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Assessing Pressurized Liquid Extraction for the High-Throughput Extraction of Marine-Sponge Derived Natural Products[⊥]

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Abstract

In order to compare the utility of standard solvent partitioning (SSP) versus accelerated solvent extraction (ASE), a series of experiments were performed and evaluated. Overall yields, solvent consumption, processing time and chemical stability of the fractions obtained by both methods were compared. Five marine sponges were selected for processing and analysis containing twelve structurally distinct, bioactive natural products. Extracts generated using SSP and ASE were assessed for chemical degradation using comparative LC MS-ELSD. The extraction efficiency (EE) of the ASE apparatus was three times greater than the SSP method on average, while the total extraction yields (TEY) were roughly equivalent. Furthermore, the ASE methodology required only two hours to process each sample versus 80 hours for SSP and the LC MS-ELSD from extracts of both methods appeared comparable. These results demonstrate that ASE can serve as an effective high-throughput methodology for extracting marine organisms to streamline the discovery of novel and bioactive natural products.

Early milestone discoveries in marine natural products chemistry can be traced back to the seminal research conducted during the 1970s by Prof. Richard E. Moore on the metabolites of marine cyanobacteria.^{1–3} Today, descriptions of nearly 20,000 marine-derived compounds⁴ can be found in the literature and/or in commercial databases. Some of these structures are extremely significant and examples to underscore this point include ziconotide (Prialt)⁴ and ET-743 (trabectedin or Yondelis),⁴ which are now available as clinical therapeutics. There are numerous other marine-derived lead compounds undergoing clinical evaluation⁵ with dozens more undergoing advanced preclinical studies.⁶

The classical way to work-up natural product containing extracts is often labor intensive and time consuming.⁴ Many discovery programs based on screening of extract libraries, bioassay-guided isolation, and dereplication/structure elucidation now use high-throughput screening (HTS) as an important filter.⁷ Surprisingly, few investigators have explored a high-throughput approach for generating extracts. Several years ago we began to de-emphasize the classic Kupchan extraction scheme,^{8, 9} which involves standard solvent partitioning (SSP), in favor of the pressurized liquid extraction system¹⁰ called accelerated solvent extraction (ASE).¹¹

[⊥]Dedicated to the late Dr. Richard E. Moore of the University of Hawaii at Manoa for his pioneering work on bioactive natural products.

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Supporting Information Available. Two charts, eight tables and four figures are provided. These data include the general experimental procedures, schematics of the experimental procedures, along with the comparative extract yields, solvent consumption, extraction times, and LC MS-ELSD analysis of coll. nos. 03505, 03501, 05417, 00102 using SSP or ASE processing methods. This material is available free of charge via the Internet at <http://pubs.acs.org>

The ASE apparatus is now widely used in marine environmental studies^{12–15} and terrestrial based natural products research¹⁰ as several comparative studies have validated its use as being both time and cost effective.^{16–19} However, there are no reports specifically describing the benefits or problems of employing ASE for the rapid discovery of bioactive marine natural products.

We can cite several successful examples from our recent research that have employed ASE as the first step in the isolation of novel sponge-derived natural products possessing varying functional groups.^{20–24} Examples of new structures obtained using ASE are shown in Figure 1 and consist of a variety of biosynthetic classes ranging from terpenoids, alkaloids, and peptides as well as compounds assembled from mixed biosynthetic origins. The specific examples shown include isojaspic acid (**1**),²⁰ aignopsanoic acid A (**2**),²¹ plakinidine E (**3**),²² psymbamide A (**4**)²³ and CTP-431 (**5**).²⁴ One early concern in employing the ASE apparatus during these and subsequent studies was that the high temperature (~100 °C) and pressure (~1700 p.s.i.) conditions utilized would alter or cause decomposition of the metabolites being isolated. Alternatively, the cycle time for extraction was minutes rather than the hours or days associated with standard extraction protocols. It seemed important to rigorously evaluate the ASE method from the view point of comparing extraction efficiency (EE) and total extraction yields (TEY) to that associated with the traditional protocols.⁹ We now report our experimental results of SSP versus ASE with an evaluation that considers overall extraction yields, solvent consumption, extraction time, and chemical stability.

