Pergamon

Tetrahedron 58 (2002) 1533–1540

TETRAHEDRON

Synthesis of naphtho[2,3-*b*][1,4]dioxin, 2-substituted naphtho[2,3-*b*][1,4]dioxins and 2,3-disubstituted naphtho[2,3-*b*][1,4]dioxins

Sylvain Clavier,[a] Mostafa Khouili,[b] Pascal Bouyssou[a] and Gérard Coudert[a,*]

[a]*Institut de Chimie Organique et Analytique associé au CNRS, Université d'Orléans, BP 6759, 45067 Orleans cedex 02, France*
[b]*Laboratoire de Chimie Organique et Analytique, Faculté des Sciences et Techniques, Université Cadi-Ayyad, BP 523-23000 Beni-Mellal, Morocco*

Received 19 June 2001; revised 10 September 2001; accepted 14 December 2001

Abstract—In view of their potential biological properties, various 2,3-disubstituted naphtho[2,3-*b*][1,4]dioxins and 2-substituted furo[3,4-*b*]naphtho[2,3-*e*][1,4]dioxins have been synthesized. These novel compounds are intermediates to further extended heterocyclic systems.

1. Introduction

Tri or tetracyclic benzodioxinic planar structures have shown to be attractive chromophores for the design of potential antitumor agents.[1] Indeed, a lot of benzodioxinic derivatives have exhibited potent in vitro cytotoxicity and significant in vivo antitumor activity.[2]

In the search for new organic materials with interesting electrical and/or magnetic properties, series of new annulated dioxins have also been prepared.[3]

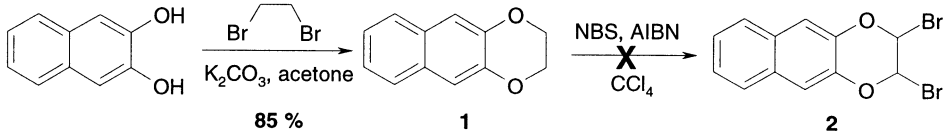
With a view to obtain further extended heterocyclic systems, it would be of great interest to have available a versatile and general method allowing an easy access to naphthodioxins properly substituted on the heterocyclic moiety. Such derivatives could then give access to more sophisticated linear or angular annulated dioxins likely to be of interest both for their electrochemical or therapeutical properties. To the best of our knowledge, only one compound of this kind has so far been described.[4]

2. Results and discussions

By analogy with that of the 1,4-benzodioxinic series, formation of the naphthodioxinic ring was first envisaged via a bromination–debromination process.[5] Indeed, reaction of 1,2-dibromoethane with 2,3-dihydroxynaphthalene, under classical conditions, led to 2,3-dihydronaphtho[2,3-*b*][1,4]dioxin moiety **1** in good yield. Unfortunately, radical bromination of **1** with *N*-bromosuccinimide in carbon tetrachloride did not afford the desired dibromo derivative **2** but an unexploitable mixture of brominated products (Scheme 1).

We postulated that the presence of a withdrawing group on the heterocyclic moiety could improve the selectivity of the reaction.

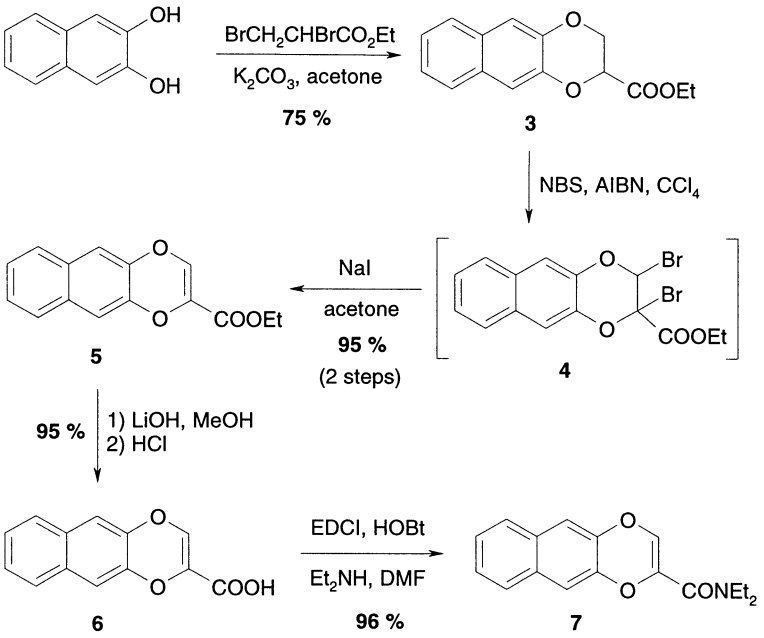
That is why we prepared ethyl 2,3-dihydronaphtho[2,3-*b*][1,4]dioxin-2-carboxylate **3** by treating 2,3-dihydroxynaphthalene with ethyl 2,3-dibromopropionate in refluxing acetone, in the presence of potassium carbonate (Scheme 2). Bromination of **3** with NBS led, as expected, to the



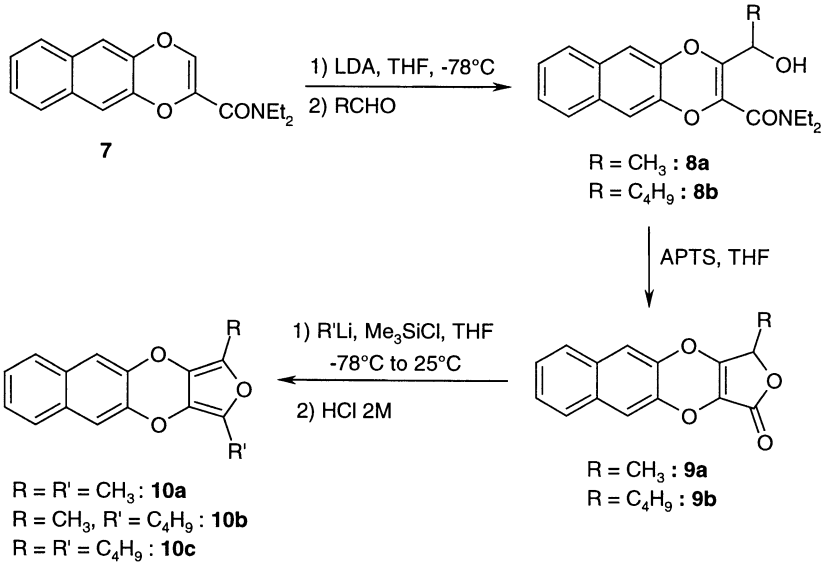
Scheme 1.

Keywords: naphtho[2,3-*b*][1,4]dioxin; 2-substituted naphtho[2,3-*b*][1,4]dioxins; 2,3-disubstituted naphtho[2,3-*b*][1,4]dioxins; furo[3,4-*b*]naphtho[2,3-*e*][1,4]dioxins.
* Corresponding author. Tel.: +2-38-49-45-89; fax: +2-38-41-72-81; e-mail: gerard.coudert@univ-orleans.fr

0040–4020/02/$ - see front matter
PII: S0040-4020(02)00017-0



Scheme 2.



Scheme 3.

corresponding dibromo derivative **4**. The required ethyl naphtho-[2,3-*b*][1,4]dioxin-2-carboxylate **5** was obtained in high yield by treating **4** with sodium iodide in refluxing acetone. Hydrolysis of **5** led to the corresponding acid **6** in 92% yield. Finally, **6** was converted into 2-diethylamido derivative **7** in nearly quantitative yield, using a classical method.[6]

When treated with lithium diisopropylamid (2 equiv., −78°C), compound **7** afforded the corresponding 3-metallated intermediate which reacted with aldehydes, providing 2,3-disubstituted derivatives **8** in high yields after hydrolysis and chromatographic purification.

