^2H_6$]acetone) 10.09 (1 H, d, *J* 1 Hz), 9.94 (1 H, d, *J* 1.2 Hz), 7.93–7.91 (m, both isomers), 7.84 (1 H, s, 2,4-isomer), 7.23 (1 H, d, *J* 5.1 Hz, 2,3-isomer), 4.12 (2 H, s, 2,3-isomer), and 3.76 (2 H, s, 2,4-isomer); *m/z* 170 (M^+, 48%), 152 (6), 142 (11), 125 (100), and 97 (56).

Thieno[2,3c]pyran-3-one (**7a**).—To a 1:1 mixture of 2-formyl-3-thienylacetic acid (**10**; R^2 = H) and 2-formyl-4-thienylacetic acid (1.0 g, 6.04 mmol) and triethylamine (1.83 g, 18.13 mmol) in dry THF (100 ml) at 0 °C was added isobutyl chloroformate (0.99 g, 7.25 mmol) dropwise with stirring. The mixture was allowed to warm to room temperature and stirred overnight. The mixture was poured into brine (200 ml) and extracted with ethyl acetate. The combined organic extracts were evaporated and the residue chromatographed (ether) to give the *title compound* (**7a**) (268 mg, 29%), m.p. 110 °C (darkens) (Found: C, 55.4; H, 2.6. $C_7H_4O_2S$ requires C, 55.25; H, 2.65%); ν_{max}(Nujol) 3 118, 3 073, 1 765, 1 704, 1 684, 1 620, and 1 537 cm^{-1}; λ_{max}(EtOH) 219 (ε 17 119 dm^3 mol^{-1} cm^{-1}) and 400 nm (4 448); δ_H(270 MHz; [$^2H_6$]acetone) 8.31 (1 H, dd, *J* 1.5, 0.7 Hz), 7.92 (1 H, d, *J* 5.6 Hz), 6.94 (1 H, dd, *J* 5.6, 0.5 Hz), and 6.38 (1 H, d, *J* 1.5 Hz); *m/z* 152 (M^+, 100%), 124 (87), 96 (64), and 70 (28).

Acetylation of Ethyl-3-thienylacetate.—Tin(IV) chloride (2.0 ml, 17 mmol) was added dropwise to a stirred solution of ethyl-3-thienylacetate (0.965 g, 5.67 mmol) and acetyl chloride (0.48 ml, 6.80 mmol) in dry dichloromethane (30 ml) under nitrogen. The mixture was stirred overnight, poured into dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with aqueous sodium hydrogen carbonate, water, and brine, and dried ($MgSO_4$). Concentration under reduced pressure and chromatography [ether–light petroleum (3:1)] gave a 6:1 *mixture* of ethyl 2-acetyl-3-thienylacetate (**9**; R^2 = Me) and ethyl 2-acetyl-4-thienylacetate (0.94 g, 78%), m.p. 42–55 °C, characterised as a mixture (Found: C, 56.2; H, 5.5; S, 15.2. $C_{10}H_{12}O_3S$ requires C, 56.6; H, 5.7; S, 15.1%); ν_{max}(Nujol) 1 732 and 1 662 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.63 (1 H, d, *J* 1.6 Hz, minor), 7.44 (1 H, d, *J* 5 Hz, major), 7.43 (1 H, d, *J* 1.6 Hz, minor), 7.05 (1 H, d, *J* 5 Hz, major), 4.17 (2 H, q, *J* 7.5 Hz, minor), 4.16 (2 H, q, *J* 7.5 Hz, major), 4.04 (2 H, s, major), 3.81 (2 H, s, minor), 2.52 (3 H, s, minor), 2.51 (3 H, s, major), 1.27 (3 H, t, *J* 7.5 Hz, minor), and 1.26 (3 H, t, *J* 7.5 Hz, major); *m/z* 212 (M^+, 61%), 197 (10), 166 (82), 139 (100), 125 (27), 111 (13), and 97 (27).

2-Acetyl-3-thienylacetic Acid (**10**; R^2 = Me).—A 6:1 mixture of ethyl-2-acetyl-3-thienylacetate and ethyl 2-acetyl-4-thienylacetate (0.75 g, 3.55 mmol) was dissolved in THF–MeOH 9:1 (10 ml) and aqueous potassium hydroxide (2M; 5 ml) added dropwise with stirring and external cooling. The mixture was stirred at room temperature for 2 h, diluted with water, and extracted with ether. The aqueous phase was acidified with dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with water and brine, dried ($MgSO_4$), and evaporated to give 2-acetyl-3-thienylacetic (**10**; R^2 = Me) and 2-acetyl-4-thienylacetic acid as a 6:1 mixture (0.49 g, 2.66 mmol, 75%) m.p. 130–152 °C, characterised as a mixture (Found: C, 52.35; H, 4.3; S, 17.1. $C_8H_8O_3S$ requires C, 52.2; H, 4.4; S, 17.4%); ν_{max} 3 200–2 600br, 1 713, and 1 659 cm^{-1}; δ_H(270 MHz; [$^2H_6$]acetone) 7.80 (1 H, d, *J* 1.5 Hz, minor), 7.71 (1 H, d, *J* 6 Hz, major), 7.68 (1 H, m, minor), 7.18 (1 H, d, *J* 6 Hz, major), 4.06 (2 H, s, major), 3.71 (2 H, s, minor), 2.52 (3 H, s, minor), and 2.49 (3 H, s, major); *m/z* 184 (M^+, 34%), 169 (58), 141 (100), 125 (78), 97 (42), and 43 (61).

1-Methylthieno[2,3-c]pyran-3-one (**7b**).—A 6:1 mixture of 2-acetyl-3-thienylacetic acid and 2-acetyl-4-thienylacetic acid (400 mg, 2.17 mmol) in acetic anhydride (20 ml) was heated to reflux for 4 h. The reaction mixture was concentrated under reduced pressure and the residue dissolved in ether (60 ml), washed with aqueous sodium hydrogen carbonate, water, and brine, dried ($MgSO_4$), and evaporated to give the *title compound* (**7b**) (278 mg, 1.67 mmol, 77%), m.p. 137–141 °C (Found: C, 57.8; H, 3.5; S, 19.0. $C_8H_6O_2S$ requires C, 57.8; H, 3.6; S, 19.3%); ν_{max}(Nujol) 1 712, 1 689, 1 556, and 1 096 cm^{-1}; δ_H(270 MHz; [$^2H_6$]acetone) 7.87 (1 H, d, *J* 6 Hz), 6.93 (1 H, d, *J* 6 Hz), 6.19 (1 H, s), and 2.44 (3 H, s); *m/z* 166 (M^+, 76%), 151 (13), 138 (100), 123 (18), 110 (30), and 95 (29).

1-Methylthieno[2,3-c]pyran-3-one (**7b**).—(Alternative Method) Freshly distilled boron trifluoride–diethyl ether (1 ml) was added dropwise over 15 min to a stirred solution of 3-thienylacetic acid (998 mg, 7.03 mmol) in acetic anhydride (2 ml) at room temperature. The reaction was stirred for 45 min and then diluted with ether (20 ml). The resulting yellow solid was filtered, washed with ether (20 ml), water (2 × 5 ml) and

again with ether (5 ml), and dried under reduced pressure to give the *title compound* (**7b**) (332 mg, 28%) (analyses as above).

Ethyl 2-(3-*Thienyl*)*propanoate* (**11**; R^1 = Me).—Butyllithium (1.5M in hexane; 4.6 ml) was added dropwise to a solution of *N*-isopropylcyclohexylamine (968 mg, 6.86 mmol) in dry THF (30 ml) at −78 °C under nitrogen. The mixture was left to warm to 0 °C, stirred for 5 min, and then recooled to −78 °C. Ethyl 3-thienylacetate (1.06 g, 6.23 mmol) in dry THF (15 ml) was added dropwise. The mixture was allowed to warm to room temperature, and then added dropwise to a solution of methyl iodide (2.65 g, 18.7 mmol) in dry dimethyl sulphoxide (DMSO) (3 ml) under nitrogen. The resulting solution was stirred at room temperature overnight. Water (100 ml) was added and the mixture extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated under reduced pressure and the residue chromatographed [ether–light petroleum (1:4)] to give the *title compound* (**11**; R^1 = Me) (963 mg, 84%) as a colourless oil (Found: C, 58.5; H, 6.6. $C_9H_{12}O_2S$ requires C, 58.7; H, 6.6%); ν_{max}(film) 3 107, 1 734, and 1 182 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.27 (1 H, dd, *J* 5, 3 Hz), 7.12 (1 H, m), 7.06 (1 H, dd, *J* 5, 1.3 Hz), 4.13 (2 H, q, *J* 7 Hz, with additional fine splitting), 3.82 (1 H, q, *J* 7 Hz), 1.50 (3 H, d, *J* 7 Hz), and 1.23 (3 H, t, *J* 7 Hz); *m/z* 184 (M^+, 29%) and 111 (100).

