Studies on pyrazines. Part 37.[1] Synthesis of 6-propionylpteridine-2,4(1*H*,3*H*)-dione and its 1- and/or 3-methyl derivatives from marine natural products

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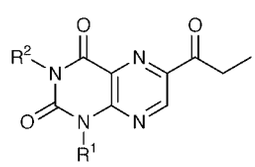
The synthesis of 1,3-dimethyl-6-propionylpteridine-2,4(1*H*,3*H*)-dione is described, which is completed by the cross-coupling reaction of 6-bromolumazine with a 1-ethoxyprop-1-enyl tin compound in the presence of a palladium catalyst and copper iodide. Similarly, 1,3-demethylated, and 1- and 3-methyl derivatives are prepared from the corresponding bromolumazines which are obtained by cyclization of 6-bromo-3-acetylamino- or -3-methylamino-pyrazinecarbonitrile with methyl isocyanate or methyl chloroformate. In contrast, the synthesis of 6-propynyl-lumazine relies on the palladium-catalyzed cross-coupling reaction of 6-bromo-3-methylaminopyrazinecarbonitrile with propyne, yielding 6-acetonylpteridine on treatment with aqueous mercury(II) sulfate.

A series of lumazines having a propionyl, β-alkoxy- or β-hydroxy-propionyl group at C-6 were recently isolated from the metabolites of a swimming polychaete, *Odontosyllis undecimdonta*.[2] This marine creature is commonly called fire worm since it luminesces during spawning at sunset in the middle of autumn at Toyama Bay, Japan. Because of the connection with the *Odontosyllis* bioluminescence or its biorhythm,[3] these lumazine products are of considerable interest. Synthesis of 6-acyllumazines has been realized only by homolytic acylation of 1,3-dimethyllumazines,[4] but we found some drawbacks in yield and regioselectivity of the radical-acylation products in the course of our existing work. A widely used procedure for synthesis of pteridines utilizes a manipulation of 3-amino-pyrazinecarboxylic acid derivatives, and promises an unequivocal synthesis of the 6-substituted isomer.[5] In this paper, we report on a program aimed at the synthesis of 6-propionyl-pteridine-2,4(1*H*,3*H*)-diones **1**–**4**, of which all except **2** are

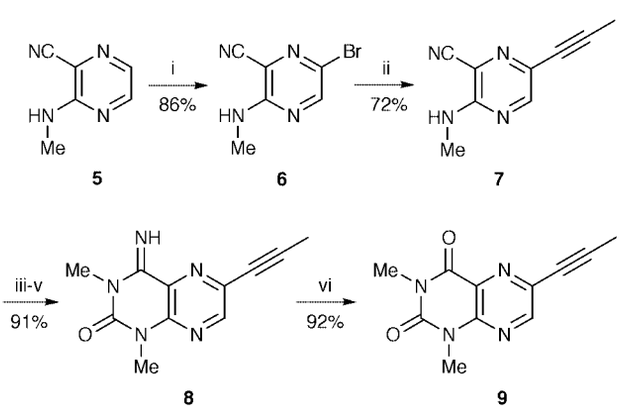


1 $R^1 = R^2 = Me$
2 $R^1 = Me$, $R^2 = H$
3 $R^1 = H$, $R^2 = Me$
4 $R^1 = R^2 = H$

natural products, starting from 6-bromo-3-aminopyrazine-carbonitriles.

Most of the reported syntheses[6,7] of pyrazinyl ketones involve treatment of a pyrazinecarboxylic ester or carbonitrile with an alkyllithium or Grignard reagent.[6] An alternative method involves lithiation of pyrazines with an organolithium reagent followed by carbonylation, for example with *N*,*N*-dialkylcarboxamides.[7] These routes, however, seem to be less suited for our synthesis because of the limited accessibility of the starting materials and the susceptibility of the pyrimidine-dione ring to organometallic reagents, and so we needed some other synthetic strategy to meet our goal. The palladium-catalyzed cross-coupling reaction of halogenopyrazines with terminal acetylenes is an efficient method for synthesis of alkynylpyrazines,[8–10] which are expected to be useful intermediates for the target acyllumazines since hydration of an acetylene is a known method for preparation of ketones.

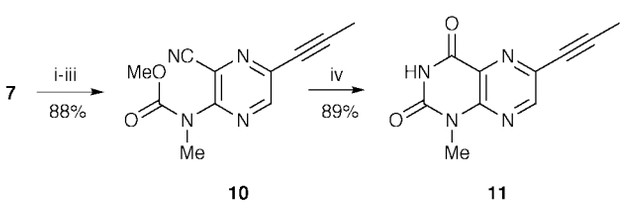
The key compound, 6-prop-1-ynyl-1,3-dimethylpteridine-2,4(1*H*,3*H*)-dione **9**, was synthesized by a four-step sequence of reactions starting from 3-methylaminopyrazinecarbonitrile **5**[11,12] (Scheme 1). Bromination of **5** was unexpectedly accom-



Scheme 1 *Reagents and conditions*: i, Br_2, NaOAc, AcOH; ii, MeC≡CH, $Pd(dba)_2$, (*o*-tolyl)$_3$P, CuI, Et_3N, MeCN (reflux); iii, NaH, THF; iv, MeNCO; v, aq. HCl then $NaHCO_3$; vi, aq. HCl, MeCN (reflux) then $NaHCO_3$.

plished by the classical procedure, by treatment with bromine in aqueous acetic acid containing sodium acetate affording an 86% yield of bromopyrazine **6**. Treatment of **5** with bromine in chloroform in the presence of pyridine or with *N*-bromo-succinimide (NBS) in aqueous dimethyl sulfoxide (DMSO), which greatly improved the bromination of aminopyrazines[13] in comparison with the above traditional method, was ineffective in the present conversion to **6**, and almost all of the amino-pyrazine **5** was recovered. Cross-coupling of bromopyrazine **6** with propyne proceeded smoothly to form the alkynylpyrazine **7** in 72% yield; the success of this reaction was due to the use of bis(dibenzylideneacetone)palladium(0), $Pd(dba)_2$, and particularly tri-*o*-tolylphosphine. Conversely, none of the desired product was obtained when tetrakis(triphenylphosphine)-palladium(0)[8,10] or dichlorobis(triphenylphosphine)palladium(II)[9] was used as the catalyst.

