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Synthesis of Amino-Substituted Indanes and Tetralins via Consecutive Multibond-Forming Tandem Processes

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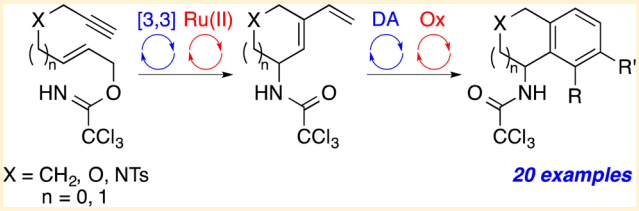
Supporting Information

ABSTRACT: A rapid and general approach for the synthesis of amino-substituted indanes and tetralins from readily available alkyne-derived allylic alcohols via consecutive multibond-forming tandem processes has been developed. In the first one-pot tandem process, a series of cyclic dienes were prepared using an Overman rearrangement under thermal conditions, followed by a ruthenium(II)-catalyzed ring closing enyne metathesis reaction. The resulting *exo*-dienes were then subjected to a second one-pot tandem process involving a highly regioselective Diels–Alder reaction with alkynes, quinones or nitriles and a subsequent oxidation step to give a diverse library of C-1 amino-substituted indanes and tetralins in good overall yields.



INTRODUCTION

Indane and tetralin scaffolds with C-1 amino functionality have generated significant interest due to their wide-ranging pharmacological properties. For example, (+)-sertaline **1** (Zoloft) is prescribed for the treatment of depression,[1] (+)-indatraline **2** is a nonselective monoamine transporter,[2] while rasagiline **3** (Azilect) is used to treat Parkinson's disease (Figure 1).[3] Other examples include indinavir, a component of

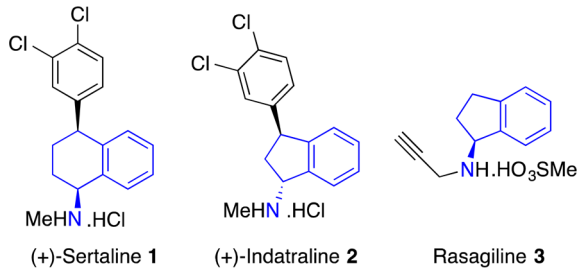


Figure 1. Biologically active amino-substituted indanes and tetralins.

HIV therapy, and irindalone, which selectively blocks the 5-HT_2 receptor.[4,5] Heteroatom analogues are also potent medicinal agents and have been used as inhibitors of aldosterone synthase for the treatment of hypertension and heart failure.[6]

As a result of these wide-ranging pharmacological activities, various synthetic approaches have been developed for the preparation of C-1 amino-substituted indanes and tetralins. A common approach involves stepwise construction of aryl substituted carbonyl derivatives that are subjected to an intramolecular Friedel–Crafts acylation.[2,7,8] The amine moiety can then be introduced via reductive amination of the resulting bicyclic aryl ketones. Other more specific methods also focus on construction of the partially saturated ring system and include the intramolecular cyclization of lithium anions with imines,[9] a CAN-mediated Ritter-type cyclodimerization[10] and an aryne Diels–Alder reaction with acyclic dienes.[11] While many of these methods involve the use of elegant chemistry, they are generally limited to the preparation of a particular bicyclic ring system and restricted in scope by the available substituents on the aryl ring. We were interested in developing a flexible approach for the generation of either bicyclic motif that would also allow the late stage introduction of various aryl ring substituents. Herein, we now report a rapid and general approach for the synthesis of C-1 amino-substituted indanes and tetralins from readily available alkyne-derived allylic alcohols, using consecutive multibond-forming tandem processes.[12] The use of each tandem process to construct first the amino-substituted partially saturated ring and then the aryl ring allows the preparation of a diverse set of compounds incorporating a range of functional groups.

RESULTS AND DISCUSSION

Our approach involved the conversion of alkyne-derived allylic alcohols **4** to the corresponding allylic amine derivatives **5** using a [3,3]-sigmatropic rearrangement (Scheme 1). Ring-closing enyne metathesis (RCEYM) to form dienes **6** would then be followed by a Diels–Alder reaction with a suitable dienophile to generate a bicyclic dihydrobenzene. Oxidation would then give C-1 amino-substituted indanes and tetralins **7**.

The study began with the development of a general and efficient approach for the preparation of alkyne-derived allylic alcohols (Table 1). Analogues with an all-carbon backbone were prepared from commercially available 4-pentyn-1-ol (**8a**)

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Scheme 1. Proposed Approach to C-1 Amino-Substituted Indanes and Tetralins

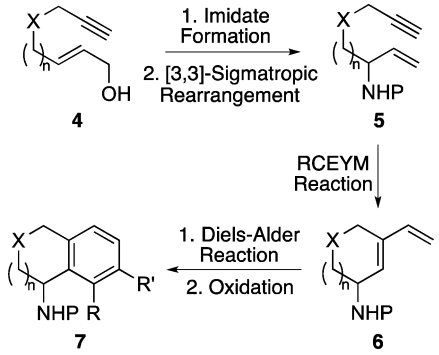
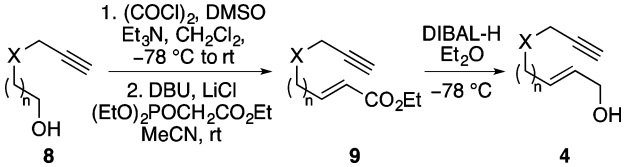


Table 1. Synthesis of Alkyne-Derived Allylic Alcohols

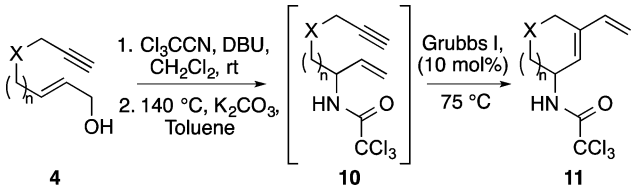


entry	8	yield (%)	yield (%)
1	**8a** X = CH_2, n = 0	**9a** (95)	**4a** (93)
2	**8b** X = CH_2, n = 1	**9b** (99)	**4b** (97)
3	**8c** X = O, n = 1	**9c** (75)	**4c** (83)
4	**8d** X = NTs, n = 1	**9d** (83)	**4d** (99)

and 5-hexyn-1-ol (**8b**) using a one-pot Swern oxidation and Horner−Wadsworth−Emmons reaction, performed under Masumune−Roush conditions.[13,14] This gave the corresponding (*E*)-*α*,*β*-unsaturated esters, **9a** and **9b** in 95 and 99% yield, respectively (entries 1 and 2). Subsequent reduction of the (*E*)-*α*,*β*-unsaturated esters with DIBAL-H gave the alkyne-derived (*E*)-allylic alcohols, **4a** and **4b** in excellent overall yields.[15] Two further substrates incorporating an oxygen atom **4c** or a *N*-tosyl group **4d** were also prepared in high yields using a similar approach from known alcohols, 2-(2′-propynloxy)ethanol (**8c**)[16] and 2-(*N*-*p*-toluenesulfonyl-2′-propynlamino)ethanol (**8d**) (entries 3 and 4).[17]

It was envisaged that the C-1 amino substituent of the indanes and tetralins could be installed using an Overman rearrangement[18] and that the transformation could be performed as a one-pot tandem process in combination with a RCEYM reaction leading directly to the cyclic *exo*-dienes.[19,20] Reaction of (*E*)-allylic alcohols **4a−d** with trichloroacetonitrile and a catalytic amount of DBU gave the corresponding allylic trichloroacetimidates, and these were subjected to an Overman rearrangement under thermal conditions (Table 2). In the case of analogues with an all-carbon side-chain (entries 1 and 2), subsequent addition of Grubbs first generation catalyst (10 mol %) resulted in the efficient preparation of the target dienes **11a** and **11b** in 71 and 86% yields, respectively, over the three steps. The RCEYM reactions of enynes **10c** and **10d** were significantly slower (4−6 days), requiring higher catalyst loading (20 mol %) to generate dihydropyran **11c** and tetrahydropyridine **11d** in only modest overall yields (30−34%). Methods for improving the RCEYM step were investigated, and the use of 1,7-octadiene as an in situ source of ethylene was found to be beneficial during the preparation of dihydropyran **11c**,[21] allowing a more efficient tandem synthesis (46% overall yield) at much lower catalyst loading (10 mol %,

Table 2. Tandem Synthesis of Dienes 11a−d



entry	4	yield (%)
1	**4a** X = CH_2, n = 0	**11a** (71)
2	**4b** X = CH_2, n = 1	**11b** (86)
3	**4c** X = O, n = 1	**11c** (46)[a]
4	**4d** X = NTs, n = 1	**11d** (40)[a,b]

[a]RCEYM was done at 90 °C using 1,7-octadiene. [b]RCEYM was done using Hoveyda−Grubbs 2nd generation catalyst (5 mol %).

entry 3). For the synthesis of tetrahydropyridine **11d**, an effective tandem process was realized using Hoveyda−Grubbs second generation catalyst in combination with 1,7-octadiene during the RCEYM step. At a catalyst loading of 5 mol %, **11d** was isolated in 40% yield over the three steps (entry 4).[22]

The next stage of the study investigated the preparation of a diverse library of C-1 amino-substituted indanes and tetralins using a second, one-pot, multibond-forming tandem process involving a Diels−Alder reaction with electron-deficient alkynes or 1,4-benzoquinones, followed by an oxidation step (Scheme 2).[23] It was found that Lewis acid mediated Diels−Alder reaction of dienes **11a−d** with diethyl acetylenedicarboxylate followed by oxidation of dihydrobenzenes **12** with DDQ could be performed using microwave heating, resulting in the rapid preparation of indanes and tetralins **13a−d** in good yields over the two steps. Standard thermal conditions were found to be more efficient during the highly regioselective Diels−Alder reaction of dienes **11a,b** with methyl propiolate. Oxidation with DDQ then generated **13e** and **13f** in 52 and 66% overall yields, respectively.[24] The Diels−Alder reactions of dienes **11a−d** with 1,4-benzoquinone, 2-*tert*-butyl-1,4-benzoquinone and 1,4-naphthoquinone for the synthesis of tri- and tetracyclic indanes and tetralins **14a−h** were again found to be more efficient using standard thermal conditions, while microwave heating was used for the rapid oxidation step of the one-pot process. In general, manganese dioxide was established as the best oxidizing agent for this series of compounds. For analogues **14c**, **14f** and **14g**, the use of manganese dioxide to perform the oxidation step also led to trace amounts of products formed from benzylic oxidation. In these cases, DDQ provided the tetralins in higher yields. It should be noted that Diels−Alder reaction of dienes **11a−11d** with 2-*tert*-butyl-1,4-benzoquinone followed by oxidation gave the corresponding indanes or tetralins (**14d−g**) solely as a single regioisomer. The regiochemical outcome of these reactions was determined by X-ray analysis of **14e**.[25] This showed that the 8-*tert*-butyl regioisomer was the product generated, suggesting these reactions are sterically controlled.