2-(3-*Thienyl*)*propanoic Acid* (**12**; R^1 = Me).—A mixture of the ester (**11**; R^1 = Me) (957 mg, 5.19 mmol) and aqueous potassium hydroxide (2M; 25 ml) in THF (27 ml) and methanol (3 ml) was stirred at room temperature for 2 h. The mixture was diluted with water (50 ml), extracted with ether and the ether layer discarded. The aqueous layer was acidified and extracted with ether. The ether extracts were washed with water and brine, dried ($MgSO_4$) and evaporated to give the *title compound* (**12**; R^1 = Me) (705 mg, 87%) as a yellow oil (Found: C, 54.0; H, 5.1. $C_7H_8O_2S$ requires C, 53.8; H, 5.2%); ν_{max}(film) 3 400–2 200 and 1 708 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.29 (1 H, dd, *J* 5 and 3 Hz), 7.16 (1 H, m), 7.08 (1 H, dd, *J* 5 and 1.2 Hz), 3.86 (1 H, q, *J* 7.3 Hz), and 1.53 (3 H, d, *J* 7.3 Hz) (CO_2H not observed); *m/z* 156 (M^+, 35%) and 111 (100).

1,4-*Dimethylthieno*[2,3-c]*pyran*-3-*one* (**7c**).—Boron trifluoride–diethyl ether (0.7 ml, 5.7 mmol) was added dropwise to a stirred solution of the acid (**12**; R^1 = Me) (681 mg, 4.36 mmol) in acetic anhydride (1.6 ml, 17.4 mmol) at 0 °C. The mixture was allowed to warm to room temperature and stirred for 3 h. Water (50 ml) was added and the mixture extracted with ethyl acetate. The combined organic extracts were washed with saturated aqueous sodium hydrogen carbonate, water, and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [(ether–light petroleum (4:1)] to give the *title compound* (**7c**) (193 mg, 25%) as a yellow solid, m.p. 143–146 °C (Found: C, 59.7; H, 4.35. $C_9H_8O_2S$ requires C, 60.0; H, 4.5%); ν_{max}(Nujol) 3 101, 1 680, 1 627, 1 559, and 781 cm^{-1}; λ_{max}(EtOH) 223 (ε 21 344 dm^3 mol^{-1} cm^{-1}) and 404 nm (7 204); δ_H(270 MHz; $CDCl_3$), 7.47 (1 H, d, *J* 5.6 Hz), 6.85 (1 H, d, *J* 5.6 Hz), 2.45 (3 H, s), and 2.23 (3 H, s); *m/z* 180 (M^+, 100%), 152 (94), 151 (83), 137 (83), and 109 (22).

Ethyl 2-(3-*Thienyl*)*pentanoate* (**11**; R^1 = Pr).—Butyllithium (1.5M; 3.67 ml) was added dropwise to a solution of *N*-isopropylcyclohexylamine (0.90 ml, 5.5 mmol) in dry THF (20 ml) at −78 °C under nitrogen. The mixture was allowed to warm to 0 °C, stirred for 5 min and then recooled to −78 °C. Ethyl 3-thienylacetate (851 mg, 5.00 mmol) in dry THF (10 ml) was added dropwise. The mixture was allowed to warm to room temperature and added dropwise to a solution of propyl iodide (1.0 ml, 10.25 mmol) in dry DMSO (4 ml) under nitrogen. The resulting solution was stirred at room temperature overnight. Water (100 ml) was added and the mixture extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:4)] to give the *title compound* (**11**; R^1 = Pr) (908 mg, 86%) as a colourless oil (Found: C, 62.3; H, 7.7. $C_{11}H_{16}O_2S$ requires C, 62.2; H, 7.6%); ν_{max}(film) 3 107, 2 960, 1 734, and 1 178 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.25 (1 H, dd, *J* 4.5, 3 Hz), 7.13 (1 H, m), 7.06 (1 H, dd, *J* 5, 1.5 Hz), 4.19–4.07 (2 H, m), 3.69 (1 H, t, *J* 7.7 Hz), 2.08–1.94 (1 H, m), 1.82–1.68 (1 H, m), 1.34–1.22 (2 H, m), 1.23 (3 H, t, *J* 7.1 Hz), and 0.92 (3 H, t, *J* 7.2 Hz); *m/z* 212 (M^+, 16%), 170 (28), 139 (30), and 97 (100).

2-(3-*Thienyl*)*pentanoic Acid* (**12**; R^1 = Pr).—A mixture of the ester (**11**; R^1 = Pr) (862 mg, 4.06 mmol) and aqueous potassium hydroxide (2M; 10 ml) in THF (9 ml) and methanol (1 ml) was stirred at room temperature for 12 h. The mixture was diluted with water (50 ml), extracted with ether and the ether layer discarded. The aqueous layer was acidified and extracted with ether. The combined ether extracts were washed with water and brine, dried ($MgSO_4$) and evaporated to give the *title compound* (**12**; R^1 = Pr) (635 mg, 85%) as a colourless oil (Found: C, 58.8; H, 6.8. $C_9H_{12}O_2S$ requires C, 58.7; H, 6.6%); ν_{max}(film) 3 200–2 400 and 1 708 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.28 (1 H, dd, *J* 5, 3 Hz), 7.15 (1 H, dd, *J* 2.7, 1 Hz), 7.07 (1 H, dd, *J* 5.1, 1.2 Hz), 3.72 (1 H, t, *J* 7.7 Hz), 2.07–1.95 (1 H, m), 1.84–1.70 (1 H, m), 1.34–1.28 (2 H, m), and 0.92 (3 H, t, *J* 7.3 Hz); *m/z* 184 (M^+, 27%), 142 (55), and 97 (100).

1-*Methyl*-4-*propylthieno*[2,3-c]*pyran*-3-*one* (**7d**).—Boron trifluoride–diethyl ether (0.55 ml) was added dropwise to a stirred solution of the acid (**12**; R^1 = Pr) (551 mg, 2.99 mmol) in acetic anhydride (1.1 ml) and ether (2 ml) at 0 °C. The mixture was allowed to warm to room temperature and stirred for 3 h. Water was added and the mixture extracted with ethyl acetate. The combined organic extracts were washed with saturated aqueous sodium hydrogen carbonate, water, and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (4:1)] to give the *title compound* (**7d**) (189 mg, 30%), m.p. 66–72 °C (Found: C, 63.6; H, 5.9. $C_{11}H_{12}O_2S$ requires C, 63.3; H, 5.8%); ν_{max}(Nujol) 3 104, 3 072, 1 690, 1 633, and 1 562 cm^{-1}; λ_{max}(EtOH) 222 (ε 26 321 dm^3 mol^{-1} cm^{-1}), 224 (26 386), and 406 nm (9 867); δ_H(270 MHz; $CDCl_3$) 7.46 (1 H, d, *J* 5.9 Hz), 6.87 (1 H, d, *J* 5.6 Hz), 2.63 (2 H, t, *J* 7.6 Hz), 2.45 (3 H, s), 1.67–1.58 (2 H, m), and 0.96 (3 H, t, *J* 7.3 Hz); *m/z* 208 (M^+, 13%), 179 (17), 153 (100), and 111 (37).

1-*Pentylthieno*[2,3-c]*pyran*-3-*one* (**7e**).—Boron trifluoride–diethyl ether (2 ml) was added dropwise over 35 min to a stirred solution of 3-thienylacetic acid (998 mg, 7.03 mmol) in hexanoic anhydride (4 ml) at 0 °C. The reaction was stirred at 0 °C for a further 1.5 h and then the cooling bath removed and the reaction mixture allowed to warm to room temperature over 1 h. Water (20 ml) was added followed by pyridine (1 ml) and after 15 min the mixture was extracted with ether. The combined ether extracts were washed with dilute aqueous sodium hydrogen carbonate, then brine, dried ($MgSO_4$), and evaporated to give an orange oil which was chromatographed (light petroleum with an increasing proportion of ether) to give the *title compound* (**7e**) (1.04 g, 44%) as a viscous yellow oil (Found: M^+, 222.0711. $C_{12}H_{14}O_2S$ requires *M*, 222.0715); ν_{max}(film) 1 713, 1 628, 1 549, 1 499, and 824 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.52 (1 H, d, *J* 5.6 Hz), 6.78 (1 H, d, *J* 5.6 Hz), 6.24 (1 H, s), 2.69 (2 H, t, *J* 7 Hz), 1.73–1.86 (2 H, m), 1.27–1.43 (4 H, m), and 0.89 (3 H, approx. t, *J* 7.2 Hz); *m/z* 222 (M^+, 1%), 210 (20), 139 (100), and 111 (41).

