Furo[3,4-*b*]benzofurans: synthesis and reactions

Tim Traulsen and Willy Friedrichsen

Institute of Organic Chemistry, University of Kiel, Otto-Hahn-Platz 4, D-24098 Kiel, Germany

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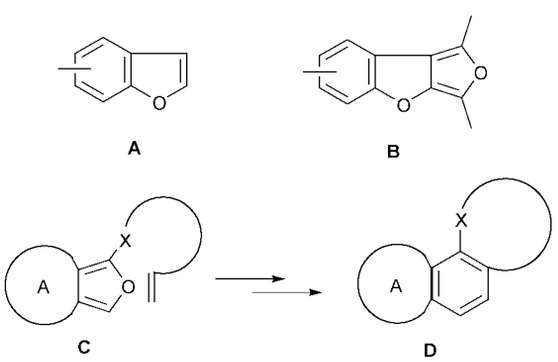
Starting with coumarin (**1**) furo[3,4-*b*]benzofuran **4** was synthesized using the Hamaguchi–Ibata methodology. *Inter*molecular Diels–Alder reactions provide compounds **5**–**8**. In a [4 + 3] cycloaddition reaction with oxyallyl compound **9** was obtained. The *C*-annulated furans **16a** (*in situ*) and **16b** have been prepared by a similar methodology starting with **10a**,**b**. In an *intra*molecular Diels–Alder reaction compounds **17a**,**b** were obtained. Computational studies concerning the reactivity of furo[3,4-*b*]benzofurans in *inter*- and *intra*molecular Diels–Alder reactions using both semiempirical (AM1, PM3) and density functional theoretical methods (B3LYP/6-31G*) are reported.

Introduction

Annulated derivatives of benzofuran **A**[1] (Scheme 1) constitute



Scheme 1

a major class of natural products. It can be expected that furo[3,4-*b*]benzofurans of type B offer the opportunity to give access to a variety of condensed benzofuran derivatives, as it is well known that *C*-annulated furans of type **C** (A = benzo,[2] furo,[3] thiopheno,[4,5] oxazolo,[6] isoxazolo,[7] thiazolo,[6b,8] indolo[4f,9] and others[2]) as more or less stable analogues of *o*-quinodimethanes[10] may serve as starting materials for the synthesis of a great variety of polycyclic systems (*e.g.*, **C**→**D**). In this paper we report on a new synthesis of furo[3,4-*b*]benzofurans[11] and some cycloaddition reactions of this system.

Preparative results

The starting material for furo[3,4-*b*]benzofuran **4** (**3a**) (Scheme 2) has been reported in the literature.[12] In our hands the preparation of this compound from coumarin **1** *via* diesters **2a** and **2b** could be improved considerably (see Experimental section). Diazo group transfer (Regitz reaction)[13] with 4-azidosulfonylbenzoic acid[14]–DBU in acetonitrile gives **3b** as citrine crystals in 77% yield. Nitrogen extrusion under the catalytic influence of $Rh_2(OAc)_4$ (Hamaguchi–Ibata reaction)[15] results in the generation of **4** as colorless crystals in 78% yield. Although less reactive than other *C*-annulated furans (see Computational results), compound **4** undergoes Diels–Alder reactions with *N*-phenylmaleimide and naphtho-1,4-quinone (ZnI_2 as Lewis catalyst)[16] to form cycloadducts **5** and **6**. With benzo-1,4-quinone compound **7** an *endo–exo* mixture is obtained. Adding ZnI_2 to the reaction mixture of **4** and benzo-1,4-quinone results in the formation of a 1:2 adduct (**8**)[17] in 35% yield. A [4 + 3] cycloaddition with oxyallyl[18,19] (generated from 2,4-dibromopentanone with NaI–Cu in acetonitrile) gave compound **9** (as *cis-endo*, *cis-exo* mixture).

*Intra*molecular cycloadditions of *C*-annulated furans offer the possibility for the preparation of a great variety of polycyclic systems.[20] Especially 2-benzofurans have been used repeatedly for this purpose.[21,22] This type of reaction has also been carried out with suitably substituted furo[3,4-*b*]benzofurans (**16a**,**b**). The starting materials are available as follows: saponification of **3a** yields **10a** which on treatment with acetyl chloride gives the corresponding anhydride **11**. Nucleophilic ring opening with methanol occurs regioselectively[23] to give monoester **12a**. The second regioisomer (**14**) has been prepared from **3a** by (regioselective) transesterification with benzylic alcohol (to **13a** with **13b** as by-product) and subsequent catalytic hydrogenation. Esterification of **14** with *O*-pentenyl-*N*,*N*′-dicyclohexylisourea[25] (to **15a**) with subsequent diazotransfer gives **15b**. Treatment of **15b** with $Rh_2(OAc)_4$ and subsequently with ZnI_2 yields **17a** (*via* **16a**, not isolated) in 47% yield. A methoxy-substituted dioxabenzo[*a*]fluorene (**17b**) was similarly accessible. Starting with dicarboxylic acid **10b**,[26] anhydride **11b** was prepared with acetyl chloride and without further purification treated with methanol to give **12b**. Esterification with *O*-pentenyl-*N*,*N*′-dicyclohexylisourea with subsequent diazo transfer gives **15d**. Treatment of this diazoester with $Rh_2(OAc)_4$ yields furo[3,4-*b*]-benzofuran **16b**, which in this case was isolated as a stable crystalline compound. The annulated furan **17b** was available in a one-step reaction from **15d** after heating with $Rh_2(OAc)_4$ and subsequent treatment with ZnI_2 in 39% yield. Obviously furo[3,4-*b*]benzofurans of type **4** and **16a**,**b** offer a convenient way to prepare condensed systems with a 1-benzofuran moiety. Although it was also possible to prepare diazoester **18b** (transesterification of **3a** with allylic alcohol and diazo group transfer with 4-azidosulfonylbenzoic acid) and **18e** (from **14** with *O*-pentenyl-*N*,*N*′-dicyclohexylisourea and subsequent diazo transfer) intramolecular cycloadditions to **20** (or related compounds) failed.

Computational results

(a) As has been pointed out in the preceding section the ring opening reaction of anhydrides **11a**,**b** with methanol occurs regioselectively to give **12a**,**b**.[23,27] From a computational point of view this result is not unexpected. If one *assumes* that in the first—fast and reversible—reaction step orthoesters of type **21** and **22** are formed (Scheme 3), then the product ratio of the

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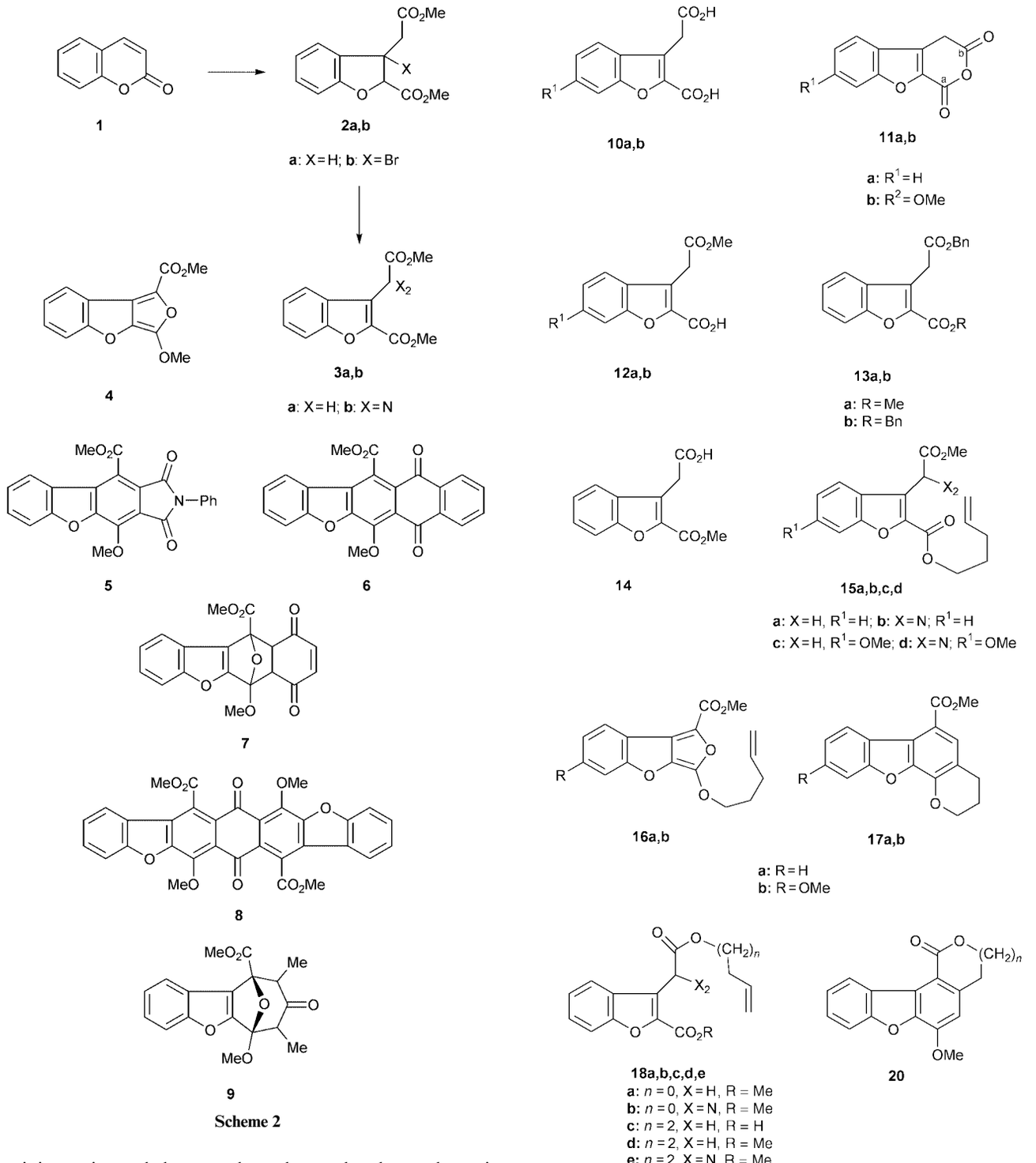


Scheme 2

regioisomeric methyl esters depends on the thermodynamic stability of **21** and **22**. An *ab initio* calculation (density functional theory, DFT)[28,29,30] reveals, that—at least for the gas phase—**21** is more stable than **22** by 6.7 kcal mol^{-1}. This result also holds for similar reactions.[22]

(b) *Qualitative* observations suggest that furo[3,4-*b*]benzofurans are *less reactive* in Diels–Alder reactions than corresponding 2-benzofurans. This is in agreement with *ab initio* studies on model systems. These computations reveal that the transition state energies (ΔE(ts)) of the *inter*molecular reactions (3) and (4) (Scheme 4) are 5 kcal mol^{-1} *higher* than those for reactions (1) and (2)[22] (Tables 1 and 2). The introduction of substituents into the diene (as in **29a**,**b**; reactions (5), (6) and (7), (8)) seems to have only a minor effect on ΔE(ts) (in contrast to the corresponding values of 2-benzofuran).[22]

A comparison of an *intra*molecular Diels–Alder reaction (*e.g.* (13), Scheme 5) with the corresponding *inter*molecular reaction (5) reveals similar transition state energies (Table 2). Additionally, the transition state energies for the *endo*-products (see *e.g.*, Fig. 1) are generally higher than those for the *exo*-products (see *e.g.*, Fig. 2). According to these results compounds **17a**,**b** are probably formed in an *exo* cycloaddition reaction with subsequent loss of water. In Table 3 the transition state geometries of reactions (1)–(16) are given. As can be seen from these values AM1 and PM3 calculations[24] give more tightly bound transition states than the B3LYP/6-31G* methodology.[31] In line with these results AM1 and PM3 transition state energies are higher than the B3LYP/6-31G* values. Additionally, there is only a poor relationship between ΔE(ts)(B3LYP/6-31G*) and ΔE(ts)(PM3) (Fig. 3, $r^2 = 0.76$). Generally speaking, geometries of AM1 and PM3[24] transition states may differ considerably from *ab initio* results. If the asyn-

chronicity of the transition states (defined as $\Delta r = (r_{ac} - r_{bd})/(r_{ac} + r_{bd}) \times 100$, for a definition of a, b, c, d see Scheme 4) for DFT and PM3 results is compared, again only a poor relationship is observed (Fig. 4, $r^2 = 0.67$). For these reasons it seems inappropriate to carry out single point *ab initio* calculations of transition state geometries, which have been optimized on a semiempirical (*e.g.*, PM3) level.[32,33]

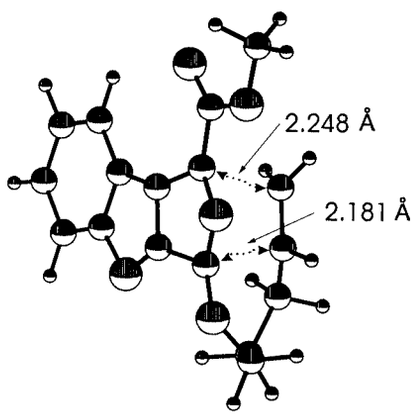
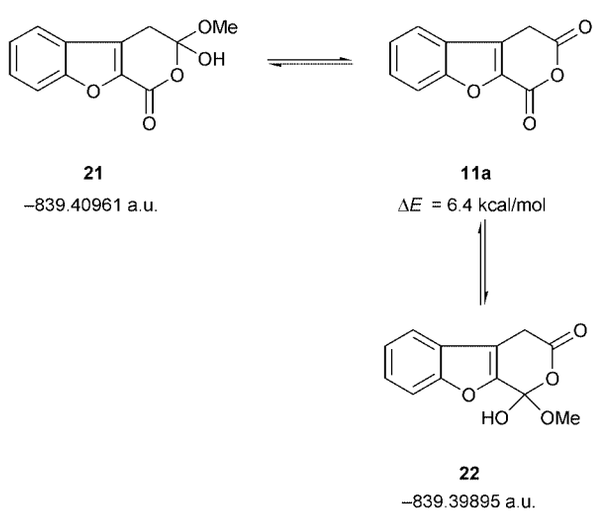


Fig. 1 Transition state geometry for reaction (14) (B3LYP/6-31G*).