The scope of this process was extended to include heteroaromatic derivatives (Scheme 3). Hetero Diels−Alder reaction of dienes **11a** or **11b** with electron-deficient nitriles such as *p*-toluenesulfonyl cyanide, ethyl cyanoformate or trichloroacetonitrile at 160 °C gave the corresponding pyridines directly as single regioisomers, without the need of an oxidant.[24,26] During the reaction of **11b** with trichloroacetonitrile, aromatization of the resulting dihydropyridine was facilitated by loss of a chlorine atom to give dichloromethyl

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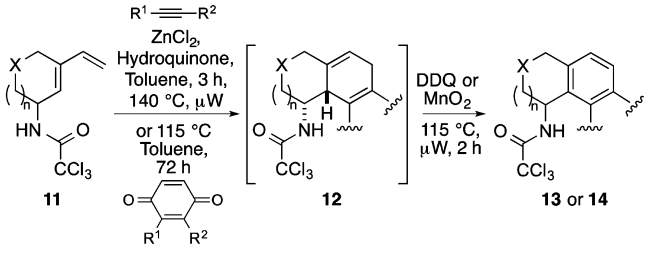
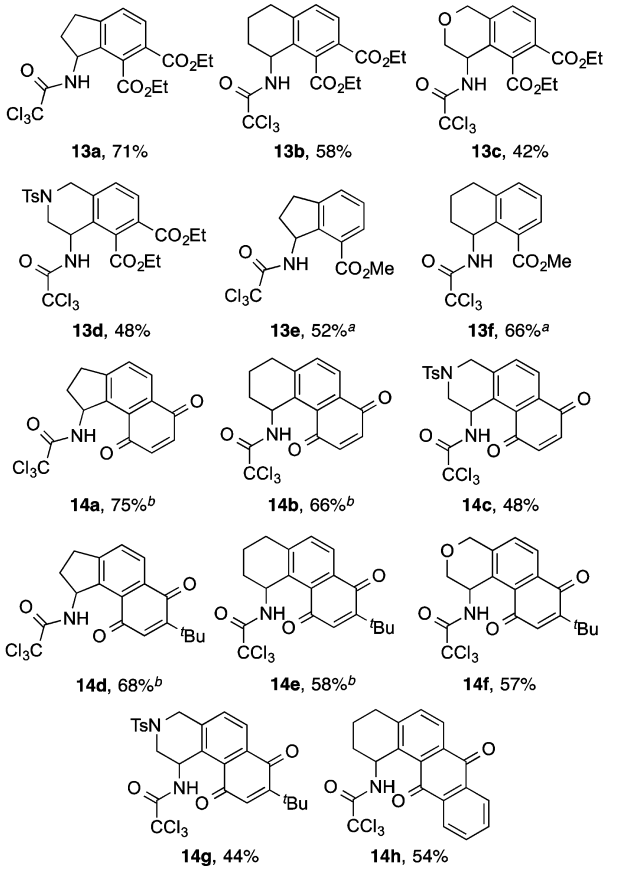
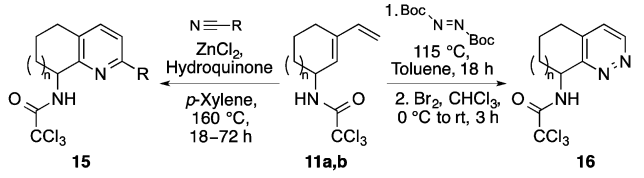
Scheme 2. One-Pot Tandem Synthesis of Amino-Substituted Indanes and Tetralins 13 and 14

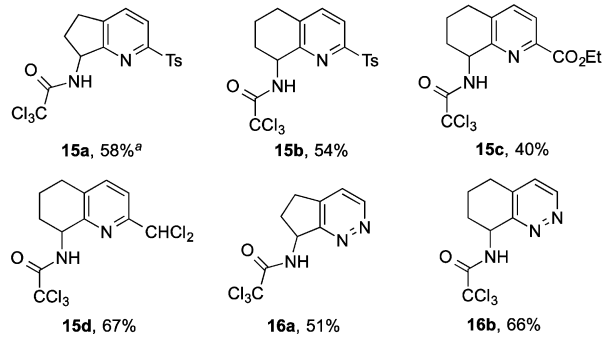




[a]Both steps were performed under standard thermal conditions in a Schlenk tube. [b]Oxidation done using MnO_2.

Scheme 3. One-Pot Tandem Synthesis of Heteroaromatic Analogues 15 and 16





[a]Reaction was performed at 125 °C.

derivative **15d**. Pyridazines were also generated, via the hetero-Diels–Alder reaction of **11a** or **11b** with di-*tert*-butyl azodicarboxylate. Treatment of the resulting adducts with bromine promoted the known sequence of bromination, *N*-Boc deprotection and aromatization giving pyridazines **16a** and **16b** in good overall yields.[27]

CONCLUSIONS

In summary, a novel approach for the synthesis of a diverse library of compounds containing C-1 amino-substituted indanes and tetralins, privileged structures found within a range of pharmaceutically important agents, has been developed. The use of consecutive multibond-forming tandem processes allowed rapid access to structures with varying ring sizes, incorporating heteroatoms and substituents in a regioselective fashion. An asymmetric version of this approach involving a palladium(II)-catalyzed Overman rearrangement with chiral catalysts,[28] for the preparation of natural products and medicinally important compounds, is currently under investigation.[29]

EXPERIMENTAL SECTION

All reagents and starting materials were obtained from commercial sources and used as received. All dry solvents were purified using a solvent purification system. All reactions were performed under an atmosphere of argon unless otherwise mentioned. Brine refers to a saturated solution of sodium chloride. Flash column chromatography was performed using silica gel 60 (35–70 μm). Aluminum-backed plates precoated with silica gel $60F_{254}$ were used for thin layer chromatography and were visualized with a UV lamp or by staining with potassium permanganate. ^{1}H NMR spectra were recorded on a NMR spectrometer at either 400 or 500 MHz, and data are reported as follows: chemical shift in ppm relative to tetramethylsilane as the internal standard, multiplicity (s = singlet, d = doublet, t = triplet, q = quartet, m = multiplet or overlap of nonequivalent resonances, integration). ^{13}C NMR spectra were recorded on a NMR spectrometer at either 101 or 126 MHz, and data are reported as follows: chemical shift in ppm relative to tetramethylsilane or the solvent as internal standard ($CDCl_3$, δ 77.0 ppm or CD_3OD, δ 44.0 ppm), multiplicity with respect to proton (deduced from DEPT experiments, C, CH, CH_2 or CH_3). Infrared spectra were recorded on a FTIR spectrometer; wavenumbers are indicated in cm^{-1}. Mass spectra were recorded using electron impact, chemical ionization, electrospray or fast atom bombardment techniques. HRMS spectra were recorded using a dual-focusing magnetic analyzer mass spectrometer. Melting points are uncorrected. Microwave reactions were conducted using a CEM Discover Explorer Synthesis Unit and performed in glass tubes (capacity 10 mL) sealed with a septum. Temperatures of the reaction mixtures were monitored by an internal infrared temperature control probe.

Ethyl (2*E*)-hept-2-en-6-ynoate (9a).[30] Dimethyl sulfoxide (3.60 mL, 50.8 mmol) was added to a stirred solution of oxalyl chloride (2.49 mL, 28.4 mmol) in dichloromethane (100 mL) at −78 °C. The mixture was stirred for 0.3 h before 4-pentyn-1-ol (**8a**) (1.70 g, 20.3 mmol) in dichloromethane (25 mL) was slowly added. The mixture was stirred for a further 0.3 h before triethylamine (14.1 mL, 102 mmol) was added. This reaction mixture was stirred for 0.5 h at −78 °C and then allowed to warm to room temperature and stirred for a further 3 h. A solution of lithium chloride (1.55 g, 36.5 mmol), triethyl phosphonoacetate (7.24 mL, 36.5 mmol) and 1,8-diazabicyclo[5,4,0]-

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undec-7-ene (5.14 mL, 36.5 mmol) in acetonitrile (70 mL) was then prepared and stirred for 1 h. The Swern solution was concentrated in vacuo, and then the Horner Wadsworth Emmons solution was added, and the reaction mixture was stirred at room temperature overnight. The reaction was quenched with a saturated solution of ammonium chloride (50 mL) and concentrated to give an orange residue, which was then extracted with diethyl ether (4 × 75 mL). The organic layers were combined, dried ($MgSO_4$) and concentrated to give an orange oil. Purification by flash column chromatography (diethyl ether/petroleum ether, 1:9) gave ethyl (2*E*)-hept-2-en-6-ynoate (**9a**) (2.93 g, 95%) as a yellow oil. Spectroscopic data consistent with literature:[30] R_f (25% diethyl ether/petroleum ether) 0.63; IR (neat) 3302, 2984, 1715, 1657, 1445, 1368, 1267, 1155, 1038, 756 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.30 (t, 3H, *J* 7.1 Hz), 2.01 (t, 1H, *J* 2.5 Hz), 2.34−2.39 (m, 2H), 2.41−2.48 (m, 2H), 4.20 (q, 2H, *J* 7.1 Hz), 5.90 (dt, 1H, *J* 15.7, 1.5 Hz), 6.97 (dt, 1H, *J* 15.7, 6.7 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 14.3 (CH_3), 17.4 (CH_2), 31.0 (CH_2), 60.3 (CH_2), 69.4 (CH), 82.7 (C), 122.6 (CH), 146.3 (CH), 166.4 (C) ppm; MS (CI) *m*/*z* 153 (MH^+, 100%), 139 (5), 113 (10), 97 (5), 81 (15), 69 (15).