Diels–Alder Reactions

Dimethyl Benzothiphene-5,6-dicarboxylate (**13a**).—A mixture of thieno[2,3-*c*]pyran-3-one (**7a**) (58 mg, 0.38 mmol) and DMAD (108 mg, 0.76 mmol) in bromobenzene (6 ml) was heated under reflux for 4 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:1)] to give the *title compound* (**13a**) (73 mg, 77%), m.p. 74–75 °C (Found: C, 57.6; H, 3.9. $C_{12}H_{10}O_4S$ requires C, 57.6; H, 4.0%); ν_{max}($CHCl_3$) 1 724 cm^{-1}, δ_H(270 MHz; $CDCl_3$) 8.29 (1 H, s), 8.18 (1 H, s), 7.67 (1 H, d, *J* 5.4 Hz), 7.43 (1 H, d, *J* 5.1 Hz), and 3.94 (6 H, s); *m/z* 250 (M^+, 55%) and 219 (100).

Reaction of Thieno[2,3-c]*pyran-3-one* (**7a**) *with Ethyl Propiolate*.—A mixture of the pyranone (**7a**) (63 mg, 0.41 mmol) and ethyl propiolate (203 mg, 2.07 mmol) in bromobenzene (6 ml) was refluxed for 4 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:2)] to give a mixture of ethyl benzothiophen-6-carboxylate (**13b**) and ethyl benzothiophen-5-carboxylate (**14b**) (63 mg, 74%) in the ratio 1.3 to 1, characterised as a *mixture* (Found: C, 64.0; H, 5.1. $C_{11}H_{10}O_2S$ requires C, 64.1; H, 4.9%); ν_{max}(film) 3 102, 1 713, and 1 278 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.62 (1 H, dd, *J* 1.5, 0.7 Hz, 6-isomer), 8.54 (1 H, s, 5-isomer), 8.05–8.00 (m, both isomers) 7.92 (1 H, d, *J* 8.3 Hz, 5-isomer), 7.86 (1 H, d, *J* 8.3 Hz, 6-isomer), 7.64 (1 H, d, *J* 5.4 Hz, 6-isomer), 7.52 (1 H, d, *J* 5.4 Hz, 5-isomer), 7.43 (1 H, d, *J* 5.6 Hz, 5-isomer), 7.39 (1 H, dd, *J* 5.6, 0.7 Hz, 6-isomer), 4.42 (q, *J* 7.1 Hz, ester CH_2, both isomers), and 1.43 (t, *J* 7.1 Hz, ester CH_3, both isomers); *m/z* 206 (M^+, 61%), 191 (6), 178 (18), 161 (100), and 133 (33).

Reaction of Thieno[2,3-c]*pyran-3-one* (**7a**) *with Ethyl 3-Trimethylsilylpropynoate*.—A mixture of the pyranone (**7a**) (90 mg, 0.59 mmol) and ethyl 3-trimethylsilylpropynoate (302 mg, 1.77 mmol) in bromobenzene (10 ml) was refluxed for 4 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:3)] to give a mixture of ethyl 5-trimethylsilylbenzothiophene-6-carboxylate (**13c**) and ethyl 6-trimethylsilylbenzothiophene-5 carboxylate (**14c**) (95 mg, 58%) in the ratio 4:1, m.p. 90–91 °C, characterised as a *mixture* (Found: C, 60.5; H, 6.6. $C_{14}H_{18}O_2SSi$ requires C, 60.4; H, 6.5%); ν_{max}(Nujol) 3 086, 3 065, 1 703, 1 278, and 842 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.61 (1 H, s, major), 8.52 (1 H, s, minor), 8.18 (1 H, s, minor), 8.13 (1 H, s, major), 7.60 (1 H, d, *J* 5.4 Hz, major), 7.53 (1 H, d, *J* 5.4 Hz, minor), 7.40 (m, both isomers), 4.41 (q, *J* 7.1 Hz, ester CH_2, both isomers), 1.44 (t, *J* 7.1 Hz, ester CH_3, both isomers), and 0.38 (s, Me_3Si, both isomers); *m/z* 278 (M^+, 2%), 263 (87), 235 (100), and 219 (15).

Protodesilylation of Ethyl 5-Trimethylsilylbenzothiophene-6-carboxylate (**13c**) *and Ethyl 6-Trimethylsilylbenzothiophene-5-carboxylate* (**14c**).—A 4:1 mixture of compounds (**13c**) and (**14c**) (17 mg) was heated at 70 °C for 2 h in a mixture of trifluoroacetic acid (2 ml) and water (1 ml). The mixture was diluted with water (30 ml) and extracted with ether. The ether extracts were washed with saturated aqueous sodium hydrogen carbonate (until the washings remained basic), water, and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:2)] to give a mixture of ethyl benzothiophene-6-carboxylate (**13b**) and ethyl benzothiophene-5-carboxylate (**14b**) (10 mg, 79%) in the ratio 4:1 as a colourless oil (analytical data as given above).

Dimethyl 7-Methylbenzothiophene-5,6-dicarboxylate (**13d**).—A mixture of the thienopyranone (**7b**) (46 mg, 0.28 mmol) and DMAD (79 mg, 0.55 mmol) in bromobenzene (5 ml) was refluxed under nitrogen for 1.5 h. The solvent was evaporated and the residue chromatographed (dichloromethane) to give the *title compound* (**13d**) (43 mg, 59%), m.p. 90–91 °C (Found: C, 59.3; H, 4.45; S, 11.8. $C_{13}H_{12}O_4S$ requires C, 59.1; H, 4.6; S, 12.1%): ν_{max}(Nujol) 3 100, 3 085, 1 713, 1 437, 1 349, 1 281, 1 215, 1 157, 1 121, 1 012, 789, and 775 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.36 (1 H, s), 7.59 (1 H, d, *J* 5.4 Hz), 7.44 (1 H, d, *J* 5.4 Hz), 3.98 (3 H, s), 3.93 (3 H, s), and 2.58 (3 H, s); *m/z* 264 (M^+, 48%), 233 (100), 232 (88), and 174 (67).

Reaction of 1-Methylthienopyranone (**7b**) *with Ethyl Propiolate*.—A mixture of the thienopyranone (**7b**) (151 mg, 0.91 mmol) and ethyl propiolate (340 mg, 3.47 mmol) in bromobenzene (20 ml) was heated under reflux under nitrogen for 5 h. The solvent was evaporated and the residue chromatographed (light petroleum with an increasing proportion of dichloromethane) to give a mixture of ethyl 7-methylbenzothiophene-5-carboxylate (**14e**) and ethyl 7-methylbenzothiophene-6-carboxylate (**13e**) in the ratio of 1:2 (128 mg, 64%), as a pale yellow oil (Found: M^+, 220.0558. $C_{12}H_{12}O_2S$ requires *M*, 220.0558); ν_{max}(film) 1 714, 1 277, 1 256, 1 200, 1 111, 831, 785, 771, and 697 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.40 (1 H, s, 4-H, minor isomer), 7.94 (1 H, d, *J* 8 Hz, 4-H, major isomer), 7.83 (1 H, s, 6-H, minor isomer), 7.68 (1 H, d, *J* 8 Hz, 5-H, major isomer), 7.59 (1 H, d, *J* 5.4 Hz, 2-H, major isomer), 7.49 (1 H, d, *J* 5.4 Hz, 2-H, minor isomer), 7.44 (1 H, d, *J* 5.4 Hz, 3-H, minor isomer), 7.37 (1 H, d, *J* 5.4 Hz, 3-H, major isomer), 4.35–4.49 (m, ethoxy CH_2, both isomers), 2.88 (3 H, s, major isomer), 2.61 (3 H, s, minor isomer), and 1.39–1.48 (m, ethoxy CH_3, both isomers); *m/z* 220 (M^+, 69%), 175 (100), and 147 (60).