Scheme 3 Results of *ab initio* calculations (DFT; B3LYP/6-31G*).[28]

Table 1 DFT[28] energies (E)[a,b] for **26**–**40** and transition state energies [E(ts)] of reactions (1)–(16)[c] (in arbitrary units)

Compound	E	Reaction	E(ts)
26	−535.07523	(3)	−613.62985
27	−613.68988	(4)	−612.36434
28	−612.43004	(5)	−956.03358
29a	−877.47973	(6)	−954.76995
29b	−877.48298	(7)	−956.03362
30a	−956.08503	(8)	−954.76984
30b	−956.08331	(9)	−805.57739
31a	−954.82645	(10)	−805.57406
31b	−954.82529	(11)	−805.58270
32	−805.61808	(12)	−805.56911
33	−805.63839	(13)	−1033.46464
34	−805.63116	(14)	−1033.45053
35a	−805.61660	(15)	−1185.88490
35b	−1033.49992	(16)	−1185.88306
36a	−805.64314		
36b	−1033.51541		
37a	−805.62797		
37b	−1033.50005		
38	−1185.92821		
39	−1185.93879		
40	−1185.92628		

[a] B3LYP/6-31G*. [b] Ethylene: −78.5876 arbitrary units, acetylene: −77.32565 arbitrary units. [c] For computational reasons the Hesse matrix of the transition states has been calculated only for selected examples. In all cases only one negative eigenvalue was found.

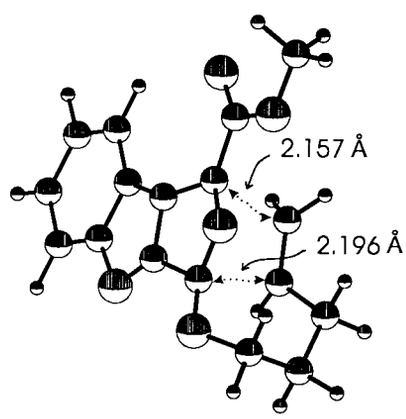
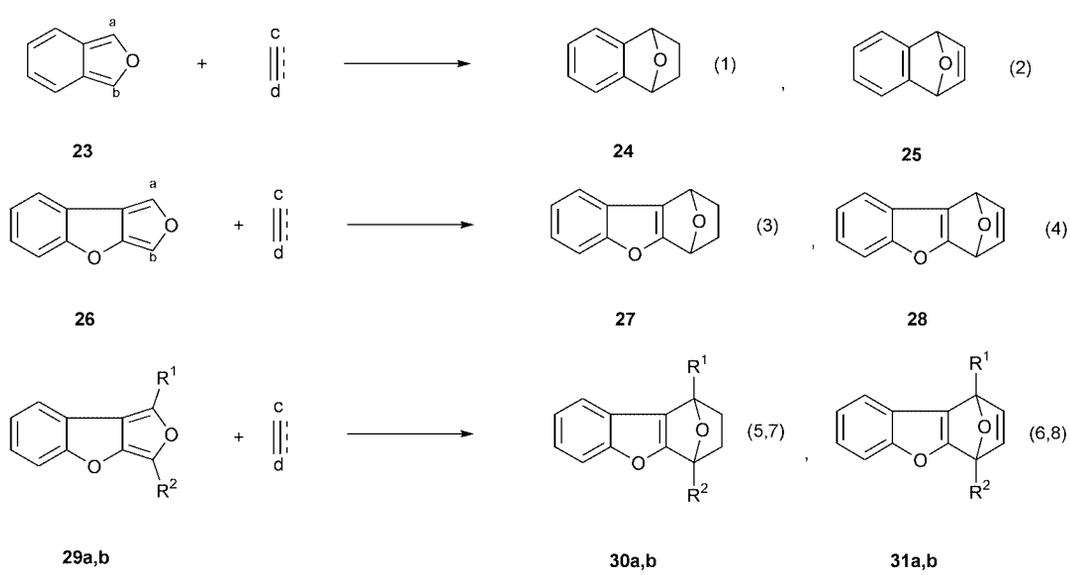


Fig. 2 Transition state geometry for reaction (13) (B3LYP/6-31G*).



a: R^1=CO_2Me, R^2=OMe; **b**: R^1=OMe, R^2=CO_2Me

Scheme 4

Experimental

All mps were determined on a Dr Tottoli melting point apparatus and are uncorrected. IR spectra were recorded on a Perkin-Elmer FTIR 1600 spectrophotometer. NMR spectra: Bruker DRX 500 (500 MHz: FT ^{1}H NMR; 125 MHz: ^{13}C NMR); Bruker AM 300 (300 MHz: FT ^{1}H NMR; 75 MHz: ^{13}C NMR); Bruker AC 200 (200 MHz: FT ^{1}H NMR; 50 MHz: ^{13}C NMR); internally referenced on Me_4Si ($CDCl_3$) or DMSO ([D_6]-DMSO). *J* values are given in Hz. UV spectra: Zeiss DMR 10 spectrophotometer; mass spectra: Finnigan MAT 8230 mass spectrometer by using 70 eV ionization potential (EI) or the chemical ionization (CI) (isobutane (2-methylpropane)) method. Radial chromatography was carried out with a Harrison-Research Chromatotron on silica gel PF_{245} (Merck, Darmstadt).

Table 2 Reaction energies (ΔE) and transition state energies [ΔE(ts)] for reactions (1)–(16) (DFT[28] results;[a] AM1 and PM3 results in parentheses); all values in kcal mol^{-1}

Reaction	ΔE[b]	ΔE(ts)[c]
(1)	−29.8 (−34.8, −32.5)	15.4 (20.2, 25.2)
(2)	−34.4 (−28.9, −28.3)	17.8 (28.2, 30.5)
(3)	−17.1 (−19.2, −17.1)	20.6 (27.2, 30.9)
(4)	−18.3 (−12.3, −12.7)	22.9 (35.7, 36.4)[d]
(5)	−11.2 (−17.7, −15.0)	21.1 (25.8, 30.3)
(6)	−13.2 (−10.5, −10.3)	22.2 (34.1, 36.3)
(7)	−8.1 (−13.4, −14.0)	23.1 (28.6, 29.9)
(8)	−10.5 (−6.4, −9.4)	24.3 (36.9, 36.0)
(9)	−12.7 (−14.4, −11.3)	25.5 (30.3, 35.7)
(10)	−8.2 (−6.7, −6.7)	27.6 (33.9, 35.8)
(11)	−22.9 (−15.2, −14.8)	21.3 (29.2, 31.7)
(12)	−7.1 (−6.2, −5.8)	29.8 (35.9, 38.7)
(13)	−9.7 (−11.1, −14.3)	22.1 (30.3, 30.1)
(14)	−0.1 (−2.4, −5.2)	31.0 (37.1, 37.2)
(15)	−6.6 (−12.1, −13.0)	27.2 (31.9, 33.9)
(16)	1.2 (−2.5, −4.5)	28.3 (34.4, 35.7)

[a] B3LYP/6-31G*. [b] ΔE = *E*(product) − *E*(reactant). [c] Energy difference between the initial state and the transition state. [d] ΔE(ts) = 16.8 kcal mol^{-1} (B3LYP/6-31G*//PM3).

Materials

All solvents were dried or purified using standard procedures.

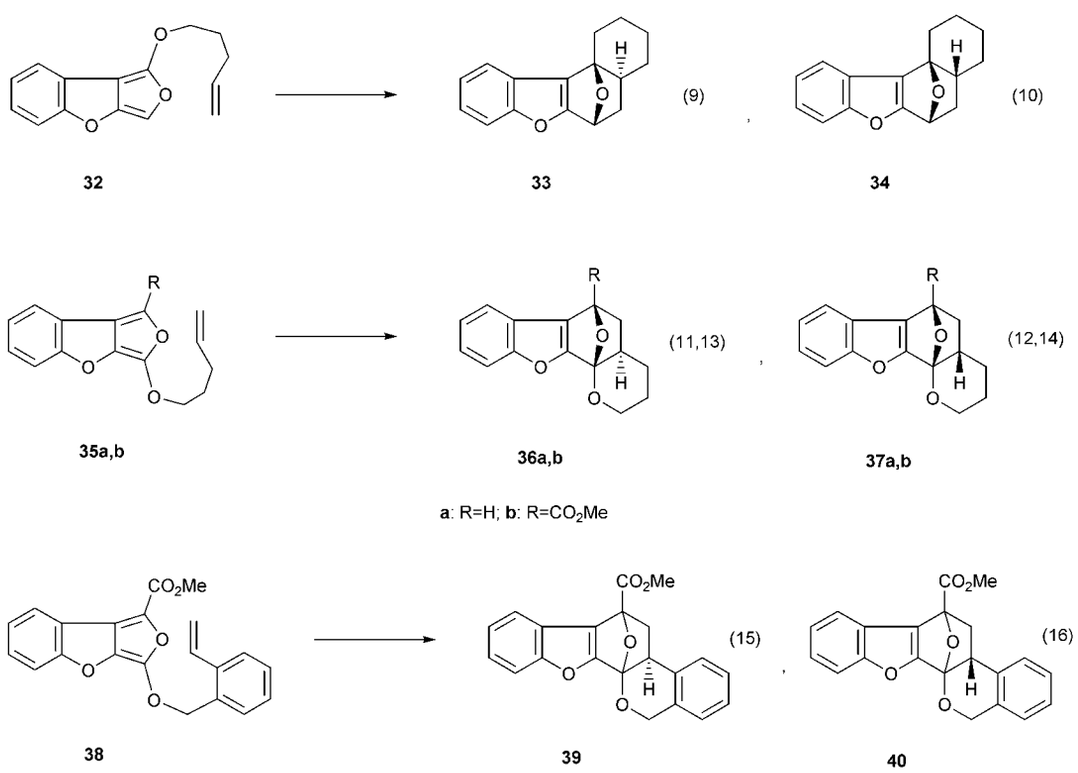
3-(2-Methoxycarbonylmethoxyphenyl)acrylic acid methyl ester

Coumarin **1** (14.6 g, 100 mmol) was added to a solution of 2.4 g (104 mmol) sodium in 35 ml dry methanol. After refluxing for 10 min, 16.0 g (105 mmol) of bromoacetic acid methyl ester was added dropwise and refluxing was continued for a further 3.5 h. The reaction mixture was cooled down to room temperature, poured into 200 ml of ice–water and was left to stand overnight. The organic layer was separated and the aqueous phase was extracted four times with diethyl ether. The combined organic phases were dried with sodium sulfate, evaporated and the residue distilled under reduced pressure (bp 170 °C, 0.04 mbar). The product (19.4 g, 77%) was obtained as a yellowish oil. It could also be purified by recrystallization from dry

Table 3 Transition state geometries for reactions (1)–(16) (B3LYP/6-31G*, AM1, PM3)