Results and Discussion

Using collections housed in our repository we developed a test bed of diverse sponges and metabolites to guide this study and validate the advantages of using ASE versus SSP. Our evaluation consisted of five parts: (a) a comparison of extraction efficiencies (coded as EE = total organic extract/organic solvent use), (b) a comparison of total extract yields (coded as TEY = total organic extract/specimen weight • 100 %), (c) the determination of whether a second or third pass through the ASE system was necessary based on the percentages of the overall extraction yields, (d) a comparison of the EE and TEYs for equivalent samples extracted using the ASE apparatus at 100 °C and at room temperature (~ 22 °C), and (e) an analysis of LC MS-ELSD chromatograms to probe for chemical degradation. A total of five marine sponges (*Cacospongia mycofijiensis*, *Auleta* cf. *constricta*, *Zyzzya fuliginosa*, *Fascaplysinopsis reticulata*, and *Jaspis coriacea*) were selected for processing and evaluated. Eleven major metabolites have previously been reported from these aforementioned sponges and similar to compounds **1–4** discussed above possess a diverse array of bioactive structural motifs. These metabolites are outlined in Figure 2 and include fijianolide B (syn. laulimalide, **6**),²⁵ latrunculin A (**7**),²⁶ mycothiazole (**8**),²⁷ milnamide C (**9**),^{28, 29} jasplakinolide^{28, 30} (syn. jaspamide, **10**),³¹ makaluvamines C, H, D, J (**11–14**),^{32, 33} fascaplysin (**15**),^{34, 35} and bengamides A (**16**) and B (**17**).^{36, 37} These structures provided an excellent starting point to validate our previous observations that high temperature and pressure conditions of ASE do not lead to the chemical degradation of the compounds being isolated.

The results displayed in Tables 1 and 2 from parallel ASE and SSP processing of an individual specimen of *C. mycofijiensis* (coll. no. 02600, 23.1g wet wt.) collected from Vanuatu were encouraging. The SSP extract (11.5 g wt weight) showed that the expected three major metabolites **6–8**²⁵ were present as illustrated in the upper panel of Figure 3. The initial focus on *C. mycofijiensis* was motivated by the circumstance that **6**³⁸ and **8**³⁹ have been previously shown to be labile and rearrange or decompose under relatively mild conditions. Thus, the ability to observe these compounds in an extract processed by the ASE procedure represents a rigorous test. Processing of the SSP sample involved a modified Kupchan extraction scheme⁹ (see Chart S1 and Experimental in the Supporting Information) and the results of this

overall extraction are summarized in Tables 1 and 2. The EE = 71.0 mg/L, and TEY = 1.4 %, and 80 h were required to carry the SSP [including overnight methanol extractions (72 h), solvent partitioning (+/- 8 h, depending on the formation of emulsions), but not including rotatory evaporation of the final extracts]. The initial ASE workup (on 11.6 g wet wt.) began with an aqueous extraction (three successive exposures to afford samples coded XWW I = 1,064.2 mg, XWW II = 43.5 mg and XWW III = 34.4 mg) to selectively remove residual inorganic salts, often encountered in large concentrations from marine extracts.⁴⁰ The organic extraction was a bit involved employing three independent runs (coded ASE Run I, etc) of three successive solvents: (a) hexanes, (sample coded XFH I = 20.5 mg, XFH II = 4.4 mg, XFH III = 2.3 mg), (b) dichloromethane (sample coded XFD I = 43.3 mg, XFD II = 8.2 mg, XFD III = 2.1 mg), and (c) methanol (sample coded XFM I = 83.5 mg, XFM II = 14.2 mg, XFM III = 9.6 mg). The EE for the first run (ASE I = 246.0 mg/L) was three orders of magnitude higher than that observed for the SSP sample (71.0 mg/L). The TEY = 1.3 %, was roughly equivalent to the SSP sample (1.4 %) yet required only 2 h to generate versus 80 h for the traditional method. Finally EE = 105.0 mg/L was the total for the combined ASE runs, which translates to a TEY = 1.6 % (total time for processing = 6.0 h). In summary, the first extraction generated the highest percent yield of the total organic extract, which was 78%. Only small quantities of the total organic extract were obtained from the next two runs: 14% and 8%, respectively, which is consistent with results in the literature.¹⁸ Shown in the bottom panel of Figure 3 is the LC MS-ELSD of the ASE crude extract demonstrating parallel results observed for SSP. These results are also consistent with previous reports that have shown no evidence for thermal degradation of compounds during ASE extractions.^{11, 16, 41–44}

A second fresh specimen of *C. mycofijiensis* (coll. no. 07327-O, 22.3g wet wt.), from a collection previously reported to contain compounds **2** and **6–8**,²¹ was selected for further EE and TEY comparative processing. This involved using the ASE at room temperature (~ 22 °C) and at 100 °C and these results are summarized in Table 3. The EE = 86 mg/mL and TEY = 0.5 % for the sample extracted at 22 °C was nearly 1/3 less than for the sample extracted at 100 °C (EE = 213 mg/mL, TEY = 1.2%). Shown in Figure 4 are the comparative LC MS-ELSD traces of the crude extracts known to contain compounds **2** and **6–8**, demonstrating that parallel results were observed for ASE processing at 22 °C and 100 °C.