It has been demonstrated that transformation of 3-methylaminopyrazinecarbonitrile **5** into pteridine derivatives is realized by treatment with sodium hydride in tetrahydrofuran (THF), followed by methyl isocyanate or methyl chloroformate.[11] In our current synthesis, however, a reasonable improvement of the reaction conditions was required to optimize the cyclization of 6-alkynyl-3-methylaminopyrazinecarbonitrile **7**. Thus, the previously published procedure using 0.3 equivalent of sodium hydride, and running for 19 h at room temperature led to the formation of 1,3-dimethyllumazine **8** in only 43% yield together with 10% recovery of the starting material. The best yield of **8** (91%) was obtained using 0.2 equivalent of sodium hydride and a reduction of the reaction time to 1 h. Hydrolysis of **8** was readily effected with refluxing 2 M hydrochloric acid for 5 h to provide pteridinedione **9** in 92% yield, whereas the reaction at room temperature[11] induced no hydrolysis. 1-Methylpteridine-2,4-dione **11** was obtained by treatment of **7** with 2 equivalents of sodium hydride and methyl chloroformate followed by cyclization with basic hydrogen peroxide in 78% overall yield (Scheme 2). When 1 equivalent of

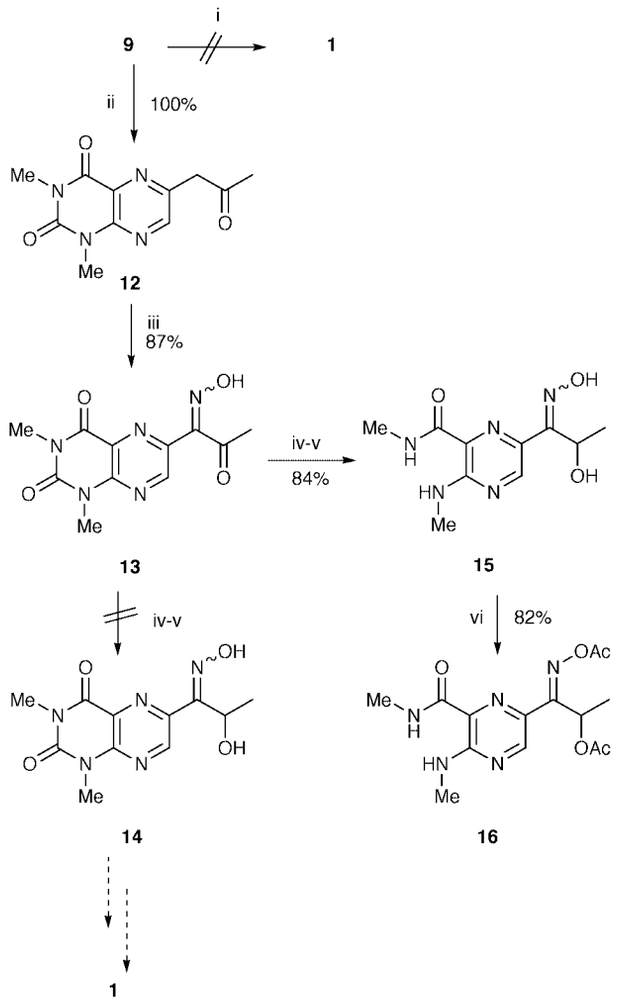


Scheme 2 *Reagents and conditions*: i, NaH, THF; ii, $ClCO_2Me$; iii, aq. HCl; iv, 30%H_2O_2, aq. NaOH, H_2O, THF.

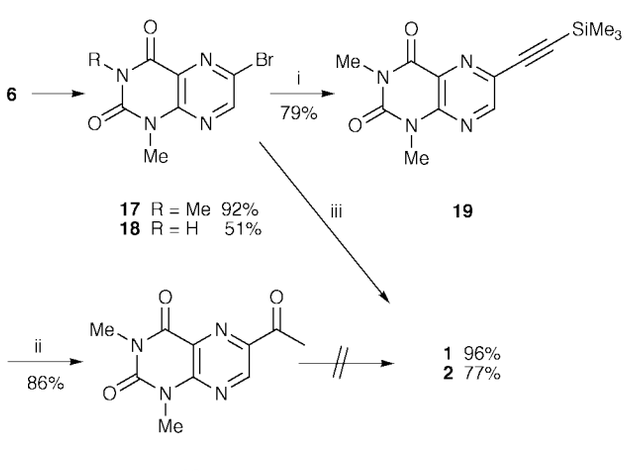
sodium hydride was used, as in the literature procedure,[11] the intermediate **11** was produced in 50% yield, with 34% recovery of starting material.

The hydration of triple bonds is usually not regioselective.[14] In this respect, the exclusive conversion of 2-alkynyl-3,5-diamino-6-chloropyrazines into the acylpyrazines, which was unexpectedly achieved by treatment with aqueous sodium sulfide and hydrochloric acid in methanol,[15] was obviously relevant, and conceivably could be helpful in the final step of our synthetic approach. However, application of this method failed to synthesize the acyllumazine **1** and gave an almost quantitative recovery of the alkyne **9**. In contrast, this substrate **9** was smoothly hydrated by mercury(II) sulfate in trifluoroacetic acid (TFA) containing a trace of water yielding the other possible isomer, acetonyllumazine **12**, as the sole product (Scheme 3). Accordingly, we attempted to transfer the oxo group to the α position: *i.e.* conversion of **12** into **1**. There are several procedures for such a transposition in the literature. We chose to use Corey's methodology,[16] consisting of *C*-nitrosation, reduction of the ketone, and finally dehydroxylation, with each step under mild reaction conditions. Surprisingly, reduction of the α-oximinoketone **13** with sodium borohydride led simultaneously to cleavage of the pyrimidinedione ring to yield pyrazinecarboxamide **15**, and not the desired compound **14** (Scheme 3). The structure of **15** was indicated by the appearance of two *N*-methyl proton doublets at δ 2.81 and 2.96 in ^{1}H NMR spectrum, and was clearly established by elementary analysis and the NMR spectra of the diacetyl derivative **16**, formed only in the (*Z*) form.

Since the hydration of the ethynyl group reliably generates an acetyl derivative, utilization of acetyllumazine is still a possible protocol for synthesis of the propionyl compound **1**. The trimethylsilylethynyllumazine **19**, a precursor of acetyllumazine **20**, was prepared as shown in Scheme 4, the sequence of reactions differing from those in the above synthesis of alkynyllumazine (Scheme 1), *i.e.* 6-bromolumazine **17** was initially constructed and subsequently cross-coupled with acetylene. The preparation of **17** and **18** from **6** was successfully realized using



Scheme 3 *Reagents and conditions*: i, Na_2S, aq. HCl, MeOH (reflux); ii, $HgSO_4$, H_2O, TFA (reflux); iii, $NaNO_2$, H_2O, AcOH (0 °C); iv, $NaBH_4$, aq. NaOH (rt); v, aq. HCl; vi, Ac_2O, pyridine.

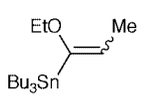


Scheme 4 *Reagents and conditions*: i, $Me_3SiC{\equiv}CH$, $Pd(PPh_3)_2Cl_2$, CuI, Et_3N (50–60 °C); ii, $HgSO_4$, H_2O, TFA; iii, **24**, $Pd(Ph_3P)_2Cl_2$, CuI, Et_3N, MeCN (reflux).

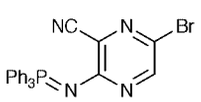
sodium hydride in the same way as the formation of **9** and **11**, respectively, when the bromo substituent on the lumazines survived exposure to even 2 equivalents of the hydride. This synthetic method for **17** is much more convenient compared to the earlier one starting from 1,3-dimethyllumazine,[17] since the use of 85% hydrogen peroxide is avoidable. The cross-coupling reaction of **17** with trimethylsilylacetylene proceeded easily in the presence of dichlorobis(triphenylphosphine)palladium(II)

and copper(I) iodide in triethylamine leading to the almost quantitative formation of alkyne **19**. Treatment of **19** with the mercury(II) ions provided directly the acetyl compound **20** in excellent yield. However, all attempts to effect the conversion of the acetyl into the propionyl group by base-promoted alkylation with methyl iodide were frustrated probably because the lumazine ring was decomposed by the strong base used: *e.g.* sodium hydride, lithium diisopropylamide, lithium hexamethyldisilazide or butyllithium, inferred from recovery of a trace of the starting material. Similarly, methylation *via* the enamine proved ineffective, and the acetyl compound **20** was almost completely recovered without forming the intermediate.