Reaction	r_1[a,b]	r_2[a,b]
(1)	2.260 (2.146, 2.188)	2.260 (2.146, 2.188)
(2)	2.277 (2.101, 2.138)	2.277 (2.101, 2.138)
(3)	2.163 (2.071, 2.123)	2.229 (2.103, 2.138)
(4)	2.181 (2.012, 2.081)	2.245 (2.088, 2.092)
(5)	2.189 (2.142, 2.170)	2.169 (2.060, 2.145)
(6)	2.223 (2.155, 2.122)	2.166 (1.966, 2.095)
(7)	2.120 (2.026, 2.125)	2.209 (2.153, 2.167)
(8)	2.128 (1.919, 2.080)	2.236 (2.197, 2.117)
(9)	2.263 (2.169, 2.195)	2.169 (2.050, 2.122)
(10)	2.102 (2.059, 2.123)	2.264 (2.096, 2.144)
(11)	2.157 (2.058, 2.130)	2.308 (2.163, 2.196)
(12)	2.211 (2.086, 2.129)	2.173 (2.091, 2.154)
(13)	2.185 (2.105, 2.157)	2.181 (2.104, 2.167)
(14)	2.248 (2.145, 2.157)	2.077 (2.032, 2.127)
(15)	2.244 (2.152, 2.194)	2.145 (2.071, 2.139)
(16)	2.127 (2.059, 2.137)	2.143 (2.107, 2.150)

[a] Values in Å. [b] Values in parentheses: results of AM1 and PM3 calculations.[24]



Scheme 5

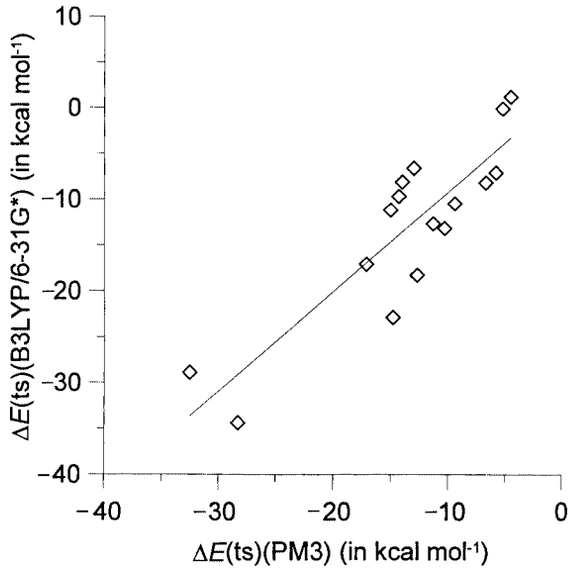


Fig. 3 ΔE(ts)(B3LYP/6-31G*) *vs.* ΔE(ts)(PM3); ΔE(ts)(B3LYP/6-31G*) = 1.084 × ΔE(ts)(PM3) + 1.579 (r^2 = 0.76).

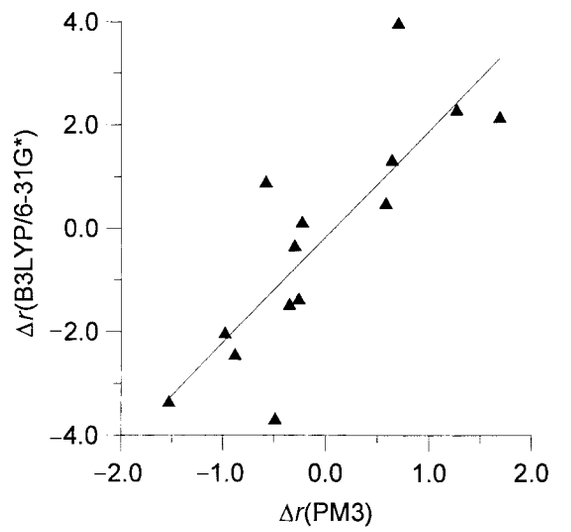


Fig. 4 Δr(B3LYP/6-31G*) *vs.* Δr(PM3); Δr(B3LYP/6-31G*) = 2.044 × Δr(PM3) − 0.169 (r^2 = 0.67) ($\Delta r = (r_{ac} - r_{bd})/(r_{ac} - r_{bd}) \times 100$).

methanol. On cooling to −20 °C 20.2 g (80%) of colorless crystals with mp 64 °C (70 °C)[34] were obtained.

ν_{max}/cm^{-1} 1758 (C=O, s), 1631 (C=C, s), 1599 (m), 1576 (m), 764 (s); λ_{max}(EtOH)/nm (log ε) 212 (4.218), 223 (4.172), 275 (4.226), 320 (3.491); δ_H(200 MHz; $CDCl_3$) 3.81 (s, 3H, CH_2-CO_2-CH_3), 3.82 (s, 3H, CH-CO_2-CH_3), 4.72 (s, 2H, CH_2), 6.66 (d, 1H, C1-CH=CH, *J* 16.36), 6.78 (dd, 1H, C5-H, J_1 0.85, J_2 8.42), 7.01 (ddd, 1H, C4-H, J_1 0.79, J_2 7.39, J_3 7.39), 7.32 (ddd, 1H, C3-H, J_1 1.59, J_2 7.69, J_3 8.18), 7.53 (dd, 1H, C6-H, J_1 1.71, J_2 7.81), 8.03 (d, 1H, C1-H, *J* 16.36); δ_C(50 MHz; $CDCl_3$) 54.93 (q, CH_2-CO_2-CH_3), 55.64 (q, CH-CO_2-CH_3), 68.78 (t, CH_2), 115.34 (d, C6), 122.47 (d, C5), 125.17 (d, C4), 127.28 (s, C1), 132.76 (d, CH=CH-CO_2), 134.60 (d, C6), 143.22 (d, CH=CH-CO_2), 159.79 (s, C2), 171.27 (s, CH_2-CO_2-CH_3), 172.27 (s, CH-CO_2-CH_3); *m/z* 250 (29%, M^+), 219 (14), 161 (100), 131 (44); $C_{13}H_{14}O_5$ requires: 250.08412. Found: 250.08390 (MS).

3-Methoxycarbonylmethyl-2,3-dihydrobenzofuran-2-carboxylic acid methyl ester 2a

A solution of 360 mg (16 mmol) sodium in 7 ml dry methanol was added dropwise at room temperature to a stirred solution of 19.4 g (77 mmol) 3-(2-methoxycarbonylmethoxyphenyl)-acrylic acid methyl ester in 40 ml of dry methanol. The yellow mixture was heated for 15 min to 70 °C, cooled down to 0 °C and poured into 100 ml of water. The mixture was acidified with 2 M acetic acid and extracted three times with diethyl ether. The ethereal layers were washed once with conc. sodium bicarbonate solution, water and a saturated sodium chloride solution, dried with magnesium sulfate and evaporated. The viscous yellowish residue could be purified by distillation (bp 155 °C, 0.04 mbar) or by recrystallization from dry methanol to provide 13.1 g (68%) colorless crystals with mp 53 °C.

ν_{max}/cm^{-1} 1735 (C=O, s), 1479 (C=C, s); λ_{max}(EtOH)/nm (log ε) 212 (3.772), 277 (3.503), 283 (3.454); δ_H(200 MHz; $CDCl_3$) 2.77 (dd, 1H, C3-CH_2, J_1 5.45, J_2 1.34), 2.80 (d, 1H, C3-CH_2, *J* 0.98), 3.73 (s, 3H, CH_2-CO_2-CH_3), 3.81 (s, 3H, C2-CO_2-CH_3), 4.05 (dt, 1H, C3-H, J_1 6.67, J_2 6.50), 4.94 (d, 1H, C2-H, *J* 6.50), 6.84–6.98, 7.10–7.25 (2m, 4H, C4-H, C5-H, C6-H, C7-H); δ_C(50 MHz; $CDCl_3$) 42.77 (t, CH_2), 46.30 (d, C3), 55.37 (q, CH_2-CO_2-CH_3), 56.08 (q, C2-CO_2-CH_3), 87.49 (d, C2), 113.52 (d, C7), 124.97 (d, C4), 127.71 (d, C5), 130.88 (s, C3a), 132.60 (d, C6), 162.11 (s, C7a), 174.29 (s, CH_2-CO_2-CH_3), 174.91 (s, C2-CO_2-CH_3); *m/z* 250 (21%, M^+), 191 (21), 190 (36), 177 (81), 131 (100); $C_{13}H_{14}O_5$ requires: 250.08441. Found: 250.08510 (MS).

3-Bromo-3-methoxycarbonylmethyl-2,3-dihydrobenzofuran-2-carboxylic acid methyl ester 2b

To a solution of 10.1 g (40 mmol) **2a** in 250 ml of dry tetrachloromethane was added 7.6 g (43 mmol) of *N*-bromosuccinimide. The radical reaction was started by adding a trace of dibenzoyl peroxide. The mixture was refluxed for 5 h under dry conditions. After cooling down to 0 °C the mixture was filtered and evaporated under reduced pressure. The viscous orange residue was taken up in ethyl acetate, refluxed for 5 min with active charcoal, filtered and evaporated. The colorless oily raw product was crystallized from 100 ml of dry methanol at −20 °C to yield 10.6 g (80%) of **2b** as colorless crystals with mp 84 °C.

ν_{max}/cm^{-1} 1732 (C=O, s), 1711 (C=O, s), 750 (s); λ_{max}(EtOH)/nm (log ε) 203 (4.296), 220 (4.186), 275 (4.424), 285 (sh, 4.082); δ_H(300 MHz; $CDCl_3$) 2.20 (s, 1H, C2-H), 3.73 (s, 3H, CH_2-CO_2-CH_3), 3.99 (s, 3H, C2-CO_2-CH_3), 4.19 (s, 2H, C3-CH_2), 7.33 (ddd, 1H, C5-H, J_1 0.99, J_2 7.05, J_3 8.01), 7.48 (ddd, 1H, C6-H, J_1 1.31, J_2 7.07, J_3 8.39), 7.58 (ddd, 1H, C7-H, J_1 0.91, J_2 0.91, J_3 8.29), 7.64 (ddd, 1H, C4-H, J_1 0.76, J_2 1.31, J_3 7.93); δ_C(50 MHz; $CDCl_3$) 29.90 (t, CH_2), 52.31 (q, CH_2-CO_2-CH_3), 55.32 (q, C2-CO_2-CH_3), 112.35 (d, C7), 121.23 (d, C4), 122.13 (s, C3), 123.69 (d, C5), 127.91 (m, C3a), 128.11 (d, C6), 141.66 (s, C2), 154.40 (s, C7a), 160.35 (s, CH_2-CO_2-CH_3), 170.27 (s, C2-CO_2-CH_3); *m/z* 249 (100%, M^+), 250 (14), 251 (5).

3-Methoxycarbonylmethylbenzofuran-2-carboxylic acid methyl ester 3a

A solution of 1.17 g (1.2 ml, 7.7 mmol) DBU in 0.8 ml dry dichloromethane was added dropwise at room temperature under nitrogen to a stirred solution of 2.48 g (7.6 mmol) **2b** in 10 ml of dry dichloromethane. The reaction mixture was stirred for about 1.5 h and afterwards subjected to column filtration on silica gel. The filtrate was evaporated and the colorless oily residue taken up with 15 ml of dry methanol. The product **3a** precipitated at room temperature as colorless crystals (1.83 g, 97%) with mp 82 °C.

ν_{max}/cm^{-1} 1732 (C=O, s), 1712 (C=O, s), 750 (s); λ_{max}(EtOH)/nm (log ε) 203 (4.281), 220 (4.127), 275 (4.354), 284 (sh, 4.300); δ_H(200 MHz; $CDCl_3$) 3.72 (s, 3H, CH_2-CO_2-CH_3), 3.99 (s, 3H, C2-CO_2-CH_3), 4.19 (s, 2H, C3-CH_2), 7.26 (ddd, 1H, C5-H, J_1 0.98, J_2 7.08, J_3 7.81), 7.41 (ddd, 1H, C6-H, J_1 1.34, J_2 6.96, J_3 8.30), 7.52 (d, C7-H, *J* 8.06), 7.58 (d, C4-H, *J* 7.81); δ_C(75 MHz; $CDCl_3$) 29.91 (t, CH_2), 52.29 (q, CH_2-CO_2-CH_3), 52.31 (q, C2-CO_2-CH_3), 112.35 (d, C7), 121.21 (d, C4), 122.22 (s, C3), 123.73 (d, C5), 127.88 (s, C3a), 128.08 (d, C6), 141.66 (s, C2),

154.40 (s, C7a), 160.33 (s, CH_2-CO_2-CH_3), 170.25 (s, C2-CO_2-CH_3); *m*/*z* 248 (48%, M^+), 216 (100), 189 (48), 188 (20), 159 (28); $C_{13}H_{12}O_5$ requires: 248.06847. Found: 248.06830 (MS).