The four additional sponges selected for comparative processing also gave encouraging but not quite parallel results. These organisms, all preserved according to our standard laboratory procedures, afforded constituents as follows: *A. constricta* (coll. no. 03505), **9** and **10**, *Z. fuliginosa* (coll. no. 03501); **11 – 14**; *F. reticulata* (coll. no. 05417), **15**; and *J. coriacea* (coll. no. 00102), **16** and **17**. Two identical samples (100 g wet wt.) were divided equally and processed by SSP and ASE according to the methods outlined above. The results of these overall extractions are summarized in Table 4 (as entries 2–5), and Tables S1–S4 in the Supporting Information. In every case the EE was greater for ASE I vs. that for SSP total. The results pertaining to TEY % fell into two categories: ASE I yielding TEYs > SSP total for entries 2 and 3, and vice versa for entries 4 and 5. An inspection of the percent yield of the total organic extract of the ASE runs I–III (see Tables S1–S4 in the Supporting Information) indicated that the majority of the extract is generated in the first ASE extraction for entries 2–5 as reported above for coll no. 02600. Comparisons using LC MS-ELSD of the crude extracts previously reported to contain the known major components of all these sponges, **9 – 16** (Figures S1–S4 in the Supporting Information) were made with those of SSP and ASE and all exhibited comparable patterns of elution time, percent composition as well as the detection of *m/z* ions for the major metabolites, indicating there was no chemical degradation.

Additional specimens of the above four sponges were also selected for EE and TEY comparative processing using the ASE at room temperature (~ 22 °C) and 100 °C. These results are summarized in Table 5 (and Supporting Information Tables S5–S8). The average EE (357.3

mg/L) and TEY (0.5 %) for entries 2–5 of samples extracted at 22 °C was several orders of magnitude lower than for those extracted at 100 °C (EE = 836.1 mg/mL, TEY = 1.3 %). These data are consistent with reports that have shown that 100 °C is an optimal temperature for generating maximum yields during ASE.^{10, 45} The LC MS-ELSD analysis of the five crude extracts known to contain compounds 9–16 showed that all could be observed (see Supporting Information Figures S1–S4) using the ASE apparatus set at either 22 °C or 100 °C.

Our experience using ASE has shown us that it can function as a robust high-throughput approach that can be both highly efficient and rewarding.^{20, 22–24} A particular advantage we have found to employing this method resides in its ability to be incorporated prior to the production of 96-well plate peak libraries to streamline HTS bioassay evaluation.⁴⁶ More recently we have appreciated added benefits from using ASE to rapidly extract a large colony of individual sponges (15 single organism specimens) of *C. mycofijiensis* for LC MS-ELSD chemical profiling that culminated in the discovery of a novel class of sesquiterpenes.²¹ These results continue to provide us with further stimulation to incorporate this added high-throughput methodology into our marine natural products discovery pipeline.

In conclusion, a number of noteworthy outcomes have emerged from our pilot survey involving comparative extractions of five marine sponges using SSP and ASE and are summarized in Tables 4 and 5. First, the average total EE (287.0 mg/L) of SSP samples is much lower than just one extraction using the ASE apparatus (ASE I, 866.0 mg/L). The average TEY are roughly equivalent ~1.5 % for both methods, however, the ASE I processing time (2 h) is considerably less than for SSP (80 h). Second, a single pass through the ASE system appears sufficient, as the average EE and TEY of the second (ASE II, 214.0 mg/L, 0.3%) or third (ASE III, 109.0 mg/L, 0.2 %) runs, were much less than the first extraction ASE I. Also noteworthy is that the ASE and SSP extractions displayed varying organic extract yields depending on the sponge specimen processed thereby indicating neither method was optimal for obtaining maximum yields. Furthermore, the average EE (357.3 mg/mL) and TEYs (0.5 %) obtained using ASE at 22 °C is clearly lower than those generated at 100 °C (EE = 836.1 mg/mL, TEY = 1.3 %). However, the former approach can be applied to samples suspected of containing thermally labile compounds, while the yields obtained are sufficient to allow for LC MS profiling and the preparation of peak libraries.^{47, 48} A final important observation is that the chemical stability of 100 °C ASE extracts using LC MS-ELSD analysis appeared comparable to those generated using SSP or ASE at room temperature. Overall, these results demonstrate that employing ASE to process marine sponges can serve as an effective high-throughput methodology for the rapid discovery of novel and bioactive marine natural products.

Experimental Section

General Experimental Procedures

Analytical LC MS analysis was performed on all samples at a concentration of approximately 5 mg/mL, using a reversed-phase 150 × 4.60 mm 5 µm C₁₈ Phenomenex Luna column. Samples were injected onto the column using a volume of 15 µL, with a flow rate of 1 mL/min that was monitored using a Waters model 996 photodiode array (PDA) UV detector. The elution was subsequently split (1:1) between a S.E.D.E.R.E. model 55 evaporative light scattering detector (ELSD) and an Applied Biosystems Mariner electrospray ionization time of flight (ESI-TOF) mass spectrometer.