Reaction of 1-Methylthienopyranone (**7b**) *with Ethyl 3-Trimethylsilylpropynoate*.—A solution of the pyrone (**7b**) (66 mg, 0.4 mmol) and ethyl 3-trimethylsilylpropynoate (203 mg, 1.19 mmol) in bromobenzene (10 ml) was refluxed for 20 h. The solvent was removed and the residue chromatographed [ether–light petroleum (1:3)] to give a 9:1 mixture of ethyl 7-methyl-5-trimethylsilylbenzothiophene-6-carboxylate (**13f**) and ethyl-7-methyl-6-trimethylsilylbenzothiophene-5-carboxylate (**14f**) (84 mg, 72%), m.p. 45–50 °C (Found: C, 61.5; H, 6.9. $C_{15}H_{20}O_2SSi$ requires C, 61.6; H, 6.9); ν_{max}(Nujol) 3 090, 1 722, 1 687, 1 290, and 841 cm^{-1}; δ_H(270 MHz; $CDCl_3$) (major isomer) 7.91 (1 H, s), 7.50 (1 H, d, *J* 5.4 Hz), 7.36 (1 H, d, *J* 5.4 Hz), 4.42 (2 H, q, *J* 7 Hz), 2.61 (3 H, s), 1.42 (3 H, t, *J* 7 Hz), and 0.34 (9 H, s); *m/z* 292 (M^+, 15%), 277 (100), and 249 (93).

Protodesilylation of Ethyl 7-Methyl-5-trimethylsilylbenzothiophene-6-carboxylate (**13f**).—The ester (**13f**) (22 mg) in aqueous trifluoroacetic acid (1:2; 3 ml) was heated at 70 °C for 2 h, and then left to stand overnight. The mixture was diluted with water (30 ml) and extracted with ether. The combined ether extracts were washed with half-saturated aqueous sodium hydrogen carbonate until the washings remained basic, and then washed with water and brine, and dried ($MgSO_4$). Evaporation of the solvent followed by chromatography [dichloromethane–light petroleum (1:1)] gave ethyl 7-methylbenzothiophene-6-carboxylate (**13c**) (15 mg, 91%) m.p. 33–35 °C (analytical data as above).

Dimethyl 4,7-Dimethylbenzothiophene-5,6-dicarboxylate (**13g**).—A mixture of 1,4-dimethylthieno[2,3-*c*]pyran-3-one (**7c**) (26 mg, 0.14 mmol) and DMAD (41 mg, 0.28 mmol) in bromobenzene (5 ml) was heated under reflux for 12 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:1)] to give the *title compound* (**13g**) (37 mg, 92%), m.p. 66–67 °C (Found: C, 60.3; H, 5.1. $C_{14}H_{14}O_4S$ requires C, 60.4; H, 5.1%); ν_{max}(Nujol) 3 088, 1 718, 1 268, and 1 212 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.61 (1 H, d, *J* 5.6 Hz), 7.50 (1 H, d, *J* 5.6 Hz), 3.90 (6 H, s), 2.65 (3 H, s), and 2.64 (3 H, s); *m/z* 278 (M^+, 54%), 247 (88), 246 (100), and 188 (73).

Reaction of 1,4-*Dimethylthieno*[2,3-c]*pyran*-3-*one* (**7c**) *with Ethyl Propiolate*.—A mixture of the pyranone (**7c**) (36 mg, 0.20 mmol) and ethyl propiolate (98 mg, 1.00 mmol) in bromobenzene (5 ml) was heated under reflux for 12 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:2)] to give an oily mixture of ethyl 4,7-dimethylbenzothiophene-5-carboxylate (**14h**) and ethyl 4,7-dimethylbenzothiophene-6-carboxylate (**13h**) (45 mg, 96%) in the ratio of 1:1; (Found: C, 66.7; H, 5.8. $C_{13}H_{14}O_2S$ requires C, 66.6; H, 6.0%); ν_{max}(film) 3 082, 1 713, 1 263, 1 232, and 1 155 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.72 (1 H, s), 7.66 (1 H, s), 7.60 (1 H, d, *J* 5.6 Hz), 7.56 (1 H, d, *J* 5.6 Hz), 7.48 (1 H, d, *J* 5.6 Hz), 7.43 (1 H, d, *J* 5.6 Hz), 4.39 (q, *J* 7.1 Hz, ester CH_2, both isomers), 2.85 (3 H, s), 2.83 (3 H, s), 2.61 (3 H, s), 2.56 (3 H, s), and 1.43 (t, *J* 7.1 Hz, ester CH_3, both isomers); *m/z* 234 (M^+, 100%), 219 (3), 205 (37), 189 (71), and 161 (40).

Dimethyl 7-*Methyl*-4-*propylbenzothiophene*-5,6-*dicarboxylate* (**13i**).—A mixture of compound (**7d**) (41 mg, 0.2 mmol) and DMAD (56 mg, 0.39 mmol) in bromobenzene (5 ml) was refluxed for 3 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:1)] to give the *title compound* (**13i**) (40 mg, 66%), m.p. 56–58 °C (Found: C, 62.7; H, 5.9. $C_{16}H_{18}O_4S$ requires C, 62.7; H, 5.9%); ν_{max}(Nujol) 3 114, 1 729, 1 266, and 1 206 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.61 (1 H, d, *J* 5.6 Hz), 7.50 (1 H, d, *J* 5.6 Hz), 3.90 (3 H, s), 3.89 (3 H, s), 2.99 (2 H, t, *J* 8 Hz), 2.64 (3 H, s), 1.74–1.65 (2 H, m), and 0.99 (3 H, t, *J* 7.3 Hz); *m/z* 306 (M^+, 49%), 275 (68), 274 (100), and 259 (61).

Reaction of 1-*Methyl*-4-*propylthieno*[2,3-c]*pyran*-3-*one with Ethyl Propiolate*.—A mixture of the pyranone (**7d**) (48 mg, 0.23 mmol) and ethyl propiolate (113 mg, 1.15 mmol) in bromobenzene (5 ml) was refluxed for 3 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:2)] to give a mixture of ethyl 7-methyl-4-propylbenzothiophene-6-carboxylate (**13j**) and ethyl 7-methyl-4-propylbenzothiophene-5-carboxylate (**14j**) (37 mg, 61%) in the ratio 1.2:1, characterised as an oily mixture (Found: M^+, C, 68.65; H, 6.9. $C_{15}H_{18}O_2S$ requires C, 68.7; H, 6.9%); ν_{max}(film) 3 081, 2 960, 1 713, 1 260, 1 234, and 1 153 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.71 (1 H, s, major), 7.63 (1 H, s, minor), 7.59 (1 H, d, *J* 5.6 Hz, major), 7.55 (1 H, d, *J* 5.6 Hz, minor), 7.49–7.45 (m, both isomers), 4.40 (2 H, q, *J* 7.1 Hz, major), 4.39 (2 H, q, *J* 7.1 Hz, minor), 3.25 (2 H, t, *J* 7.9 Hz, minor), 2.91 (2 H, t, *J* 7.7 Hz, major), 2.83 (3 H, s, major), 2.56 (3 H, d, *J* 0.7 Hz, minor), 1.79–1.67 (m, both isomers), 1.43 (3 H, t, *J* 7.1 Hz, major), 1.42 (3 H, t, *J* 7.1 Hz, minor), 1.04 (3 H, t, *J* 7.1 Hz, minor), and 1.00 (3 H, t, *J* 7.3 Hz, major); *m/z* 262 (M^+, 100%), 233 (69), 217 (39), 205 (45), and 187 (29).

Dimethyl 7-*Pentylbenzothiophene*-5,6-*dicarboxylate* (**13k**).—A mixture of the thienopyranone (**7e**) (246 mg, 1.11 mmol) and DMAD (315 mg, 2.22 mmol) in bromobenzene (20 ml) was heated under reflux, under nitrogen for 2 h. The solvent was evaporated and the residue chromatographed (light petroleum with an increasing proportion of dichloromethane) to give the *title compound* (**13k**) (237 mg, 69%) as a pale yellow oil (Found: M^+, 320.1084. $C_{17}H_{20}O_4S$ requires *M*, 320.1082); ν_{max}(film) 1 729, 1 438, 1 348, 1 277, 1 211, 1 155, 1 113, and 786 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.34 (1 H, s), 7.56 (1 H, d, *J* 5.4 Hz), 7.41 (1 H, d, *J* 5.4 Hz), 3.96 (3 H, s), 3.91 (3 H, s), 2.88 (2 H, dt, *J* 8 and 2.5 Hz), 1.68–1.81 (2 H, m), 1.29–1.47 (4 H, m), and 0.90 (3 H, approx. t, *J* 6.8 Hz); *m/z* 320 (M^+, 35%), 289 (42), 288 (72), and 245 (100).