3-[Diazo(methoxycarbonyl)methyl]benzofuran-2-carboxylic acid methyl ester 3b

A solution of 426 mg (4.17 ml, 2.8 mmol) DBU in 10 ml dry acetonitrile was added dropwise under nitrogen at room temperature to a well-stirred suspension of 318 mg (1.4 mmol) 4-azidosulfonylbenzoic acid and 306 mg (1.2 mmol) **3a** in 40 ml dry acetonitrile. The yellow solution was stirred at room temperature for 14 h, 40 ml of acetonitrile was evaporated under reduced pressure and the oily orange residue purified by column chromatography on silica gel with ether–pentane (1 : 1). The solvent was evaporated and the residue recrystallized from dry methanol to yield 260 mg (77%) yellow crystals with mp 121 °C (decomp.).

ν_{max}/cm^{-1} 2125 (C=N_2, s), 1714 (C=O, s), 753 (s); λ_{max}(EtOH)/nm (log ε) 220 (4.232), 260 (4.297), 293 (4.183), 395 (1.785); δ_H(300 MHz; $CDCl_3$) 3.89 (s, 3H, CH_2-CO_2-CH_3), 4.03 (s, 3H, C2-CO_2-CH_3), 7.34 (ddd, 1H, C5-H, J_1 1.09, J_2 7.00, J_3 8.06), 7.51 (ddd, 1H, C6-H, J_1 1.34, J_2 7.05, J_3 8.41), 7.58 (ddd, 1H, C7-H, J_1 0.86, J_2 1.01, J_3 8.39), 7.70 (d, 1H, C4-H, *J* 7.98); δ_C(75 MHz; $CDCl_3$) 52.39 (q, CH_2-CO_2-CH_3), 52.65 (q, C2-CO_2-CH_3), 73.98 (s, CN), 112.31 (d, C7), 115.17 (s, C3), 123.35 (d, C4), 123.89 (d, C5), 126.70 (s, C3a), 128.54 (d, C6), 138.95 (s, C2), 154.64 (s, C7a), 159.36 (s, CH_2-CO_2-CH_3), 165.09 (s, C2-CO_2-CH_3); *m*/*z* 274 (11%, M^+), 246 (41), 203 (100), 173 (38); $C_{13}H_{10}N_2O_5$ requires: 274.05900. Found: 274.05896 (MS).

1-Methoxy-2,8-dioxacyclopenta[*a*]indene-3-carboxylic acid methyl ester 4

A mixture of 305 mg (1.1 mmol) **3b** and 10 mg (0.023 mmol) dirhodium tetraacetate was refluxed in 25 ml dry toluene until the yellow color of the diazo compound completely disappeared. The progress of the cyclization reaction could also be monitored by TLC chromatography with ether–pentane (1 : 1). The solvent was evaporated, the residue taken up in ether–pentane (1 : 1) and filtered through a short column of silica gel to separate it from the catalyst. The filtrate was evaporated and the residue recrystallized from dry methanol to give 214 mg (78%) of compound **4** as colorless needles with mp 164 °C.

ν_{max}/cm^{-1} 1716 (C=O, s), 1669 (s), 1565 (s), 1299 (s), 1199 (s), 1145 (s), 1027 (s), 774 (m), 754 (m); λ_{max}(CH_3CN)/nm (log ε) 240 (3.771), 265 (sh, 3.582), 310 (3.582); δ_H(300 MHz; $CDCl_3$) 3.98 (s, 3H, CO_2-CH_3), 4.23 (s, 3H, O-CH_3), 7.31 (ddd, 1H, C5-H, J_1 1.06, J_2 7.28, J_3 7.73), 7.39 (ddd, 1H, C6-H, J_1 0.63, J_2 1.09, J_3 8.41), 7.49 (ddd, 1H, C7-H, J_1 1.41, J_2 7.23, J_3 8.49), 8.05 (dd, 1H, C4-H, J_1 0.81, J_2 7.68); δ_C(75 MHz; $CDCl_3$) 51.65 (q, OCH_3), 59.41 (q, CO_2CH_3), 112.19 (dd, C7), 119.09 (ddd, C3b), 120.05 (s, C8a), 123.39 (dd, C4), 124.89 (dd, C5), 127.53 (s, C3a), 129.85 (dd, C6), 130.05 (s, C1), 141.60 (s, C3), 158.58 (q, C7a), 164.19 (s, CO_2Me); *m*/*z* 246 (63%, M^+), 203 (100), 173 (27), 88 (25); $C_{13}H_{10}O_5$ requires: 246.05283. Found: 246.05280 (MS).

10-Methoxy-1,3-dioxo-2-phenyl-2,3-dihydro-1*H*-9-oxa-2-aza-cyclopenta[*b*]fluorene-4-carboxylic acid methyl ester 5

To a solution of 415 mg (2.4 mmol) of *N*-phenylmaleimide in 20 ml dry toluene 10 mg (0.023 mmol) of dirhodium tetraacetate was added. The mixture was heated to 80 °C and a solution of 165 mg (0.6 mmol) **3b** in 20 ml dry toluene was added slowly under nitrogen. After the complete addition of the diazo compound **3b** the reaction mixture was cooled down to room temperature and stirred for a further 36 h. The solvent was evaporated and the residue taken up with ethyl acetate. The insoluble solid was collected and recrystallized from toluene to yield 169 mg (70%) of yellow crystals with mp 273 °C.

ν_{max}/cm^{-1} 1763 (C=O, s), 1717 (s), 1663 (s), 1247 (m), 750 (s); λ_{max}(EtOH)/nm (log ε) (sh, 4.583), 220 (4.531), 272 (4.392), 345 (3.936); δ_H(300 MHz; $CDCl_3$) 4.13 (s, 3H, CO_2-CH_3), 4.56 (s, 3H, O-CH_3), 7.38 (dd, 1H, C6-H, J_1 7.03, J_2 2.96), 7.41–7.51 (m, 5H, N-Ph), 7.61 (dd, 1H, C7-H, J_1 7.82, J_2 1.23), 7.68 (d, 1H, C8-H, *J* 8.37), 7.98 (d, 1H, C5-H, *J* 8.03); δ_C(125 MHz; $CDCl_3$) 53.28 (s, CO_2-CH_3), 62.54 (s, O-CH_3), 112.43 (dd, C8), 117.22 (s, C10a), 118.64 (s, C3a), 121.84 (s, C4a), 123.13 (d, C5), 124.46 (d, C6), 125.31 (s, N-C1′), 126.82 (d, C2′), 128.81 (d, C3′), 128.39 (s, C4b), 129.09 (d, C3′), 130.06 (d, C7), 131.89 (s, C4), 144.99 (s, C10), 149.77 (s, C9a), 157.70 (s, C8a), 164.54 (s, C1), 165.11 (s, C3), 165.93 (s, CO-CH_3); *m*/*z* 401 (100%, M^+), 386 (10), 370 (19), 342 (20); $C_{23}H_{15}NO_6$ requires: 401.08994. Found: 401.08977 (MS).

12-Methoxy-6,11-dioxo-6,11-dihydro-13-oxaindeno[1,2-*b*]-anthracene-5-carboxylic acid methyl ester 6

A solution of 308 mg (1.3 mmol) of compound **4** in 20 ml dry dioxane was added at 100 °C under nitrogen to a mixture of 198 mg (1.3 mmol) naphtho-1,4-quinone and 399 mg (1.3 mmol) of zinc iodide in 20 ml dry dioxane. After further stirring for 30 min the reaction mixture was allowed to cool down to room temperature. The precipitated crystals were collected, washed with 1 M hydrochloric acid and water and dried under reduced pressure over diphosphorus pentaoxide. The reaction yielded 391 mg (79%) of **6** as yellow crystals with mp 260 °C.

ν_{max}/cm^{-1} 1723 (C=O, s), 1671 (s), 1371 (s), 1258 (s); λ_{max}(CH_3CN)/nm (log ε) 215 (3.770), 245 (3.638), 290 (3.994), 375 (3.078); δ_H(500 MHz; $CDCl_3$) 4.22 (s, 3H, CO_2-CH_3), 4.42 (s, O-CH_3), 7.44 (dd, 1H, C3-H, J_1 7.57, J_2 0.73), 7.63 (ddd, 1H, C2-H, J_1 8.37, J_2 7.19, J_3 1.17), 7.70 (d, 1H, C1-H, *J* 8.36), 7.76 (dd, 1H, C8-H, J_1 7.45, J_2 1.51), 7.80 (dd, 1H, C9-H, J_1 7.44, J_2 1.51), 7.89 (d, 1H, C4-H, *J* 7.45), 8.24 (dd, 1H, C10-H, J_1 7.51, J_2 1.34), 8.29 (dd, 1H, C7-H, J_1 7.61, J_2 1.09); δ_C(125 MHz; $CDCl_3$) 53.31 (q, CO_2CH_3), 62.17 (q, O-CH_3), 112.42 (d, C1), 121.56 (s, C4b), 122.60 (d, C4), 123.51 (s, C5a), 123.81 (s, C11a), 124.45 (d, C3), 127.04 (d, C10), 127.24 (d, C7), 127.50 (s, C10a), 127.55 (s, C4a), 130.23 (d, C2), 132.46 (s, C6a), 133.68 (d, C8), 134.47 (d, C9), 134.93 (s, C5), 147.30 (s, C12), 150.95 (s, C12a), 157.50 (s, C13a), 168.94 (s, CO_2Me), 182.11 (s, C6), 182.45 (s, C11); *m*/*z* 386 (100%, M^+), 355 (27), 327 (27), 299 (23); $C_{23}H_{14}O_6$ requires: 386.07904. Found: 386.07890 (MS).

6,11-Epoxy-6-methoxy-7,10-dioxo-7,10-dihydrobenzo[*b*]-naphtho[2,3-*d*]furan-11-carboxylic acid methyl ester 7

A solution of 35.3 mg (0.3 mmol) benzo-1,4-quinone in 10 ml dry toluene was added at 50 °C dropwise to a solution of 78.8 mg (0.3 mmol) **4** in 10 ml dry toluene. The reaction mixture was stirred at 50 °C for 2.5 h and for a further 16 h at room temperature. The solvent was evaporated under reduced pressure at 50 °C, the residue taken up with dichloromethane and subjected to column chromatography on alumina. The excess of benzo-1,4-quinone and by-products of the reaction were eluted with dichloromethane, whereas the product **7** was eluted with ethyl acetate. After evaporation of the solvent an *endo–exo*-mixture of **7** was obtained. Yellow crystals (11 mg, 10%) with mp 158–160 °C.

ν_{max}/cm^{-1} 1734 (C=O, s), 1661 (s), 1342 (m), 1304 (s), 1256 (m), 743 (w); λ_{max}(EtOH)/nm (log ε) 226 (4.020), 285 (4.073); δ_H(300 MHz; $CDCl_3$) (signals marked with * and ** could not be clearly assigned and could be interchanged) 3.49 (q, J_{AB} 7.73), 3.69, 3.97, 4.16, 4.39 (4s, OCH_3), 6.09 (q, J_{AB} 10.47), 6.92 (s, 1H, C8-H*, C9-H**), 6.93 (s, 1H, C8-H*, C9-H**), 7.28–7.88 (m, 4H, C1-H, C2-H, C3-H, C4-H); δ_C(75 MHz; $CDCl_3$) 52.96 [53.36] (CO_2CH_3), 53.96 [62.08] (C6-OCH_3), 112.42 [112.65] (C4), 122.53 [122.53] (C1), 124.41 [124.51] (C2), 121.27 [121.43] (C6), 123.03 [125.98] (C11), 122.53 [122.89] (C10a), 124.41 [124.51] (C6a), 127.28 [127.74] (C11b), 136.73 [137.76] (C9), 138.73 [140.94] (C8), 145.36 [146.84] (C5a), 150.33

[154.43] (C11a), 157.41 [158.80] (C4a), 168.50 [169.20] (C11-CO_2CH_3), 183.67 [184.13] (C10), 190.06 [192.11] (C7); *m*/*z* 354 (100%, M^+), 336 (63), 295 (85).