Biological Material, Collection and Identification

The sponges profiled for these experiments were obtained using SCUBA at depths between 15–30 m. Specimens of *Cacospongia mycofijiensis* (coll. no. 02600; 23 g wet wt. and 07327-O 20 g wet wt.) were collected in 2002 from Mele Bay, Vanuatu,²⁵ and Kimbe Bay, Papua

New Guinea. 21 Samples of *Auletta* cf. *constricta* (coll. no. 03505; 100.3 g wet wt.) and *Zyzya fuliginosa* (coll. no. 03501; 100.3 g wet wt.) were acquired in 2003 from Milne Bay, Papua New Guinea. Specimens of *Jaspis coriacea* (coll. no. 00102; 100.5 g wet wt.) were collected in 2000 from the Beqa lagoon, Fiji, while samples of *Fascaplysinopsis reticulata* (coll. no. 05417, 100.8 g wet wt.) were obtained in 2005 from the Rabaul Province in Papua New Guinea. Taxonomic identifications were based on comparison of the biological features to other voucher samples in our repository. The secondary metabolite chemistry is also consistent with these identifications.^{25, 28, 32, 34, 36} Voucher specimens and underwater photos are available.

Extraction and Isolation

Samples were preserved in the field by being immersed in a 50:50 MeOH:H₂O solution. After approximately 24 h this solution was decanted and discarded. The damp organisms were placed in collection bottles (Nalgene) and shipped back to UCSC at ambient temperature and then stored at 4 °C until further processed. Individual specimens of each sponge (100g wet wt.) were bifurcated into equal portions (approximately 50 g each unless otherwise specified) and processed by standard solvent partitioning (SSP) using a modified Kupchan extraction scheme (see Supporting Information Chart S1) or four times using accelerated solvent extraction (ASE) (see Supporting Information Chart S2). Samples undergoing SSP were first extracted using 100% methanol three successive times for 24 h. The solvent was evaporated at room temperature and the resulting oil was partitioned between water (sample coded “W”), and dichloromethane (sample coded “F” for fats). The W fraction was next partitioned between water (sample coded “WW”), which contained mostly inorganic salts and *sec*-butyl alcohol (sample coded “WB”). The concentrated F was then partitioned between hexanes three times (sample coded FH) to remove unwanted lipids and steroid components and 10% aqueous methanol. The methanol layer was adjusted to 50% aqueous methanol and an equal volume of dichloromethane was added. The dichloromethane fraction (coded “FD”) and the methanol fraction (coded “FM”) were evaluated separately.

Accelerated solvent extraction (ASE) samples were processed using a Dionex model 100 ASE.¹¹ The experimental settings of the ASE model 100 used in this study are outlined in the supporting information. Samples were extracted after being preserved, and stored according to the method described above. Based on the hydroscopic nature of the sponge, samples were processed immediately as damp specimens (02600, 07327, 03505, 00102) or dried in a fume hood for 12 h (03501, 05417) prior to extraction. During each ASE extraction, samples were exposed to 200 mL of solvent for around 30 min at 100 °C or 22 °C under a pressure of ~ 1700 p.s.i. (using nitrogen) based on successful experimental parameters reported by others.^{10, 45} The samples were initially extracted using distilled H₂O (sample coded XWW) to obtain the aqueous extract and to remove residual inorganic salts. The organic extraction involved three successive passes with solvents of (a) hexanes to remove unwanted lipids (samples coded as XFH, I–III), (b) dichloromethane (samples coded as XFD, I–III), and (c) methanol (samples coded as XFM, I–III). The XFD and XFM extracts were evaluated separately. Between each separate solvent extraction (water, hexanes, dichloromethane, and methanol) a rinse step was employed by removing the sample cell from the apparatus and replacing it with a “rinse cell” for approximately ~ 3 min to flush the system of residual solvents between runs. The sample cell was then reinserted into the apparatus, and subsequent extractions were performed as described above. Samples did not need to be removed from the cell to be dried or washed with a miscible solvent prior to going from extractions with water to hexanes, followed by dichloromethane, and methanol. Our experience with the ASE system processing marine sponges of sample size ≤ 50 grams would occasionally lead to added back-pressure, (e.g., preventing the solvent from filling the sample cell) requiring the operator to abort the method, delaying overall processing times, and complicating the extraction process. Furthermore, we saw no evidence that yields were increased if specimens were blended into a fine powder versus