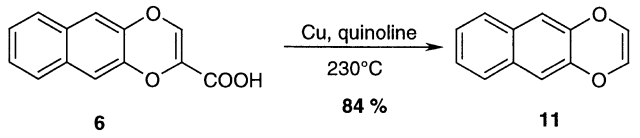
Hydroxyamides **8** were then easily converted into lactones **9** using acidic conditions[7] (Scheme 3).

According to Cooke's procedure,[8] lactones **9** were then submitted to the attack of the appropriate organolithium R′Li (3 equiv., −78°C) in the presence of Me_3SiCl (6 equiv.), leading after workup and chromatographic purification to furo[3,4-*b*]naphtho[2,3-*e*][1,4]dioxins **10** in good yields (Table 1).

Furo derivatives **10** could then be engaged in Diels–Alder

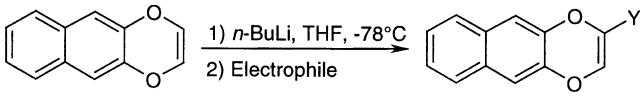
Table 1.

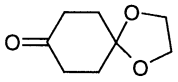
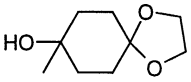
R	R′	Yield (%)		
CH_3	CH_3	**8a**: 88	**9a**: 78	**10a**: 76
CH_3	C_4H_9	–	–	**10b**: 78
C_4H_9	CH_3	**8b**: 84	**9b**: 85	**10b**: 82
C_4H_9	C_4H_9	–	–	**10c**: 74



Scheme 4.

Table 2.



Compound	Electrophile	Y–	Yield (%)[a]
12a	Bu_3SnCl	Bu_3Sn–	65
12b	I_2	I–	89
12c	CH_3CHO	CH_3CHOH–	70
12d			80

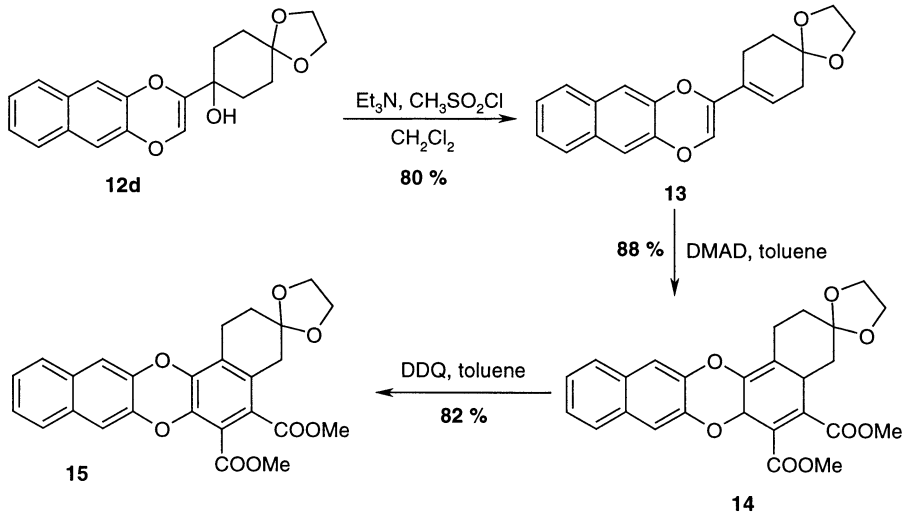
[a] Isolated yield.

reaction as previously described for the corresponding benzodioxinic series.[2c,7] These sequences could allow the synthesis of a wide range of substituted linear annulated dioxins by using different aldehydes, organolithium compounds and dienophiles.

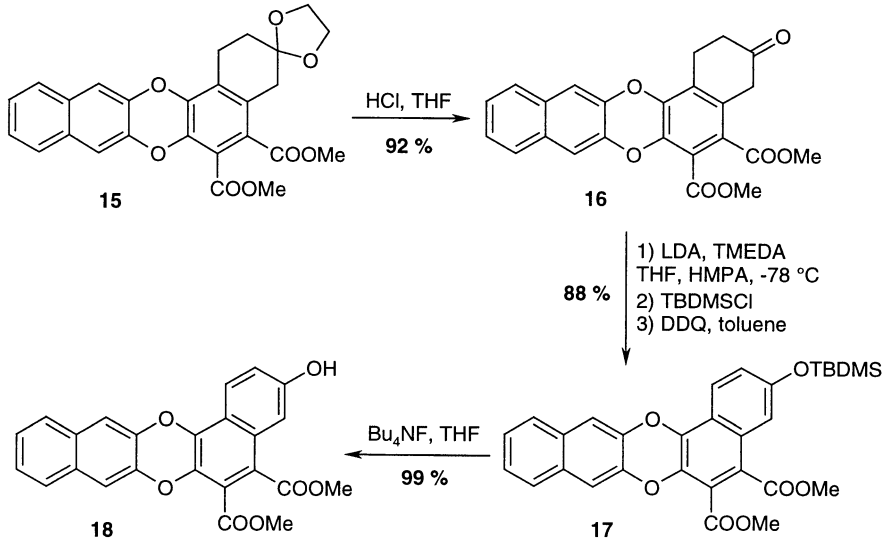
Furthermore, the decarboxylation of acid **6** was carried out by heating, in the presence of copper and quinoline, leading to naphtho[2,3-*b*][1,4]dioxin **11** in 84% yield (Scheme 4).

When **11** was reacted with *n*-butyllithium in dry tetrahydrofuran at low temperature, deprotonation occurred easily and the reaction of the 2-lithio intermediate with electrophiles led to 2-substituted naphtho[2,3-*b*][1,4]dioxins **12** (Table 2).

The choice was made to prepare allylic alcohols **12c** and **12d** because dienic systems could be easily obtained from these derivatives and used in Diels–Alder reactions for the preparation of substituted angular annulated dioxins as examplified in Schemes 5 and 6.



Scheme 5.



Scheme 6.

Thus, alcohol **12d** was converted in good yield into diene **13** which was engaged in a Diels–Alder reaction with dimethyl acetylenedicarboxylate. Adduct **14** was then submitted to dehydrogenation with DDQ, affording derivative **15**.

The ketal was cleaved and total aromatization of the pentacyclic system was realised thanks to an enol silyl ether, leading finally to phenol **18** (Scheme 6).

Moreover, compounds **12a** and **12b** constitute interesting intermediates for palladium-catalyzed coupling reactions (Stille, Suzuki, Sonogashira) allowing an easy access to a large number of extended heterocyclic systems.

In conclusion, we have described convenient and effective pathways for the synthesis of 2-substituted naphtho[2,3-*b*][1,4]dioxins, 2,3-disubstituted naphtho[2,3-*b*][1,4]dioxins and furo[3,4-*b*]naphtho[2,3-*e*][1,4]dioxins. These derivatives could be then used to elaborate more sophisticated heterocyclic systems with biological or electrochemical properties.

3. Experimental

3.1. General

Melting points were determined with a Büchi SMP-20 melting point apparatus and were uncorrected. IR spectra were recorded on a Perkin–Elmer FT PARAGON 1000 PC. ^{1}H and ^{13}C NMR were recorded on a Bruker Avance DPX250 spectrometer (250.13 MHz ^{1}H, 62.89 MHz ^{13}C); multiplicities were determined by the DEPT 135 sequence. MS were recorded on a Perkin–Elmer SCIEX API 3000 spectrometer. All reactions were carried out in a flame-dried glassware under argon atmosphere. Thin-layer chromatography (TLC) was carried out on Merck silica gel 60F_{254} precoated plates.