A significant finding of the above unsuccessful project is the facile synthesis of 6-bromolumazine **17** and its high reactivity to palladium-catalyzed reaction so that we turned our attention to transition metal mediated acylation of bromolumazines to reach our goal. Since it is seemingly impossible to metallate the 6-bromolumazines due to the susceptibility of the lumazine ring to strong bases, an alternative method utilizing an organometallic acylation agent was explored. (1-Ethoxyvinyl)-tributyltin was found to be effective as such a reagent, *i.e.* the organotin compound can couple with bromobenzenes in the presence of dichlorobis(triphenylphosphine)palladium(II) in toluene at 100 °C for 20 h yielding acetophenones.[18] Under identical conditions, however, the acylation of **17** with (1-ethoxyprop-1-enyl)tributyltin **21**, which was easily prepared from ethyl prop-1-enyl ether, did not go to completion, and a more difficult problem was the impossible isolation of ketone **1** from the unreacted starting substrate. Finally, when the reaction was carried out in acetonitrile containing 6 mol% of copper(I) iodide and triethylamine at reflux for 5 h, the cross-coupling was best effected affording a 96% yield of the desired product **1** (Scheme 4). Copper iodide stimulates the substitution reaction, because in the absence of the reagent the substrate was not completely consumed even after refluxing for 24 h. Acylation of bromolumazine **18** with organotin **21** similarly



21 (*E*):(*Z*) 4:1



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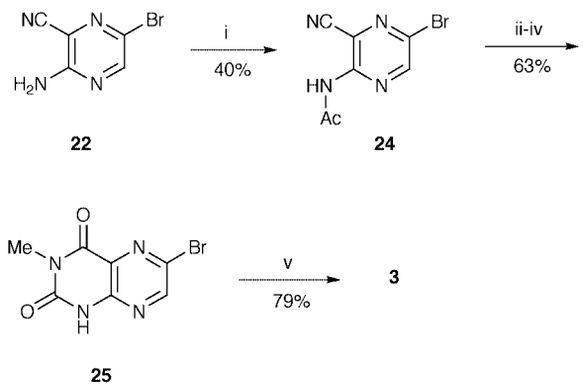
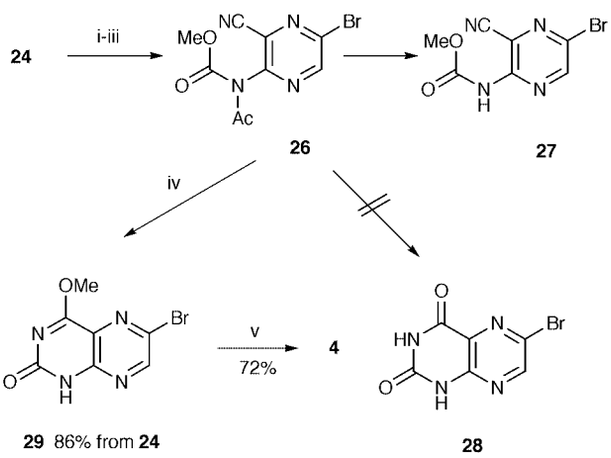
produced propionyllumazine **2** in 77% yield when 1 equivalent of copper iodide was employed.

Our success in preparing 6-propionyllumazine **1** and **2** prompted us to examine the synthesis of the 1-demethylated derivatives **3** and **4**. Compared to 3-methyllumazines **17** and **18**, preparation of 6-bromolumazines **25** and **28** was much more troublesome, *e.g.* 3-amino-6-bromopyrazinecarbonitrile **22** failed to undergo cyclization with methyl isocyanate in the same way using sodium hydride or butyllithium as described above, and with recovery of 10–60% of the starting material. Instead a tandem aza-Wittig and cyclization methodology[19] was attempted, but the iminophosphorane **23**, whose synthesis was easily realized from **22** by a modified Kirsanov method using a triphenylphosphine–hexachloroethane–triethylamine system, resisted aza-Wittig reaction with methyl isocyanate and was completely recovered. However, the required bromolumazine **25** was successfully synthesized by the reaction sequence shown in Scheme 5. Acetylation of **22** in acetic anhydride containing 4-dimethylaminopyridine (DMAP) at >100 °C gave mainly the diacetylamino product. The desired monoacetylamino compound **24** was obtained in 40% yield under controlled condition using 1.3 equivalents of acetic anhydride in refluxing 1,2-dichloroethane, when 54% of the starting substrate was recovered. This acetyl compound **24** was treated with



Scheme 5 *Reagents and conditions*: i, Ac_2O, $ClCH_2CH_2Cl$ (reflux); ii, NaH, THF; iii, MeNCO; iv, aq. HCl (reflux); v, **24**, $Pd(Ph_3P)_2Cl_2$, CuI, Et_3N, MeCN (reflux).

0.6 equivalent of sodium hydride and then worked up in the same manner as in the synthesis of 3-methylated lumazine **17** to afford a 63% yield of lumazine **25**. The amide **24** was also acylated with methyl chloroformate yielding imide **26**, which was partially hydrolyzed during chromatographic work-up leading to carbamate **27** (Scheme 6). The mixture of **26** and **27**



Scheme 6 *Reagents and conditions*: i, NaH, THF; ii, $ClCO_2Me$; iii, aq. HCl; iv, NaOMe, MeOH (reflux); v, **24**, $Pd(Ph_3P)_3Cl_2$, CuI, Et_3N, MeCN (reflux).

was treated with refluxing methanolic sodium methoxide to provide 4-methoxylumazine **29** in an overall yield of 86% from **24**. Attempted cyclization of **26** or **27** with basic hydrogen peroxide gave a mixture of complex products and a trace of the slightly soluble bromolumazine **28**, whose structure was inferred from its NMR spectrum. Acylation of bromo compounds **25** and **29** was accomplished by the same procedure for synthesis of propionyllumazines **1** and **2** to furnish the 1-demethylated products **3** and **4** in about 70% yield.

In conclusion, a convenient synthetic method for 6-bromolumazine was developed; the preparation of the 1-demethylated derivatives is noteworthy. These products could be versatile intermediates for other inaccessible lumazine compounds. As an example, the bromolumazines undergo palladium-catalyzed acylation with (1-ethoxyprop-1-enyl)tributyltin **21** affording propionyllumazines in good yields. We also found that copper iodide plays an important role in completing the cross-coupling reaction.