specimens processed as diced size whole organisms. In actuality, samples prepared to an amorphous powder using the blender method posed additional complications related to system backpressure as noted above. At present, when a priority extract has been identified in our laboratory, we continue to employ our modified Kupchan extraction scheme on a macro scale level to maximize our overall yields as this method is independent of sample size.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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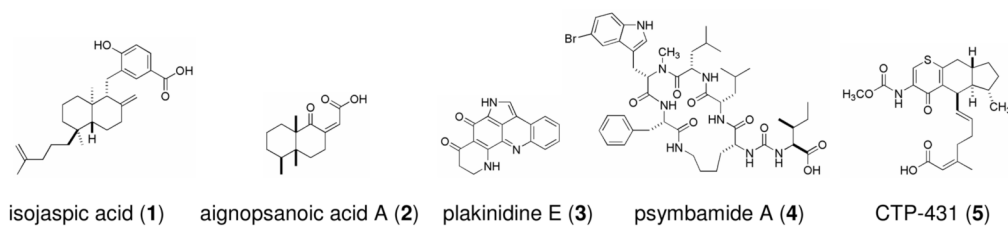
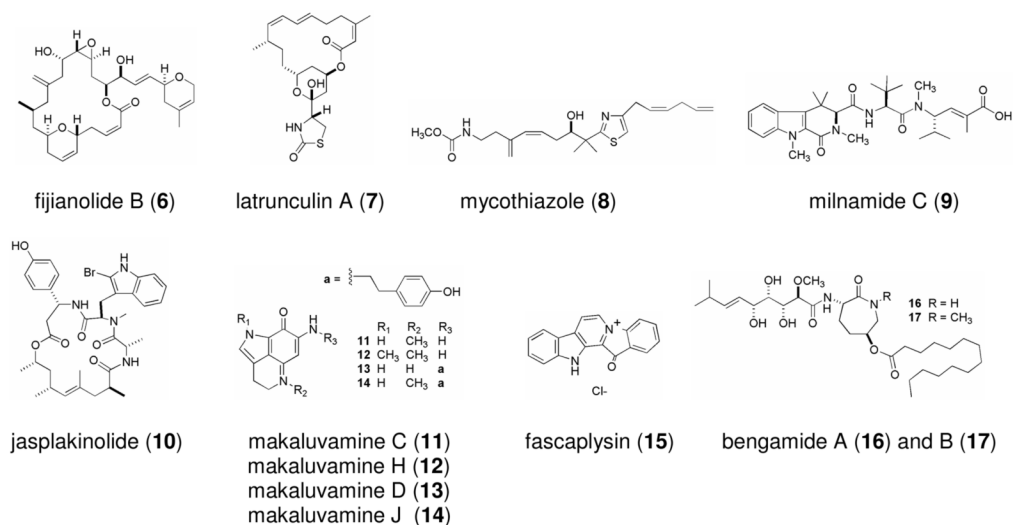
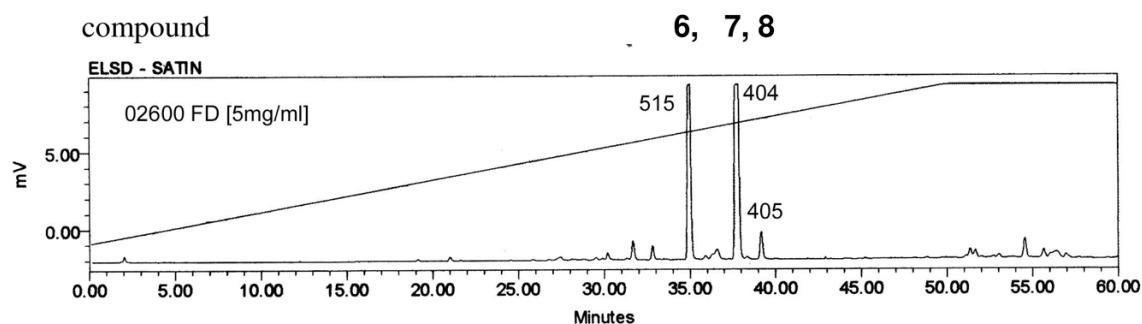


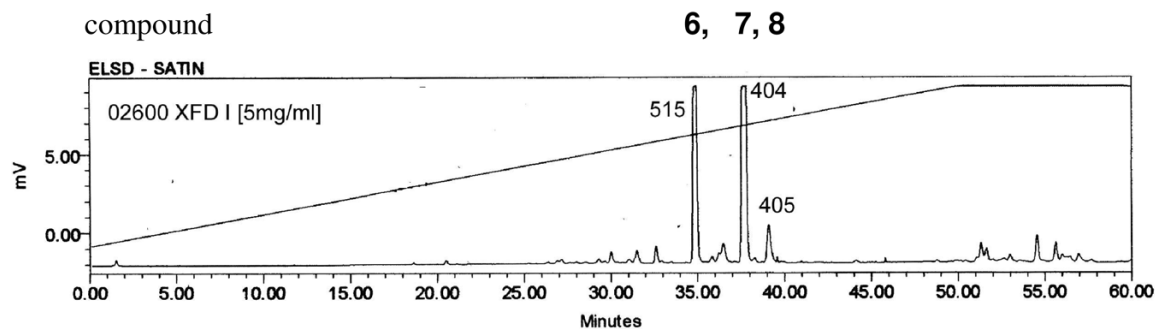
Figure 1.
Examples of different marine natural product scaffolds isolated using Accelerated Solvent Extraction (ASE).