3.1.1. 2,3-Dihydronaphtho[2,3-*b*][1,4]dioxin (1). Dry potassium carbonate (1.29 g, 9.36 mmol) and 1,2-dibromoethane (0.40 ml, 4.68 mmol) were added to a solution of 2,3-dihydroxynaphthalene (500 mg, 3.12 mmol) in acetone (20 ml). The reaction mixture was refluxed for 24 h. After cooling and filtration, the residue was diluted with ethyl acetate and washed with brine. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **1** as a white solid (493 mg, 85%). CAS: 117009-31-1. Mp: 82°C. IR (KBr): ν cm^{-1} 1507, 1471 (C=C); 1069 (C–O). ^{1}H NMR ($CDCl_3$): δ ppm 4.35 (s, 4H, OCH_2CH_2O); 7.27–7.32 (m, 4H, H_6–H_9); 7.64–7.67 (m, 2H, H_5 and H_{10}). ^{13}C NMR ($CDCl_3$): δ ppm 64.9 (OCH_2CH_2O); 113.0 (*CH*); 124.6 (*CH*); 126.8 (*CH*); 130.0 (*C*); 144.4 (*C*). MS: m/z=187 $(M+H)^+$.

3.1.2. Ethyl 2,3-dihydronaphtho[2,3-*b*][1,4]dioxin-2-carboxylate (3). To a solution of 2,3-dihydroxynaphthalene (10 g, 62.43 mmol) in acetone (150 ml) was added dry potassium carbonate (6.5 g, 47 mmol) and ethyl 2,3-dibromopropionate (2.5 ml, 17.2 mmol). The resulting mixture was refluxed and the latter additions were repeated twice, every 15 min. The reaction mixture was then refluxed for 18 h. After filtration over celite, the filtrate was concentrated. The reaction mixture was extracted with ethyl acetate and the organic layer was washed with water, dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **3** as a colorless oil (12.10 g, 75%). IR (NaCl film): ν cm^{-1} 1759 (C=O). ^{1}H NMR ($CDCl_3$): δ ppm 1.29 (t, 3H, CH_3CH_2O, J_{vic}=7.1 Hz); 4.27 (q, 2H, CH_3CH_2O, J_{vic}=7.1 Hz); 4.50 (d, 2H, $2H_3$, $J_{3,2}$=4.4 Hz); 4.92 (t, 1H, H_2, $J_{2,3}$=4.4 Hz); 7.28–7.34 (m, 3H, $3H_{arom}$); 7.41 (s, 1H, H_{arom}); 7.64–7.70 (m, 2H, $2H_{arom}$). ^{13}C NMR ($CDCl_3$): δ ppm 14.5 (CH_3CH_2O); 62.5 (CH_3CH_2O); 65.5 (CH_2, C_3); 72.5 (CH, C_2); 113.2 (2CH, C_5 and C_{10}); 124.9 (2*CH*); 127.0 (2*CH*); 130.0 (*C*); 130.3 (*C*); 142.9 (*C*); 143.6 (*C*); 168.4 (C, *C*=*O*). MS: m/z=259 $(M+H)^+$.

3.1.3. Ethyl naphtho[2,3-*b*][1,4]dioxin-2-carboxylate (5). To a solution of ester **3** (300 mg, 1.16 mmol) in carbon tetrachloride (20 ml) were added *N*-bromosuccinimide (455 mg, 2.56 mmol) and a catalytic amount of AIBN. The resulting mixture was refluxed for 2.5 h under irradiation (60 W). After cooling, filtration and evaporation of the solvent, acetone (150 ml) and sodium iodide (19.5 g, 130 mmol) were added to the crude reaction mixture which was refluxed for 2 h. The reaction mixture was concentrated, extracted with ethyl acetate and washed with a 1 M sodium thiosulfate solution. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **5** as a white solid (282 mg, 95%). Mp: 98°C. IR (KBr): ν cm^{-1} 1724 (C=O); 1682 (C=C). ^{1}H NMR ($CDCl_3$): δ ppm 1.35 (t, 3H, CH_3CH_2O, J=7 Hz); 4.30 (q, 2H, CH_3CH_2O, J=7 Hz); 7.08 (s, 1H, H_3); 7.10 (s, 1H, H_5); 7.21 (s, 1H, H_{10}); 7.32–7.35 (m, 2H, H_7 and H_8); 7.57–7.62 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 14.6 (CH_3CH_2O); 61.7 (CH_3CH_2O); 113.0 and 113.2 (2CH, C_5 and C_{10}); 126.0 and 126.3 (2CH, C_7 and C_8); 127.3 and 127.4 (2CH, C_6 and C_9); 129.1 (*C*); 131.4 (*C*); 131.9 (*C*); 135.3 (CH, C_3); 140.5 (*C*); 141.6 (*C*); 161.6 (C, *C*=*O*). MS: m/z=257 $(M+H)^+$. Anal. Calcd for $C_{15}H_{12}O_4$: C, 70.31; H, 4.72. Found: C, 70.42; H, 4.80.

3.1.4. Naphtho[2,3-*b*][1,4]dioxin-2-carboxylic acid (6). A solution of **5** (6.5 g, 25.36 mmol) in methanol (25 ml) was refluxed for 1 h with a 1 M lithium hydroxyde solution (20 ml). After cooling, the reaction mixture was concentrated and acidified with hydrochloric acid solution until pH 1. The solution was filtrated to give the acid **6** as a white solid (5.67 g, 98%). Mp>330°C. IR (KBr): ν cm^{-1} 3450 (OH); 1678 (C=O); 1661 (C=C). ^{1}H NMR (DMSO-d_6): δ ppm 7.32–7.37 (m, 5H, $4H_{arom}$ and H_3); 7.70–7.73 (m, 2H, H_5 and H_{10}); 13.25 (sl, 1H, *OH*). ^{13}C NMR (DMSO-d_6): δ ppm 113.1 (*CH*); 113.3 (*CH*); 125.4 (*CH*); 126.5 (*CH*); 126.7 (*CH*); 127.1 (*CH*); 127.8 (*CH*); 129.1 (*C*); 131.5 (*C*); 132.0 (*C*); 135.7 (*C*); 140.4 (*C*); 141.6 (*C*); 162.5 (C, *C*=*O*). MS: m/z=229 $(M+H)^+$. Anal. Calcd for $C_{13}H_8O_4$: C, 68.42; H, 3.53. Found: C, 68.52; H, 3.58.

3.1.5. *N*,*N*-Diethylnaphtho[2,3-*b*][1,4]dioxin-2-carboxamide (7). To a cold (0°C) solution of **6** (1 g, 4.38 mmol) in DMF (15 ml) were added diethylamine (0.54 ml, 5.26 mmol), 1,3-dimethylaminopropyl-3-ethylcarbodiimide (1 g, 5.26 mmol) and hydroxybenzotriazole (711 mg,

5.26 mmol). The reaction mixture was then allowed to warm up to room temperature and stirred overnight. The reaction mixture was concentrated, extracted with ethyl acetate and washed with water. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2). **7** was obtained as a white solid (1.19 g, 96%). Mp: 78°C. IR (KBr): ν cm^{-1} 1687 (C=O); 1617 (C=C); 1509, 1469, 1449 (C=C_{arom}); 1253 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.17 (t, 6H, CH_3CH_2N, J_{vic}=6.9 Hz); 3.36 (q, 4H, CH_3CH_2N, J_{vic}=6.9 Hz); 6.67 (s, 1H, H_3); 6.95 (s, 1H, H_5); 6.98 (s, 1H, H_{10}); 7.20–7.24 (m, 2H, H_7 and H_8); 7.46–7.50 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 14.1 ($2CH_3CH_2N$); 42.3 ($2CH_3CH_2N$); 112.5 and 112.8 (2CH, C_5 and C_{10}); 126.0 (*CH*); 126.1 (*CH*); 127.1 (*CH*); 127.3 (*CH*); 131.5 (*C*); 131.6 (*C*); 131.9 (*CH*, C_3); 133.7 (*C*); 141.4 (*C*); 141.8 (*C*); 162.3 (C, *C*=*O*). MS: *m*/*z*=284 $(M+H)^+$. Anal. Calcd for $C_{17}H_{17}NO_3$: C, 72.07; H, 6.05; N, 4.94. Found: C, 72.24; H, 5.95; N, 4.75.