Ethyl (2*E*)-octa-2-en-7-ynoate (9b).[31] The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-ynoate (**9a**) using 5-hexyn-1-ol (**8b**) (3.00 g, 30.6 mmol). Purification by flash column chromatography (diethyl ether/petroleum ether, 1:9) gave ethyl (2*E*)-octa-2-en-7-ynoate (**9b**) (4.99 g, 99%) as a yellow oil. Spectroscopic data consistent with literature:[31] R_f (50% diethyl ether/petroleum ether) 0.74; IR (neat) 3295, 2940, 1713, 1651, 1265, 1188, 1150, 1042, 979, 756, 633 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.29 (t, 3H, *J* 7.1 Hz), 1.70 (quin, 2H, *J* 6.9 Hz), 1.98 (s, 1H), 2.23 (t, 2H, *J* 6.9 Hz), 2.33 (q, 2H, *J* 6.9 Hz), 4.18 (q, 2H, *J* 7.1 Hz), 5.86 (d, 1H, *J* 15.6 Hz), 6.94 (dt, 1H, *J* 15.6, 6.9 Hz) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.3 (CH_3), 17.9 (CH_2), 26.7 (CH_2), 30.9 (CH_2), 60.2 (CH_2), 69.0 (CH), 83.5 (C), 122.1 (CH), 147.8 (CH), 166.6 (C) ppm; MS (CI) *m*/*z* 167 (MH^+, 100%), 139 (42), 113 (10), 97 (12), 81 (25), 71 (30).

Ethyl (2*E*)-4-(2′-propynloxy)but-2-enoate (9c).[32] The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-ynoate (**9a**) using 2-(2′-propynloxy)ethan-1-ol (**8c**) (1.20 g, 12.0 mmol). Purification by flash column chromatography (diethyl ether/petroleum ether, 1:3) gave ethyl (2*E*)-4-(2′-propynloxy)but-2-enoate (**9c**) (1.50 g, 75%) as a yellow oil. Spectroscopic data consistent with literature:[32] R_f (25% diethyl ether/petroleum ether) 0.61; IR (neat) 3291, 2982, 1715, 1663, 1368, 1304, 1265, 1177, 1119, 1036, 966 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.28 (t, 3H, *J* 7.1 Hz), 2.44 (t, 1H, *J* 2.4 Hz), 4.17−4.24 (m, 6H), 6.08 (dt, 1H, *J* 15.8, 2.0 Hz), 6.93 (dt, 1H, *J* 15.8, 4.6 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 14.3 (CH_3), 58.1 (CH_2), 60.5 (CH_2), 68.3 (CH_2), 75.0 (CH), 79.3 (C), 122.3 (CH), 143.3 (CH), 166.2 (C) ppm; MS (CI) *m*/*z* 169 (MH^+, 19%), 155 (5), 145 (87), 131 (7), 127 (7).

Ethyl (2*E*)-4-(*N*-*p*-toluenesulfonyl-2′-propynlamino)but-2-enoate (9d). The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-ynoate (**9a**) using 2-(*N*-*p*-toluenesulfonyl-2′-propynlamino)ethan-1-ol (**8d**) (1.24 g, 4.90 mmol). Purification by flash column chromatography (diethyl ether/petroleum ether, 11:9) gave ethyl (2*E*)-4-(*N*-*p*-toluenesulfonyl-2′-propynlamino)but-2-enoate (**9d**) (1.31 g, 83%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.30; mp 69−71 °C; IR (neat) 3273, 2982, 1717, 1661, 1348, 1275, 1157, 1094 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.28 (t, 3H, *J* 7.2 Hz), 2.08 (t, 1H, *J* 2.5 Hz), 2.42 (s, 3H), 3.98 (dd, 2H, *J* 6.0 1.6 Hz), 4.09 (d, 2H, *J* 2.5 Hz), 4.19 (q, 2H, *J* 7.2 Hz), 6.01 (dt, 1H, *J* 15.7, 1.6 Hz), 6.78 (dt, 1H, *J* 15.7, 6.0 Hz), 7.30 (d, 1H, *J* 8.3 Hz), 7.72 (d, 1H, *J* 8.3 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 14.1 (CH_3), 21.4 (CH_3), 36.7 (CH_2), 47.1 (CH_2), 60.5 (CH_2), 74.2 (CH), 76.3 (C), 124.7 (CH), 127.7 (2 × CH), 129.6 (2 × CH), 136.0 (C), 141.1 (CH), 143.8 (C), 165.4 (C) ppm; MS *m*/*z* 321 (M^+, 18), 276 (40), 248 (16), 166 (100), 155 (50), 120 (35), 91 (50), 65 (10); HRMS (EI) calcd for $C_{16}H_{19}NO_4S$ (M^+), 321.1035, found 321.1031.

(2*E*)-Hept-2-en-6-yn-1-ol (4a).[33] Ethyl (2*E*)-hept-2-en-6-ynoate (**9a**) (1.50 g, 9.87 mmol) was dissolved in diethyl ether (50 mL) and cooled to −78 °C. DIBAL-H (1 M in hexane) (21.7 mL, 21.7 mmol) was added dropwise, and the reaction mixture was stirred at −78 °C for 3 h, before warming to room temperature overnight. The solution was cooled to 0 °C and quenched by the addition of a saturated solution of ammonium chloride (10 mL) and warmed to room temperature with vigorous stirring over 1 h, producing a white precipitate. The precipitate was filtered through a pad of Celite and washed with diethyl ether (3 × 50 mL). The filtrate was then dried ($MgSO_4$) and concentrated in vacuo. Purification by flash column chromatography (diethyl ether/petroleum ether, 1:1) gave (2*E*)-hept-2-en-6-yn-1-ol (**4a**) (1.01 g, 93%) as a yellow oil. Spectroscopic data consistent with literature:[33] R_f (50% diethyl ether/petroleum ether) 0.33; IR (neat) 3360, 3295, 2915, 1670, 1433, 1084, 997, 968 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.42 (br s, 1H), 1.99 (t, 1H, *J* 2.5 Hz), 2.28−2.33 (m, 4H), 4.14 (d, 2H, *J* 4.0 Hz), 5.70−5.81 (m, 2H) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 18.5 (CH_2), 31.1 (CH_2), 63.5 (CH_2), 68.8 (CH), 83.7 (C), 130.5 (CH), 130.6 (CH) ppm; MS (CI) *m*/*z* 111 (MH^+, 3%), 107 (15), 93 (100), 81 (10), 69 (10).

(2*E*)-Octa-2-en-7-yn-1-ol (4b).[34] The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-yn-1-ol (**4a**) using ethyl (2*E*)-octa-2-en-7-ynoate (**9b**) (4.10 g, 24.7 mmol). Purification by flash column chromatography (diethyl ether/petroleum ether, 1:1) gave (2*E*)-octa-2-en-7-yn-1-ol (**4b**) (2.95 g, 97% yield) as a yellow oil. Spectroscopic data consistent with literature:[34] R_f (50% petroleum ether/diethyl ether) 0.29; IR (neat) 3361, 3302, 2932, 1674, 1435, 1219, 1088, 972 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.29 (br s, 1H), 1.63 (quin, 2H, *J* 6.9 Hz), 1.96 (t, 1H, *J* 2.6 Hz), 2.15−2.25 (m, 4H), 4.09−4.15 (m, 2H), 5.63−5.74 (m, 2H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ 17.8 (CH_2), 27.8 (CH_2), 31.1 (CH_2), 63.7 (CH_2), 68.5 (CH), 84.2 (C), 129.9 (CH), 131.9 (CH) ppm; MS (CI) *m*/*z* 125 (MH^+, 20%), 107 (95), 97 (40), 81 (80), 71 (100).

(2*E*)-4-(2′-Propynloxy)but-2-en-1-ol (4c). The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-yn-1-ol (**4a**) using ethyl (2*E*)-4-(2′-propynloxy)but-2-enoate (**9c**) (1.46 g, 8.70 mmol). Purification by flash column chromatography (ethyl acetate/petroleum ether, 1:1) gave (2*E*)-4-(2′-propynloxy)but-2-en-1-ol (**4c**) (0.91 g, 83%) as a colorless oil: R_f (50% ethyl acetate/petroleum ether) 0.36; IR (neat) 3385, 3289, 2920, 2855, 1356, 1090, 999, 970 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.58 (br s, 1H), 1.99 (t, 1H, *J* 2.4 Hz), 4.08 (dd, 2H, *J* 5.8, 1.1 Hz), 4.13−4.18 (m, 4H), 5.80 (dtt, 1H, *J* 15.6, 5.8, 1.4 Hz), 5.93 (dtt, 1H, *J* 15.6, 5.3, 1.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 57.3 (CH_2), 63.0 (CH_2), 69.7 (CH_2), 74.5 (CH), 79.8 (C), 127.1 (CH), 133.2 (CH) ppm; MS *m*/*z* 127 (MH^+, 11), 109 (56), 71 (100); HRMS (CI) calcd for $C_7H_{11}O_2$ (MH^+), 127.0759, found 127.0762.