**Figure 2.**

Summary of structurally distinct marine natural products from sponges selected for comparative processing using Standard Solvent Partitioning (SSP) and Accelerated Solvent Extraction (ASE).



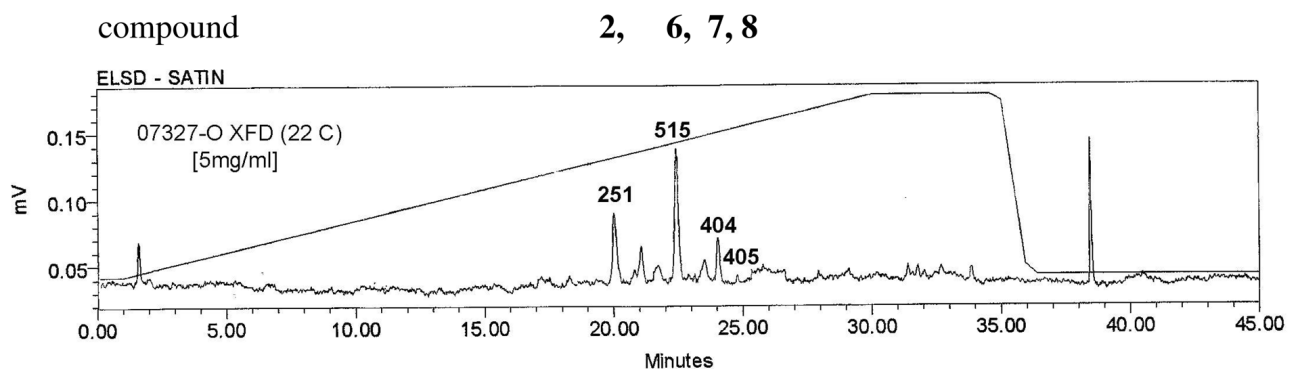
(a)



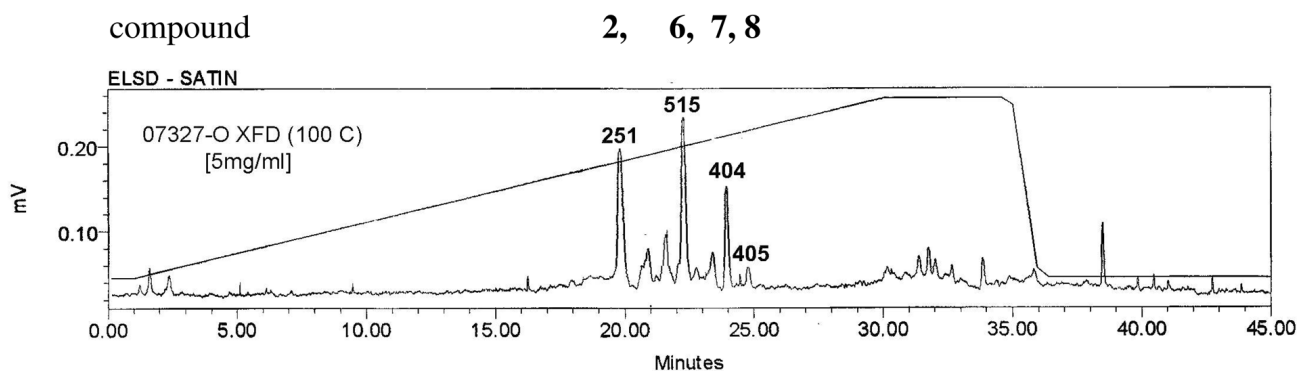
(b)

Figure 3.

Examples of an ELSD analysis of *C. mycofijiensis* (coll. no. 02600) extracts processed using (a) SSP (FD) vs (b) ASE (XFD I) with annotations of m/z ions. (Fijianolide B (**6**), $m/z = 515$; $[M+H]^+$; isotopic molecular weight (IMW) = 514 amu; latrunculin A (**7**), $m/z = 404$; $[M-H_2O+H]^+$; isotopic molecular weight (IMW) = 421 amu; mycothiazole (**8**), $m/z = 405$; $[M+H]^+$; isotopic molecular weight (IMW) = 404 amu).



(a)



(b)

Figure 4.