Experimental

General

Melting points were determined using a Büchi 535 or a

Meltemp apparatus and are uncorrected. IR spectra were recorded on a Perkin Elmer Spectrum One. NMR spectra were obtained with a JEOL JNM EX270 (270 MHz ^{1}H, 67.8 MHz ^{13}C) and a Bruker Avance 400 (400 MHz ^{1}H, 100.6 MHz ^{13}C) instrument for solutions in $CDCl_3$, unless otherwise noted, containing Me_4Si as internal standard. *J* Values are given in Hz. Mass spectra were recorded on a JEOL JMS-AM II at 70 eV. Column chromatography was performed using Silica Gel 60. Drying refers to drying over $MgSO_4$. Evaporation refers to evaporation under reduced pressure.

3-*N*-Methylamino-6-bromopyrazinecarbonitrile 6

Cyanopyrazine **5** (1.070 g, 8.0 mmol) was added to a solution of NaOAc (1.969 g, 24 mmol) in AcOH (25 ml) containing water (1.3 ml), and to the mixture was added a solution of Br_2 (1.9 g, 12 mmol) in AcOH (4 ml) over 10 min. The resulting mixture was stirred at rt for 4 h and then poured into ice–water. The aqueous solution was extracted with $CHCl_3$ (4 × 50 ml), and the combined extracts were washed with 10% aqueous NaOH solution and then water. After drying, the solution was evaporated, and the residue was sublimed at 80 °C (2.5 mmHg) providing bromopyrazine **6** (1.472 g, 86%) as pale yellow needles, mp 140–141 °C (hexane–EtOAc, 6:1) (Found: C, 33.8; H, 2.5; N, 26.3. $C_6H_5N_4Br$ requires C, 33.8; H, 2.4; N, 26.3%); ν_{max} (KBr)/cm^{-1} 3473, 3358 (NH), 2227 (C≡N), 1586, 1506, 1403, 1217 and 1149; δ_H 3.07 (3H, d, *J* 5.0, NCH_3), 5.39 (1H, br s, NH) and 8.32 (1H, s, ArH); δ_C 28.3 (NCH_3), 112.8 (Ar C), 114.3 (C≡N), 124.4 (Ar C), 149.1 (Ar CH) and 155.3 (Ar C).

3-*N*-Methylamino-6-(prop-1-ynyl)pyrazinecarbonitrile 7

A mixture of **6** (2.130 g, 10.0 mmol), $Pd(dba)_2$ (0.290 g, 0.50 mmol), tri-*o*-tolylphosphine (0.304 g, 1.0 mmol) and CuI (95%, 0.095 g, 0.47 mmol) was purged by passage of argon after evacuation of air, and then dry MeCN (50 ml) and triethylamine (7.0 ml, 50 mmol) were added *via* a syringe. The mixture was refluxed with stirring and propyne (3.2 g, 80 mmol) was bubbled into it for 2 h. After being cooled, the mixture was filtered through Celite and evaporated. The residue was twice subjected to chromatography on silica (40 g × 2, hexane–EtOAc, 5:1) affording the acetylene **7** (1.242 g, 72%) as pale yellow needles, mp 177–178 °C (hexane–EtOAc, 5:1) (Found: C, 62.4; H, 4.55; N, 32.7. $C_9H_8N_4$ requires C, 62.8; H, 4.7; N, 32.5%); ν_{max} (KBr)/cm^{-1} 3363 (NH), 2228 (C≡C and C≡N), 1594, 1517, 1336 and 1203; δ_H 2.08 (3H, s, CH_3), 3.08 (3H, d, *J* 5.0, NCH_3), 5.45 (1H, br s, NH) and 8.28 (1H, s, ArH); δ_C 4.4 (CH_3), 28.1 (NCH_3), 75.7 (C≡C), 88.4 (C≡C), 113.4 (Ar C), 114.7 (C≡N), 128.6 (Ar C), 149.1 (Ar CH) and 154.3 (Ar C).

1,3-Dimethyl-6-(prop-1-ynyl)pteridine-2,4(1*H*,3*H*)-dione 9

A mixture of NaH (60% dispersion in mineral oil, 16 mg, 0.4 mmol) and aminocyanopyrazine **7** (0.344 g, 2.0 mmol) was placed under argon, and dry THF (10 ml) was added *via* a syringe. The resulting wine-red mixture was stirred for 20 min at rt and then methyl isocyanate (0.4 ml, 6.8 mmol) was added dropwise. After stirring at rt for 1 h, the mixture was diluted with 2 M hydrochloric acid (20 ml), filtered, neutralized with $NaHCO_3$ and extracted with $CHCl_3$ (3 × 20 ml). After washing with water and drying, the solution was concentrated to dryness under reduced pressure. The residue was purified by chromatography on silica (40 g, hexane–EtOAc, 1:1) to give 4-iminopteridinone **8** (0.419 g, 91%) as a pale yellow solid, δ_H 2.17 (3H, s, CH_3), 3.58 (s, 3H, NCH_3), 3.61 (3H, s, NCH_3), 8.50 (1H, s, ArH) and 9.28 (1H, br s, NH). This product was partially hydrolyzed with time at rt or recrystallization work-up leading to lumazine **9**.

A mixture of the imine **8** (0.917 g, 4.0 mmol) in 2 M hydrochloric acid (13 ml) and MeCN (8 ml) was refluxed with stirring for 5 h. After being cooled, the precipitate was collected by filtration to give lumazine **9** (0.787 g, 85%) as pale yellow needles. The filtrate was neutralized with $NaHCO_3$ and extracted with $CHCl_3$ (3 × 20 ml). Drying the extract and removal of the solvent gave a second crop (0.065 g, 92% total yield), mp 258–259 °C (EtOH) (Found: C, 57.6; H, 3.95; N, 24.8. $C_{11}H_{10}N_4$ requires C, 57.4; H, 4.4; N, 24.3%); ν_{max} (KBr)/cm^{-1} 2229 (C≡C), 1716, 1672 (C=O), 1538, 1496, 1450, 1327, 1206 and 750; δ_H 2.13 (3H, s, CH_3), 3.54 (3H, s, NCH_3), 3.71 (3H, s, NCH_3) and 8.61 (1H, s, ArH); δ_C 4.6 (CH_3), 29.1 (NCH_3), 29.5 (NCH_3), 76.2 (C≡C), 91.8 (C≡C), 127.0 (Ar C), 135.9 (Ar C), 146.1 (Ar C), 150.1 (Ar CH), 150.4 (2-C=O) and 159.3 (4-C=O); *m*/*z* (EI) 230 (100%, M$^+$), 144 (65) and 118 (46).