Reaction of 1-*Pentylthienopyranone* (**7e**) *with Ethyl Propiolate*.—A mixture of the thienopyranone (**7e**) (358 mg, 1.61 mmol) and ethyl propiolate (632 mg, 6.45 mmol) in bromobenzene (30 ml) was heated under reflux under nitrogen for 12 h. The solvent was evaporated and the residue chromatographed (light petroleum with an increasing proportion of dichloromethane) to give a *mixture of* ethyl 7-pentylbenzothiophene-5-carboxylate (**14l**) and ethyl 7-pentylbenzothiophene-6-carboxylate (**13l**) (1:1.8; 274 mg, 62%) as a pale yellow oil (Found: M^+, 276.1191. $C_{16}H_{20}O_2S$ requires *M*, 276.1184); ν_{max}(film) 1 718, 1 466, 1 367, 1 275, 1 252, 1 202, 1 109, 1 026, 832, 798, 773, and 700 cm^{-1}; δ_H(250 MHz; $CDCl_3$) 8.41 (1 H, d, *J* 1.2 Hz, 4-H, minor isomer), 7.94 (1 H, d, *J* 8.4 Hz, 4-H, major isomer), 7.86 (1 H, s, 6-H, minor isomer), 7.66 (1 H, d, *J* 8.4 Hz, 5-H, major isomer), 7.54 (1 H, d, *J* 5.5 Hz, 2-H, major isomer), 7.45 (1 H, d, *J* 5.4 Hz, 2-H, minor isomer), 7.40 (1 H, d, *J* 5.4 Hz, 3-H, minor isomer), 7.32 (1 H, d, *J* 5.5 Hz, 3-H, major isomer), 4.36–4.50 (m, ethoxy CH_2, both isomers), 3.29 (2 H, approx. t, *J* 8 Hz, major isomer), 2.91 (2 H, approx. t, *J* 7.8 Hz, minor isomer), 1.72–1.80 (m, both isomers), 1.35–1.56 (m, both isomers), and 0.89–1.00 (m, both isomers); *m/z* 276 (M^+, 100%), 231 (52), 220 (31), 191 (41), 187 (31), and 147 (46).

Reaction of 1-*Pentylthieno*[2,3-c]*pyran*-3-*one* (**7e**) *with Ethyl* 3-*Trimethylsilylpropynoate*.—A mixture of the pyrone (**7e**) (87 mg, 0.39 mmol) and ethyl trimethylsilylpropynoate (200 mg, 1.18 mmol) in bromobenzene (10 ml) was refluxed for 24 h. The solvent was removed and the residue chromatographed [ether–light petroleum (1:3)] to give an oily *mixture of* ethyl-7-pentyl-5-trimethylsilylbenzothiophene-6-carboxylate (**13m**) and ethyl-7-pentyl-6-trimethylsilylbenzothiophene-5-carboxylate (**14m**) in the ratio 12:1 (32 mg, 23%) (Found: M^+, 348.1579. $C_{19}H_{28}O_2SSi$ requires *M*, 348.1579); ν_{max}(film) 1 723, 1 261, and 842 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.90 (1 H, s), 7.48 (1 H, d, *J* 5.4 Hz), 7.34 (1 H, d, *J* 5.4 Hz), 4.40 (2 H, q, *J* 7 Hz), 2.92 (2 H, m), 1.77 (2 H, m), 1.35–1.45 (7 H, m), 0.90 (3 H, t, *J* 7 Hz), and 0.33 (9 H, s); *m/z* 348 (M^+, 10%), 333 (100), 319 (2), 305 (36), and 295 (14).

Intramolecular Diels–Alder Reactions

Acylation of Ethyl 3-*Thienylacetate with Hex*-5-*ynoyl Chloride*.—Oxalyl chloride (0.63 ml, 7.25 mmol) and hex-5-ynoic acid (0.541 g, 4.83 mmol) in dry ether (20 ml) were stirred at room temperature overnight, concentrated under reduced pressure, dissolved in dry dichloromethane (25 ml), and added to anhydrous zinc chloride (1.97 g, 14.49 mmol). Ethyl 3-thienylacetate (0.766 g, 4.50 mmol) in dry dichloromethane (5 ml) was added and the mixture stirred at room temperature overnight. The reaction mixture was poured into dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with dilute aqueous sodium hydrogen carbonate and brine, dried ($MgSO_4$), evaporated, and the residue chromatographed [ether–light petroleum (3:1)] to give a 5:1 mixture of ethyl 2-hex-5-ynoyl-3-thienylacetate (**15**) and ethyl 2-hex-5-ynoyl-4-thienylacetate (0.51 g, 1.93 mmol, 43%), m.p. 45–52 °C (Found: C, 63.4; H, 6.2; S, 11.9. $C_{14}H_{16}O_3S$ requires C, 63.6; H, 6.1; S, 12.1%); ν_{max}(Nujol) 3 266, 3 111, 3 082, 1 728, 1 687, 1 647, and 1 524 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.68 (1 H, d, *J* 1.5 Hz, minor), 7.45 (1 H, d, *J* 6 Hz, major), 7.44 (1 H, d, *J* 1.5 Hz, minor), 7.07 (1 H, d, *J* 6 Hz, major), 4.17 (2 H, q, *J* 7 Hz, minor), 4.16 (2 H, q, *J* 7 Hz, major), 4.05 (2 H, s, major), 3.63 (2 H, s, minor), 3.04 (2 H, t, *J* 8 Hz, minor), 3.01 (2 H, t, *J* 8 Hz, major), 2.29 (m, 2 H minor + 2 H major), 1.94 (m, 3 H minor + 3 H major), 1.27 (3 H, t, *J* 7 Hz, minor), and 1.25 (3 H, t, *J* 7 Hz, major); *m/z* 264 (M^+, 4%), 219 (45), 212 (60), 197 (12), 190 (29), 177 (37), 166 (81), 151 (16), and 141 (100).

2-*Hex*-5-*ynoyl*-3-*thienylacetic Acid* (**16**).—The mixture of ethyl 2-hex-5-ynoyl-3-thienylacetate and ethyl 2-hex-5-ynoyl-4-thienylacetate (0.202 g, 0.77) mmol) was dissolved in THF–methanol (9:1; 10 ml), and aqueous potassium hydroxide (2M; 5

ml) was added dropwise with external cooling to the stirred solution. When the addition was complete, the mixture was stirred at room temperature for 2 h, then diluted with water (50 ml) and extracted with ether. The aqueous phase was acidified with dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with water and brine, dried ($MgSO_4$), and evaporated to give a 5:1 mixture of 2-hex-5-ynoyl-3-thienylacetic acid and 2-hex-5-ynoyl-4-thienylacetic acid (0.149 g, 82%). Recrystallisation from ether gave the *title compound* (**16**) (119 mg, 66%), m.p. 95–97 °C (Found: C, 60.85; H, 5.1; S, 12.15. $C_{12}H_{12}O_3S$ requires C, 61.0; H, 5.1; S, 13.6%); ν_{max}(Nujol) 3 278, 3 103, 1 708, 1 666, and 1 526 cm^{-1}; δ_H(270 MHz; [$^2H_6$]acetone) 7.71 (1 H, d, *J* 6 Hz), 7.18 (1 H, d, *J* 6 Hz), 4.06 (2 H, s), 3.02 (2 H, t, *J* 7.5 Hz), 2.37 (1 H, t, *J* 3 Hz), 2.28 (2 H, td, *J* 7.5, 3 Hz), and 1.88 (2 H, m); *m/z* 237 (MH^+, 3%), 236 (M^+, 1%), 218 (M − H_2O, 2%), 184 (40), 177 (23), 169 (9), 166 (26), 141 (100), 138 (21), and 125 (16).

7,8-*Dihydroindeno*[4,5-b]*thiophene* (**18**).—2-Hex-5-ynoyl-3-thienylacetic acid (**16**) (100 mg, 0.424 mmol) was refluxed in acetic anhydride (20 ml) under nitrogen for 5 h. The mixture was concentrated and the residue chromatographed [ether–light petroleum (1:3)] to give the *title compound* (**18**) (57 mg, 77%) as a colourless oil (Found: C, 75.9; H, 6.0; S, 18.1. $C_{11}H_{10}S$ requires C, 75.8; H, 5.8; S, 18.4%); ν_{max}(film) 3 053, 2 953, 2 842, 1 592, 1 571, 1 459, and 1 437 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.64 (1 H, d, *J* 8 Hz), 7.37 (2 H, m), 7.29 (1 H, d, *J* 8 Hz), 3.12 (2 H, t, *J* 7 Hz), 3.11 (2 H, t, *J* 7 Hz), and 2.25 (2 H, m); *m/z* 174 (M^+, 100%), 173 (71), 171 (16), 147 (7), 129 (11), 115 (3), 86 (6), 74 (3), and 45 (6).