8,16-Dimethoxy-7,15-dihydro-7,15-dioxo-anthra[2,3-*b*:6,7-*b*′]-bis[1]benzofuran-6,14-dicarboxylic acid dimethyl ester 8

A solution of 313 mg (1.3 mmol) **4** in 20 ml of dry dioxane was added dropwise at 100 °C to a mixture of 137 mg (1.3 mmol) benzo-1,4-quinone and 406 mg (1.3 mmol) of zinc iodide in 20 ml of dry dioxane. After complete addition the reaction mixture was kept at this temperature for 10 min, the solvent was evaporated and the residue taken up with ethyl acetate. The insoluble yellow solid was collected and recrystallized from dry toluene to yield 25 mg (35%) yellow crystals which decomposed at about 320 °C.

ν_{max}/cm^{-1} 1720 (C=O, s), 1339 (s), 1239 (s), 1207 (s), 1006 (m), 749 (m); λ_{max}(CH_3CN)/nm (log ε) 218 (3.718), 306 (3.956), 385 (3.113); δ_H(500 MHz; $CDCl_3$) 4.21 (s, 6H, C5-CO_2-CH_3, C13-CO_2-CH_3), 4.39 (s, 6H, C7-O-CH_3, C15-O-CH_3), 7.44 (dd, 2H, C3-H, C11-H, J_1 7.50, J_2 0.76), 7.63 (dd, 2H, C2-H, C10-H, J_1 7.79, J_2 1.30), 7.70 (d, 2H, C1-H, C9-H, J 8.25), 7.95 (d, 2H, C4-H, C12-H, J 7.33); δ_C(125 MHz; $CDCl_3$) 53.31 (C5-CO_2CH_3, C13-CO_2CH_3), 62.37 (C7-O-CH_3, C15-O-CH_3), 112.38 (C1, C9), 121.64 (C4b, C12b), 122.78* (C4, C12), 122.78* (C14a, C6a), 122.93 (C5a, C13a), 124.37 (C3, C11), 127.89 (d, C4a, C12a), 130.24 (C2, C10), 135.46 (C5, C13), 146.80 (C7, C15), 150.13 (C6a, C15a), 157.59 (C16a, C8a), 168.69 (C5-CO_2CH_3, C13-CO_2CH_3), 181.57 (C6, C14); *m*/*z* 564 (94%, M^+), 534 (37), 532 (100), 504 (57), 502 (53).

5,9-Epoxy-9-methoxy-6,8-dimethyl-7-oxo-6,7,8,9-tetrahydro-10-oxabenzo[*a*]azulene-5-carboxylic acid methyl ester 9

Copper powder (1.55 g, 24 mmol) and 4.87 g (33 mmol) of sodium iodide were suspended in a solution of 2.00 g (8 mmol) **4** in 50 ml of dry acetonitrile. Within 15 min a solution of 4.95 g (20 mmol) 2,4-dibromopentan-3-one in 20 ml acetonitrile was added at room temperature under nitrogen. The mixture was stirred for a further 16 h at room temperature, 100 ml of dichloromethane were added, after 10 min of vigorous shaking the organic layer was separated and the aqueous phase was extracted twice with dichloromethane. The combined organic layers were washed twice with 2 M ammonia solution and once with conc. sodium hydrogen carbonate solution, and were dried with sodium sulfate and evaporated. The residue was taken up with ethyl acetate–cyclohexane (1 : 1) and filtered through a short column of silica gel. The filtrate was evaporated, taken up with ethyl acetate–cyclohexane (1 : 3) and subjected to column chromatography on silica gel to give 2.17 g (81%) of a colorless oil.

ν_{max}/cm^{-1} 1280 (s), 1241 (s), 1749 (s), 1715 (s), 1616 (w), 1442 (s), 750 (m); λ_{max}(CH_3CN)/nm (log ε) 210 (3.063), 252 (2.749); δ_H(300 MHz; $CDCl_3$) 1.06 [1.07] (d, 3H, C6-CH_3, J 5.86 [5.86]), 1.14 [1.15] (d, 3H, C8-CH_3, J 7.03 [7.03]), 3.065 [3.07] (q, 1H, C6-H, J 6.92 [6.92]), 3.13 [3.14] (q, 1H, C8-H, J 6.97 [6.92]), 3.59 [3.61] (s, 3H, C5-CO_2CH_3), 3.997 [4.00] (s, 3H, C9-OCH_3), 7.29–7.81 (m, 3H, C1-H-C4-H); δ_C(75 MHz; $CDCl_3$) 8.24 [8.29] (dq, C6-CH_3), 9.61 [9.67] (dq, C8-CH_3), 50.54 [50.63] (dq, C6), 52.99 [53.09], (q, C5-CO_2CH_3), 53.73 [53.74] (q, C9-OCH_3), 54.53 [54.53] (dq, C8), 83.17 [83.23] (s, C5), 107.79 [107.80] (s, C9), 112.80 [112.90] (d, C1), 117.35 [117.48] (m, C4b), 123.65 [123.74] (m, C4), 124.13 [124.24] (d, C3), 125.30 [125.20] (s, C4a), 128.06 [128.32] (d, C2), 159.84 [159.86] (s, C10a), 161.17 [161.29] (C9a), 168.05 [168.33] (C5-CO_2CH_3), 205.22 [205.59] (s, C7); *m*/*z* 330 (7%, M^+), 322 (25), 271 (47), 242 (100).

3-Carboxymethylbenzofuran-2-carboxylic acid 10a

A solution of 3.6 g (64 mmol) potassium carbonate in 25 ml water was added to a suspension of 1.55 g (4.7 mmol) **2b** in 25 ml methanol. The mixture was refluxed until a clear yellowish solution was obtained and left to stand at room temperature for 15 h. The alcohol was evaporated completely and the aqueous layer acidified with 5 M hydrochloric acid. The separated solid was filtered off, dried under reduced pressure over diphosphorus pentaoxide and recrystallized from glacial acetic acid. Compound **10a** was obtained as colorless crystals (581 mg, 56%) with mp 225 °C (decomp.).

ν_{max}/cm^{-1} 2920 (s), 1720 (s), 1767 (s); λ_{max}(CH_3CN)/nm (log ε) 220 (3.756), 273 (3.976), 282 (sh, 3.905); δ_H(200 MHz; $CDCl_3$) 4.12 (s, 2H, C3-CH_2), 7.37 (dd, 1H, C5-H, J_1 6.94, J_2 6.94), 7.53 (dd, 1H, C6-H, J_1 7.13, J_2 7.13), 7.69 (d, 1H, C7-H, J 8.41), 7.82 (d, 1H, C4-H, J 7.68), 13.10 (s, 2H, CO_2H, exchanges with D_2O); δ_C(50 MHz; $CDCl_3$) 29.69 (t, CH_2), 112.00 (d, C7), 121.96 (d, C4), 122.26 (s, C3), 123.51 (d, C5), 127.87 (d, C6), 128.27 (s, C3a), 142.41 (s, C2), 153.62 (s, C7a), 160.87 (s, CH_2-CO_2-CH_3), 171.22 (s, C2-CO_2-CH_3); *m*/*z* 220 (51%, M^+), 202 (14), 176 (100), 175 (30), 131 (38); $C_{11}H_8O_5$ requires: 220.03710. Found: 220.03717 (MS).

3-Carboxymethyl-6-methoxybenzofuran-2-carboxylic acid 10b

This compound was prepared according to literature procedures. (7-Methoxy-2-oxo-2*H*-chromen-4-yl)acetic acid was prepared from 3-oxopentanedioic acid dimethyl ester and 3-methoxyphenol (mp 169 °C, yield 84%).[35] This compound was brominated to give (3-bromo-7-methoxy-2-oxo-2*H*-chromen-4-yl)acetic acid (mp 205–206 °C, yield 68%),[26] which was subsequently used in a ring contraction reaction to obtain 3-carboxymethyl-6-methoxybenzofuran-2-carboxylic acid **10b** (mp 212 °C (decomp.), yield 59%).[26]

4*H*-2,9-Dioxafluorene-1,3-dione 11a and 7-methoxy-4*H*-2,9-dioxafluorene-1,3-dione 11b

A mixture of 4.15 g (18 mmol) **10a** (3.35 g (13 mmol) **10b**) and 15 ml freshly distilled acetyl chloride in 40 ml dry benzene was refluxed for 5 h. The reaction mixture was evaporated and traces of the solvent and acetyl chloride removed under reduced pressure. As several attempts to purify the anhydrides **11a** and **11b** by recrystallization or sublimation failed the solid product **11a** (**11b**) was used for the following reactions without further purification.

3-Methoxycarbonylmethylbenzofuran-2-carboxylic acid 12a and 6-methoxy-3-methoxycarbonylmethylbenzofuran-2-carboxylic acid 12b

The anhydride **11a** (prepared from 4.15 g (18 mmol) **10a**) (**11b**, prepared from 3.35 g (13 mmol) **10b**) was refluxed in 30 ml dry methanol for 4 h, the excess of methanol was evaporated and the residue recrystallized from toluene. The reaction yielded the half-ester **12a** (3.53 g (80% calculated on consumed starting material **10a**)) as colorless crystals with mp 125 °C or **12b** (2.83 g (68% calculated on consumed starting material **10b**)) as colorless crystals with mp 193 °C (decomp.).

Spectroscopic data of **12a**: ν_{max}/cm^{-1} 3500 (OH, m), 1740 (C=O, s), 1680 (s), 1599 (s), 1442 (s), 1305 (s), 751 (s); λ_{max}(CH_3CN)/nm (log ε) 220 (3.492), 273 (3.671); δ_H(500 MHz; $CDCl_3$) 3.63 (s, 3H, CO_2-CH_3), 4.20 (s, 2H, C3-CH_2), 7.36 (ddd, 1H, C5-H, J_1 0.92, J_2 7.53, J_3 7.53), 7.52 (ddd, 1H, C6-H, J_1 1.20, J_2 7.16, J_3 8.42), 7.69 (ddd, 1H, C7-H, J_1 0.74, J_2 0.74, J_3 8.42), 7.80 (ddd, 1H, C4-H, J_1 0.74, J_2 1.20, J_3 7.96), 12.50–15.00 (s, 1H, CO_2H, exchanges with D_2O); δ_C(125 MHz; $CDCl_3$) 29.31 (t, CH_2), 51.95 (q, CO_2CH_3), 112.01 (d, C7), 121.48 (s, C3), 121.82 (d, C4), 123.56 (d, C5), 127.90 (d, C6), 128.04 (m, C3a), 142.51 (m, C2), 153.64 (dddd, C7a), 160.77 (s, C2-CO_2-CH_3), 170.23 (tq, C3-CH_2-CO_2-CH_3); *m*/*z* 234 (78%), 202 (100), 175 (81); $C_{12}H_{10}O_5$ requires: 234.05283. Found: 234.05260 (MS).

Spectroscopic data of **12b**: ν_{max}/cm^{-1} 3500 (OH, m), 1740 (C=O, s), 1676 (C=O, s), 1583 (s), 1439 (m), 1243 (s); λ_{max}(EtOH)/nm (log ε) 205 (4.444), 240 (4.087), 281 (4.308), 311 (4.565); δ_H(200 MHz; $CDCl_3$) 3.62 (s, 3H, CO_2-CH_3), 3.83 (s, 3H, O-CH_3), 4.14 (s, 2H, C3-CH_2), 6.97 (dd, 1H, C5-H, J_1 2.19, J_2 8.77), 7.26 (d, 1H, C4-H, J 2.19), 7.65 (d, 1H, C7-H, J 8.77), 12.50–15.00 (s, 1H, CO_2H, exchanges with D_2O); δ_C(75 MHz; [D_6]DMSO) 29.38 (t, CH_2), 51.93 (q, CO_2CH_3), 55.79 (q, OCH_3), 95.75 (d, C5), 113.55 (d, C4), 121.29 (s, C3), 121.93 (ddd, C3a), 122.20 (d, C7), 141.60 (s, C2), 155.18 (ddd, C7a), 160.41 (s, C2-CO_2-CH_3), 160.73 (s, C6), 170.26 (tq, C3-CH_2-CO_2-CH_3); *m*/*z* 264 (100%, M^+), 232 (43), 205 (53); $C_{13}H_{12}O_6$ requires: 264.06339. Found: 264.06330 (MS).