3-(*N*-Methoxycarbonyl-*N*-methylamino)-6-(prop-1-ynyl)-pyrazinecarbonitrile 10

A mixture of NaH (60%, 0.120 g, 3.0 mmol) and aminocyanopyrazine **7** (0.172 g, 1.0 mmol) was placed under argon, and dry THF (5.0 ml) was added *via* a syringe. The resulting wine-red mixture was stirred for 30 min at rt and then methyl chloroformate (0.12 ml, 1.5 mmol) was added dropwise. After stirring at rt for 7 h, the mixture was diluted with 2 M hydrochloric acid (10 ml) and extracted with $CHCl_3$ (3 × 10 ml). The extract was washed with aqueous $NaHCO_3$ and then water, dried and evaporated. The residue was subjected to chromatography on silica (20 g; hexane–EtOAc, 3:1) to give carbamate **10** (0.203 g, 88%) as tiny needles, mp 117.5–118 °C (MeOH) (Found: C, 57.1; H, 4.4; N, 24.4. $C_{11}H_{10}N_4O_4$ requires C, 57.4; H, 4.4; N, 24.3%); ν_{max} (KBr)/cm^{-1} 2240 (C≡C and C≡N), 1746 (C=O), 1466, 1440, 1297, 938 and 755; δ_H 2.15 (3H, s, CH_3), 3.43 (3H, s, NCH_3), 3.86 (3H, s, OCH_3) and 8.55 (1H, s, ArH); δ_C 4.6 (CH_3), 35.3 (NCH_3), 53.8 (OCH_3), 75.4 (C≡C), 93.4 (C≡C), 114.0 (C≡N), 127.0 (Ar C), 137.1 (Ar C), 147.6 (Ar CH), 151.3 (Ar C) and 154.3 (C=O). The starting material was recovered from further elution (11 mg, 6%).

1-Methyl-6-prop-1-ynylpteridine-2,4(1*H*,3*H*)-dione 11

The carbamate **10** (0.230 g, 1.0 mmol) in a solution of hydrogen peroxide (30%, 1.0 ml), 0.5 M aqueous NaOH (3.2 ml), THF (1.0 ml) and water (1.6 ml) was stirred at rt for 2 h, and then adjusted to pH 5 with concentrated sulfuric acid. The precipitated product was collected by filtration to provide **11** (0.169 g, 78%) as pale yellow needles. The filtrate was evaporated and the residue was extracted with $CHCl_3$–MeOH to afford a second crop (0.023 g, 89% total yield), mp 287.5–288 °C (EtOH) (Found: C, 55.6; H, 3.5; N, 25.9. $C_{10}H_8N_4$ requires C, 55.6; H, 3.7; N, 25.9%); ν_{max} (KBr)/cm^{-1} 2232 (C≡C), 1722, 1703 (C=O), 1537, 1496 and 1299; δ_H [$(CD_3)_2SO$] 2.15 (3H, s, CH_3), 3.44 (3H, s, NCH_3), 8.77 (1H, s, ArH) and 11.98 (1H, br s, NH); δ_C [$(CD_3)_2SO$] 3.8 (CH_3), 28.1 (NCH_3), 76.4 (C≡C), 90.3 (C≡C), 128.4 (Ar C), 133.2 (Ar C), 147.6 (Ar C), 149.2 (Ar CH), 149.8 (2-C=O) and 159.2 (4-C=O); *m*/*z* (EI) 216 (100%, M$^+$), 144 (46) and 118 (30).

1,3-Dimethyl-6-acetonylpteridine-2,4(1*H*,3*H*)-dione 12

To a slurry of $HgSO_4$ (0.265 g, 0.9 mmol) in TFA (45 ml) containing water (4 ml) was added alkyne **9** (1.032 g, 4.48 mmol), and the mixture was stirred under reflux for 1.5 h. After evaporation, the residue was diluted with water and extracted with $CHCl_3$ (3 × 20 ml). The combined extracts were washed with aqueous $NaHCO_3$ and then brine, dried and evaporated. The residue was purified by chromatography on silica (25 g; hexane–EtOAc, 2:1) to provide ketone **12** (1.110 g, 100%) as golden tiny needles, mp 197–197.5 °C (MeOH) (Found: C, 53.3; H, 4.6; N, 22.3. $C_{11}H_{12}N_4O_3$: C, 53.2; H, 4.9; N, 22.6%); ν_{max} (KBr)/cm^{-1} 1720 (C=O), 1673 (C=O), 1547, 1504, 1336 and 750; δ_H 2.34 (3H, s, CH_3), 3.55 (3H, s, NCH_3), 3.73 (3H, s, NCH_3), 4.18 (2H, s, CH_2) and 8.58 (1H, s, ArH); δ_C 29.1 (NCH_3), 29.4 (NCH_3), 30.3 (CH_3), 49.0 (CH_2), 126.6 (Ar C),

145.9 (Ar C), 147.0 (Ar C), 148.9 (Ar CH), 150.5 (2-C=O), 160.2 (4-C=O) and 203.7 (C=O); *m/z* (EI) 248 (15%, M^+), 233 (6), 206 (100) and 120 (15).

1,3-Dimethyl-6-(1-hydroxyimino-2-oxopropyl)pteridine-2,4(1*H*,3*H*)-dione 13

A solution of $NaNO_2$ (0.272 g, 4.0 mmol) in water (2.7 ml) was added dropwise to a stirred solution of acetonyllumazine **12** (0.495 g, 2.0 mmol) in AcOH (10 ml) at <5 °C, and the resulting mixture was stirred for 30 min and slowly warmed to rt over 1 h. After adding water, the solution was extracted with $CHCl_3$ (4 × 30 ml) and the combined extracts were washed with aqueous $NaHCO_3$, dried and evaporated. The residue was chromatographed on silica (25 g; hexane–EtOAc, 1:1) affording oxime **13** (0.482 g, 87%) as light tan tiny needles, mp 188–193 °C (EtOH) (Found: C, 47.7; H, 4.1; N, 25.0. $C_{11}H_{11}N_5O_4$ requires C, 47.7; H, 4.0; N, 25.3%); ν_{max} (KBr)/cm^{-1} 3443, 1718 (C=O), 1668 (C=O), 1546, 1505, 1297 and 749; δ_H 2.59 (0.8 × 3H, s, CH_3), 2.63 (0.2 × 3H, s, CH_3), 3.53 (0.2 × 3H, s, NCH_3), 3.56 (0.8 × 3H, s, NCH_3), 3.74 (0.2 × 3H, s, NCH_3), 3.76 (0.8 × 3H, s, NCH_3), 9.07 (0.2H, s, ArH) and 9.18 (0.8H, s, ArH).

N-Methyl-(3-*N*′-methylamino)-6-(1-acetoxyimino-2-acetoxypropyl)pyrazinecarboxamide 16

Sodium borohydride (34 mg, 0.9 mmol) was added in portions to a stirred solution of oxime **13** (0.253 g, 0.91 mmol) in 0.5 M NaOH solution (10 ml) at ambient temperature, and the mixture was stirred for 1 h. After addition of 1 M hydrochloric acid (12 ml), the solution was extracted with EtOAc (3 × 15 ml), and the combined extracts were washed with brine, dried and evaporated to give pyrazinecarboxamide **15** (0.193 g, 84%). The crude product was dissolved in Ac_2O (15 ml) containing pyridine (1.5 ml), and the mixture was stirred at rt for 3 h and then evaporated. The residual oil was diluted with EtOAc (20 ml) and the organic phase was washed with aqueous $CuSO_4$ and brine, dried and evaporated. The residue was purified by chromatography on silica (7 g; hexane–EtOAc, 2:1) to afford an oil, which was crystallized by ultrasonic work-up in hexane followed by evaporation to provide acetate **16** (0.210 g, 82%) as pale yellow tiny needles, mp 121–122 °C (hexane) (Found: C, 50.1, H, 5.7; N, 20.8. $C_{14}H_{19}N_5O_5$ requires C, 49.9; H, 5.7; N, 20.8%); ν_{max} (KBr)/cm^{-1} 3396 (NH), 1798, 1732 (C=O), 1664 (C=O), 1588, 1244, 1181 and 939; δ_H 1.59 (3H, d, *J* 6.6, C*H*$_3$CH), 1.98 (3H, s, CH_3C=O), 2.27 (3H, s, CH_3C=O), 2.98 (3H, d, *J* 5.0, NCH_3), 3.10 (3H, d, *J* 5.0, NCH_3), 6.58 (1H, q, *J* 6.6, CH), 7.90 (1H, br s, NH), 9.03 (1H, s, ArH) and 9.13 (1H, br s, NH); δ_C 17.1 (CH_3), 19.8 (CH_3), 21.1 (CH_3), 25.9 (NCH_3), 27.5 (NCH_3), 68.3 (CH), 125.6 (Ar C), 128.0 (Ar C), 150.5 (Ar CH), 154.3 (Ar C), 157.3 NC=O), 166.2 (C=N), 168.0 (CH_3C=O) and 170.9 (CH_3C=O).