Examples of an ELSD analysis of *C. mycofijiensis* (coll. no. 07327-O) extracts processed using (a) ASE 22 °C (XFD) vs (b) ASE 100 °C (XFD) with annotations of m/z ions. (Aignopsanoic acid A (2), m/z = 251; $[M+H]^+$; isotopic molecular weight (IMW) = 250 amu; fijianolide B (6), m/z = 515; $[M+H]^+$; isotopic molecular weight (IMW) = 514 amu; latrunculin A (7), m/z = 404; $[M-H_2O+H]^+$; isotopic molecular weight (IMW) = 421 amu; mycothiazole (8), m/z = 405; $[M+H]^+$; isotopic molecular weight (IMW) = 404 amu).

Table 1Extraction Yields of *C. mycofijiensis* (coll. no. 02600) Using SSP

| standard solvent partitioning (SSP)* | | | |
|---|-------------------------------|-----------------------------|------------|
| fraction codes (volume) | MeOH extractions ^a | solvent partition/evaporate | total |
| TPE | ND | 1,371.4 mg | 1,371.4 mg |
| W (100 mL) | ND | 1,289.3 mg | 1,289.3 mg |
| F (100 mL) | ND | 80.1 mg | 80.1 mg |
| WW (100 mL) "salts" | ND | 1,213.4 mg | 1,213.4 mg |
| WB (100 mL) | ND | 75.1 mg | 75.1 mg |
| FH (300 mL) | ND | 21.1 mg | 21.1 mg |
| FD (180 mL) | ND | 20.7 mg | 20.7 mg |
| FM (100 mL) | ND | 38.2 mg | 38.2 mg |
| total organic extract | ND | 154.9 mg | 154.9 mg |
| organic solvent use | 1.5 L | 0.68 L | 2.18 L |
| process time | 72 h | 8 h | 80 h |
| extraction efficiency (EE) ^b | ND | ND | 71.0 mg/L |
| total extraction yield (TEY) ^c | ND | ND | 1.4 % |

* Sample processed using an 11.5 g weight specimen.

^a Three successive extractions using MeOH (500 mL each) were performed and decanted after 24 hrs.

^b Total organic extract (mg)/Solvent Use (L).

^c Total organic extract (mg)/specimen weight (mg) • 100%. Codes: ND = Not Determined; TPE = Total Polar Extract; W = Water soluble; F = Fat soluble; WW = Water soluble/Water; WB = Water soluble/Butanol; FH = Fat soluble/Hexanes; FD = Fat soluble/Dichloromethane; FM = Fat soluble/Methanol.

Table 2Extraction Yields of *C. mycofijsensis* (coll. no. 02600) Using ASE

| accelerated solvent extraction (ASE)[*] | | | | |
|---|------------------|-------------------|--------------------|--------------|
| fraction codes (volume) | ASE run I | ASE run II | ASE run III | total |
| XWW (200 mL) "salts" | 1,064.2 mg (93%) | 43.5 mg (4%) | 34.4 mg (3%) | 1,145.5 mg |
| XFH (200 mL) | 20.5 mg (75%) | 4.4 mg (16%) | 2.3 mg (8%) | 27.2 mg |
| XFD (200 mL) | 43.3 mg (80%) | 8.2 mg (15%) | 2.1 mg (4%) | 53.6 mg |
| XFM (200 mL) | 83.5 mg (78%) | 14.2 mg (13%) | 9.6 mg (9%) | 107.3 mg |
| total organic extract | 147.3 mg (78%) | 26.8 mg (14%) | 14.0 mg (8%) | 188.1 mg |
| organic solvent use | 0.6 L | 0.6 L | 0.6 L | 1.8 L |
| process time | 2.0 h | 2.0 h | 2.0 h | 6.0 h |
| extraction efficiency (EE) ^a | 245.5 mg/L | 44.7 mg/L | 23.3 mg/L | 104.5 mg/L |
| total extraction yield (TEY) ^b | 1.3 % | 0.2 % | 0.2 % | 1.6 % |

^{*} Sample processed using an 11.6 g weight specimen with percent yield in parenthesis.

^a Total organic extract (mg)/solvent use (L).

^b Total organic extract (mg)/specimen weight (mg) • 100%. Codes: X = ASE; XWW = Water soluble/Water; XFH = Fat soluble/Hexanes; XFD = Fat soluble/Dichloromethane; XFM = Fat soluble/Methanol. Note: Processing time using ASE/solvent: ~30 min not including rotatory evaporation.

Table 3Extraction Yields of *C. mycofijiensis* (coll. no. 07327 O) Using ASE at 22 °C and 100 °C

| accelerated solvent extraction (ASE)[*] | | |
|---|--------------|---------------|
| temperature fraction codes (volume) | 22 °C | 100 °C |
| XWW (200 mL) “salts” | 254.7 mg | 992.4 mg |
| XFH (200 mL) | 10.3 mg | 25.0 mg |
| XFD (200 mL) | 14.1 mg | 35.2 mg |
| XFM (200 mL) | 27.8 mg | 67.8 mg |
| total organic extract | 51.5 mg | 128.0 mg |
| organic solvent use | 0.6 L | 0.6 L |
| process time | 2.0 h | 2.0 h |
| extraction efficiency (EE) ^a | 85.8 mg/L | 213.0 mg/L |
| total extraction yield (TEY) ^b | 0.5 % | 1.2 % |

^{*} Sample processed using 10.5 g wet weight specimens.