(2*E*)-4-(*N*-*p*-Toluenesulfonyl-2′-propynlamino)but-2-en-1-ol (4d). The reaction was carried out as described for the synthesis of (2*E*)-hept-2-en-6-yn-1-ol (**4a**) using ethyl (2*E*)-4-(*N*-*p*-toluenesulfonyl-2′-propynlaminobut-2-enoate (**9d**) (0.241 g, 0.75 mmol). Purification by flash column chromatography (ethyl acetate/petroleum ether, 11:9) gave (2*E*)-4-(*N*-*p*-toluenesulfonyl-2′-propynlamino)but-2-en-1-ol (**4d**) (0.21 g, 99%) as a colorless oil: R_f (50% ethyl acetate/petroleum ether) 0.33; IR (neat) 3538, 3273, 2922, 2864, 1597, 1447, 1344, 1327, 1155, 1090, 893, 735 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.44 (br s, 1H), 2.03 (t, 1H, *J* 2.5 Hz), 2.42 (s, 3H), 3.84 (dd, 4H, *J* 6.5, 1.2 Hz), 4.09 (d, 2H, *J* 2.5 Hz), 4.13 (br m, 2H), 5.64 (dtt, 1H, *J* 15.5, 6.5, 1.6 Hz), 5.88 (dtt, 2H, *J* 15.5, 4.0, 1.2 Hz), 7.29 (d, 2H, *J* 8.2 Hz), 7.73 (d, 2H, *J* 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 21.5 (CH_3), 36.0 (CH_2), 48.0 (CH_2), 62.7 (CH_2), 73.7 (CH), 125.0 (CH), 127.8 (2 × CH), 129.5 (2 × CH), 134.7 (CH), 136.4 (C), 143.6 (C) ppm; MS *m*/*z* 280 (MH^+, 22), 263 (100), 210 (6), 157 (2), 113 (4), 85 (5), 69 (6); HRMS (CI) calcd for $C_{14}H_{18}NO_3S$ (MH^+), 280.1007, found 280.1012.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-ene-cyclopent-4-ene (11a). (2*E*)-Hept-2-en-6-yn-1-ol (**4a**) (0.40 g, 3.64 mmol) was dissolved in dichloromethane (30 mL) and cooled to 0 °C. To the solution, 1,8-diazabicyclo[5.4.0]undec-7-ene (0.10 mL, 0.728 mmol) and trichloroacetonitrile (0.55 mL, 5.45 mmol) were added. The reaction mixture was allowed to warm to room temperature before stirring for 3 h. The reaction mixture was filtered through a short pad of silica gel, and the filtrate was concentrated in vacuo to

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give the allylic trichloroacetimidate, which was used without further purification. The allylic trichloroacetimidate was dissolved in toluene (10 mL) containing potassium carbonate (0.05 g) and purged with argon. The reaction mixture was then heated to 140 °C in a sealed tube for 24 h. The reaction mixture was then cooled to room temperature, and toluene (68 mL) was added to achieve a concentration of 0.048 M of starting material. Grubbs first generation catalyst (0.225 g, 0.273 mmol) was added, and the reaction mixture was heated for 18 h at 75 °C. A further portion of Grubbs first generation catalyst (0.070 g, 0.085 mmol) was added, and the reaction mixture was stirred at 75 °C for 24 h. The reaction mixture was then cooled to room temperature, and the solvent was evaporated. Purification by flash column chromatography (petroleum ether/diethyl ether 7:1) gave 1-(2′,2′,2′-trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.66 g, 71%) as a yellow oil: R_f (50% diethyl ether/petroleum ether) 0.81; IR (neat) 3320, 2930, 2855, 1690, 1508, 1236, 1065, 908, 818 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.66−1.74 (m, 1H), 2.35−2.52 (m, 2H), 2.54−2.62 (m, 1H), 4.92−4.99 (m, 1H), 5.18 (d, 1H, *J* 10.5 Hz), 5.19 (d, 1H, *J* 17.6 Hz), 5.61 (d, 1H, *J* 1.7 Hz), 6.51 (dd, 1H, *J* 17.6, 10.5 Hz), 6.54 (br s, 1H) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 29.4 (CH_2), 31.0 (CH_2), 57.8 (CH), 92.7 (C), 117.6 (CH_2), 127.7 (CH), 132.4 (CH), 147.3 (C), 161.1 (C) ppm; MS *m*/*z* 254 (MH^+, 100), 220 (58), 184 (17), 132 (5), 85 (23), 69 (37); HRMS (CI) calcd for $C_9H_{11}{}^{35}Cl_3NO$ (MH^+), 253.9906, found 253.9906.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (11b). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) was synthesized as described for **11a** using (2*E*)-octa-2-en-7-yn-1-ol (**4b**) (0.050 g, 0.40 mmol). The reaction mixture was stirred with Grubbs first generation catalyst (0.024 g, 0.030 mmol) at 75 °C for 18 h. A further portion of Grubbs first generation catalyst (0.010 g, 0.010 mmol) was added, and the reaction mixture was stirred at 75 °C for 4 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 7:1) afforded 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1′-enecyclohex-5-ene (**11b**) (0.092 g, 86%) as a white solid: R_f (50% diethyl ether/petroleum ether) 0.86; mp 77−79 °C; IR (neat) 3258, 2942, 1703, 1684, 1535, 1310, 1273, 1248, 1157, 1073, 993, 907, 824 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.57−1.68 (m, 1H), 1.70−1.83 (m, 2H), 1.96−2.07 (m, 1H), 2.16−2.26 (m, 2H), 4.53−4.63 (m, 1H), 5.10 (d, 1H, *J* 10.6 Hz), 5.26 (d, 1H, *J* 17.7 Hz), 5.65 (br s, 1H), 6.36 (dd, 1H, *J* 17.7, 10.6 Hz), 6.60 (br s, 1H) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 19.4 (CH_2), 23.5 (CH_2), 28.7 (CH_2), 47.7 (CH), 92.7 (C), 113.7 (CH_2), 126.4 (CH), 138.6 (CH), 140.5 (C), 161.1 (C) ppm; MS *m*/*z* 268 (MH^+, 68), 234 (38), 200 (9), 164 (3), 107 (100), 87 (22), 69 (33); HRMS (CI) calcd for $C_{10}H_{13}{}^{35}Cl_3NO$ (MH^+), 268.0063, found 268.0059.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-5-ethyl-1″-ene-1,4-dihydro-1*H*-pyran (11c). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-5-ethyl-1″-ene-1,4-dihydro-1*H*-pyran (**11c**) was synthesized as described for **11a** using (2*E*)-4-(2′-propynloxy)but-2-en-1-ol (**4c**) (0.079 g, 0.62 mmol). The allylic trichloroacetimidate was dissolved in toluene (15 mL) containing potassium carbonate (0.075 g) and purged with argon. The reaction mixture was then heated to 140 °C in a sealed tube for 5 days. The reaction mixture was then stirred with Grubbs first generation catalyst (0.025 g, 0.030 mmol) and 1,7-octadiene (0.37 mL, 2.49 mmol) at 90 °C for 18 h. A further portion of Grubbs first generation catalyst (0.025 g, 0.030 mmol) and 1,7-octadiene (0.37 mL, 2.49 mmol) was added, and the reaction mixture was stirred at 90 °C for 24 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 4:1) gave 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-ene-1,4-dihydro-1*H*-pyran (**11c**) (0.077 g, 46%) as a colorless oil: R_f (50% diethyl ether/petroleum ether) 0.43; IR (neat) 3318, 2942, 2857, 1697, 1499, 1454, 1236, 1117, 1071, 1028, 1011, 988, 910, 860, 758 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 3.76 (dd, 1H, *J* 11.9, 3.1 Hz), 3.92 (d, 1H, *J* 11.9 Hz), 4.25 (d, 1H, *J* 15.9 Hz), 4.42−4.49 (m, 2H), 5.15 (d, 1H, *J* 17.9 Hz), 5.16 (d, 1H, *J* 11.1 Hz), 5.86 (d, 1H, *J* 5.1 Hz), 6.28 (dd, 1H, *J* 17.9, 11.1 Hz), 6.94 (br d, 1H, *J* 5.6 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 45.4 (CH), 65.2 (CH_2), 68.4 (CH_2), 92.5 (C), 114.5 (CH_2), 122.0 (CH), 134.7 (CH), 139.6 (C), 161.3 (C) ppm; MS *m*/*z* 270 (MH^+, 38), 236 (29), 200 (11), 146 (24), 113 (15), 73 (100); HRMS (CI) calcd for $C_9H_{11}{}^{35}Cl_3NO_2$ (MH^+), 269.9855, found 269.9855.

3-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (11d). 3-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (**11d**) was synthesized as described for **11a** using (2*E*)-4-(*N*-*p*-toluenesulfonyl-2′-propynlamino)but-2-en-1-ol (**4d**) (0.074 g, 0.26 mmol). The allylic trichloroacetimidate was dissolved in toluene (6 mL) containing potassium carbonate (0.030 g) and purged with argon. The reaction mixture was then heated to 140 °C and stirred for 5 days. The reaction mixture was stirred with Hoveyda−Grubbs second generation catalyst (0.011 g, 0.013 mmol) and 1,7-octadiene (0.15 mL, 1.0 mmol) at 90 °C for 24 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 1:1) gave 3-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (**11d**) (0.044 g, 40%) as a colorless oil: R_f (50% diethyl ether/petroleum ether) 0.55; IR (neat) 3335, 2922, 1705, 1597, 1499, 1454, 1346, 1240, 1161, 1090, 1022, 991, 815 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.45 (s, 1H), 2.82 (dd, 1H, *J* 12.4, 3.4 Hz), 3.33 (d, 1H, *J* 15.9 Hz), 3.72 (br d, 1H, *J* 12.4 Hz), 4.27 (d, 1H, *J* 15.9 Hz), 4.57−4.64 (m, 1H), 5.20 (d, 1H, *J* 11.1 Hz), 5.25 (d, 1H, *J* 17.8 Hz), 5.82 (br d, 1H, *J* 5.7 Hz), 6.30 (dd, 1H, *J* 17.8, 11.1 Hz), 7.00 (br d, 1H, *J* 8.2 Hz), 7.37 (d, 2H, *J* 8.2 Hz), 7.72 (d, 2H, *J* 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 21.6 (CH_3), 44.3 (CH_2), 45.6 (CH), 47.8 (CH_2), 92.2 (C), 115.3 (CH_2), 123.1 (CH), 127.7 (2 × CH), 130.0 (2 × CH), 132.9 (C), 135.1 (CH), 137.1 (C), 144.3 (C), 161.5 (C) ppm; HRMS (ESI) calcd for $C_{16}H_{17}{}^{35}Cl_3N_2NaO_3S$ (MNa^+), 444.9918, found 444.9905.

Diethyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-2,3-dihydroindene-6,7-dicarboxylate (13a). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.084 g, 0.33 mmol) was dissolved in toluene (5 mL) and transferred to a microwave vial containing anhydrous zinc chloride (0.041 g, 0.33 mmol) and hydroquinone (0.011 g, 0.010 mmol). To this, diethyl acetylenedicarboxylate (0.16 mL, 0.99 mmol) was added with a silicon carbide bar, and the tube was purged with argon and sealed. The reaction mixture was stirred at 140 °C in a microwave reactor for 3 h. The solution was then cooled to room temperature, and 2,3-dichloro-5,6-dicyanobenzoquinone (0.17 g, 0.73 mmol) was added. The tube was sealed and stirred at 115 °C in a microwave reactor for 2 h. The solution was then cooled to room temperature, and the solvent was evaporated. Purification by flash column chromatography (petroleum ether/diethyl ether, 1:1) gave diethyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-2,3-dihydroindene-6,7-dicarboxylate (**13a**) (0.099 g, 71%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.32; mp 108−110 °C; IR (neat) 3337, 2983, 2361, 1714, 1507, 1368, 1282, 1021 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.37 (t, 6H, *J* 7.2 Hz), 2.17 (dtd, 1H, *J* 13.4, 8.9, 4.7 Hz), 2.62−2.72 (m, 1H), 2.99 (ddd, 1H, *J* 17.0, 8.9, 5.0 Hz), 3.13−3.22 (m, 1H, m), 4.32−4.45 (m, 4H), 5.52 (td, 1H, *J* 7.5, 4.7 Hz), 6.98 (br d, 1H, *J* 6.8 Hz), 7.42 (d, 1H, *J* 7.9 Hz), 7.94 (d, 1H, *J* 7.9 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 13.9 (CH_3), 14.1 (CH_3), 30.5 (CH_2), 32.7 (CH_2), 56.0 (CH), 61.6 (CH_2), 62.2 (CH_2), 92.4 (C), 126.2 (CH), 128.2 (C), 131.0 (CH), 132.5 (C), 138.4 (C), 149.9 (C), 161.2 (C), 165.7 (C), 167.7 (C) ppm; MS *m*/*z* 422 (MH^+, 30), 376 (100), 342 (6), 261 (18), 214 (6), 187 (5); HRMS (CI) calcd for $C_{17}H_{19}{}^{35}Cl_2{}^{37}ClNO_5$ (MH^+), 424.0302, found 424.0300.

Diethyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-7,8-dicarboxylate (13b). Diethyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-7,8-dicarboxylate (**13b**) was synthesized as described for **13a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.10 g, 0.37 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 11:9) gave diethyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-7,8-dicarboxylate (**13b**) (0.095 g, 58%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.49; mp 134−136 °C; IR (neat) 3318,

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2940, 1690, 1597, 1520, 1366, 1258, 1134, 1011, 826 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.36 (t, 3H, J 7.2 Hz), 1.38 (t, 3H, J 7.2 Hz), 1.71−1.97 (m, 3H), 2.23−2.30 (m, 1H), 2.84 (ddd, 1H, J 17.7, 11.5, 6.2 Hz), 2.94−3.03 (m, 1H), 4.29−4.48 (m, 4H), 5.30 (dt, 1H, J 7.1, 3.5 Hz), 6.74 (d, 1H, J 7.1 Hz), 7.28 (d, 1H, J 8.1 Hz), 7.90 (d, 1H, J 8.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 13.9 (CH_3), 14.2 (CH_3), 17.3 (CH_2), 27.8 (CH_2), 29.6 (CH_2), 46.4 (CH), 61.6 (CH_2), 62.4 (CH_2), 92.5 (C), 127.0 (C), 129.8 (CH), 130.7 (CH), 130.9 (C), 137.3 (C), 143.4 (C), 160.3 (C), 165.4 (C), 168.2 (C) ppm; MS m/z 438 (MH^+, 73), 390 (100), 371 (77), 356 (70), 275 (25), 271 (18), 231 (11), 153 (10), 69 (70); HRMS (CI) calcd for $C_{18}H_{21}{}^{35}Cl_2{}^{37}ClNO_5$ (MH^+), 438.0459, found 438.0456.

Diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)-isochroman-5,6-dicarboxylate (13c). Diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)isochroman-5,6-dicarboxylate (**13c**) was synthesized as described for **13a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-ene-1,4-dihydro-1*H*-pyran (**11c**) (0.082 g, 0.30 mmol). Purification by flash column chromatography (petroleum ether/ethyl acetate, 7:3) gave diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)isochroman-5,6-dicarboxylate (**13c**) (0.056 g, 42%) as a brown solid: R_f (50% ethyl acetate/petroleum ether) 0.63; mp 141−143 °C; IR (neat) 3322, 2978, 2938, 1724, 1695, 1598, 1522, 1369, 1287, 1260, 1150, 1093, 822 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.36 (t, 3H, J 7.4 Hz), 1.38 (t, 3H, J 7.4 Hz), 3.82 (dd, 1H, J 12.2, 2.2 Hz), 4.24 (br d, 1H, J 12.2 Hz), 4.30−4.40 (m, 3H), 4.42−4.51 (m, 1H), 4.78 (d, 1H, J 16.1 Hz), 4.95 (d, 1H, J 16.1 Hz), 5.22 (br d, 1H, J 7.8 Hz), 7.06 (br d, 1H, J 7.8 Hz), 7.21 (d, 1H, J 8.2 Hz), 7.98 (d, 1H, J 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 13.9 (CH_3), 14.2 (CH_3), 44.8 (CH), 61.8 (CH_2), 62.6 (CH_2), 67.9 (CH_2), 69.2 (CH_2), 92.2 (C), 125.7 (CH), 128.0 (C), 128.3 (C), 130.3 (CH), 137.0 (C), 140.2 (C), 160.7 (C), 165.0 (C), 167.4 (C) ppm; MS m/z 438 (MH^+, 100), 404 (70), 398 (62), 370 (27), 251 (17), 113 (22), 73 (76); HRMS (CI) calcd for $C_{17}H_{19}{}^{35}Cl_3NO_6$ (MH^+), 438.0278, found 438.0275.

Diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)isoquinoline-5,6-dicarboxylate (13d). Diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)isoquinoline-5,6-dicarboxylate (**13d**) was synthesized as described for **13a** using 3-(trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (**11d**) (0.090 g, 0.21 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 3:7) gave diethyl 4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)isoquinoline-5,6-dicarboxylate (**13d**) (0.060 g, 48%) as a red solid: R_f (100% diethyl ether) 0.67; mp 172−174 °C; IR (neat) 3323, 2988, 1716, 1507, 1267, 1164, 1018, 753 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.35 (t, 3H, J 7.2 Hz), 1.36 (t, 3H, J 7.2 Hz), 2.44 (m, 3H), 2.70 (dd, 1H, J 12.6, 2.4 Hz), 3.77 (d, 1H, J 15.8 Hz), 4.10 (br d, 1H, J 12.6 Hz), 4.27−4.48 (m, 4H), 4.85 (d, 1H, J 15.8 Hz), 5.43 (br d, 1H, J 8.5 Hz), 7.06 (d, 1H, J 8.5 Hz), 7.26 (d, 1H, J 8.0 Hz), 7.35 (d, 2H, J 8.2 Hz), 7.73 (d, 2H, J 8.2 Hz), 7.97 (d, 1H, J 8.0 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 13.9 (CH_3), 14.1 (CH_3), 21.6 (CH_3), 45.5 (CH), 47.9 (CH_2), 48.6 (CH_2), 61.9 (CH_2), 62.7 (CH_2), 92.0 (C), 127.7 (CH), 127.9 (2 × CH), 128.3 (C), 128.6 (C), 130.1 (2 × CH), 130.4 (CH), 132.3 (C), 137.2 (C), 137.7 (C), 144.6 (C), 161.0 (2 × C), 167.2 (C) ppm; HRMS (ESI) calcd for $C_{24}H_{24}{}^{35}Cl_3N_2O_7S$ ($M-H^-$), 589.0375, found 589.0371.

Methyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-2,3-dihydroindene-7-carboxylate (13e). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.11 g, 0.43 mmol) was dissolved in toluene (6 mL) and transferred to a Schlenk tube containing anhydrous zinc chloride (0.059 g, 0.43 mmol) and hydroquinone (0.014 g, 0.13 mmol). Methyl propiolate (0.12 mL, 1.29 mmol) was added, and the tube was purged with argon. The reaction mixture was stirred at 140 °C for 9 days. The solution was then cooled to room temperature, and 2,3-dichloro-5,6-dicyanobenzoquinone (0.21 g, 0.95 mmol) was added. The tube was resealed under argon and stirred at 115 °C for 24 h. The solution was cooled to room temperature, and the solvent was then evaporated. Purification by flash column chromatography (petroleum ether/diethyl ether, 12:9) gave methyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-2,3-dihydroindene-7-carboxylate (**13e**) (0.075 g, 52%) as a red solid: R_f (50% diethyl ether/petroleum ether) 0.57; mp 108−110 °C; IR (neat) 3279, 2949, 1711, 1689, 1533, 1432, 1290, 1136, 818 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.23 (ddt, 1H, J 14.0, 8.6, 2.4 Hz), 2.43 (dq, 1H, J 14.0, 8.6 Hz), 2.90 (ddd, 1H, J 16.4, 8.6, 2.4 Hz), 3.19 (dt, 1H, J 16.4, 8.6 Hz), 3.82 (s, 3H), 5.68 (td, 1H, J 8.6, 2.4 Hz), 6.90 (br d, 1H, J 5.1 Hz), 7.34 (t, 1H, J 7.6 Hz), 7.44 (d, 1H, J 7.6 Hz), 7.86 (d, 1H, J 7.6 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 30.7 (CH_2), 31.7 (CH_2), 52.5 (CH), 57.4 (CH_3), 92.9 (C), 127.4 (C), 129.3 (CH), 129.5 (CH), 129.6 (CH), 141.4 (C), 146.7 (C), 160.9 (C), 166.7 (C) ppm; MS m/z 336 (MH^+, 100), 302 (16), 257 (12), 175 (98), 137 (54), 121 (38), 81 (6); HRMS (CI) calcd for $C_{13}H_{13}{}^{35}Cl_3NO_3$ (MH^+), 335.9961, found 335.9952.

Methyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-8-carboxylate (13f). Methyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-8-carboxylate (**13f**) was synthesized as described for **13e** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.10 g, 0.37 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 7:3) gave methyl 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydronaphthalene-8-carboxylate (**13f**) (0.085 g, 66%) as a colorless solid: R_f (50% diethyl ether/petroleum ether) 0.56; mp 133−135 °C; IR (neat) 3324, 2933, 1726, 1695, 1517, 1431, 1285, 1262, 1137, 754 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 1.72−1.82 (m, 1H), 1.85−1.98 (m, 2H), 2.15−2.22 (m, 1H), 2.84 (ddd, 1H, J 17.1, 10.7, 5.8 Hz), 2.94 (dt, 1H, J 17.1, 4.6 Hz), 3.87 (s, 3H), 5.77 (dt, 1H, J 6.3, 4.3 Hz), 6.68 (d, 1H, J 6.3 Hz), 7.30−7.34 (m, 2H), 7.86 (dd, 1H, J 6.0, 3.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 18.1 (CH_2), 28.5 (CH_2), 29.8 (CH_2), 46.8 (CH_3), 52.6 (CH), 92.8 (C), 128.0 (CH), 129.2 (CH), 131.8 (C), 133.4 (CH), 133.7 (C), 139.2 (C), 160.4 (C), 168.1 (C) ppm; HRMS (ESI) calcd for $C_{14}H_{14}{}^{35}Cl_3NNaO_3$ (MNa^+), 371.9931, found 371.9925.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3-trihydrocyclopent[*a*]naphthalene-6,9-dione (14a). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-5-ene (**11a**) (0.071 g, 0.28 mmol) was dissolved in toluene (10 mL) and *p*-benzoquinone (0.034 g, 0.37 mmol) was added. The reaction mixture was stirred at 115 °C for 72 h. The solution was then cooled to room temperature, and manganese oxide (0.244 g, 2.80 mmol) was added with a silicon carbide bar. The mixture was stirred at 115 °C in a microwave reactor for 2 h. The solution was then cooled to room temperature, and the solvent was evaporated under a vacuum. Purification by flash column chromatography (petroleum ether/diethyl ether, 1:1) gave 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3-trihydrocyclopent[*a*]naphthalene-6,9-dione (**14a**) (0.076 g, 75%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.35; mp 153−155 °C; IR (neat) 3350, 2926, 1688, 1663, 1510, 1298, 1078, 820 cm^{-1}; ^1H NMR (500 MHz, $CDCl_3$) δ 2.48−2.61 (m, 2H), 3.03 (ddd, 1H, J 17.4, 8.7, 2.8 Hz), 3.52 (dt, 1H, J 17.4, 8.7 Hz), 5.62 (ddd, 1H, J 8.7, 6.4, 2.8 Hz), 6.90 (d, 1H, J 10.3 Hz), 6.96 (d, 1H, J 10.3 Hz), 7.47 (br d, 1H, J 6.4 Hz), 7.67 (d, 1H, J 7.9 Hz), 8.11 (d, 1H, J 7.9 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 30.5 (CH_2), 31.5 (CH_2), 57.2 (CH), 92.9 (C), 127.9 (C), 128.3 (CH), 130.3 (CH), 131.9 (C), 138.3 (CH), 138.8 (CH), 140.7 (C), 154.2 (C), 161.0 (C), 184.4 (C), 186.2 (C) ppm; HRMS (ESI) calcd for $C_{15}H_{10}{}^{35}Cl_2{}^{37}ClNNaO_3$ (MNa^+), 381.9589, found 381.9578.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]naphthalene-7,10-dione (14b). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]naphthalene-7,10-dione (**14b**) was synthesized as described for **14a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.070 g, 0.34 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 5:4) gave 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]-naphthalene-7,10-dione (**14b**) (0.084 g, 66%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.30; mp 165−167 °C; IR (neat) 3345, 2947, 1709, 1663, 1586, 1512, 1304, 1096, 822 cm^{-1}; ^1H NMR (400 MHz, $CDCl_3$) δ 1.80−1.97 (m, 3H), 2.33−2.47 (m, 1H), 2.89−3.00 (m, 1H), 3.04−3.14 (m, 1H), 5.90−5.96 (m, 1H), 6.76 (br d, 1H,

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J 6.4 Hz), 6.88 (d, 1H, *J* 10.2 Hz), 6.92 (d, 1H, *J* 10.2 Hz), 7.57 (d, 1H, *J* 8.1 Hz), 8.09 (d, 1H, *J* 8.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 17.8 (CH_2), 27.9 (CH_2), 30.7 (CH_2), 47.1 (CH), 92.9 (C), 126.9 (CH), 129.6 (C), 132.5 (C), 135.2 (C), 135.3 (CH), 136.4 (CH), 140.4 (CH), 146.3 (C), 160.5 (C), 184.8 (C), 186.4 (C) ppm; MS *m*/*z* 372 (MH^+, 36), 338 (30), 304 (10), 268 (15), 243 (84), 229 (100), 213 (60), 162 (75), 128 (40); HRMS (CI) calcd for $C_{16}H_{13}{}^{35}Cl_3NO_3$ (MH^+), 371.9961, found 371.9960.

4-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)benzo[*f*]isoquinoline-5,8-dione (14c). 4-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)benzo[*f*]isoquinoline-5,8-dione (**14c**) was synthesized as described for **14a** using 3-(trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (**11d**) (0.075 g, 0.18 mmol). The reaction mixture was stirred at 115 °C for 72 h. The solution was then cooled to room temperature, and 2,3-dichloro-5,6-dicyanobenzoquinone (0.088 g, 0.39 mmol) and a silicon carbide bar were added. The mixture was stirred at 115 °C in a microwave reactor for 2 h. Purification by flash column chromatography (petroleum ether/ethyl acetate, 3:1) gave 4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)-benzo[*f*]isoquinoline-5,8-dione (**14c**) (0.045 g, 48%) as a brown solid: R_f (50% ethyl acetate/petroleum ether) 0.51; mp 192−194 °C; IR (neat) 3329, 2924, 1707, 1663, 1593, 1508, 1303, 1165, 1096, 1071, 961, 816 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 2.44 (s, 3H), 2.77 (dd, 1H, *J* 12.6, 2.8 Hz), 3.94 (d, 1H, *J* 16.1 Hz), 4.12 (ddd, 1H, *J* 12.6, 2.8, 1.7 Hz), 4.85 (d, 1H, *J* 16.1 Hz), 6.07 (dt, 1H, *J* 7.6, 2.8 Hz), 6.91−6.97 (m, 3H), 7.38 (d, 2H, *J* 8.2 Hz), 7.55 (d, 1H, *J* 8.2 Hz), 7.75 (d, 2H, *J* 8.2 Hz), 8.18 (d, 1H, *J* 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 21.6 (CH_3), 46.5 (CH), 48.2 (CH_2), 48.4 (CH_2), 92.3 (C), 127.7 (CH), 127.9 (2 × CH), 129.6 (C), 130.1 (2 × CH), 132.4 (CH), 132.4 (C), 133.1 (2 × C), 136.7 (CH), 140.3 (CH), 140.5 (C), 144.5 (C), 161.1 (C), 184.2 (C), 185.6 (C) ppm; HRMS (ESI) calcd for $C_{22}H_{17}{}^{35}Cl_3N_2NaO_5S$ (MNa^+), 548.9816, found 548.9813.

7-*tert*-Butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3-trihydrocyclopent[*a*]naphthalene-6,9-dione (14d). 7-*tert*-Butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3-trihydrocyclopent[*a*]naphthalene-6,9-dione (**14d**) was synthesized as described for **14a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.071 g, 0.28 mmol) and 2-*tert*-butyl-*p*-benzoquinone (0.054 g, 0.33 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 7:3) gave 7-*tert*-butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3-trihydrocyclopent[*a*]naphthalene-6,9-dione (**14d**) (0.079 g, 68%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.53; mp 198−200 °C; IR (neat) 3325, 2954, 1680, 1661, 1597, 1504, 1290, 1250, 1068, 910, 816 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.36 (s, 9H), 2.48−2.57 (m, 2H), 3.00 (ddd, 1H, *J* 17.1, 7.8, 3.7 Hz), 3.49 (dt, 1H, *J* 17.1, 8.8 Hz), 5.54−5.61 (m, 1H), 6.77 (s, 1H), 7.50 (d, 1H, *J* 5.5 Hz), 7.63 (d, 1H, *J* 7.9 Hz), 8.11 (d, 1H, *J* 7.9 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 29.4 (3 × CH_3), 30.4 (CH_2), 31.4 (CH_2), 35.7 (C), 57.1 (CH), 92.9 (C), 127.5 (C), 128.8 (CH), 130.1 (CH), 133.5 (C), 134.1 (CH), 139.8 (C), 153.4 (C), 158.1 (C), 161.0 (C), 184.4 (C), 187.0 (C) ppm; MS *m*/*z* 413 (M^+, 12), 378 (57), 268 (30), 252 (100), 237 (41), 185 (23), 165 (22), 143 (13), 115 (22), 84 (79), 49 (76); HRMS (EI) calcd for $C_{19}H_{18}{}^{35}Cl_3NO_3$ (M^+), 413.0352, found 413.0354.

8-*tert*-Butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]naphthalene-7,10-dione (14e). 8-*tert*-Butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]naphthalene-7,10-dione (**14e**) was synthesized as described for **14a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.10 g, 0.37 mmol) and 2-*tert*-butyl-*p*-benzoquinone (0.073 g, 0.47 mmol). Purification by flash column chromatography (petroleum ether/diethyl ether, 7:3) gave 8-*tert*-butyl-1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]naphthalene-7,10-dione (**14e**) (0.092 g, 58%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.61; mp 128−130 °C; IR (neat) 3225, 2957, 1705, 1661, 1607, 1541, 1341, 1252, 1121, 1078, 816 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.34 (s, 9H), 1.75−1.92 (m, 3H), 2.37−2.46 (m, 2H), 2.85−2.95 (m, 1H), 3.04 (dt, 1H, *J* 17.7, 4.7 Hz), 5.85−5.90 (m, 1H), 6.73 (s, 1H), 6.75 (d, 1H, *J* 5.9 Hz), 7.50 (d, 1H, *J* 8.1 Hz), 8.07 (d, 1H, *J* 8.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 17.9 (CH_2), 27.8 (CH_2), 29.2 (3 × CH_3), 30.5 (CH_2), 35.1 (C), 47.2 (CH), 93.1 (C), 127.3 (CH), 129.4 (C), 134.3 (C), 134.4 (C), 134.9 (CH), 135.5 (CH), 145.4 (C), 156.3 (C), 160.4 (C), 184.7 (C), 187.1 (C) ppm; MS *m*/*z* 428 (MH^+, 5), 408 (6), 370 (29), 285 (100), 162 (58), 128 (48), 71 (31); HRMS (CI) calcd for $C_{20}H_{21}{}^{35}Cl_3NO_3$ (MH^+), 428.0587, found 428.0584.