1,3-Dimethyl-6-bromopteridine-2,4(1*H*,3*H*)-dione 17

This compound was prepared by the above procedure for the synthesis of alkynyllumazine **9**. When bromopyrazine **6** (2.130 g, 10.0 mmol) was treated with NaH (60%, 0.080 g, 2.0 mmol) and methyl isocyanate (1.78 ml, 30 mmol) in THF (50 ml), the crude 4-iminolumazine (2.790 g) was obtained. Acidic hydrolysis gave the title compound **17** (2.506 g, 92%) as needles, mp 198–199 °C (EtOH) (lit.,[17] mp 107–108 °C) (Found: C, 35.5; H, 2.4; N, 20.8. $C_8H_7N_4O_2Br$ requires C, 35.45; H, 2.6; N, 20.7%); ν_{max} (KBr)/cm^{-1} 1719, 1667 (C=O), 1537, 1479, 1167 and 751; δ_H 3.53 (3H, s, NCH_3), 3.70 (3H, s, NCH_3) and 8.71 (1H, s, ArH); δ_C 29.2 (NCH_3), 29.7 (NCH_3), 127.6 (Ar C), 134.1 (Ar C), 147.2 (Ar C), 150.2 (2-C=O), 150.5 (Ar CH) and 158.7 (4-C=O); *m/z* (EI) 272 (100%), 269 (100%, M^+), 243 (23), 241 (22), 215 (30), 213 (30), 187 (77), 185 (75), 160 (56), 158 (57), 106 (39) and 79 (61).

1-Methyl-6-bromopteridine-2,4(1*H*,3*H*)-dione 18

This compound was prepared by the above procedure for the synthesis of 1-methyllumazine **11**. Treatment of bromopyrazine **6** (0.320 g, 1.5 mmol) with NaH (60%, 0.115 g, 2.9 mmol) and methyl chloroformate (0.2 ml, 2.6 mmol) in THF (6 ml), and then flash chromatography (38 g; hexane–EtOAc 4:1) afforded the carbamate (0.339 g, 83%). A mixture of the carbamate (0.701 g, 2.6 mmol) in 0.5 M NaOH (8.5 ml), THF (5 ml) and water (4.3 ml) was treated with hydrogen peroxide (30%, 2.4 ml) and worked up as described in the synthesis of **11** to yield the title compound **18** (0.341 g, 51%) as light tan tiny needles, mp 250–251.5 °C (MeOH) (Found: C, 32.9; H, 1.8; N, 21.45. $C_7H_5N_4O_2Br$ requires C, 32.7; H, 2.0; N, 21.8%); ν_{max} (KBr)/cm^{-1} 3195, 3076 (NH), 1696 (C=O), 1567, 1539, 1482, 1307, 1284 and 1163; δ_H 3.67 (3H, s, NCH_3), 8.74 (1H, s, ArH) and 8.95 (1H, br s, NH); δ_C 29.2 (CH_3), 128.4 (Ar C), 134.4 (Ar C), 148.6 (Ar C), 149.2 (2-C=O), 150.8 (Ar CH) and 158.2 (4-C=O); *m/z* (EI) 258 (98%), 256 (100, M^+), 215 (22), 213 (22), 187 (43), 185 (44), 160 (41), 158 (43), 106 (32) and 79 (46).

6-(Trimethylsilylethynyl)-1,3-dimethylpteridine-2,4(1*H*,3*H*)-dione 19

A mixture of **17** (1.084 g, 4.0 mmol), $Pd(PPh_3)_2Cl_2$ (0.140 g, 0.20 mmol), and CuI (95%, 0.038 g, 0.20 mmol) was placed under argon, and then dry triethylamine (13 ml) and ethynyltrimethylsilane (0.85 ml, 6.0 mmol) were added *via* a syringe. The mixture was heated at 50–60 °C with stirring for 0.5 h. After being cooled with ice–water, the precipitate was collected by filtration and the filtrate was evaporated. The residue was purified by chromatography on silica (30 g; hexane–EtOAc 1:1). Recrystallization of the combined products gave alkyne **19** (0.887 g, 79%) as pale yellow prisms, mp 131–131.5 °C (hexane–MeOH) (Found: C, 54.0; H, 5.65; N, 19.3. $C_{13}H_{16}N_4O_2Si$ requires C, 54.1; H, 5.6; N, 19.4%); ν_{max} (KBr)/cm^{-1} 2961, 1727, 1684 (C=O), 1490, 1204 and 847; δ_H 0.24 [9H, s, $Si(CH_3)_3$], 3.47 (3H, s, NCH_3), 3.66 (3H, s, NCH_3) and 8.63 (1H, s, ArH); δ_C −0.5 ($SiCH_3$), 29.1 (NCH_3), 29.5 (NCH_3), 99.7 (C≡C), 100.4 (C≡C), 127.1 (Ar C), 135.1 (Ar C), 146.3 (Ar C), 150.3 (2-C=O), 150.5 (Ar CH) and 159.1 (4-C=O).

6-Acetyl-1,3-dimethylpteridine-2,4(1*H*,3*H*)-dione 20

The ethynyllumazine **19** (0.200 g, 0.69 mmol) was added to a vigorously stirring solution of $HgSO_4$ (0.124 g, 0.42 mmol) in TFA (21 ml) containing water (2.1 ml), and the mixture was refluxed for 1 h. After evaporation, to the residue was added $CHCl_3$, and the organic phase was washed with saturated $NaHCO_3$ solution and then brine. Drying and evaporation gave ketone **20** (0.140 g, 86%) as light tan tiny needles, mp 203–204 °C (MeOH) (Found: 51.3; H, 4.3; N, 23.8. $C_{10}H_{10}N_4O_3$ requires C, 51.3; H, 4.3; N, 23.9%); ν_{max} (KBr)/cm^{-1} 1723 (C=O), 1679 (C=O), 1545, 1502, 1279, 1121 and 749; δ_H 2.82 (3H, s, CH_3), 3.57 (3H, s, NCH_3), 3.77 (3H, s, NCH_3) and 9.29 (1H, s, ArH); δ_C 25.7 (CH_3), 29.1 (NCH_3), 29.8 (NCH_3), 125.7 (Ar C), 143.5 (Ar C), 147.0 (Ar CH), 149.7 (Ar C), 150.3 (2-C=O), 159.2 (4-C=O) and 197.7 (C=O); *m/z* (EI) 234 (98%, M^+), 219 (35), 206 (100), 191 (89), 165 (75), 134 (46) and 107 (100).