5-*Iodopent*-1-*yne*.—A mixture of 5-chloropent-1-yne (850 mg, 8.29 mmol) and sodium iodide (6.2 g, 41.44 mmol) in methyl ethyl ketone (30 ml) was refluxed for 15 h. After cooling, the mixture was filtered. The filtrate was diluted with water and extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated to give the *title compound* (1.182 g, 73%) sufficiently pure for use without further purification, ν_{max}(film) 3 296, 2 119, 1 428, 1 222, and 641 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 3.32 (2 H, t, *J* 6.7 Hz), 2.34 (2 H, td, *J* 6.6, 2.7 Hz), 2.05–1.96 (2 H, m), and 1.99 (1 H, t, *J* 2.7 Hz); *m/z* 194 (M^+, 61%), 169 (12), 127 (11), and 67 (100).

Ethyl 2-(3-*Thienyl*)*hept*-6-*ynoate* (**19a**).—Butyl-lithium (1.5M; 2.60 ml) was added dropwise to a solution of *N*-isopropylcyclohexylamine (0.64 ml, 3.90 mmol) in dry THF (20 ml) at −78 °C under nitrogen. The mixture was allowed to warm to 0 °C, stirred for 5 min, and then recooled to −78 °C. Ethyl 3-thienylacetate (604 mg, 3.55 mmol) in dry THF (5 ml) was added dropwise. The mixture was warmed to room temperature and added dropwise to a solution of 5-iodopent-1-yne (1.15 g, 5.93 mmol) in dry DMSO (4 ml) under nitrogen. The resulting solution was stirred overnight. Water (100 ml) was added and the mixture extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:4)] to give the *title compound* (**19a**) (0.639 g, 76%) as a colourless oil (Found: C, 66.0; H, 6.9. $C_{13}H_{16}O_2S$ requires C, 66.1; H, 6.8%); ν_{max}(film) 3 293, 3 105, 2 953, 2 117, 1 732, and 1 152 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.27 (1 H, dd, *J* 4.6, 2.7 Hz), 7.14 (1 H, m), 7.06 (1 H, dd, *J* 4.9, 1.2 Hz), 4.20–4.08 (2 H, m), 3.69 (1 H, t, *J* 7.7 Hz), 2.20 (2 H, td, *J* 7.1, 2.7 Hz), 2.16–2.06 (1 H, m), 1.95 (1 H, t, *J* 2.7 Hz), 1.95–1.87 (1 H, m), 1.54–1.47 (2 H, m), and 1.23 (3 H, t, *J* 7.1 Hz); *m/z* 236 (M^+, 8%), 163 (96), and 97 (100).

2-(3-*Thienyl*)*hept*-6-*ynic Acid* (**20a**).—A mixture of ester (**19a**) (551 mg, 2.33 mmol) and aqueous potassium hydroxide (2M; 10 ml) in THF (9 ml) and methanol (1 ml) was stirred at room temperature for 24 h. The mixture was diluted with water (50 ml), extracted with ether, and the ether layer discarded. The aqueous layer was acidified and extracted with ether. The ether extracts were washed with water and brine, dried ($MgSO_4$), and evaporated to give the *title compound* (**20a**) (456 mg, 94%) as a colourless oil (Found: c, 63.7; H,6.0. $C_{11}H_{12}O_2S$ requires C, 63.4; h, 5.8%, ν_{max}(film) 3 295, 3 200–2 400, 2 117, and 1 708 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.29 (1 H, dd, *J* 5, 3 Hz), 7.17 (1 H, dd, *J* 3, 1 Hz), 7.07 (1 H, dd, *J* 5, 1.3 Hz), 3.73 (1 H, t, *J* 7.7 Hz), 2.20 (2 H, td, *J* 6.8, 2.7 Hz), 2.17–2.11 (1 H, m), 1.98–1.92 (1 H, m), 1.95 (1 H, t, *J* 2.7 Hz), and 1.56–1.49 (2 H, m); *m/z* 208 (M^+, 17%), 163 (100), and 97 (96).

1-*Methyl*-4-(*Pent*-1-*yn*-5-*yl*)*thieno*[2,3-c]*pyran*-3-*one* (**21a**).—Boron trifluoride–diethyl ether (0.35 ml) was added dropwise to a stirred solution of the acid (**20a**) (382 mg, 1.83 mmol) in acetic anhydride (0.7 ml) and ether (1 ml) at 0 °C. The mixture was allowed to warm to room temperature and stirred for 3 h. Water was added and the mixture extracted with ethyl acetate. The combined organic extracts were washed with saturated aqueous sodium hydrogen carbonate, water, and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (4:1)] to give the *title compound* (**21a**) (96 mg, 23%), m.p. 90–92 °C (Found: C, 67.5; H, 5.2. $C_{13}H_{12}O_2S$ requires C, 67.2; H, 5.2%); ν_{max}(Nujol) 3 251, 3 227, 3 105, 3 081, 2 111, 1 679, 1 633, and 1 557 cm^{-1}; λ_{max}(EtOH) 223 (ε 26 049 dm^3 mol^{-1} cm^{-1}) and 407 nm (10 211); δ_H(270 MHz; $CDCl_3$) 7.49 (1 H, d, *J* 5.9 Hz), 6.97 (1 H, d, *J* 5.6 Hz), 2.79 (2 H, t, *J* 7.5 Hz), 2.46 (3 H, s), 2.23 (2 H, td, *J* 6.9, 2.7 Hz), 2.00 (1 H, t, *J* 2.7 Hz), and 1.89–1.79 (2 H, m); *m/z* 232 (M^+, 2%), 188 (100), 187 (46), and 173 (53).

4-*Methyl*-6,7-*dihydroindeno*[5,4-b]*thiophene* (**22a**).—A solution of the pyran-3-one (**21a**) (35 mg, 0.15 mmol) in bromobenzene (10 ml) was refluxed for 4 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:3)] to give the *title compound* (**22a**) (23 mg, 81%), m.p. 30–32 °C (Found: M^+, 188.0660. $C_{12}H_{12}S$ requires *M*, 188.0660); ν_{max}(Nujol) 3 100, 3 016, 1 448, 861, 760, and 692 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.44 (1 H, d, *J* 5.4 Hz), 7.30 (1 H, d, *J* 5.6 Hz), 7.08 (1 H, s), 3.14 (2 H, t, *J* 7.4 Hz), 3.02 (2 H, t, *J* 7.3 Hz), 2.55 (3 H, s), and 2.23–2.17 (2 H, m); *m/z* 188 (M^+, 100%), 187 (46), and 173 (52).

6-(*Toluene*-p-*sulphonyloxy*)*hex*-1-*yne*.—A mixture of hex-5-yn-1-ol (681 mg, 6.94 mmol) and tosyl chloride (2.65 g, 13.88 mmol) in pyridine (5 ml) was stirred at 0 °C for 6 h. Water was added and the mixture extracted with ether. The combined ether extracts were washed with saturated aqueous copper(II) sulphate, water, and brine, and dried ($MgSO_4$). The solvent was evaporated to give the title compound (1.715 g, 98%) as a colourless oil, sufficiently pure for use without further purification; ν_{max}(film) 3 294, 1 359, 1 190, and 1 176 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.79 (2 H, d, *J* 8.3 Hz), 7.35 (2 H, d, *J* 8.5 Hz), 4.06 (2 H, t, *J* 6.2 Hz), 2.45 (3 H, s), 2.17 (2 H, td, *J* 6.8, 2.7 Hz), 1.92 (1 H, t, *J* 2.7 Hz), 1.81–1.75 (2 H, m), and 1.58–1.53 (2 H, m); *m/z* 252 (M^+, 0.2%), 155 (50), and 91 (100).

6-*Iodohex*-1-*yne*.—A mixture of 6-(toluene-*p*-sulphonyloxy)-hex-1-yne (1.63 g, 6.46 mmol) and sodium iodide (1.94 g, 12.94 mmol) in acetone (20 ml) was stirred at room temperature for 24 h. Water was added and the mixture extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:4)] to give the title compound (1.201 g, 89%) as a colourless liquid; ν_{max}(film) 3 297, 2 118, 1 213, and 640 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 3.21 (2 H, t, *J*

6.8 Hz), 2.23 (2 H, td, *J* 6.8, 2.7 Hz), 1.98–1.90 (3 H, m), and 1.67–1.61 (2 H, m); *m/z* 208 (M^+, 9%), 127 (6), and 81 (100).