3.1.6. *N*,*N*-Diethyl-3-(1-hydroxyethyl)naphtho[2,3-*b*][1,4]-dioxin-2-carboxamide (8a). To a cold (−78°C) solution of **7** (300 mg, 1.06 mmol) in dry THF (5 ml) was added a solution of LDA 2 M in heptane/THF (1.05 ml, 2.1 mmol). The reaction mixture was stirred at −78°C for 3.5 h and acetaldehyde (0.36 ml, 6.36 mmol) was added dropwise. The reaction mixture was then allowed to warm up to room temperature overnight, treated with a saturated ammonium chloride solution and extracted with ethyl acetate. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 7/3) to give **8a** as a colorless oil (305 mg, 88%). IR (NaCl film): ν cm^{-1} 3400 (OH); 1734 (C=O); 1635 (C=C); 1512, 1475 (C=C_{arom}); 1292 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.18 (t, 3H, CH_3CH_2N, *J*=6.9 Hz); 1.28 (t, 3H, CH_3CH_2N, *J*=6.9 Hz); 1.44 (d, 3H, CH_3CH, *J*=6.6 Hz); 3.40–3.46 (m, 4H, CH_3CH_2N); 4.09 (m, 1H, *OH*, D_2O exchange); 4.52 (m, 1H, *CH*OH); 6.98 (s, 1H, H_{10}); 7.11 (s, 1H, H_5); 7.26–7.30 (m, 2H, H_7 and H_8); 7.51–7.56 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 13.0 (CH_3CH_2N); 14.7 (CH_3CH_2N); 19.1 (CH_3); 40.5 (CH_3CH_2N); 43.8 (CH_3CH_2N); 64.5 (*CH*OH); 111.9 (CH, C_{10}); 112.7 (CH, C_5); 125.8 and 125.9 (2CH, C_7 and C_8); 127.1 and 127.3 (2CH, C_6 and C_9); 131.4 (*C*); 131.5 (*C*); 141.6 (*C*); 142.0 (*C*); 142.6 (*C*); 163.5 (C, *C*=*O*). MS: *m*/*z*=328 $(M+H)^+$; 310.5 $(M+H-H_2O)^+$.

3.1.7. *N*,*N*-Diethyl-3-(1-hydroxypentyl)-naphtho[2,3-*b*][1,4]dioxin-2-carboxamide (8b). The reaction was carried out as described earlier for the synthesis of compound **8a** with valeraldehyde (0.28 ml, 2.12 mmol). Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 7/3) gave **8b** as a colorless oil (329 mg, 84%). IR (NaCl film): ν cm^{-1} 3416 (OH); 1683 (C=O); 1621 (C=C); 1511, 1471 (C=C_{arom}); 1262, 1251 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 0.88 (t, 3H, CH_3CH_2, *J*=4.3 Hz); 1.18–1.32 (m, 8H, $4CH_2$); 1.79 (m, 2H, CH_2CH); 3.40–3.47 (m, 4H, CH_3CH_2N); 4.05 (m, 1H, *OH*, D_2O exchange); 4.31 (t, 1H, *CH*OH, *J*=7.22 Hz); 6.99 (s, 1H, H_{10}); 7.12 (s, 1H, H_5); 7.26–7.31 (m, 2H, H_7 and H_8); 7.51–7.56 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 12.9 (CH_2CH_3); 14.4 (CH_3CH_2N); 14.6 (CH_3CH_2N); 22.9 (CH_2); 28.0 (CH_2); 32.8 (CH_2); 40.3 (CH_3CH_2N); 43.8 (CH_3CH_2N); 68.3 (*CH*OH); 111.9 and 112.8 (2CH, C_5 and C_{10}); 125.8 and 126.0 (2CH, C_7 and C_8); 127.1 and 127.2 (2CH, C_6 and C_9); 129.8 (*C*); 131.4 (*C*); 131.5 (*C*); 131.6 (*C*); 141.7 (*C*); 142.1 (*C*); 163.3 (C, *C*=*O*). MS: *m*/*z*=370.5 $(M+H)^+$; 352 $(M+H-H_2O)^+$.

3.1.8. 3-Methylfuro[3,4-*b*]naphtho[2,3-*e*][1,4]dioxin-1(3*H*)-one (9a). APTS (146 mg) was added to a stirred solution of **8a** (292 mg, 0.89 mmol) in THF (10 ml) and the reaction mixture was refluxed for 2 days. After cooling, the reaction mixture was diluted with ethyl acetate and washed with water. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **9a** as a white solid (177 mg, 78%). Mp: 212°C. IR (NaCl film): ν cm^{-1} 1778 (C=O); 1730 (C=C); 1506, 1471 (C=C_{arom}); 1265 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.60 (d, 3H, CH_3, *J*=6.6 Hz); 5.01 (q, 1H, *CH*CH_3, *J*=6.6 Hz); 7.29 (s, 2H, H_{10} and H_5); 7.38–7.42 (m, 2H, H_7 and H_8); 7.63–7.67 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 18.0 (CH_3); 72.0 (*CH*CH_3); 114.8 (*CH*); 122.3 (*C*); 126.3 (*CH*); 126.7 (*CH*); 126.8 (*CH*); 127.1 (*CH*); 127.6 (*CH*); 131.3 (*C*); 132.1 (*C*); 140.4 (*C*); 140.8 (*C*); 155.7 (*C*); 163.6 (C, *C*=*O*). MS: *m*/*z*=255.5 $(M+H)^+$.

3.1.9. 3-Butylfuro[3,4-*b*]naphtho[2,3-*e*][1,4]dioxin-1(3*H*)-one (9b). APTS (130 mg, 50% weight) was added to a stirred solution of **8b** (260 mg, 0.70 mmol) in THF (10 ml) and the reaction mixture was refluxed for 24 h. After cooling, the reaction mixture was diluted with ethyl acetate and washed with water. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **9b** as a white solid (176 mg, 85%). Mp: 130°C. IR (NaCl film): ν cm^{-1} 1765 (C=O); 1728 (C=C); 1505, 1466 (C=C_{arom}); 1265 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 0.93 (t, 3H, CH_3CH_2, *J*=7.2 Hz); 1.38–1.47 (m, 4H, $2CH_2$); 1.72–1.77 (m, 2H, CH_2); 4.87 (dd, 1H, H_3, *J*=3.2, 11.9 Hz); 7.24 (s, 2H, H_{10}); 7.26 (s, 1H, H_5); 7.36–7.40 (m, 2H, H_7 and H_8); 7.61–7.65 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 14.2 (CH_3); 22.7 (CH_2CH_3); 26.5 (CH_2); 31.7 (CH_2); 75.6 (*CH*, C_3); 114.7 and 114.8 (2CH, C_5 and C_{10}); 126.7 and 127.1 (2CH, C_7 and C_8); 127.2 and 127.5 (2CH, C_6 and C_9); 131.2 (*C*); 132.0 (*C*); 140.3 (*C*); 140.8 (*C*); 141.9 (*C*); 154.8 (*C*); 163.8 (C, *C*=*O*). MS: *m*/*z*=297 $(M+H)^+$.