3-Benzyloxycarbonylmethylbenzofuran-2-carboxylic acid methyl ester 13a

To a solution of 180 mg (0.7 mmol) **3a** in 20 ml dry benzylic alcohol a trace of toluene-*p*-sulfonic acid was added and the mixture refluxed for 14 h. The excess of benzylic alcohol was evaporated under reduced pressure, the oily residue taken up with ether–pentane (1 : 1) and filtered over a short column of silica gel. The filtrate was evaporated and the residue subjected to radial chromatography on silica gel with ether–pentane (1 : 10). The first fraction gave 74 mg (25%) of 3-benzyloxycarbonylmethylbenzofuran-2-carboxylic acid benzyl ester **13b** as a colorless oil. The second fraction was evaporated and taken up with methanol to give 70 mg (35%) of ester **13a** as colorless crystals with mp 103–105 °C.

ν_{max}/cm^{-1} 1726 (C=O, s), 1621 (s), 1398 (m), 1124 (m), 1057 (m), 847 (m); λ_{max}(EtOH)/nm (log ε) 220 (3.649), 227 (sh, 3.453), 277 (3.521), 287 (sh, 3.440); δ_H(300 MHz; $CDCl_3$) 3.93 (s, 3H, CO_2CH_3), 4.21 (s, 2H, C3-CH_2), 5.17 (s, 2H, Bn-CH_2), 7.27–7.70 (3 overlapping m, 9H, aromatic rings); δ_C(75 MHz; $CDCl_3$) 30.24 (t, C3-CH_2), 52.24 (q, C2-CO_2CH_3), 66.93 (t, Bn-CH_2), 112.35 (d, C7), 121.34 (d, C4), 121.98 (s, C3), 123.66 (d, C5), 128.54 (d, C6), 129.6–129.5 (3 overlapping m, benzyl), 135.53 (m, C1, Bn), 141.77 (s, C2), 154.43 (s, C7a), 160.33 (s, C2-CO_2CH_3), 169.65 (s, C3-CH_2-CO_2-Bn); *m*/*z* 324 (29%, M^+), 265 (11), 189 (62), 91 (100); $C_{19}H_{16}O_5$ requires: 324.09976. Found: 324.09970 (MS).

3-Carboxymethylbenzofuran-2-carboxylic acid methyl ester 14

Palladium (5 mg) on charcoal (10%) was added to a solution of 60 mg (0.2 mmol) **13a** in 30 ml of absolute ethanol and hydrogenated at room temperature. The formation of compound **14** could be monitored by TLC chromatography with cyclohexane–ethyl acetate–triethylamine (10 : 20 : 1). The catalyst was filtered off and the solvent evaporated. The residue was recrystallized from toluene at −20 °C to yield **14** (37 mg, 89%) as colorless crystals with mp 185–187 °C (decomp.).

ν_{max}/cm^{-1} 1702 (s), 1305 (m), 1147 (s), 750 (s); λ_{max}(CH_3CN)/nm (log ε) 220 (4.370), 225 (sh, 4.307), 275 (4.600), 286 (sh, 4.536); δ_H(300 MHz; $CDCl_3$) 3.89 (s, 3H, CO_2-CH_3), 4.11 (s, 2H, C3-CH_2), 7.38 (ddd, 1H, C5-H, J_1 0.99, J_2 7.15, J_3 7.10), 7.54 (ddd, 1H, C6-H, J_1 1.34, J_2 7.15, J_3 8.45), 7.70 (ddd, 1H, C7-H, J_1 0.81, J_2 0.84, J_3 8.37), 7.83 (ddd, 1H, C4-H, J_1 0.73, J_2 0.77, J_3 7.90); δ_C(75 MHz; $CDCl_3$) 29.61 (t, CH_2), 52.18 (q, CO_2CH_3), 112.05 (d, C7), 122.07 (s, C3), 123.21 (d, C4), 123.72 (d, C5), 127.29 (d, C6), 128.27 (m, C3a), 141.18 (m, C2), 153.72 (dddd, C7a), 159.77 (s, C2-CO_2-CH_3), 170.99 (tq, C3-CH_2-CO_2-CH_3); *m*/*z* 234 (28%, M^+), 216 (9), 190 (63), 183 (11), 175 (26); $C_{12}H_{10}O_5$ requires: 234.05283. Found: 234.05280 (MS).

3-Methoxycarbonylmethylbenzofuran-2-carboxylic acid pent-4-enyl ester 15a

To a solution of 500 mg (2.1 mmol) **12a** in 15 ml dry THF 465 mg (1.6 mmol) dicyclohexyl-2-pent-4-enylisourea[25] was added. The mixture was refluxed for 3 h, and a further 150 mg (0.5 mmol) isourea was added and refluxing continued for 1.5 h. The suspension was filtered, evaporated, the residue taken up with cyclohexane–ethyl acetate (3 : 1) and filtered through a short column of silica gel. The solvents were evaporated and the oily raw product subjected to radial chromatography on silica gel with cyclohexane–ethyl acetate (5 : 1) to yield 569 mg (89%) of **15a** as a colorless oil.

ν_{max}/cm^{-1} 1742 (s), 1711 (s), 1601 (m), 1298 (s), 1152 (s), 749 (s); λ_{max}(EtOH)/nm (log ε) 220 (4.168), 275 (4.410), 285 (sh, 4.333); δ_H(200 MHz; $CDCl_3$) 1.91 (tt, 2H, O-CH_2-CH_2, J_1 7.06, J_2 7.01), 2.23 (dt, 2H, O-CH_2-CH=CH_2, J_1 6.97, J_2 7.14), 3.72 (s, 3H, CO_2CH_3), 4.18 (s, 2H, C3-CH_2), 4.41 (t, 2H, O-CH_2, J 6.65), 5.02 (ddt, 1H, CH=CH_2, Z, J_1 1.48, J_2 1.52, J_3 10.21), 5.08 (ddt, 1H, CH=CH_2, E, J_1 1.80, J_2 1.82, J_3 17.26) ($^3J(E) > {}^3J(Z)$), 5.86 (ddt, 2H, CH=CH_2, J_1 6.61, J_2 10.30, J_3 17.02), 7.10–7.85 (m, 4H, C4-H, C5-H, C6-H, C7-H); δ_C(50 MHz; $CDCl_3$) 27.62 (t, C3-CH_2), 29.80 (t, CH_2-CH=CH_2), 29.99 (t, O-CH_2-CH_2-CH_2), 52.27 (q, CO_2CH_3), 64.85 (t, O-CH_2-CH_2), 112.37 (dd, C7), 115.60 (t, CH=CH_2), 116.79 (s, C3), 121.19 (dd, C4), 123.64 (dd, C5), 127.98 (dd, C6), 128.06 (s, C3a), 137.13 (d, CH=CH_2), 141.98 (s, C2), 157.47 (s, C7a), 160.29 (s, C2-CO), 170.25 (s, CO_2CH_3); *m*/*z* 302 (14%, M^+), 234 (87), 202 (96), 189 (30), 168 (33), 68 (100); $C_{17}H_{18}O_5$ requires: 302.11542. Found: 302.11520 (MS).

3-[Diazo(methoxycarbonyl)methyl]benzofuran-2-carboxylic acid pent-4-enyl ester 15b

In a solution of 252 mg (0.8 mmol) **15a** in 10 ml dry acetonitrile 200 mg (0.8 mmol) 4-azidosulfonylbenzoic acid was suspended. A solution of 307 mg (0.3 ml, 2.0 mmol) DBU in 0.7 ml acetonitrile was added dropwise under nitrogen at room temperature. Stirring was continued for 1 h, the mixture filtered and 8 ml of acetonitrile evaporated under reduced pressure. The oily residue was taken up with ether–pentane (1 : 2) and filtered through a short column of silica gel. The filtrate was evaporated and purified by radial chromatography on silica gel with ether–pentane (1 : 10) to give 156 mg (58%) of **15b** as a yellow oil.

ν_{max}/cm^{-1} 2111 (C=N_2, s), 1711 (C=O, s), 1287 (s), 1166 (m), 747 (m); λ_{max}(EtOH)/nm (log ε) 215 (sh, 4.141), 260 (4.188), 285 (4.024), 295 (4.024); δ_H(300 MHz; $CDCl_3$) 1.93 (tt, 2H, O-CH_2-CH_2, J_1 7.24, J_2 7.24), 2.22 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.07, J_2 7.17), 3.88 (s, 3H, CO_2CH_3), 4.43 (t, 2H, O-CH_2, J 6.77), 5.02 (ddt, 1H, CH=CH_2, Z, J_1 1.48, J_2 1.52, J_3 10.21), 5.08 (ddt, 1H, CH=CH_2, E, J_1 1.80, J_2 1.82, J_3 17.26), 5.85 (ddt, 1H, CH=CH_2, J_1 6.69, J_2 10.27, J_3 17.01), 7.34 (ddd, 1H, C5-H, J_1 1.04, J_2 7.05, J_3 8.05), 7.49 (ddd, 1H, C6-H, J_1 1.34, J_2 7.10, J_3 8.46), 7.59 (ddd, 1H, C7-H, J_1 0.91, J_2 0.91, J_3 8.29), 7.69 (ddd, 1H, C4-H, J_1 0.73, J_2 1.29, J_3 8.01); δ_C(75 MHz; $CDCl_3$) 26.93 (s, CN_2), 29.86 (t, O-CH_2-CH_2-CH_2), 29.97 (t, O-CH_2-CH_2), 53.37 (q, CO_2CH_3), 65.25 (t, O-CH_2), 112.41 (dd, C7), 114.67 (s, C3), 115.61 (t, CH=CH_2), 123.19 (dd, C4), 123.86 (dd, C5), 126.84 (s, C3a), 128.41 (dd, C6), 137.16 (d, CH=CH_2), 139.52 (s, C2), 154.71 (s, C7a), 159.11 (s, C2-CO_2-pentenyl), 165.19 (s, CO_2CH_3); *m*/*z* 328 (8%, M^+), 232 (100), 203 (68), 189 (60), 173 (29), 145 (23); $C_{17}H_{16}N_2O_5$ requires: 328.10593. Found: 328.10580 (MS).

3,4-Dihydro-2*H*-1,11-dioxabenzo[*a*]fluorene-6-carboxylic acid methyl ester 17a

A mixture of 1 mg dirhodium tetraacetate and 102 mg (0.3 mmol) **15b** in 10 ml dry toluene was heated to 90 °C until complete decomposition of the diazo compound (monitored by TLC chromatography) and 100 mg (0.3 mmol) zinc iodide was added and the mixture heated for a further 2 h at 90 °C. The solution was filtered, washed with 0.5 M hydrochloric acid and water and subsequently dried with sodium sulfate. After evaporation of the solvent the residue was taken up with

cyclohexane–ethyl acetate (5:1), filtered through a short column of silica gel and purified by radial chromatography on silica gel with cyclohexane–ethyl acetate (8:1). The residue was recrystallized with dry methanol to give 41 mg (47%, calculated on consumed starting material **15b**) of colorless crystals with mp 169 °C.

ν_{max}/cm^{-1} 1707 (s), 1573 (m), 1334 (s), 1222 (s), 773 (m); λ_{max}(EtOH)/nm (log ε) 220 (3.685), 248 (4.229), 260 (sh, 4.071), 270 (4.071), 300 (4.211); δ_H(300 MHz; $CDCl_3$) 2.16 (tt, 2H, C3-H, J_1 6.24, J_2 10.64), 2.95 (t, 2H, C4-H, J 6.31), 4.01 (s, 3H, CO_2CH_3), 4.46 (t, 1H, C2-H, J 5.31), 7.37 (ddd, 1H, C8-H, J_1 1.11, J_2 7.17, J_3 8.13), 7.49 (ddd, 1H, C9-H, J_1 1.34, J_2 7.15, J_3 8.31), 7.61 (ddd, 1H, C10-H, J_1 0.61, J_2 1.16, J_3 8.24), 7.79 (s, 1H, C5-H), 8.82 (ddd, 1H, C7-H, J_1 0.61, J_2 1.36, J_3 8.03); δ_C(75 MHz; $CDCl_3$) 22.06 (t, C4), 24.47 (tt, C3), 51.91 (q, CO_2CH_3), 67.58 (t, C2), 111.49 (dd, C10), 116.16 (d, C4a), 120.05 (d, C11a), 122.90 (dd, C7), 123.88 (s, C5), 123.44 (s, C6a), 126.02 (s, C6b), 127.74 (dd, C8), 128.13 (dd, C9), 144.63 (d, C6), 144.93 (s, C11a), 156.82 (d, C10a), 166.94 (s, CO_2CH_3); *m*/*z* 282 (100%, M^+), 251 (50), 223 (21); $C_{17}H_{14}O_4$ requires: 282.08920. Found: 282.08910 (MS).