7-*tert*-Butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,3-dihydro-4*H*-benzo[*f*]isochromene-5,8-dione (14f). 7-*tert*-Butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,3-dihydro-4*H*-benzo[*f*]-isochromene-5,8-dione (**14f**) was synthesized as described for **14a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-ene-1,4-dihydro-1*H*-pyran (**11c**) (0.070 g, 0.26 mmol) and 2-*tert*-butyl-*p*-benzoquinone (0.051 g, 0.31 mmol). The solution was then cooled to room temperature, and 2,3-dichloro-5,6-dicyanobenzoquinone (0.129 g, 0.57 mmol) and a silicon carbide bar were added. The mixture was stirred at 115 °C in a microwave reactor for 2 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 11:9) gave 7-*tert*-butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,3-dihydro-4*H*-benzo[*f*]isochromene-5,8-dione (**14f**) (0.064 g, 57%) as a yellow solid: R_f (50% diethyl ether/petroleum ether) 0.24; mp 192−194 °C; IR (neat) 3379, 2969, 1708, 1661, 1592, 1513, 1274, 1250, 1091, 908, 819 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.34 (s, 9H), 3.79 (dd, 1H, *J* 12.3, 2.3 Hz), 4.34 (dd, 1H, *J* 12.3, 1.2 Hz), 4.85 (d, 1H, *J* 16.2 Hz), 5.00 (d, 1H, *J* 16.2 Hz), 5.78 (br d, 1H, *J* 7.4 Hz), 6.77 (s, 1H), 6.90 (d, 1H, *J* 7.4 Hz), 7.44 (d, 1H, *J* 8.1 Hz), 8.17 (d, 1H, *J* 8.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 29.2 (3 × CH_3), 35.4 (C), 45.9 (CH), 68.3 (CH_2), 68.9 (CH_2), 92.6 (C), 127.9 (CH), 129.1 (C), 130.0 (CH), 130.6 (C), 134.5 (C), 135.4 (CH), 142.1 (C), 156.6 (C), 161.0 (C), 184.3 (C), 186.4 (C) ppm; MS *m*/*z* 430 (MH^+, 43), 396 (21), 287 (20), 245 (37), 207 (32), 162 (95), 128 (62), 85 (65), 73 (100); HRMS (CI) calcd for $C_{19}H_{19}{}^{35}Cl_3NO_4$ (MH^+), 430.0380, found 430.0370.

7-*tert*-Butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)benzo[*f*]isoquinoline-5,8-dione (14g). 7-*tert*-Butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)benzo[*f*]isoquinoline-5,8-dione (**14g**) was synthesized as described for **14a** using 3-(trichloromethylcarbonylamino)-1,2,3,6-tetrahydro-1-(*p*-toluenesulfonyl)-5-ethyl-1″-enepyridine (**11d**) (0.091 g, 0.21 mmol) and 2-*tert*-butyl-*p*-benzoquinone (0.083 g, 0.51 mmol). The solution was then cooled to room temperature, and 2,3-dichloro-5,6-dicyanobenzoquinone (0.252 g, 1.11 mmol) and a silicon carbide bar were added. The mixture was stirred at 115 °C in a microwave reactor for 3 h. Purification by flash column chromatography (petroleum ether/ethyl acetate, 3:1) gave 7-*tert*-butyl-4-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydro-2-(*p*-toluenesulfonyl)benzo[*f*]isoquinoline-5,8-dione (**14g**) (0.056 g, 44%) as a yellow solid: R_f (50% ethyl acetate/petroleum ether) 0.53; mp 187−189 °C; IR (neat) 3335, 2959, 1717, 1655, 1522, 1454, 1339, 1254, 1161, 964, 818 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.33 (s, 9H), 2.44 (s, 3H), 2.75 (dd, 1H, *J* 12.6, 2.8 Hz), 3.92 (d, 1H, *J* 16.0 Hz), 4.12 (ddd, 1H, *J* 12.6, 2.8, 1.7 Hz), 4.83 (d, 1H, *J* 16.0 Hz), 6.04 (dt, 1H, *J* 7.4, 2.8 Hz), 6.76 (s, 1H), 6.92 (d, 1H, *J* 7.4 Hz), 7.37 (d, 2H, *J* 8.4 Hz), 7.50 (d, 1H, *J* 8.2 Hz), 7.75 (d, 2H, *J* 8.4 Hz), 8.16 (d, 1H, *J* 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 21.6 (CH_3), 29.2 (3 × CH_3), 35.4 (C), 46.5 (CH), 48.2 (CH_2), 48.3 (CH_2), 92.4 (C), 127.9 (2 × CH), 128.1 (CH), 129.2 (C), 130.1 (2 × CH), 130.9 (C), 132.0 (CH), 132.5 (C), 134.8 (C), 135.5 (CH), 139.6 (C), 144.5 (C), 156.6 (C), 161.1 (C), 184.1 (C), 186.3 (C) ppm; HRMS (ESI) calcd for $C_{26}H_{25}{}^{35}Cl_2{}^{37}ClN_2NaO_5S$ (MNa^+), 607.0412, found 607.0414.

1-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]anthracene-7,12-dione (14h). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]anthracene-7,12-dione (**14h**) was synthesized as described for **14a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.036 g, 0.14 mmol) and 1,4-naphthoquinone (0.042 g, 0.20 mmol). The reaction mixture was then cooled to room temperature,

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and 2,3-dichloro-5,6-dicyanobenzoquinone (0.13 g, 0.60 mmol) and a silicon carbide bar were added. The mixture was stirred at 115 °C in a microwave reactor for 4 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 13:7) gave 1-(2′,2′,2′-trichloromethylcarbonylamino)-1,2,3,4-tetrahydrobenz[*a*]anthracene-7,12-dione (**14h**) (0.034 g, 54%) as a colorless solid: R_f (50% diethyl ether/petroleum ether) 0.48; mp 180−182 °C; IR (neat) 3335, 2922, 2361, 1701, 1668, 1589, 1501, 1327, 1290, 818 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.86−1.97 (m, 3H), 2.37−2.47 (m, 1H), 2.91−3.03 (m, 1H), 3.05−3.17 (m, 1H), 6.00−5.96 (m, 1H), 6.79 (br d, 1H, *J* 6.3 Hz), 7.59 (d, 1H, *J* 8.2 Hz), 7.73−7.79 (m, 2H), 8.20−8.27 (m, 2H), 8.32 (d, 1H, *J* 8.2 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 17.8 (CH_2), 28.1 (CH_2), 30.9 (CH_2), 47.6 (CH), 93.0 (C), 126.5 (CH), 127.6 (CH), 127.7 (CH), 131.6 (C), 132.2 (C), 133.7 (CH), 134.2 (C), 134.4 (CH), 134.9 (C), 135.5 (CH), 135.8 (C), 146.5 (C), 160.6 (C), 183.1 (C), 184.6 (C) ppm; HRMS (ESI) calcd for $C_{20}H_{14}{}^{35}Cl_3NNaO_3$ (MNa^+), 443.9931, found 443.9919.

7-(2′,2′,2′-Trichloromethylcarbonylamino)-6,7-dihydro-2-(*p*-toluenesulfonyl)-5*H*-cyclopenta[*b*]pyridine (15a). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.024 g, 0.094 mmol) was dissolved in *p*-xylene (4 mL) and transferred to a sealable vial containing anhydrous zinc chloride (0.013 g, 0.094 mmol) and hydroquinone (0.001 g, 0.0094 mmol). *p*-Toluenesulfonyl cyanide (0.026 g, 0.14 mmol) was added, and the vial was purged with argon and sealed. The reaction mixture was stirred at 125 °C for 24 h. The solution was then cooled to room temperature, and the solvent was evaporated. Purification by flash column chromatography (petroleum ether/ethyl acetate, 1:1) gave 7-(2′,2′,2′-trichloromethylcarbonylamino)-6,7-dihydro-2-(*p*-toluenesulfonyl)-5*H*-cyclopenta[*b*]pyridine (**15a**) (0.024 g, 58%) as a green solid: R_f (50% diethyl ether/petroleum ether) 0.45; mp 124−126 °C; IR (neat) 3335, 2926, 1699, 1518, 1420, 1302, 1144, 1076, 816 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.91−2.05 (m, 1H), 2.41 (s, 3H), 2.91−3.10 (m, 3H), 5.10−5.18 (m, 1H), 7.19 (br d, 1H, *J* 4.6 Hz), 7.30 (d, 2H, *J* 8.2 Hz), 7.84 (d, 1H, *J* 8.1 Hz), 7.93 (d, 2H, *J* 8.2 Hz), 8.09 (d, 1H, *J* 8.1 Hz) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ 21.7 (CH_3), 28.0 (CH_2), 32.4 (CH_2), 56.2 (CH), 92.3 (C), 121.4 (CH), 129.2 (2 × CH), 129.7 (2 × CH), 134.5 (CH), 135.6 (C), 141.0 (C), 144.9 (C), 158.1 (C), 161.9 (C), 162.6 (C) ppm; HRMS (ESI) calcd for $C_{17}H_{15}{}^{35}Cl_3N_2NaO_3S$ (MNa^+), 454.9761, found 454.9747.