Ethyl 2-(3-*Thienyl*)*oct*-7-*ynoate* (**19b**).—Butyllithium (1.5M; 1.75 ml) was added dropwise to a solution of *N*-isopropylcyclohexylamine (0.43 ml. 2.61 mmol) in dry THF (15 ml) under nitrogen at −78 °C. The mixture was allowed to warm to 0 °C, stirred for 5 min, and recooled to −78 °C. A solution of ethyl thienylacetate (404 mg, 2.37 mmol) in dry THF (10 ml) was added dropwise. The mixture was left to warm to room temperature and added to a solution of 6-iodohex-1-yne (1.0 g, 4.8 mmol) in dry DMSO (4 ml) under nitrogen. The mixture was stirred overnight. Water was added, and the resulting mixture extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:4)] to give the *title compound* (**19b**) (404 mg, 68%) as a colourless oil (Found: M^+, 250.1028. $C_{14}H_{18}O_2S$ requires *M*, 250.1028); ν_{max}(film) 3 295, 3 105, 2 117, and 1 733 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.27 (1 H, dd, *J* 5.2, 2.6 Hz), 7.13 (1 H, m), 7.06 (1 H, dd, *J* 5.0, 1.3 Hz), 4.14 (2 H, m), 3.68 (1 H, t, *J* 7.6 Hz), 2.17 (2 H, td, *J* 7, 2.7 Hz), 2.14–2.00 (1 H, m), 1.92 (1 H, t, *J* 2.7 Hz), 1.91–1.75 (1 H, m), 1.58–1.49 (2 H, m), 1.44–1.33 (2 H, m), and 1.23 (3 H, t, *J* 7.2 Hz); *m/z* 250 (M^+, 4%), 177 (20), 170 (24), and 97 (100).

2-(3-*Thienyl*)*oct*-7-*ynoic Acid* (**20b**).—A mixture of compound (**19b**) (360 mg, 1.44 mmol) and aqueous potassium hydroxide (2M; 10 ml) in THF (9 ml) and methanol (1 ml) was stirred at room temperature for 24 h. The mixture was diluted with water (30 ml), extracted with ether and the ether layer discarded. The aqueous layer was acidified and extracted with ether. The combined ether extracts were washed with water and brine, dried ($MgSO_4$), and evaporated to give the *title compound* (**20b**) (299 mg, 93%), m.p. 62–64 °C (Found: C, 64.9; H, 6.35. $C_{12}H_{14}O_2S$ requires C, 64.8; H, 6.35%); ν_{max}(Nujol) 3 300–2 400, 3 295, 2 117, and 1 708 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.29 (1 H, dd, *J* 4.9, 2.9 Hz), 7.16 (1 H, m), 7.07 (1 H, dd, *J* 4.9, 1.3 Hz), 3.71 (1 H, t, *J* 7.8 Hz), 2.17 (2 H, td, *J* 6.8, 2.7 Hz), 2.10–2.01 (1 H, m), 1.92 (1 H, t, *J* 2.7 Hz), 1.85–1.77 (1 H, m), 1.58–1.49 (2 H, m), and 1.44–1.36 (2 H, m); (CO_2H not observed); *m/z* 222 (M^+, 12%), 177 (31), 142 (47), and 97 (100).

4-(*Hex*-5-*ynyl*)-1-*methylthieno*[2,3-c]*pyran*-3-*one* (**21b**).—Boron trifluoride–diethyl ether (0.19 ml, 1.54 mmol) was added dropwise to a stirred solution of 2-(3-thienyl)oct-7-ynoic acid (**20b**) (263 mg, 1.18 mmol) in acetic anhydride (0.45 ml, 4.77 mmol) at 0 °C. The mixture was allowed to warm to room temperature and stirred for 3 h. Water was added and the mixture extracted with ether. The combined ether extracts were washed with saturated aqueous sodium hydrogen carbonate, water, and brine, and dried ($MgSO_4$). The solvent was evaporated and the residue chromatographed [ether–light petroleum (4:1)] to give the *title compound* (**21b**) (30 mg, 10%), m.p. 105–109 °C (Found: C, 68.2; H, 5.8. $C_{14}H_{14}O_2S$ requires C, 68.3; H, 5.7%); ν_{max}(Nujol) 3 243, 1 677, 1 632, and 1 558 cm^{-1}; λ_{max}(EtOH) 223 (ε 23 049 $dm^3\ mol^{-1}\ cm^{-1}$) and 406 nm (8 481); δ_H(270 MHz; $CDCl_3$) 7.48 (1 H, d, *J* 5.9 Hz), 6.88 (1 H, d, *J* 5.6 Hz), 2.67 (2 H, t, *J* 7.1 Hz), 2.45 (3 H, s), 2.23 (2 H, td, *J* 6.8, 2.6 Hz), 1.93 (1 H, t, *J* 2.6 Hz), 1.73–1.69 (2 H, m), and 1.62–1.56 (2 H, m); *m/z* 246 (M^+, 26%), 179 (48), 151 (100), and 43 (85).

4-*Methyl*-6,7,8,9-*tetrahydronaphtho*[2,1-b]*thiophene* (**22b**).—A solution of pyran-3-one (**21b**) (24 mg, 0.097 mmol) in bromobenzene (10 ml) was refluxed for 2 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:3)] to give the *title compound* (**22b**) (14 mg, 71%), m.p. 32–33 °C (Found: C, 76.9; H, 7.3. $C_{13}H_{14}S$ requires C, 77.2; H, 7.0%); ν_{max}(Nujol) 3 098, 1 444, 758, and 688 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.43 (1 H, d, *J* 5.6 Hz), 7.38 (1 H, d, *J* 5.6 Hz), 6.91 (1 H, s), 3.02 (2 H, t, *J* 6 Hz), 2.86 (2 H, t, *J* 5.9 Hz), 2.52 (3 H, s), and 1.93–1.84 (4 H, m); *m/z* 202 (M^+, 100%), 187 (30), and 174 (61).

Preparation of 6-*Bromo*-1-*methylthieno*[3,2-c]*pyran*-3-*one*

Ethyl 5-*Bromo*-2-*thienylacetate* (**23**).—Ethyl 2-thienylacetate (3.185 g, 18.74 mmol) and *N*-bromosuccinimide (3.52 g, 19.76 mmol) in chloroform–acetic acid (1:1 v/v; 25 ml) were stirred at room temperature overnight. The mixture was diluted with an equal volume of water and the organic layer separated, washed with aqueous potassium hydroxide, water, and brine, and dried ($MgSO_4$). After evaporation of the solvent the residual oil was chromatographed [toluene–light petroleum (1:3)] to give the *title compound* (**23**) as a yellow oil (3.282 g, 70% (Found: M^+, 247.9507. $C_8H_9BrO_2S$ requires *M*, 247.9507); ν_{max}(film) 1 741 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 6.89 (1 H, d, *J* 3.7 Hz), 6.68 (1 H, dt, *J* 3.7, 1 Hz), 4.18 (2 H, q, *J* 7 Hz), 3.75 (2 H, d, *J* 1 Hz), and 1.28 (3 H, t, *J* 7 Hz); *m/z* 250 (M^+, 30%), 248 (29), 177 (96), and 175 (100).

Ethyl 3-*Acetyl*-5-*bromo*(2-*thionyl*)*acetate* (**24**).—To a solution of acetyl chloride (0.43 ml, 6.1 mmol) and tin(IV) chloride (2.85 ml, 24.4 mmol) in 1,2-dichloroethane (20 ml) under nitrogen was added a solution of ethyl 5-bromo-2-thienylacetate (**23**) (1.011 g, 4.06 mmol) in 1,2-dichloroethane (5 ml). The mixture was warmed to 50 °C, stirred for 36 h, poured into dilute hydrochloric acid, and extracted with dichloromethane. The combined dichloromethane extracts were washed with water and brine, and dried ($MgSO_4$). After evaporation of the solvent, the residue was chromatographed [ether–light petroleum (3:1)] to give the *title compound* (**24**) (448 mg, 38%), m.p. 38–42 °C (Found: C, 41.15; H, 3.55. $C_{10}H_{11}BrO_3S$ requires C, 41.25; H, 3.8%); ν_{max}(Nujol) 1 732 and 1 669 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.34 (1 H, s), 4.19 (2 H, q, *J* 7 Hz), 4.13 (2 H, s), 2.47 (3 H, s), and 1.28 (3 H, t, *J* 7 Hz); *m/z* 292/290 (M^+, 23/22%), 246/244 (80), 219/217 (77), and 43 (100).