6-Methoxy-3-methoxycarbonylmethylbenzofuran-2-carboxylic acid pent-4-enyl ester 15c

To a solution of 2.61 g (10 mmol) **12b** in 50 ml dry THF, 2.88 g (10 mmol) 1,3-dicyclohexyl-2-pent-4-enylisourea was added. After refluxing for 3 h the precipitated solid was filtered off, the solvent evaporated and the residue taken up with a few millilitres of dry acetone. The solution was cooled to −20 °C for a few hours, filtered and the oily raw product filtered through a short column of silica gel with cyclohexane–ethyl acetate (3:1). The filtrate was evaporated and purified by radial chromatography using silica gel and cyclohexane–ethyl acetate (15:1) to give 900 mg (27%) of a yellowish oil.

ν_{max}/cm^{-1} 1734 (C=O, s), 1597 (m), 1438 (s), 1148 (s), 1096 (s), 802 (s), 749 (s); λ_{max}(EtOH)/nm (log ε) 220 (sh, 3.300), 264 (sh, 3.367), 275 (3.425), 286 (sh, 3.238); δ_H(300 MHz; $CDCl_3$) 1.95 (tt, 2H, O-CH_2-CH_2, J_1 7.53, J_2 6.61), 2.22 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.13, J_2 7.26), 3.72 (s, 3H, CO_2CH_3), 3.99 (s, 3H, C6-OCH_3), 4.19 (s, 2H, C3-CH_2), 4.43 (t, 2H, O-CH_2, J 6.74), 4.99–5.12 (overlapping m, 2H, CH=CH_2), 5.86 (ddt, 1H, CH=CH_2, J_1 6.74, J_2 10.26, J_3 22.65), 7.32 (dd, 1H, C4-H, J_1 7.96, J_2 2.27), 7.48 (d, 1H, C7-H, J 2.02), 7.64 (d, 1H, C5-H, J 8.89); δ_C(75 MHz; $CDCl_3$) 25.70 (t, C3-CH_2), 25.45 (t, O-CH_2-CH_2-CH_2), 29.94 (t, O-CH_2-CH_2), 52.31 (q, CO_2CH_3), 55.76 (q, 3H, OCH_3), 64.63 (t, O-CH_2), 95.65 (d, C4), 112.38 (d, C5), 115.52 (t, CH=CH_2), 115.52 (s, C3), 121.24 (s, C3), 123.70 (s, C3a), 128.11 (d, C7), 137.28 (d, CH=CH_2), 141.69 (s, C2), 154.44 (s, C7a), 160.38 (s, C3-CH_2-CO_2CH_3), 170.28 (s, C2-CO_2-pentenyl); *m*/*z* 332 (76%, M^+), 264 (100), 232 (82), 205 (38), 189 (23), 161 (19); $C_{18}H_{20}O_6$ requires: 332.12598. Found: 332.12570 (MS).

3-[Diazo(methoxycarbonyl)methyl]-6-methoxybenzofuran-2-carboxylic acid pent-4-enyl ester 15d

A solution of 920 mg (0.9 ml, 6.0 mmol) DBU in 1 ml dry acetonitrile was added under nitrogen at room temperature to a mixture of 0.88 g (2.7 mmol) **15c** and 0.68 g (3 mmol) 4-azidosulfonylbenzoic acid in 30 ml dry acetonitrile. The mixture was stirred for 16 h, filtered, 25 ml of the solvent evaporated under reduced pressure and the residue purified by column chromatography on silica gel using cyclohexane–ethyl acetate (1:1). The reaction yielded 807 mg (85%) of yellow crystals with mp 55 °C (decomp.).

ν_{max}/cm^{-1} 2104 (C=N_2, s), 1700 (C=O, s), 1290 (s), 1108 (m), 1010 (m); λ_{max}(EtOH)/nm (log ε) 250 (sh, 3.367), 260 (3.446), 312 (3.513); δ_H(300 MHz; $CDCl_3$) 1.92 (tt, 2H, O-CH_2-CH_2, J_1 7.51, J_2 6.65), 2.22 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.12, J_2 7.10), 3.87 (s, 3H, CO_2CH_3), 3.88 (s, 3H, OCH_3), 4.41 (t, 2H, O-CH_2, J 6.77), 5.02 (ddt, 1H, CH=CH_2, Z, J_1 1.70, J_2 1.52, J_3 10.19), 5.08 (ddt, 1H, CH=CH_2, E, J_1 1.68, J_2 1.73, J_3 17.15), 5.85 (ddt, 1H, CH=CH_2, J_1 6.69, J_2 10.31, J_3 17.04), 6.96 (dd, 1H, C4-H, J_1 8.84, J_2 2.27), 7.04 (d, 1H, C7-H, J 2.02), 7.55 (d, 1H, C5-H, J 8.89); δ_C(75 MHz; $CDCl_3$) 27.92 (t, O-CH_2-CH_2-CH_2), 29.99 (t, O-CH_2-CH_2), 52.34 (q, CO_2CH_3), 55.75 (q, 3H, OCH_3), 56.62 (s, CN_2), 64.99 (t, O-CH_2), 95.40 (d, C4), 114.21 (d, C5), 115.15 (s, C3), 115.56 (t, CH=CH_2), 120.07 (s, C3a), 123.67 (d, C7), 137.22 (d, CH=CH_2), 138.50 (s, C2), 156.16 (s, C6), 159.06 (s, C7a), 161.08 (s, C2-CO_2), 165.18 (s, CO_2CH_3); *m*/*z* 358 (15%, M^+), 271 (38), 262 (100), 233 (98), 219 (63), 203 (30), 175 (21); $C_{18}H_{18}N_2O_6$ requires: 358.11649. Found: 358.11650 (MS).

6-Methoxy-1-pent-4-enyloxy-2,8-dioxacyclopenta[*a*]indene-3-carboxylic acid methyl ester 16b

A solution of 101 mg (0.3 mmol) of **15d** in 5 ml of dry benzene was refluxed with a catalytic amount of dirhodium tetraacetate for 2 h until complete decomposition of the diazo compound (monitored by TLC chromatography). The solvent was removed under reduced pressure, the residue taken up with cyclohexane–ethyl acetate (5:1), filtered through a short column of silica gel and purified by radial chromatography on silica gel with cyclohexane–ethyl acetate (8:1) to give 68 mg (74%) of colorless crystals with mp 73 °C (decomp.).

ν_{max}/cm^{-1} 1723 (C=O, s), 1706 (s), 1672 (s), 1614 (s), 1565 (s), 1256 (s), 1098 (s); λ_{max}(CH_3CN)/nm (log ε) 245 (3.267), 285 (3.528), 295 (sh, 3.454), 335 (3.411); δ_H(300 MHz; $CDCl_3$) 1.95 (tt, 2H, O-CH_2-CH_2-CH_2, J_1 6.55, J_2 7.24), 2.28 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.12, J_2 7.14), 3.88 (s, 3H, CO_2CH_3), 3.96 (s, 3H, OCH_3), 4.45 (t, 2H, O-CH_2, J 6.37), 5.03 (ddt, 1H, CH=CH_2, Z, J_1 10.16, J_2 1.87, J_3 1.21), 5.09 (ddt, 1H, CH=CH_2, E, J_1 17.16, J_2 1.70, J_3 1.74), 5.84 (ddt, 1H, CH=CH_2, J_1 17.04, J_2 10.27, J_3 6.75), 6.88 (dd, 1H, C5-H, J_1 8.34, J_2 2.27), 6.90 (d, 1H, C4-H, J 1.52), 7.90 (d, 1H, C7-H, J 8.08); δ_C(75 MHz) $CDCl_3$ 27.46 (t, O-CH_2-CH_2-CH_2), 29.58 (t, O-CH_2-CH_2), 51.33 (q, CO_2CH_3), 55.76 (q, 3H, OCH_3), 72.17 (t, O-CH_2), 97.30 (dd, C5), 111.17 (d, C4), 112.11 (s, C3b), 115.75 (ddt, CH=CH_2), 119.31 (s, C8a), 125.16 (d, C7), 128.18 (d, C3a), 130.08 (s, C1), 137.08 (d, CH=CH_2), 140.86 (s, C3), 158.81 (s, C7a), 161.82 (s, C6), 165.90 (s, CO_2CH_3); *m*/*z* 330 (8%, M^+), 271 (57), 262 (100), 233 (91), 219 (88), 203 (28), 175 (21).

9-Methoxy-3,4-dihydro-2*H*-1,11-dioxabenzo[*a*]fluorene-6-carboxylic acid methyl ester 17b

A solution of 95 mg (0.3 mmol) **15d** in 40 ml dry dioxane was refluxed with a catalytic amount of dirhodium tetraacetate until complete decomposition of the diazo compound (monitored by TLC chromatography), and 93 mg (0.3 mmol) of zinc iodide was added and refluxing continued for a further 1 h. After evaporation of the solvent the residue was taken up with cyclohexane–ethyl acetate (1:1), filtered through a short column of silica gel and purified by radial chromatography on silica gel with cyclohexane–ethyl acetate (3:1) to give 35 mg (39%, calculated on consumed starting material **15d**) of colorless crystals with mp 166–167 °C.

ν_{max}/cm^{-1} 1708 (C=O, s), 1570 (m), 1333 (s), 1186 (s), 1099 (s), 785 (m); λ_{max}(EtOH)/nm (log ε) 225 (4.231), 252 (4.494), 272 (4.231), 311 (4.152); δ_H(300 MHz; $CDCl_3$) 2.15 (tt, 2H, C3-H, J_1 6.38, J_2 6.46), 2.94 (t, 2H, C4-H, J 6.24), 3.90 (s, 3H, OCH_3), 4.00 (s, 3H, CO_2CH_3), 4.45 (t, 1H, J 5.25), 6.95 (dd, 1H, C8-H, J_1 2.42, J_2 10.13), 7.10 (d, 1H, C7-H, J 2.39), 7.76 (s, 1H, C5-H), 8.93 (d, 1H, J 8.93); δ_C(75 MHz; $CDCl_3$) 22.14 (t, C4), 24.40 (tt, C3), 51.82 (q, CO_2CH_3), 55.60 (q, 3H, OCH_3), 67.56 (t, C2), 97.87 (d, C8), 111.14 (d, C7), 115.20 (s, C4a), 116.70 (s, C6a), 119.02 (s, C11b), 124.36 (s, C6b), 126.54 (d, C10), 127.92 (d, C5), 144.34 (s, C6), 144.83 (s, C11a), 158.12 (s, C10a), 160.23 (s, C9), 167.03 (s, CO_2CH_3); *m*/*z* 312 (100%, M^+), 281 (26), 253

(13), 202 (7); $C_{18}H_{16}O_5$ requires: 312.09976. Found: 312.09970 (MS).

3-Pent-4-enyloxycarbonylmethylbenzofuran-2-carboxylic acid 18c

A mixture of 7.12 g (32 mmol) **11a** and 3.38 g (4.5 ml, 39.3 mmol) of pent-4-en-1-ol was heated to 50 °C for 3 h. The reaction mixture was cooled in an ice bath and taken up with ice-cold conc. sodium hydrogen carbonate solution. The aqueous solution was extracted three times with methyl *tert*-butyl ether (MTBE), acidified at 0 °C with 2 M hydrochloric acid and extracted four times with 100 ml portions of MTBE. The organic layer was washed with conc. sodium chloride solution, dried with sodium sulfate, the solvent evaporated and the residue subjected to column chromatography on silica gel with cyclohexane–ethyl acetate–glacial acetic acid (16:4:1). After recrystallization from benzene–*n*-hexane 5.22 g the acid (56% calculated on starting material **11a**) was isolated as colorless crystals (mp 87–88 °C).