6-Bromo-3-(triphenylphosphoranylidene)aminopyrazinecarbonitrile 23

Triethylamine (0.6 ml, 4.3 mmol) was added dropwise under argon to a stirred mixture of aminopyrazine **22**[13] (0.352 g, 1.8 mmol), hexachloroethane (0.627 g, 2.7 mmol) and triphenylphosphine (0.696 g, 2.7 mmol) in dry benzene (20 ml), and the resulting mixture was refluxed for 5 h. After being cooled, undissolved material was filtered off and the filtrate was evaporated. The residue was purified by chromatography on silica (30 g; hexane–EtOAc 4:1) to give iminophosphorane **23** (0.771

g, 95%) as yellow tiny needles, mp 214–215 °C (EtOH) (Found: 60.0; H, 3.4; N, 12.1. $C_{23}H_{16}N_4PBr$ requires C, 60.15; H, 3.5; N, 12.2%); ν_{max} (KBr)/cm^{-1} 1528, 1453, 1435, 1109, 992, 884, 721 and 691; δ_H 7.45–7.52 (6H, m, PhH), 7.55–7.59 (3H, m, PhH), 7.76–7.84 (6H, m, PhH) and 7.92 (1H, s, ArH).

3-Acetylamino-6-bromopyrazinecarbonitrile 24

Acetic anhydride (0.065 ml, 0.7 mmol, 1.3 equivalents) was added to a stirred solution of aminopyrazine **22** (0.100 g, 0.51 mmol) and DMAP (7 mg) in 1,2-dichloroethane (4 ml), and the mixture was refluxed for 22 h. After being cooled, MeOH was added and the mixture was evaporated. The residue was chromatographed on silica (14 g; hexane–EtOAc 5:1) to give recovery of the starting material as the first fraction (0.054 g, 54%). The next fraction (hexane–EtOAc 1:1) afforded acetylamino compound **24** (0.048 g, 40%) as tiny needles, mp 192–193 °C (benzene) (Found: C, 35.2; H, 1.9; N, 23.2. $C_7H_5N_4OBr$ requires C, 34.9; H, 2.1; N, 23.2%); ν_{max} (KBr)/cm^{-1} 3239 (NH), 2239 (C≡N), 1687 (C=O), 1493, 1422, 1344, 1120 and 915; δ_H 2.39 (3H, s, CH_3), 7.83 (1H, br s, NH) and 8.63 (1H, s, ArH); δ_C 24.3 (CH_3), 113.1 (C≡N), 128.3 (Ar C), 134.2 (Ar C), 147.9 (Ar C), 148.7 (Ar CH) and 168.1 (C=O).

6-Bromo-3-methylpteridine-2,4(1*H*,3*H*)-dione 25

This compound was prepared by the above procedure for synthesis of **9**. Thus, a solution of acetylaminopyrazine **24** (0.405 g, 1.7 mmol) in dry THF (12 ml) was treated with NaH (60%, 0.041 g, 1.0 mmol) followed by methyl isocyanate (0.3 ml, 5.1 mmol), and the resulting mixture was worked up as described above to give bromolumazine **25** (0.225 g, 63%) after chromatography on silica (45 g; hexane–EtOAc 4:1), as tiny needles, mp 249–250 °C (benzene) (Found: 33.1; H, 1.7; N, 21.3. $C_7H_5N_4O_2Br$ requires C, 32.7; H, 2.0; N, 21.8); ν_{max} (KBr)/cm^{-1} 3475 (NH), 3043, 1722 (C=O), 1632, 1541, 1477, 1437, 1316 and 1175; δ_H 3.67 (3H, s, NCH_3), 8.74 (1H, s, ArH) and 9.03 (1H, br s, NH); δ_C 29.2 (NCH_3), 128.4 (Ar C), 134.5 (Ar C), 148.6 (Ar C), 149.2 (2-C=O), 150.9 (Ar CH) and 158.2 (4-C=O); *m*/*z* (EI) 258 (100%), 256 (98, M$^+$), 215 (26), 213 (27), 187 (50), 185 (50), 160 (48), 158 (47), 106 (33) and 79 (48).

6-Bromo-4-methoxypteridin-2(1*H*)-one 29

To a solution of acetylaminopyrazine **24** (0.603 g, 2.5 mmol) in dry THF (20 ml) was added in portions NaH (60%, 0.150 g, 3.8 mmol), and the mixture was stirred at rt for 0.5 h. Methyl chloroformate (0.35 ml, 4.5 mmol) was added *via* a syringe, and the mixture was stirred for 2.5 h. After acidification with 2 M hydrochloric acid, the mixture was extracted with EtOAc (3 × 20 ml), and the combined extracts were washed with aqueous $NaHCO_3$, dried and evaporated. The residue was chromatographed on silica (35 g; hexane–EtOAc 4:1) to give a mixture of **26** and its deacetylated product **27** (0.704 g). These crude compounds were dissolved in dry MeOH (40 ml), and sodium methoxide (0.180 g, 3.2 mmol) was added. The solution was refluxed with stirring for 12 h and then cooled. The precipitated product was collected by filtration, and the filtrate was evaporated and purified by chromatography on silica (42 g; hexane–EtOAc 1:1) to give methoxylumazine **29** (combined yield: 0.555 g, 86% overall yield from **24**) as tiny needles, mp 226–228 °C (EtOH) (Found: C, 32.75; H, 1.8; N, 21.5. $C_7H_5N_4O_2Br$ requires C, 32.7; H, 2.0; N, 21.8%); ν_{max} (KBr)/cm^{-1} 1672 (C=O), 1604, 1458, 1395 and 1128; δ_H [$(CD_3)_2SO$] 4.05 (3H, s, OCH_3), 8.90 (1H, s, ArH) and 12.35 (1H, br s, NH); δ_C [$(CD_3)_2SO$] 55.1 (OCH_3), 122.6 (Ar C), 131.8 (Ar C), 149.0 (Ar C), 151.6 (Ar CH), 154.3 (2-C=O) and 166.3 (4-C); *m*/*z* (EI) 258 (100%), 256 (100, M$^+$), 228 (80), 226 (77), 200 (66), 198 (62), 177 (19), 150 (21), 82 (32) and 70 (75).