3.1.10. 1,3-Dimethylfuro[3,4-*b*]naphtho[2,3-*e*][1,4]dioxin (10a). To a cold (−78°C) solution of lactone **9a** (80 mg, 0.31 mmol) and trimethylsilyl chlorid (0.24 ml, 1.89 mmol) in THF (5 ml) was added a solution of methyllithium 1.6 M in diethyl ether (0.59 ml, 0.94 mmol). After stirring at −78°C for 30 min, the reaction mixture was allowed to warm up to room temperature and quenched with a 2 M HCl solution (10 ml). The reaction mixture was stirred for another 30 min at room temperature and extracted with ethyl acetate. The organic layer was washed with water, dried over $MgSO_4$ and concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2) afforded the diene **10a** as a white solid (59 mg, 76%). Mp: 134°C. IR (KBr): ν cm^{-1} 1644 (C=C); 1484, 1464 (C=C_{arom}); 1268 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 2.23 (s, 6H, $2CH_3$); 7.31–7.35 (m, 4H, H_6–H_9); 7.63–7.66 (m, 2H, H_5 and H_{10}). ^{13}C NMR ($CDCl_3$): δ

ppm 11.0 (2CH_3); 113.4 (2CH, C_5 and C_{10}); 125.5 (2CH, C_7 and C_8); 127.0 (2CH, C_6 and C_9); 129.1 (2*C*); 129.5 (2*C*); 130.7 (2*C*); 141.3 (2*C*). MS: *m*/*z*=253 $(M+H)^+$. Anal. Calcd for $C_{16}H_{12}O_3$: C, 76.18; H, 4.79. Found: C, 76.25; H, 4.82.

3.1.11. 1-Butyl-3-methylfuro[3,4-*b*]naphtho[2,3-*e*][1,4]-dioxin (10b). *From lactone* ***9a***. To a cold (−78°C) solution of lactone **9a** (85 mg, 0.33 mmol) and trimethylsilyl chlorid (0.26 ml, 2 mmol) in THF (5 ml) was added a solution of *n*-butyllithium 1.6 M in hexanes (0.63 ml, 1 mmol). After stirring at −78°C for 30 min, the reaction mixture was allowed to warm up to room temperature and quenched with a 2 M HCl solution (10 ml). The reaction mixture was stirred for another 30 min at room temperature and extracted with ethyl acetate. The organic layer was washed with water, dried over $MgSO_4$ and concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2) afforded diene **10b** as a colorless oil (76 mg, 78%).

From lactone ***9b***. To a cold (−78°C) solution of lactone **9b** (50 mg, 0.17 mmol) and trimethylsilyl chlorid (0.13 ml, 1.01 mmol) in THF (5 ml) was added a solution of methyllithium 1.6 M in diethyl ether (0.32 ml, 0.51 mmol). After stirring at −78°C for 30 min, the reaction mixture was allowed to warm up to room temperature and quenched with a 2 M HCl solution (10 ml). The reaction mixture was stirred for another 30 min at room temperature and extracted with ethyl acetate. The organic layer was washed with water, dried over $MgSO_4$ and concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2) afforded diene **10b** as a colorless oil (41 mg, 82%). IR (NaCl film): ν cm^{-1} 1648 (C═C); 1485, 1460 (C═C_{arom}); 1262 (C–O–C). ^{1}H NMR ($CDCl_3$): δ ppm 0.99 (t, 3H, CH_3CH_2, *J*=7.2 Hz); 1.39–1.48 (m, 2H, CH_2CH_3); 1.63–1.70 (m, 2H, $CH_2CH_2CH_2$); 2.27 (s, 3H, CH_3); 2.63 (t, 2H, C–CH_2, *J*=7.2 Hz); 7.34–7.37 (m, 4H, 4H_{arom}); 7.64–7.68 (m, 2H, 2H_{arom}). ^{13}C NMR ($CDCl_3$): δ ppm 11.1 (CH_3CH_2); 14.2 (CH_3); 22.7 (CH_2CH_3); 25.6 (C–CH_2); 30.1 ($CH_2CH_2CH_2$); 113.4 (2*CH*); 125.4 (2*CH*); 127.0 (2*CH*); 129.1 (*C*); 129.2 (*C*); 129.4 (*C*); 130.7 (2*C*); 133.5 (*C*); 141.3 (2*C*). MS: *m*/*z*=295 $(M+H)^+$.

3.1.12. 1,3-Dibutylfuro[3,4-*b*]naphtho[2,3-*e*][1,4]dioxin (10c). To a cold (−78°C) solution of lactone **9b** (60 mg, 0.20 mmol) and trimethylsilyl chlorid (0.155 ml, 1.2 mmol) in THF (5 ml) was added a solution of *n*-butyllithium 1.6 M in hexanes (0.38 ml, 0.6 mmol). After stirring at −78°C for 30 min, the reaction mixture was allowed to warm up to room temperature and quenched with a 2 M HCl solution (10 ml). The reaction mixture was stirred for another 30 min at room temperature and extracted with ethyl acetate. The organic layer was washed with water, dried over $MgSO_4$ and concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2) afforded diene **10c** as a colorless oil (50 mg, 74%). IR (NaCl film): ν cm^{-1} 1649 (C═C); 1485, 1462 (C═C_{arom}); 1272 (C–O–C). ^{1}H NMR ($CDCl_3$): δ ppm 0.96 (t, 6H, 2CH_3CH_2, *J*=7.3 Hz); 1.39–1.44 (m, 4H, 2CH_2CH_3); 1.62–1.68 (m, 4H, 2$CH_2CH_2CH_2$); 2.61 (t, 4H, 2C–CH_2, *J*=7.3 Hz); 7.31–7.35 (m, 4H, 4H_{arom}); 7.64–7.68 (m, 2H, 2H_{arom}). ^{13}C NMR ($CDCl_3$): δ ppm 14.1 (2CH_3); 22.6 (2CH_2CH_3); 25.5 (2C–CH_2); 30.0 (2CH_2); 113.4 (2*CH*); 125.4 (2*CH*); 127.0 (2*CH*); 129.1 (2*C*); 130.6 (2*C*); 133.3 (2*C*); 141.4 (2*C*). MS: *m*/*z*=337.5 $(M+H)^+$.

3.1.13. Naphtho[2,3-*b*][1,4]dioxin (11). A solution of acid **6** (150 mg, 0.66 mmol) in quinoline (1 ml) was heated at 220°C for 3 h with a catalytic amount of copper powder. After cooling, the reaction mixture was diluted with ethyl acetate and washed with a 1 M HCl solution. The organic layer was dried over $MgSO_4$ and concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) afforded **11** as a white solid (102 mg, 84%). Mp: 96–98°C. IR (KBr): ν cm^{-1} 1665 (C═C); 1593, 1507 and 1407 (C═C_{arom}); 1296 (C–O–C). ^{1}H NMR ($CDCl_3$): δ ppm 5.96 (s, 2H, H_2 and H_3); 6.96 (s, 2H, H_5 and H_{10}); 7.24–7.28 (m, 2H, H_7 and H_8); 7.50–7.54 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 112.3 (*CH*); 112.6 (*CH*); 125.8 (*CH*); 126.5 (*CH*); 126.6 (*CH*); 127.0 (*CH*); 127.3 (*CH*); 127.7 (*CH*); 131.8 (2*C*); 142.7 (2*C*). Anal. Calcd for $C_{12}H_8O_2$: C, 78.25; H, 4.38. Found: C, 78.07; H, 4.47.