ν_{max}/cm^{-1} 1725 (C=O, s), 1684 (s), 1595 (s), 1440 (m), 1298 (s), 1177 (s), 748 (m); λ_{max}(EtOH)/nm (log ε) 220 (4.029), 285 (4.209); δ_H(300 MHz; $CDCl_3$) 1.72 (tt, 2H, O-CH_2-CH_2, J_1 7.11, J_2 6.64), 2.06 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.04, J_2 7.16), 4.15 (t, 2H, O-CH_2, J 6.59), 4.21 (s, 2H, C3-CH_2), 4.95 (ddt, 1H, CH=CH_2, Z, J_1 1.32, J_2 2.23, J_3 8.11), 4.99 (ddt, 1H, CH=CH_2, E, J_1 1.39, J_2 3.33, J_3 9.67), 5.20–6.40 (br s, 1H, COOH, exchanges with D_2O), 5.75 (ddt, 1H, CH=CH_2, J_1 6.68, J_2 10.30, J_3 16.98), 7.35 (ddd, 1H, C5-H, J_1 1.00, J_2 7.02, J_3 7.99), 7.51 (ddd, 1H, C6-H, J_1 1.33, J_2 7.08, J_3 8.44), 7.61 (ddd, 1H, C7-H, J_1 0.91, J_2 0.91, J_3 8.28), 7.67 (ddd, 1H, C4-H, J_1 1.00, J_2 1.00, J_3 7.92); δ_C(75 MHz; $CDCl_3$) 27.66 (t, CH_2), 29.92 (t, O-CH_2-CH_2-CH_2), 30.31 (t, O-CH_2-CH_2), 64.82 (t, O-CH_2), 112.53 (dd, C7), 121.51 (dd, C4), 124.29 (s, C3), 115.37 (t, CH=CH_2), 123.85 (dd, C5), 128.70 (s, C3a), 128.70 (dd, C6), 137.26 (d, CH=CH_2), 141.02 (s, C2), 154.90 (s, C7a), 164.88 (s, C2-CO_2-pentenyl), 169.74 (s, CO_2CH_3); *m*/*z* 288 (13%, M^+), 220 (40), 202 (14), 176 (100); $C_{16}H_{16}O_5$ requires: 288.09976. Found: 288.09960 (MS).

3-Pent-4-enyloxycarbonylmethylbenzofuran-2-carboxylic acid methyl ester 18d

To a solution of 450 mg (1.6 mmol) 3-pent-4-enyloxycarbonylmethylbenzofuran-2-carboxylic acid in 15 ml dry THF 375 g (1.6 mmol) 1,3-dicyclohexyl-2-methylisourea was added. The mixture was refluxed for 2 h and stirred for a further 16 h at room temperature. The precipitated solid was filtered off, the solvent evaporated and the oily raw product filtered through a short column of silica gel with cyclohexane–ethyl acetate (1:1). The filtrate was evaporated and purified by radial chromatography using silica gel and cyclohexane–ethyl acetate (6:1) to give 385 mg (82%) of colorless oil.

ν_{max}/cm^{-1} 1738 (s), 1601 (w), 1300 (s), 1151 (s), 749 (m); λ_{max}(EtOH)/nm (log ε) 220 (4.003), 275 (4.117); δ_H(300 MHz; $CDCl_3$) 1.71 (tt, 2H, O-CH_2-CH_2, J_1 6.55, J_2 7.39), 2.05 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 6.84, J_2 7.38), 3.99 (s, 3H, CO_2CH_3), 4.13 (t, 2H, O-CH_2, J 6.57), 4.17 (s, 2H, C3-CH_2), 4.95 (m, 1H, CH=CH_2, Z), 4.98 (ddt, 1H, CH=CH_2, E, J_1 1.80, J_2 1.81, J_3 8.37), 5.75 (ddt, 1H, CH=CH_2, J_1 6.59, J_2 10.37, J_3 16.91), 7.32 (ddd, 1H, C5-H, J_1 0.96, J_2 7.07, J_3 7.98), 7.47 (ddd, 1H, C6-H, J_1 1.31, J_2 7.07, J_3 8.39), 7.57 (ddd, 1H, C7-H, J_1 0.91, J_2 0.91, J_3 8.34), 7.64 (ddd, 1H, C4-H, J_1 0.81, J_2 1.31, J_3 7.88); δ_C(75 MHz; $CDCl_3$) 27.69 (t, CH_2), 30.01 (t, O-CH_2-CH_2-CH_2), 30.16 (t, O-CH_2-CH_2), 52.25 (q, CO_2CH_3), 64.61 (t, O-CH_2), 112.34 (dd, C7), 115.35 (t, CH=CH_2), 116.85 (s, C3), 121.23 (dd, C4), 123.63 (dd, C5), 127.99 (s, C3a), 128.05 (dd, C6), 137.30 (d, CH=CH_2), 141.68 (s, C2), 154.42 (s, C7a), 160.37 (s, C2-CO_2-pentenyl), 169.76 (s, CO_2CH_3); *m*/*z* 302 (14%, M^+), 234 (14), 216 (23), 190 (100), 189 (59), 159 (29); $C_{17}H_{18}O_5$ requires: 302.11542. Found: 302.11520 (MS).

3-[Diazo(pentyloxycarbonyl)methyl]benzofuran-2-carboxyclic acid methyl ester 18e

A solution of 500 mg (0.51 ml, 3.3 mmol) DBU in 2 ml dry acetonitrile was added dropwise under nitrogen at room temperature to a mixture of 385 mg (1.3 mmol) **18c** and 361 mg (1.6 mmol) 4-azidosulfonylbenzoic acid in 30 ml dry acetonitrile. The mixture was stirred for 16 h, filtered, 25 ml of the solvent evaporated under reduced pressure and the residue purified by column chromatography on silica gel using cyclohexane–ethyl acetate (12:1) to give 415 mg (99%) of a yellow oil.

ν_{max}/cm^{-1} 2110 (s), 1711 (s), 1575 (m), 1442 (m), 1263 (s), 748 (s); λ_{max}(CH_3CN)/nm (log ε) 220 (4.245), 260 (4.268), 295 (4.136); δ_H(300 MHz; $CDCl_3$) 1.80 (tt, 2H, O-CH_2-CH_2, J_1 7.12, J_2 7.11), 2.14 (dt, 2H, O-CH_2-CH_2-CH_2, J_1 7.15, J_2 7.28), 4.02 (s, 3H, CO_2CH_3), 4.31 (t, 2H, O-CH_2, J 6.62), 4.31–5.08 (2m, 2H, CH=CH_2), 5.81 (ddt, 1H, CH=CH_2, J_1 6.67, J_2 10.32, J_3 17.06), 7.34 (ddd, 1H, C5-H, J_1 1.09, J_2 7.00, J_3 8.06), 7.50 (ddd, 1H, C6-H, J_1 1.34, J_2 7.05, J_3 8.41), 7.58 (ddd, 1H, C7-H, J_1 0.81, J_2 1.01, J_3 8.34), 7.71 (ddd, 1H, C4-H, J_1 0.76, J_2 1.21, J_3 8.03); δ_C(50 MHz; $CDCl_3$) 27.93 (t, O-CH_2-CH_2-CH_2), 27.97 (t, O-CH_2-CH_2), 52.62 (q, CO_2CH_3), 55.50 (s, CN_2), 64.89 (t, O-CH_2), 112.34 (dd, C7), 115.45 (t, CH=CH_2), 115.28 (s, C3), 123.43 (dd, C4), 123.81 (dd, C5), 126.72 (s, C3a), 128.53 (dd, C6), 137.29 (d, CH=CH_2), 141.02 (s, C2), 154.66 (s, C7a), 159.41 (s, C2-CO_2-pentenyl), 164.98 (s, CO_2CH_3); *m*/*z* 328 (27%, M^+), 279 (6), 271 (40), 229 (74), 203 (52), 189 (100); $C_{17}H_{16}N_2O_5$ requires: 328.10593. Found: 328.10580 (MS).

3-Allyloxycarbonylmethylbenzofuran-2-carboxylic acid methyl ester 18a and 3-allyloxycarbonylmethylbenzofuran-2-carboxylic acid allyl ester

To a suspension of 221 mg (0.5 mmol) **3a** in 20 ml of dry, freshly distilled allylic alcohol 8 mg of toluene-*p*-sulfonic acid was added and the mixture refluxed for 14 h. The excess of allylic alcohol was evaporated under reduced pressure, the oily residue taken up with ether–pentane (1:1) and filtered through a short column of silica gel. The filtrate was evaporated and the residue subjected to radial chromatography on silica gel with ether–pentane (1:7). The first fraction gave 9 mg (6%) of allyloxycarbonylmethylbenzofuran-2-carboxylic acid allyl ester as colorless oil. The second fraction contained 46 mg (34%) 3-allyloxycarbonylmethylbenzofuran-2-carboxylic acid methyl ester **18a** as colorless oil and finally the third fraction gave 10 mg (8%) **3a**.

Spectroscopic data of **18a**: ν_{max}/cm^{-1} 1737 (C=O, s), 1601 (m), 1438 (s), 1301 (s), 1272 (s), 1151 (s), 749 (s); λ_{max}(EtOH)/nm (log ε) 221 (4.005), 265 (sh, 4.201), 276 (4.256), 285 (4.239); δ_H(500 MHz; $CDCl_3$) 3.99 (s, 3H, CO_2CH_3), 4.21 (s, 2H, C3-CH_2), 4.63 (td, 2H, O-CH_2, J_1 1.42, J_2 5.69), 5.22 (ddt, 1H, CH=CH_2, Z, J_1 1.30, J_2 1.30, J_3 10.43), 5.28 (ddt, 1H, CH=CH_2, E, J_1 1.51, J_2 1.53, J_3 17.15), 5.89 (ddt, 1H, CH=CH_2, J_1 5.71, J_2 10.48, J_3 17.18), 7.33 (ddd, 1H, C5-H, J_1 0.92, J_2 7.11, J_3 7.95), 7.48 (ddd, 1H, C6-H, J_1 1.30, J_2 7.15, J_3 8.41), 7.58 (ddd, 1H, C7-H, J_1 0.79, J_2 0.79, J_3 8.41), 7.64 (ddd, 1H, C4-H, J_1 0.84, J_2 1.17, J_3 7.78); δ_C(125 MHz; $CDCl_3$) 30.06 (t, C3-CH_2), 52.31 (q, CO_2CH_3), 65.81 (t, O-CH_2), 112.36 (ddd, C7), 118.47 (t, CH=CH_2), 121.25 (dd, C4), 122.03 (s, C3), 123.68 (dd, C5), 127.93 (s, C3a), 128.10 (dd, C6), 131.79 (ddd, CH=CH_2), 141.74 (s, C2), 154.44 (s, C7a), 160.37 (s, C3-CH_2-$COCH_3$), 169.46 (s, C2-CO_2CH_3); *m*/*z* 274 (43%, M^+), 216 (24), 189 (100), 159 (26); $C_{15}H_{12}O_5$ requires: 274.08414. Found: 274.08390 (MS).

3-[Diazo(allyloxycarbonyl)methyl]benzofuran-2-carboxylic acid methyl ester 18b

A solution of 470 mg (0.48 ml, 3.1 mmol) DBU in 5 ml of dry acetonitrile was added dropwise under nitrogen at room temperature to a mixture of 336 mg (1.2 mmol) **18a** and 333 mg (1.5 mmol) of 4-azidosulfonylbenzoic acid in 15 ml dry acetonitrile.

The mixture was stirred for 5 h, filtered and 15 ml of the solvent evaporated under reduced pressure and the residue purified by column chromatography on silica gel with ether. The product **18b** was recrystallized from ether–pentane to give 340 mg (93%) of yellow crystals with mp 114 °C.

ν_{max}/cm^{-1} 2112 (s), 1713 (s), 1574 (m), 1443 (m), 1281 (s), 1162 (m), 748 (m); λ_{max}(CH_3CN)/nm (log ε) 295 (1.011), 224 (sh, 3.273), 260 (3.330), 295 (3.154), 400 (1.398); δ_H(300 MHz; $CDCl_3$) 4.02 (s, 3H, CO_2CH_3), 4.79 (td, 2H, O-CH_2, J_1 1.33, J_2 5.75), 5.25–5.50 (2m, 2H, CH=CH_2), 5.97 (ddt, 1H, C*H*=CH_2, J_1 5.77, J_2 11.28, J_3 16.36), 7.34 (ddd, 1H, C5-H, J_1 1.05, J_2 7.02, J_3 8.02), 7.50 (ddd, 1H, C6-H, J_1 1.30, J_2 7.05, J_3 8.38), 7.58 (d, 1H, C7-H, J 8.85), 7.71 (d, 1H, C4-H, J 7.74); δ_C(75 MHz; $CDCl_3$) 52.64 (q, CO_2CH_3), 65.99 (t, O-CH_2), 66.16 (s, CN_2), 112.36 (s, C3), 113.83 (ddd, C7), 118.74 (t, CH=CH_2), 123.41 (dd, C4), 123.86 (dd, C5), 126.68 (s, C3a), 128.54 (dd, C6), 131.87 (ddd, CH=CH_2), 139.02 (s, C2), 154.67 (s, C7a), 159.41 (s, C3-CH_2-CO_2CH_2), 164.38 (s, C2-CO_2CH_3).

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