8-(2′,2′,2′-Trichloromethylcarbonylamino)-5,6,7,8-tetrahydro-2-(*p*-toluenesulfonyl)quinoline (15b). 8-(2′,2′,2′-Trichloromethylcarbonylamino)-5,6,7,8-tetrahydro-2-(*p*-toluenesulfonyl)-quinolone (**15b**) was synthesized as described for **15a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1′-enecyclohex-5-ene (**11b**) (0.035 g, 0.13 mmol) and *p*-toluenesulfonyl cyanide (0.035 g, 0.20 mmol). The reaction mixture was heated at 160 °C for 18 h. Purification by flash column chromatography (petroleum ether/ethyl acetate, 11:9) gave 8-(2′,2′,2′-trichloromethylcarbonylamino)-5,6,7,8-tetrahydro-2-(*p*-toluenesulfonyl)quinoline (**15b**) (0.030 g, 54%) as a colorless solid: R_f (50% ethyl acetate/petroleum ether) 0.44; mp 85−87 °C; IR (neat) 3335, 2926, 1705, 1510, 1316, 1155, 1078, 814 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.59 (qd, 1H, *J* 11.5, 4.2 Hz), 1.97−2.05 (m, 2H), 2.42 (s, 3H), 2.75 (dq, 1H, *J* 11.5, 4.8 Hz), 2.85−2.97 (m, 2H), 4.76 (dt, 1H, *J* 11.5, 4.8 Hz), 7.31 (d, 2H, *J* 8.2 Hz), 7.69 (d, 1H, *J* 8.0 Hz), 7.76 (br d, 1H, *J* 3.8 Hz), 7.91 (d, 2H, *J* 8.2 Hz), 8.09 (d, 1H, *J* 8.0 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 19.8 (CH_2), 21.7 (CH_3), 27.7 (CH_2), 27.9 (CH_2), 52.7 (CH), 92.6 (C), 120.8 (CH), 129.1 (2 × CH), 129.8 (2 × CH), 135.5 (C), 137.2 (C), 139.0 (CH), 145.0 (C), 155.4 (C), 156.2 (C), 161.9 (C); HRMS (ESI) calcd for $C_{18}H_{18}{}^{35}Cl_3N_2O_3S$ (MH^+), 447.0098, found 447.0093.

Ethyl 8-(2′,2′,2′-trichloromethylcarbonylamino)-5,6,7,8-tetrahydroquinoline-2-carboxylate (15c). Ethyl 8-(2′,2′,2′-trichloromethylcarbonylamino)-5,6,7,8-tetrahydroquinoline-2-carboxylate (**15c**) was synthesized as described for **15a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1′-enecyclohex-5-ene (**11b**) (0.056 g, 0.21 mmol) and ethyl cyanoformate (0.12 mL, 1.25 mmol). The reaction mixture was heated at 160 °C for 72 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 1:1) gave ethyl 8-(2′,2′,2′-trichloromethylcarbonylamino)-5,6,7,8-tetrahydroquinoline-2-carboxylate (**15c**) (0.030 g, 40%) as a colorless oil: R_f (50% diethyl ether/petroleum ether) 0.23; IR (neat) 3345, 2926, 2361, 1707, 1506, 1314, 1258, 1086, 1024, 820 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.40 (t, 1H, *J* 7.1 Hz), 1.62 (dtd, 1H, *J* 12.7, 11.3, 4.7 Hz), 1.93−2.09 (m, 2H), 2.85−3.02 (m, 2H), 4.37 (dq, 1H, *J* 10.8, 7.1 Hz), 4.45 (dq, 1H, *J* 10.8, 7.1 Hz), 4.79 (dt, 1H, *J* 10.9, 4.7 Hz), 7.62 (d, 1H, *J* 7.9 Hz), 8.01 (d, 1H, *J* 7.9 Hz), 8.48 (br s, 1H) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ 14.2 (CH_3), 19.8 (CH_2), 27.6 (CH_2), 27.8 (CH_2), 53.0 (CH), 61.7 (CH_2), 92.9 (C), 124.1 (CH), 136.8 (C), 138.1 (CH), 145.3 (C), 154.1 (C), 162.1 (C), 164.9 (C) ppm; HRMS (ESI) calcd for $C_{14}H_{15}{}^{35}Cl_3N_2NaO_3$ (MNa^+), 387.0040, found 387.0036.

8-(2′,2′,2′-Trichloromethylcarbonylamino)-2-(dichloromethyl)-5,6,7,8-tetrahydroquinoline (15d). 8-(2′,2′,2′-Trichloromethylcarbonylamino)-2-(dichloromethyl)-5,6,7,8-tetrahydroquinoline (**15d**) was synthesized as described for **15a** using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1′-enecyclohex-5-ene (**11b**) (0.035 g, 0.13 mmol) and trichloroacetonitrile (0.078 mL, 0.78 mmol). The reaction mixture was heated at 160 °C for 18 h. Purification by flash column chromatography (petroleum ether/diethyl ether, 2:1) gave 8-(2′,2′,2′-trichloromethylcarbonylamino)-2-(dichloromethyl)-5,6,7,8-tetrahydroquinoline (**15d**) (0.043 g, 67%) as a colorless oil: R_f (50% diethyl ether/petroleum ether) 0.49; IR (neat) 3343, 2930, 2361, 1705, 1503, 1462, 1408, 1256, 1215, 1088, 926, 818 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.62−1.72 (m, 1H), 1.87−2.08 (m, 2H), 2.75−2.83 (m, 1H), 2.84−2.95 (m, 2H), 4.81 (dt, 1H, *J* 10.5, 5.3 Hz), 6.67 (s, 1H), 7.60 (d, 1H, *J* 8.1 Hz), 7.65 (d, 1H, *J* 8.1 Hz), 8.01 (br s, 1H) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 19.9 (CH_2), 27.7 (CH_2), 27.9 (CH_2), 52.6 (CH), 71.2 (CH), 92.9 (C), 120.2 (CH), 134.1 (C), 138.9 (CH), 153.0 (C), 155.1 (C), 162.1 (C) ppm; HRMS (ESI) calcd for $C_{12}H_{11}{}^{35}Cl_5N_2NaO$ (MNa^+), 396.9206, found 396.9191.

7-(2′,2′,2′-Trichloromethylcarbonylamino)-5,6-dihydrocyclopenta[c]pyridazine (16a). 1-(2′,2′,2′-Trichloromethylcarbonylamino)-4-ethyl-1″-enecyclopent-4-ene (**11a**) (0.13 g, 0.41 mmol) was dissolved in toluene (10 mL), and di-*tert*-butyl azodicarboxylate (0.15 g, 0.63 mmol) was added. The reaction mixture was stirred at 115 °C for 18 h. The solution was then cooled to room temperature, and the solvent was then evaporated. Purification by flash column chromatography (petroleum ether/diethyl ether, 3:2) gave a colorless oil. The oil was dissolved in degassed chloroform (12 mL) and cooled to 0 °C. Bromine (0.10 mL, 2.03) was then added dropwise. The ice bath was then removed, and the mixture was stirred for 3 h as the reaction was allowed to warm to room temperature. The reaction mixture was quenched with a 10% aqueous solution of sodium sulfite (15 mL), stirred for 0.5 h, and then basified with a saturated solution of sodium hydrogencarbonate (30 mL). The aqueous layer was then extracted with chloroform (4 × 75 mL). The organic layers were combined, dried ($MgSO_4$) and concentrated to give a yellow oil. Purification by flash column chromatography (dichloromethane/methanol, 25:1) gave 7-(2′,2′,2′-trichloromethylcarbonylamino)-5,6-dihydrocyclopenta[c]pyridazine (**16a**) (0.072 g, 51%) as a brown oil: IR (neat) 3327, 2955, 1695, 1518, 1393 1263, 820 cm^{-1}; ^{1}H NMR (400 MHz, $CDCl_3$) δ 1.91−2.05 (m, 1H), 2.87−3.12 (m, 3H), 5.32 (td, 1H, *J* 8.5, 5.2 Hz), 7.36 (d, 1H, *J* 5.1 Hz), 7.74 (br s, 1H), 8.97 (d, 1H, *J* 5.1 Hz) ppm; ^{13}C NMR (101 MHz, $CDCl_3$) δ 28.2 (CH_2), 31.8 (CH_2), 56.0 (CH), 92.1 (C), 123.3 (CH), 142.0 (C), 150.6 (CH), 162.4 (C), 164.3 (C) ppm; HRMS (ESI) calcd for $C_9H_8{}^{35}Cl_3N_3NaO$ (MNa^+), 301.9625, found 301.9631.

8-(2′,2′,2′-Trichloromethylcarbonylamino)-5,6,7,8-tetrahydrocinnoline (16b). 8-(2′,2′,2′-Trichloromethylcarbonylamino)-5,6,7,8-tetrahydrocinnoline (**16b**) was synthesized according to the above procedure using 1-(2′,2′,2′-trichloromethylcarbonylamino)-5-ethyl-1″-enecyclohex-5-ene (**11b**) (0.11 g, 0.41 mmol) and di-*tert*-butyl azodicarboxylate (0.12 g, 0.51 mmol). Purification by flash column chromatography (dichloromethane/methanol, 25:1) gave 8-(2′,2′,2′-trichloromethylcarbonylamino)-5,6,7,8-tetrahydrocinnoline (**16b**) (0.079 g, 66%) as a colorless oil: IR (neat) 3339, 2947, 2361, 1697, 1508, 1377, 1265, 1090, 818, 731 cm^{-1}; ^{1}H NMR (500 MHz, $CDCl_3$) δ 1.67−1.76 (m, 1H), 1.93−2.08 (m, 2H), 2.81−2.97 (m, 3H), 5.01 (dt, 1H, *J* 10.3, 5.0 Hz), 7.27 (d, 1H, *J* 5.1 Hz), 8.29 (br s,

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1H), 9.04 (d, 1H, *J* 5.1 Hz) ppm; ^{13}C NMR (126 MHz, $CDCl_3$) δ 19.2 (CH_2), 27.1 (CH_2), 27.6 (CH_2), 51.8 (CH), 92.5 (C), 126.6 (CH), 137.9 (C), 150.6 (CH), 157.7 (C), 162.2 (C) ppm; HRMS (ESI) calcd for $C_{10}H_{10}{}^{35}Cl_3N_3NaO$ (MNa^+), 315.9782, found 315.9776.

■ ASSOCIATED CONTENT

Supporting Information

^{1}H and ^{13}C NMR spectra for all new compounds and crystal data (CIF). This material is available free of charge via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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(22) For the synthesis of diene **11d**, it was found that a separate Overman rearrangement (89% yield) and RCEYM reaction (with HG-II, 5 mol % and 1,7-octadiene, 67% yield) was more efficient overall than the one-pot tandem process.

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(24) The regiochemistry of the Diels−Alder step for compounds **13f** and **15d** was established by NOE experiments (see Supporting Information for full details). The regiochemical outcome for all other compounds (**13e** and **15a−c**) was determined using standard one- and two-dimensional NMR spectroscopy.

(25) See Supporting Information for ORTEP drawing of **14e**. The structure has been deposited with the Cambridge Crystallographic Data Centre, with code CCDC 930479.

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