3.1.14. 2-(Tributyltin)naphtho[2,3-*b*][1,4]dioxin (12a). To a cold (−78°C) solution of **11** (150 mg, 0.81 mmol) in dry THF (5 ml) was added a solution of *n*-butyllithium 2 M in hexanes (0.76 ml, 1.21 mmol). The reaction mixture was stirred at −78°C for 2 h and a solution of tributyltin chloride (0.44 ml, 1.62 mmol) in THF was added dropwise. The reaction mixture was stirred at −78°C for 2 h, allowed to warm up to room temperature and extracted with ethyl acetate. The organic layer was washed with a saturated potassium fluoride solution, dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 95/5) to give **12a** as a colorless oil (249 mg, 65%). IR (KBr): ν cm^{-1} 1660 (C═C); 1469 (C═C_{arom}); 1247, 1166 (C–O–C). ^{1}H NMR ($CDCl_3$): δ ppm 0.93–1.10 (m, 15H, 3CH_3 and 3CH_2CH_3); 1.35–1.44 (m, 6H, 3CH_2); 1.56–1.66 (m, 6H, 3SnCH_2); 5.75 (s, 1H, H_3, $J(^{119}Sn, H_3)$=14 Hz, $J(^{117}Sn, H_3)$=12 Hz); 6.95 (s, 2H, H_5 and H_{10}); 7.26–7.29 (m, 2H, H_7 and H_8); 7.54–7.56 (m, 2H, H_6 and H_{10}). ^{13}C NMR ($CDCl_3$): δ ppm 11.0 (CH_2); 13.7 (CH_3); 28.4 (CH_2); 30.1 (CH_2); 112.5 (*CH*); 125.9 (*CH*); 126.0 (*CH*); 127.1 (*CH*); 127.7 (*CH*); 127.8 (*CH*); 132.1 (*C*); 132.2 (*C*); 132.6 (*CH*); 141.7 (*C*); 144.8 (*C*); 144.9 (*C*). MS: *m*/*z*=471 (M+H, $^{116}Sn)^+$, 473 (M+H, $^{118}Sn)^+$, 475 (M+H, $^{120}Sn)^+$.

3.1.15. 2-Iodonaphtho[2,3-*b*][1,4]dioxin (12b). The reaction was carried out as described earlier for the synthesis of compound **12a** with iodine (413 mg, 1.62 mmol). Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 95/5) gave **12b** as a white solid (224 mg, 89%). Mp: 86°C. IR (KBr): ν cm^{-1} 1659 (C═C); 1109, 1169 (C–O–C); 740 (C–I). ^{1}H NMR ($CDCl_3$): δ ppm 6.16 (s, 1H, H_3); 7.03 (s, 1H, H_5); 7.08 (s, 1H, H_{10}); 7.31–7.35 (m, 2H, H_7 and H_8); 7.58–7.61 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 85.6 (*C*, C_2); 112.7 (*CH*); 125.9 (*CH*); 126.1 (*CH*); 126.2 (*CH*); 127.4 (*CH*); 127.6 (*CH*); 130.2 (*CH*); 131.4 (*C*); 131.6 (*C*); 141.3 (*C*); 142.5 (*C*).

3.1.16. 1-Naphtho[2,3-*b*][1,4]dioxin-2-ylethan-1-ol (12c). The reaction was carried out as described earlier for the

synthesis of compound **12a** with acetaldehyde (0.27 ml, 4.86 mmol). Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 3/2) gave **12c** as a colorless oil (129 mg, 70%). IR (KBr): ν cm^{-1} 3300 (OH); 1510, 1476 (C=C); 1255, 1169 (C–O). ^1H NMR ($CDCl_3$): δ ppm 1.41 (d, 3H, CH_3, J=6.6 Hz); 4.23 (q, 1H, C*H*OH, J=6.6 Hz); 6.10 (s, 1H, H_3); 7.00 (s, 1H, H_{10}); 7.06 (s, 1H, H_5); 7.26–7.30 (m, 2H, H_7 and H_8); 7.53–7.57 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 19.6 (CH_3); 65.0 (*C*HOH); 111.6 and 111.8 (2*C*H, C_5 and C_{10}); 122.3 and 125.1 (2*C*H, C_7 and C_8); 126.6 and 126.7 (2*C*H, C_6 and C_9); 131.0 (*C*); 131.1 (*C*); 139.0 (*C*); 141.7 (*C*); 142.2 (*C*). MS: m/z=229 $(M+H)^+$.

3.1.17. 8-Naphtho[2,3-*b*][1,4]dioxin-2-yl-1,4-dioxaspiro-[4,5]decan-8-ol (12d). To a cold (−78°C) solution of **11** (3.53 g, 19.2 mmol) in dry THF (25 ml) was added a solution of *n*-butyllithium 2 M in hexanes (14.4 ml, 23 mmol). The reaction mixture was stirred at −78°C for 2 h and a solution of 1,4-dioxaspiro[4,5]decan-8-one (2 g, 12.81 mmol) in THF was added dropwise. The reaction mixture was stirred at −78°C for 3 h, allowed to warm up to room temperature and quenched with a 1 M HCl solution. After extraction with ethyl acetate, the organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 8/2) to give **12d** as a white solid (3.49 g, 80%). Mp: 122°C. IR (KBr): ν cm^{-1} 3433 (OH); 1509, 1474 (C=C); 1093 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.66–2.04 (m, 8H, $H_{6'}$, $H_{7'}$, $H_{9'}$, $H_{10'}$); 3.94 (s, 2H, $O(CH_2)_2O$); 6.18 (s, 1H, H_3); 7.01 (s, 1H, H_{10}); 7.08 (s, 1H, H_5); 7.28–7.32 (m, 2H, H_7 and H_8); 7.54–7.58 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 29.2 (CH_2); 29.8 (CH_2); 31.3 (CH_2); 33.9 (CH_2); 63.5 ($O(CH_2)_2O$); 63.6 ($O(CH_2)_2O$); 68.8 (*C*); 107.6 (*C*); 110.7 (*CH*); 111.1 (*CH*); 121.1 (*CH*); 124.4 (*CH*); 124.5 (*CH*); 125.8 (*CH*); 125.9 (*CH*); 130.3 (*C*); 130.4 (*C*); 140.6 (*C*); 141.1 (*C*); 141.7 (*C*). MS: m/z=341.5 $(M+H)^+$; 323 $(M+H-H_2O)^+$. Anal. Calcd for $C_{20}H_{20}O_5$: C, 70.58; H, 5.92. Found: C, 70.55; H, 5.95.