^a Total organic extract (mg)/solvent use (L).

^b Total organic extract (mg)/specimen weight (mg) • 100%. Codes: X = ASE; XWW = Water soluble/Water; XFH = Fat soluble/Hexanes; XFD = Fat soluble/Dichloromethane; XFM = Fat soluble/Methanol. Note: Processing time using ASE/solvent: ~30 min not including rotatory evaporation.

Table 4
Summary of Extraction Efficiency (EE)^a and Total Extraction Yield (TEY)^b Using SSP and ASE (100 °C) of Five Marine Sponges

| entry | sample | Coll. no. | SSP total | | | ASE I | | | ASE II | | | ASE III | | | ASE total | | |
|-------|--------------------------|-----------|-----------------|------------------|--|-----------------|------------------|--|-----------------|------------------|--|-----------------|------------------|--|-----------------|------------------|--|
| | | | EE ^a | TEY ^b | | EE ^a | TEY ^b | | EE ^a | TEY ^b | | EE ^a | TEY ^b | | EE ^a | TEY ^b | |
| 1 | <i>C. mycoffijiensis</i> | 02600 | 71.0 mg/L | 1.4 % | | 246.0 mg/L | 1.3 % | | 45.0 mg/L | 0.2 % | | 23.0 mg/L | 0.2 % | | 105.0 mg/L | 1.6 % | |
| 2 | <i>A. constricta</i> | 03505 | 349.0 mg/L | 1.5 % | | 1,398.0 mg/L | 1.7 % | | 249.0 mg/L | 0.5 % | | 121.0 mg/L | 0.1 % | | 589.0 mg/L | 2.1 % | |
| 3 | <i>Z. fuliginosa</i> | 03501 | 375.0 mg/L | 1.6 % | | 1,607.0 mg/L | 1.9 % | | 303.0 mg/L | 0.4 % | | 158.0 mg/L | 0.2 % | | 688.0 mg/L | 2.5 % | |
| 4 | <i>F. reticulata</i> | 05417 | 423.0 mg/L | 1.8 % | | 596.0 mg/L | 0.7 % | | 210.0 mg/L | 0.3 % | | 127.0 mg/L | 0.3 % | | 311.0 mg/L | 0.6 % | |
| 5 | <i>J. coriacea</i> | 00102 | 216.0 mg/L | 0.9 % | | 481.0 mg/L | 0.6 % | | 264.0 mg/L | 0.3 % | | 117.0 mg/L | 0.2 % | | 287.0 mg/L | 1.0 % | |
| | average totals | | 287.0 mg/L | 1.4 % | | 866.0 mg/L | 1.5 % | | 214.0 mg/L | 0.3 % | | 109.0 mg/L | 0.2 % | | 396.0 mg/L | 1.6 % | |
| | process time | | 80 h | | | 2 h | | | 2 h | | | 2 h | | | 6 h | | |

^aExtraction efficiency (EE) = Total organic extract (mg)/solvent use (L).

^bTEY = Total organic extract (mg)/specimen weight (mg) • 100%

Table 5Summary of Extraction Efficiency (EE)^a and Total Extraction Yield (TEY)^b Using ASE at 22 °C and 100 °C of Five Marine Sponges

| entry | sample | coll. no. | temperature | | | |
|-------|-------------------------|-----------|-----------------|------------------|-----------------|------------------|
| | | | 22 °C | | 100 °C | |
| | | | EE ^a | TEY ^b | EE ^a | TEY ^b |
| 1 | <i>C. mycofijiensis</i> | 07327 | 85.8 mg/L | 0.5 % | 213.0 mg/L | 1.2 % |
| 2 | <i>A. constricta</i> | 03505 | 530.5 mg/L | 0.6 % | 1,287.8 mg/L | 1.5 % |
| 3 | <i>Z. fuliginosa</i> | 03501 | 449.0 mg/L | 0.5 % | 1,543.3 mg/L | 1.8 % |
| 4 | <i>F. reticulata</i> | 05417 | 372.5 mg/L | 0.4 % | 631.8 mg/L | 0.8 % |
| 5 | <i>J. coriacea</i> | 00102 | 348.8 mg/L | 0.7 % | 504.8 mg/L | 1.0 % |
| | average totals | | 357.3 mg/L | 0.5 % | 836.1 mg/L | 1.3 % |
| | process time | | 2 h | | 2 h | |

^aExtraction efficiency (EE) = Total organic extract (mg)/solvent use (L).^bTEY = Total organic extract (mg)/specimen weight (mg) • 100%