3-*Acetyl*-5-*bromo*(2-*thienyl*)*acetic Acid* (**25**).—To a solution of compound (**24**) (375 mg, 1.29 mmol) in methanol (3 ml) was added potassium hydroxide (2M; 3 ml) dropwise with stirring and external cooling. The reaction mixture was then stirred at room temperature for 2 h. Water (20 ml) was added and the mixture extracted with ether. The aqueous phase was acidified with dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). Evaporation of solvent gave the *title compound* (**25**) (292 mg, 86%) as a brown oil which could not be purified further; ν_{max}(Nujol) 3 200–2 400br, 3 085, 1 721, and 1 664 cm^{-1}; δ_H(270 MHz; [$^2H_6$]acetone) 7.59 (1 H, s), 4.20 (2 H, s), and 2.48 (3 H, s); *m/z* 264 (M^+, 9%), 262 (M^+, 8), 246 (12), 244 (12), and 43 (100).

6-*Bromo*-1-*methylthieno*[3,2-c]*pyran*-3-*one* (**26**).—To a solution of the ester (**24**) (781 mg, 2.68 mmol) in methanol (10 ml) was added potassium hydroxide (2M; 7 ml) dropwise with stirring and external cooling. The mixture was warmed to room temperature, stirred for 1 h, diluted with water (30 ml), and extracted with ether. The mixture was acidified with dilute hydrochloric acid and extracted with ether. The combined ether extracts were washed with water and brine, and dried ($MgSO_4$). The solvent removed and the crude acid (**25**) was dissolved in acetic anhydride (25 ml), and refluxed for 3 h. The solvent was removed under reduced pressure, and ether (25 ml) added. The precipitate was collected, and washed with ether to give the *title compound* (**26**) (402 mg, 1.64 mmol, 61%), m.p. 225 °C (decomp.) (Found: C, 39.3; H, 1.9. $C_8H_5BrO_3S$ requires C, 39.2; H, 2.1%);

ν_{max}(Nujol) 1 709 cm^{-1}; λ_{max}(EtOH) 227 (ε 20 092 dm^3 mol^{-1} cm^{-1}), 291 (2 987), and 374 (1 394); δ_H(270 MHz; [$^2H_6$]DMSO) 7.48 (1 H, s), 6.57 (1 H, s), and 2.49 (3 H, s); *m/z* 246 (M^+, 85%), 244 (M^+, 87), 218 (81), 216 (79), and 43 (100).

Diels–Alder Reactions

Dimethyl 2-Bromo-4-methylbenzothiophene-5,6-dicarboxylate (**27**).—The pyrone (**26**) (39 mg, 0.16 mmol) and DMAD (45 mg, 0.32 mmol) in bromobenzene (10 ml) were refluxed for 24 h under nitrogen. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:1)] to give the *title compound* (**27**) (38 mg, 70%), m.p. 159–161 °C (Found: C, 45.6; H, 3.0. $C_{13}H_{11}BrO_4S$ requires C, 45.5; H, 3.2%); ν_{max}(Nujol) 1 737 and 1 713 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.28 (1 H, s), 7.47 (1 H, s), 3.98 (3 H, s), 3.91 (3 H, s), and 2.52 (3 H, s); *m/z* 344 (M^+, 39%), 342 (M^+, 36), 313 (72), 312 (100), 311 (68), 310 (96), 254 (55), and 252 (53).

Reaction of 6-Bromo-1-methylthieno[3,2c]*pyran-3-one with Ethyl Propiolate*.—The pyrone (**26**) (42 mg, 0.17 mmol) and ethyl propiolate (84 mg, 0.86 mmol) in bromobenzene (10 ml) were refluxed for 48 h. The solvent was evaporated and the residue chromatographed [ether–light petroleum (1:2)] to give a 1.4:1 mixture of ethyl-2-bromo-4-methylbenzothiophen-5-carboxylate (**28**) and ethyl-2-bromo-4-methylbenzothiophene-6-carboxylate (**29**) (34 mg, 66%), m.p. 35–39 °C (Found: M^+, 297.9663. $C_{12}H_{11}BrO_2S$ requires *M*, 297.9663); ν_{max}(Nujol) 3 091 and 1 718 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 8.27 (1 H, s, minor), 7.82 (1 H, d, *J* 8.5 Hz, major), 7.79 (1 H, s, minor), 7.57 (1 H, d, *J* 8.5 Hz major), 7.51 (1 H, s, major), 7.42 (1 H, s, minor), 4.35–4.44 (m, both isomers), 2.79 (3 H, s, major), 2.57 (3 H, s, minor), and 1.41 (t, *J* 7 Hz, ester CH_3, both isomers); *m/z* 300 (M^+, 100%), 298 (M^+, 98), 255 (92), 253 (89), 227 (41), and 225 (43).

Ethyl 2-Bromo-4-methyl-6-trimethylsilylbenzothiophene-5-carboxylate (**30**).—The pyrone (**26**) (47 mg, 0.19 mmol) and ethyl trimethylsilylpropynoate (98 mg, 0.58 mmol) in bromobenzene (10 ml) were refluxed for 4 days. The solvent was removed and the residue chromatographed [ether–light petroleum (1:3)] to give the *title compound* (**30**) (48 mg, 67%), m.p. 46–49 °C (Found: M^+, 370.0058. $C_{15}H_{19}BrO_2SSi$ requires *M*, 370.0059); ν_{max}(Nujol) 1 722, 1 249, and 840 cm^{-1}; δ_H(270 MHz; $CDCl_3$) 7.77 (1 H, s), 7.42 (1 H, s), 4.40 (2 H, q, *J* 7 Hz), 2.53 (3 H, s), 1.41 (3 H, t, *J* 7 Hz), and 0.32 (9 H, s); *m/z* 372 (M^+, 3%), 370 (M^+, 3), 357 (97), 355 (87), 329 (100), and 327 (98).

Acknowledgements

We thank the SERC and Rhône Poulenc for a studentship and CASE award (to P. M. J. and P. S., respectively, Dr. P. Knowles for helpful discussion, and the Royal Society of Chemistry for a Hickinbottom Fellowship (to C. J. M.).

References

1 For a review, see: U. Pindur and H. Erfanian-Abdoust, *Chem. Rev.*, 1989, **89**, 1681.
2 P. M. S. Chauhan, G. Jenkins, S. M. Walker, and R. C. Storr, *Tetrahedron Lett.*, 1988, **29**, 117; A. P. A. Crew, G. Jenkins, R. C. Storr, and M. Yelland, *ibid.*, 1990, **31**, 1491.
3 N. Münzel and A. Schweig, *Chem. Ber.*, 1988, **121**, 791.
4 D. J. Chadwick and A. Plant, *Tetrahedron Lett.*, 1987, **28**, 6085.
5 A. M. van Leusen and K. J. van den Berg, *Tetrahedron Lett.*, 1988, **29**, 2689.
6 W. Friederichsen and A. Schöning, *Heterocycles*, 1986, **24**, 307; A. Schöning and W. Friederichsen, *Tetrahedron Lett.*, 1988, **29**, 1137; *Leibigs Ann. Chem.*, 1989, 405.
7 Y. Tamura, M. Kirihara, J. Sekihachi, R. Okunaka, S. Mohri, T. Tsugoshi, S. Akai, M. Sasho, and Y. Kita, *Tetrahedron Lett.*, 1987, **28**, 3971; Y. Kita, R. Okunaka, M. Sasho, M. Taniguchi, T. Honda, and Y. Tamura, *ibid.*, 1988, **29**, 5943.
8 J. C. Scaiano, V. Wintgens, A. Bedell, and J. A. Berson, *J. Am. Chem. Soc.*, 1988, **110**, 4050; C.-K. Sha, C.-P. Tsou, and S.-L. Wang, *J. Chem. Soc., Chem. Commun.*, 1988, 320.
9 P. M. Jackson and C. J. Moody, *J. Chem. Soc., Perkin Trans. 1*, 1990, 681.
10 Part of this work has appeared in preliminary form; P. M. Jackson, C. J. Moody, and P. Shah, *Tetrahedron Lett.*, 1988, **29**, 5817.
11 C. J. Moody and P. Shah, *J. Chem. Soc., Perkin Trans. 1*, 1988, 1407.
12 C. J. Moody and K. F. Rahimtoola, *J. Chem. Soc., Perkin Trans. 1*, 1990, 673.
13 B. Caddy, M. Martin-Smith, R. K. Norris, S. T. Reid, and S. Sternhell, *Aust. J. Chem.*, 1968, **21**, 1853.
14 C. J. Moody, P. Shah, and P. Knowles, *J. Chem. Soc., Perkin Trans. 1*, 1988, 3249.

Paper 0/01546F
Received 5th *April* 1990
Accepted 2nd *May* 1990