3.1.18. 2-(1,4-Dioxaspiro[4,5]dec-7-ene-8-yl)-naphtho-[2,3-*b*][1,4]dioxin (13). To a cold (0°C) solution of **12d** (1.53 g, 4.49 mmol) in dichloromethane (20 ml) were added triethylamine (6.28 ml, 44.9 mmol) and methanesulfonyl chloride (1.74 ml, 22.47 mmol). After stirring at 0°C for 15 min, the reaction mixture was refluxed for 2.5 h. After cooling, the reaction mixture was washed with 2% sodium hydroxide solution and extracted with dichloromethane. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 98/2) to give **13** as a white solid (1.16 g, 80%). Mp: 154°C. IR (KBr): ν cm^{-1} 1671, 1634, 1511 and 1474 (C=C); 1368, 1337, 1278, and 1121 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.85 (t, 2H, $H_{10'}$, $J_{10',9'}$=6.4 Hz); 2.31 (m, 2H, $H_{6'}$); 2.46 (m, 2H, $H_{9'}$); 3.98 (s, 4H, $O(CH_2)_2O$); 6.13 (m, 1H, $H_{7'}$); 6.20 (s, 1H, H_3); 7.04 (s, 1H, H_{10}); 7.10 (s, 1H, H_5); 7.27–7.31 (m, 2H, H_7 and H_8); 7.55–7.60 (m, 2H, H_6 and H_9). ^{13}C NMR ($CDCl_3$): δ ppm 22.6 (CH_2, $C_{9'}$); 30.6 (CH_2, $C_{10'}$); 35.6 (CH_2, $C_{6'}$); 64.5 ($O(CH_2)_2O$); 107.6 (*C*); 111.4 and 111.7 (2*C*H, C_5 and C_{10}); 117.6 (*CH*, $C_{7'}$); 120.0 and 122.6 (2*C*H, C_7 and C_8); 125.0 (*CH*, C_3); 126.6 and 126.7 (2*C*H, H_6 and H_9); 130.9 (*C*); 131.1 (*C*); 136.3 (*C*); 137.8 (*C*); 141.8 (*C*); 142.3 (*C*). MS: m/z=323 $(M+H)^+$.

3.1.19. Dimethyl 3,3-(1,2-ethylene-dioxy)-1,2,3,4,4a,6a-hexahydrodibenzo[*a,i*]oxanthrene-5,6-dicarboxylate (14). Dimethyl acetylenedicarboxylate (2.29 ml, 18.6 mmol) was added to a solution of diene **13** (1 g, 3.1 mmol) in toluene (20 ml). The reaction mixture was refluxed for 18 h. After cooling and evaporation of solvent, **14** was purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 7/3) to give a white solid (1.27 g, 88%). Mp: 204°C. IR (KBr): ν cm^{-1} 1731 (C=O); 1716 (C=O); 1509, 1471 and 1437 (C=C); 1275, 1197 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.58–1.64 (m, 2H, H_2); 1.86 (m, 1H, H_4); 2.06 (m, 1H, H_4); 2.18 (m, 1H, H_1); 3.23 (m, 1H, H_{4a}); 3.46 (m, 1H, H_1); 3.87 (s, 6H, $COOCH_3$); 3.99 (s, 4H, $O(CH_2)_2O$); 5.32 (m, 1H, H_{6a}); 7.32–7.42 (m, 4H, H_9–H_{12}); 7.67–7.71 (m, 2H, H_8 and H_{13}). ^{13}C NMR ($CDCl_3$): δ ppm 21.8 (CH_2); 34.5 (CH_2); 38.9 (*CH*); 40.8 (CH_2); 53.0 (OCH_3); 64.9 and 65.0 ($O(CH_2)_2O$); 66.7 (*CH*); 108.2 (*C*); 112.4 (*CH*); 113.7 (*CH*); 114.2 (*C*); 125.0 (*CH*); 125.1 (*CH*); 126.0 (*C*); 127.0 (*CH*); 127.1 (*CH*); 130.0 (*C*); 130.3 (*C*); 136.2 (*C*); 143.6 (*C*); 145.0 (*C*); 145.8 (*C*); 165.4 and 168.2 (2C, 2*C*=*O*). MS: m/z=465 $(M+H)^+$.

3.1.20. Dimethyl 3,3-(1,2-ethylene-dioxy)-1,2,3,4-tetrahydrodibenzo[*a,i*]oxanthrene-5,6-dicarboxylate (15). DDQ (94 mg, 0.41 mmol) was added to a solution of cycloadduct **14** (160 mg, 0.34 mmol) in toluene (5 ml) and the reaction mixture was refluxed for 6 h. After cooling and evaporation of toluene, the reaction mixture was extracted with dichloromethane and washed with 8% sodium hydroxide solution. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 3/2) to give **15** as a white solid (129 mg, 82%). Mp: 170°C. IR (KBr): ν cm^{-1} 1733 (C=O); 1341, 1266, 1211 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 1.92 (t, 2H, H_2, $J_{2,1}$=6.6 Hz); 2.97 (m, 4H, H_1 and H_4); 3.84 (s, 3H, OCH_3); 3.94 (s, 3H, OCH_3); 4.01 (s, 4H, $O(CH_2)_2O$); 7.22 (m, 2H, H_8 and H_{13}); 7.28–7.32 (m, 2H, H_{10} and H_{11}); 7.58–7.60 (m, 2H, H_9 and H_{12}). ^{13}C NMR ($CDCl_3$): δ ppm 22.6 (CH_2); 30.3 (CH_2); 37.2 (CH_2); 52.8 (OCH_3); 53.0 (OCH_3); 65.0 ($O(CH_2)_2O$); 107.7 (*C*); 112.7 (*CH*); 113.0 (*CH*); 120.3 (*C*); 126.0 (*CH*); 126.4 (*C*); 127.2 (*CH*); 127.3 (*CH*); 127.4 (*CH*); 130.7 (*C*); 130.8 (*C*); 131.2 (*C*); 131.3 (*C*); 137.6 (*C*); 140.9 (*C*); 141.1 (*C*); 141.2 (*C*);165.8 and 167.4 (2C, 2*C*=*O*). MS: m/z=463.5 $(M+H)^+$.

3.1.21. Dimethyl 3-oxo-1,2,3,4-tetrahydrodibenzo[*a,i*]-oxanthrene-5,6-dicarboxylate (16). A 1 M HCl solution (5 ml) was added to a solution of ketal **15** (150 mg, 0.32 mmol) in THF (10 ml) and the reaction mixture was refluxed for 4 h. After cooling, the reaction mixture was extracted with ethyl acetate and the organic layer was dried over $MgSO_4$, concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 3/2) afforded **16** as a white solid (123 mg, 92%). Mp: 212°C. IR (KBr): ν cm^{-1} 1729 (C=O esters); 1717 (C=O ketone); 1514, 1475, 1458 and 1431 (C=C); 1361, 1343, 1266 (C–O–C). ^1H NMR ($CDCl_3$): δ ppm 2.56 (t, 2H, H_2 $J_{2,1}$=6.6 Hz); 3.14 (t, 2H, H_1 $J_{1,2}$=6.6 Hz); 3.66 (s, 2H, H_4); 3.85 (s, 3H, OCH_3); 3.96 (s, 3H, OCH_3); 7.27–7.36

(m, 4H, H_9–H_1); 7.60–7.62 (m, 2H, H_8–H_{13}). ^{13}C NMR ($CDCl_3$): δ ppm 21.0 (*C*H_2); 36.7 (*C*H_2); 41.9 (*C*H_2); 52.7 (*OC*H_3); 52.9 (*OC*H_3); 112.5 (*CH*); 112.9 (*CH*); 120.9 (*C*); 125.1 (*CH*); 125.7 (*CH*); 125.8 (*CH*); 126.9 (*CH*); 127.0 (*C*); 127.1 (*C*); 129.2 (*C*); 130.8 (*C*); 131.0 (*C*); 137.9 (*C*); 140.2 (*C*); 140.3 (*C*); 165.1 and 166.4 (2C, 2*C*=*O esters*); 208.1 (C, *C*=*O ketone*). MS: *m*/*z*=419.5 $(M+H)^+$.