Palladium-catalyzed acylation of bromolumazines with organotin 21

(1-Ethoxyprop-1-enyl)tributyltin 21. This compound was prepared according to the method of Soderquist *et al.*[20] Ethyl prop-1-enyl ether (4.306 g, 50 mmol) was placed under argon and dry THF (18 ml) was added. The solution was stirred and cooled at −78 °C, and *tert*-butyllithium (1.6 M; 23.1 ml, 37 mmol) was added at <−70 °C. The mixture was allowed to slowly warm to 0 °C over 3 h, and subsequently recooled to −78 °C. A solution of chlorotributyltin (6.78 ml, 25 mmol) in dry THF (5 ml) was added dropwise, and the mixture was allowed to warm to rt and stirred for an additional 1 h. Saturated NH_4Cl solution was added to quench the reaction. The organic phase was dried over K_2CO_3 and distilled to give an oil (7.087 g, 76%), bp 100–110 °C at 4 mmHg (kugelrohr) (Found: C, 54.2; H, 9.9. $C_{17}H_{36}OSn$ requires C, 54.4; H, 9.7%), ν_{max} (film)/cm^{-1} 2956 (CH), 2927 (CH), 1610 (C=C), 1464, 1137 and 1094; δ_H 0.67–1.0 (18H, m, CH_3 and CH_2), 1.19–1.67 (15H, m, CH_2), 3.62 (0.8 × 2H, q, *J* 6.8, OCH_2), 3.68 (0.2 × 2H, q, *J* 6.8, OCH_2), 4.68 (0.2H, q, *J* 6.8, C=CH) and 5.27 (0.8H, q, *J* 7.0, C=CH).

1,3-Dimethyl-6-propionylpteridine-2,4(1*H*,3*H*)-dione 1

A mixture of bromolumazine **17** (0.268 g, 1.0 mmol), Pd(P-$Ph_3)_2Cl_2$ (36 mg, 5.1 mmol, 5 mol%) and CuI (95%, 12 mg, 6.0 mmol, 6 mol%) was placed under argon, and MeCN (5.0 ml), triethylamine (0.7 ml, 5.0 mmol) and organotin **21** (1.026 g, 2.7 mmol, 2.7 equivalents) were added *via* a syringe. The mixture was stirred under reflux for 5 h and then 1.5 M hydrochloric acid (30 ml) was added to quench the reaction. After refluxing for 1 h, the solution was neutralized with $NaHCO_3$, and extracted with EtOAc (3 × 15 ml). The combined extracts were dried and evaporated. The residue was chromatographed on silica (22 g; hexane–EtOAc 19:1) to remove the tin compounds. Further elution (hexane–EtOAc 4:1) gave acyllumazaine **1** as needles (0.236 g, 96%), mp 148–149 °C (EtOH) (lit.,[4] mp 141–142 °C) (Found: C, 53.2; H, 4.9; N, 22.3. $C_{11}H_{12}N_4O_3$ requires C, 53.2; H, 4.9; N, 22.6%); ν_{max} (KBr)/cm^{-1} 2989 (CH), 2897 (CH), 1671 (C=O), 1538, 1502, 1107 and 751; δ_H 1.24 (3H, t, *J* 7.3, CH_3), 3.33 (2H, q, *J* 7.3, CH_2), 3.57 (3H, s, NCH_3), 3.76 (3H, s, NCH_3) and 9.28 (1H, s, ArH); δ_C 7.5 (CH_3), 29.1 (NCH_3), 29.7 (CH_2), 31.2 (NCH_3), 125.7 (Ar C), 143.3 (Ar C), 147.0 (Ar CH), 149.7 (Ar C), 150.4 (2-C=O), 159.2 (4-C=O) and 200.3 (C=O); *m*/*z* (EI) 248 (79%, M$^+$), 221 (88), 219 (90), 193 (81), 191 (92), 165 (39), 134 (47), 107 (100) and 79 (69).

The following compounds were prepared by the above procedure except that 1 equivalent of CuI and 7–9 mol% of the palladium catalyst were used.

1-Methyl-6-propionylpteridine-2,4(1*H*,3*H*)-dione 2. This compound was obtained from **18** in 77% yield as tiny needles, mp 229.5–230.5 °C (benzene) (Found: C, 51.7; H, 4.2: N, 23.6. $C_{10}H_{10}N_4O_3$ requires C, 51.3; H, 4.3; N, 23.9%); ν_{max} (KBr)/cm^{-1} 3194 (NH), 3071 (CH), 1733 (C=O), 1688 (C=O), 1542 and 1493; δ_H [$(CD_3)_2SO$] 1.12 (3H, t, *J* 7.3, CH_3), 3.17 (2H, q, *J* 7.3, CH_2), 3.50 (3H, s, NCH_3), 9.17 (1H, s, ArH) and 12.14 (1H, br s, NH); δ_C [$(CD_3)_2SO$] 7.6 (CH_3), 28.5 (NCH_3), 30.5 (CH_2), 127.5 (Ar C), 141.8 (Ar C), 145.8 (Ar CH), 150.0 (Ar C), 151.1 (2-C=O), 159.4 (4-C=O) and 199.7 (C=O); *m*/*z* (EI) 206 (14%, M − CO), 177 (6), 107 (20) and 57 (19).

3-Methyl-6-propionylpteridine-2,4(1*H*,3*H*)-dione 3. This compound was obtained from **25** in 79% yield as tiny needles, mp 229.5–230.5 °C (benzene) (Found: C, 51.3; H, 4.1; N, 23.7. $C_{10}H_{10}N_4O_3$ requires C, 51.3; H, 4.3; N, 23.9%); ν_{max} (KBr)/cm^{-1} 3234 (NH), 3106 (CH), 1733 (C=O), 1688 (C=O), 1542 and 1494; δ_H [$(CD_3)_2SO$] 1.13 (3H, t, *J* 7.3, CH_3), 3.16 (2H, q, *J* 7.3, CH_2), 3.50 (3H, s, NCH_3), 9.16 (1H, s, ArH) and 12.09 (1H, br s, NH); δ_C [$(CD_3)_2SO$] 7.5 (CH_3), 28.4 (NCH_3), 30.4

(CH_2), 127.4 (Ar C), 141.7 (Ar C), 145.7 (Ar CH), 149.9 (Ar C), 151.0 (2-C=O), 159.3 (4-C=O) and 199.6 (C=O); *m*/*z* (EI) 220 (8%, MH − CH_3), 192 (100), 163 (42), 93 (41) and 57 (87).

6-Propionylpteridine-2,4(1*H*,3*H*)-dione 4. This compound was obtained from **29** in 72% yield as tiny needles, mp 282–284 °C (decomp.) (hexane–EtOH) (Found: C, 49.2; H, 3.9; N, 25.1. $C_9H_8N_4O_3$ requires C, 49.1; H, 3.7; N, 25.45%); ν_{max} (KBr)/cm^{-1} 3542 (NH), 3455 (NH), 3189, 1738 (C=O), 1704 (C=O), 1564, 1356 and 1249; δ_H [$(CD_3)_2SO$] 1.12 (3H, t, *J* 7.3, CH_3), 3.15 (2H, q, *J* 7.3, CH_2), 9.08 (1H, s, ArH), 11.84 (1H, br s, NH) and 12.31 (1H, br s, NH); δ_C [$(CD_3)_2SO$] 7.6 (CH_3), 30.3 (CH_2), 126.4 (Ar C), 142.5 (Ar C), 146.6 (Ar C), 149.8 (Ar CH), 151.3 (2-C=O), 160.3 (4-C=O) and 199.7 (C=O); *m*/*z* (EI) 220 (10%, M^+) 192 (100), 163 (35), 137 (11) and 120 (19).

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