3.1.22. Dimethyl 3-[(*tert*-butyldimethylsilyl)-oxy]-benzo-[*a*]oxanthrene-5,6-dicarboxylate (17). To a cold (−78°C) solution of **16** (500 mg, 1.36 mmol) in dry THF (10 ml) and HMPA (1 ml) were added TMEDA (0.3 ml, 2.04 mmol) and a solution of LDA 2 M in THF/heptane (1 ml, 2.04 mmol). The reaction mixture was stirred at −78°C for 2 h and a solution of *tert*-butyldimethylsilyl chloride (415 mg, 4.07 mmol) in THF was added dropwise. The reaction mixture was stirred at −78°C for 3 h, allowed to warm up to room temperature and concentrated under reduced pressure. The crude enol silyl ether was diluted with toluene (10 ml) and DDQ (388 mg, 1.71 mmol) was added. The reaction mixture was refluxed for 2 h. After cooling and evaporation of toluene, the reaction mixture was extracted with dichloromethane and washed with 8% sodium hydroxide solution. The organic layer was dried over $MgSO_4$, concentrated and purified by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) to give **17** as a white solid (491 mg, 68%). Mp: 120°C. IR (KBr): ν cm^{-1} 1726 (C=O); 1495 and 1385 (C=C); 1253, 1199 (C–O–C); 1015 (Si–O); 840, 786, 741 (Si–C). ^{1}H NMR ($CDCl_3$): δ ppm 0.28 (s, 6H, *Si*(*CH*$_3$)$_2$); 1.04 (s, 9H, *C*(*CH*$_3$)$_3$); 3.90 (s, 3H, *OCH*$_3$); 3.96 (s, 3H, *OCH*$_3$); 7.30 (dd, 1H, H_2, $J_{1,2}$=9.0 Hz, $J_{2,4}$=2.3 Hz); 7.36–7.42 (m, 2H, 2H_{arom}); 7.49 (s, 1H, H_{13}); 7.54 (d, 1H, H_4, $J_{4,2}$=2.3 Hz); 7.64 (s, 1H, H_8); 7.75–7.82 (m, 2H, 2H_{arom}); 8.03 (d, 1H, H_1, $J_{1,2}$=9.0 Hz). ^{13}C NMR (*CDCl*$_3$): δ ppm −4.5 (Si(*CH*$_3$)$_2$); 13.5 (*C*, *C*(CH$_3$)$_3$); 25.6 (*CH*$_3$); 52.6 (*OCH*$_3$); 52.8 (*OCH*$_3$); 108.2 (*CH*); 113.4 (*CH*); 113.5 (*CH*); 119.0 (*C*); 121.3 (*C*); 122.2 (*CH*); 123.0 (*CH*); 124.6 (*C*); 126.8 (*CH*); 126.9 (*CH*); 127.6 (*CH*); 127.8 (*CH*); 129.8 (*C*); 131.2 (*C*); 131.8 (*C*); 131.9 (*C*); 138.4 (*C*); 141.1 (*C*); 141.4 (*C*); 157.9 (*C*); 165.8 (C, *C*=*O*); 166.5 (C, *C*=*O*). MS: *m*/*z*=531 $(M+H)^+$.

3.1.23. Dimethyl 3-hydroxydibenzo[*a*,*i*]oxanthrene-5,6-dicarboxylate (18). A solution of tetrabutylammonium fluoride 1 M in THF (0.61 ml, 0.61 mmol) was added to a solution of **17** (215 mg, 0.40 mmol) in THF (3 ml). The reaction mixture was stirred for 1 h at room temperature. After hydrolysis, the reaction mixture was extracted with ethyl acetate and the organic layer was dried over $MgSO_4$, concentrated. Purification by flash chromatography on silica gel (petroleum ether/ethyl acetate 9/1) afforded **18** as an orange solid (164 mg, 99%). Mp: 160°C. IR (KBr): ν cm^{-1} 3347 (OH); 1751 (C=O); 1699 (C=O); 1513, 1474, 1384 (C=C); 1265 (C–O–C). ^{1}H NMR ($CDCl_3$): δ ppm 3.88 (s, 3H, *OCH*$_3$); 3.94 (s, 3H, *OCH*$_3$); 7.29 (dd, 1H, H_2, $J_{1,2}$=9.1 Hz, $J_{2,4}$=2.2 Hz); 7.35–7.41 (m, 2H, H_{10} and H_{11}); 7.48 (s, 1H, H_{13}); 7.52 (d, 1H, H_4, $J_{4,2}$=2.2 Hz); 7.63 (s, 1H, H_8); 7.74–7.80 (m, 2H, H_9 and H_{12}); 8.05 (d, 1H, H_1, $J_{1,2}$=9.1 Hz); 10.24 (s, 1H, *OH*). ^{13}C NMR ($CDCl_3$): δ ppm 53.6 (*OCH*$_3$); 53.8 (*OCH*$_3$); 107.9 (*CH*); 113.3 (*CH*); 113.5 (*CH*); 118.6 (*C*); 121.6 (*C*); 122.1 (*CH*); 122.9 (*CH*); 124.5 (*C*); 126.5 (*CH*); 126.6 (*CH*); 126.7 (*CH*); 127.8 (*CH*); 129.5 (*C*); 131.4 (*C*); 131.6 (*C*); 131.7 (*C*); 138.3 (*C*); 141.0 (*C*); 141.1 (*C*); 157.8 (*C*); 165.7 (C, *C*=*O*); 166.9 (C, *C*=*O*). MS: *m*/*z*=417.5 $(M+H)^+$. Anal. Calcd for $C_{24}H_{16}O_7$: C, 69.23; H, 3.87. Found: C, 69.35; H, 3.94.

References

1. (a) Palmer, B. D.; Boyd, M.; Denny, W. A. *J. Org. Chem.* **1990**, *55*, 438. (b) Lee, H. H.; Denny, W. A. *J. Chem. Soc., Perkin Trans. 1* **1990**, 1071. (c) Khatib, S.; Bouzoubaa, M.; Coudert, G. *Tetrahedron Lett.* **1998**, *39*, 989.
2. (a) Palmer, B. D.; Rewcastle, G. W.; Atwell, G. J.; Baguley, B. C.; Denny, W. A. *J. Med. Chem.* **1988**, *31*, 707. (b) Lee, H. H.; Palmer, B. D.; Boyd, M.; Baguley, B. C.; Denny, W. A. *J. Med. Chem.* **1992**, *35*, 258. (c) Ruiz, N.; Bouyssou, P.; Rapp, M.; Maurizis, J. C.; Madelmont, J. C.; Coudert, G. *Heterocycl. Commun.* **1997**, *3*, 509. (d) Coudert, G.; Khatib, S.; Moreau, P.; Caignard, D. H.; Renard, P.; Atassi, G.; Pierre, A. Eur. Pat. Appl. 97402654.4-2101, 1997.
3. (a) Czekanski, T.; Hanack, M.; Becker, J. Y.; Bernstein, J.; Bittner, S.; Kaufman-Orenstein, L.; Peleg, D. *J. Org. Chem.* **1991**, *56*, 1569. (b) Hellberg, J.; Pelcman, M. E. *Tetrahedron Lett.* **1994**, *35*, 1769.
4. Padwa, A.; Austin, D. J.; Ishida, M.; Muller, C. L.; Murphree, S. S.; Yeske, P. E. *J. Org. Chem.* **1992**, *57*, 1161.
5. Coudert, G.; Guillaumet, G.; Loubinoux, B. *Tetrahedron Lett.* **1978**, 1059.
6. König, W.; Geiger, R. *Chem. Ber.* **1970**, *103*, 788.
7. Ruiz, N.; Buon, C.; Pujol, M. D.; Guillaumet, G.; Coudert, G. *Synth. Commun.* **1996**, *26*, 2057.
8. Cooke, M. P. *J. Org. Chem.* **1986**, *51*, 951.