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Chromatographic and spectral studies of jetsam and archived ambergris

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Abstract

This is a pre-publication copy of the article published in Natural Product Research. It is recommended that readers consult a copy of the final published article.

24 We describe determination of the dichloromethane-soluble components of 12 samples of the
25 natural product, ambergris, using capillary gas chromatography-mass spectrometry (GC-MS).
26 Ambergris is produced *in vivo* in about 1% of Sperm whales and is used in perfumery and for
27 odour fixation. Whilst descriptions of ambergris chemistry appeared until about 40 years ago,
28 few accounts of analyses of whole extracts of multiple samples of ambergris by GC-MS have
29 been published before. As expected, our analyses revealed that the major component (up to
30 97% of the dichloromethane-soluble material) was ambrein, with co-occurring, variable
31 proportions of steroids. Moreover, we report apparently for the first time, mass spectra and
32 retention indices of derivatised ambrein. These data should now allow reliable, rapid
33 confirmation of even small amounts of jetsam, archived museum and customs samples of
34 ambergris and an assessment of ambergris 'quality'.

35 **Keywords:** Ambergris, Ambrein, Ambrox[®], GC, GC-MS, Sperm whale.

36 1. Introduction

37 The coprolith, ambergris, which has been known for centuries, is produced in the rectum of 1%
38 of Sperm and Pygmy Sperm whales (reviewed by Clarke 2006). On the death of the whale,
39 ambergris is liberated into the sea and may stay in the ocean for prolonged periods before
40 being washed ashore and beached, when it is termed 'jetsam ambergris'. Jetsam ambergris is
41 valued by the perfumery industry as a fixative and odorant, but the properties ('quality') vary and
42 this influences the prices attained for particular pieces. In the past, when commercial whaling
43 was practised, large lumps of ambergris were also recovered from whale carcasses (Clarke
44 1954, 2006; Anderson et al. 2012 and references therein), although the fresh material reputedly
45 has a disagreeable odour and rarely, or never, has the valued odour of the naturally weathered
46 jetsam material. However, samples of jetsam ambergris are still found and sold (subject to the
47 provisions of national laws in individual countries, which nonetheless sometimes still ban such
48 trade (Anderson et al. 2012). Such jetsam samples may require verification by analysis.
49 Museum samples of ambergris also require analysis at intervals; for example, to determine the
50 effects of storage (Moniz and Hammond 1996) and customs determinations are sometimes
51 required (Governo et al. 1977).

52 Even though a few studies of the volatile, odorous components of tinctures (ethanolic solutions)
53 of aged ambergris have been made, usually after distillation (Mookherjee and Patel 1977;
54 Awano et al. 2005) and it has long been known that the key component of fresh ambergris is
55 ambrein ((I); Lederer et al. 1946), very few analyses of whole, unfractionated, lipid-soluble
56 extracts of ambergris have ever been published, certainly by methods commonly in use today.

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57 Ambrein (**I**) is probably produced by intestinal microorganisms in the whales (Clarke 2006),
58 likely from the partial cyclisation of squalene (Oritani et al. 1970; Ueda et al 2013). Accounts of
59 the proportions of ambrein (**I**) in individual ambergris samples vary, from a few percent, to most
60 of the whole mass (Baynes-Cope 1962). Other organic constituents reported in early studies of
61 whale ambergris (as opposed to jetsam) included pristane and metabolites of mammalian
62 cholesterol metabolism, such as epicoprostanol (**III**); Lederer et al. 1946; Hardwick and Laws
63 1951; Baynes-Cope 1962). A variety of carboxylic acids, including a steroidal diacid, benzoic
64 and stearic (octadecanoic) acids have been reported in saponified ambergris (Lederer et al.
65 1946; Hardwick and Laws 1951; Taha 1989). Inorganic constituents (in addition to fragments of
66 squid beaks) identified after ashing, include up to 3% phosphate (Baynes-Cope 1962).

67 In summary, it is difficult from the existing, mostly rather old literature (Hardwick and Laws
68 1951), due to the lack of appropriate chromatographic and spectral data for whole extracts and
69 the shortage of authentic ambergris samples with known provenance, to determine confidently,
70 whether a jetsam sample is actually ambergris and if so, to assign the 'quality' or purity
71 (Hardwick and Laws 1951). Isolation of ambrein (Hardwick and Laws 1951; Baynes-Cope
72 1962) and then assignment by nuclear magnetic resonance (NMR) spectroscopy (Moniz and
73 Hammond 1996) is certainly possible, though qualitative, but details of the whole composition of
74 extracts are then lost. Also, the amounts of material required for NMR spectroscopy can be
75 quite large by comparison with combined chromatography-mass spectrometry methods, which
76 is a particular disadvantage for analysis of valuable museum samples (Moniz and Hammond
77 1996; Lambert et al. 2000). In the present study we therefore examined two museum-archived
78 samples of ambergris of known provenance, ancient perfumery samples and jetsam samples,
79 by capillary gas chromatography-mass spectrometry (GC-MS) after derivatisation. In this way,
80 we sought to provide information on the proportions and variations ('quality') of the major
81 organic soluble constituents, such as ambrein (**I**) and epicoprostanol (**III**). Importantly, we also
82 sought to record retention index and spectral data of derivatised ambrein, in order to provide a
83 method for subsequent identifications.

84 **2. Results and discussion**

85 Extraction and dissolution into dichloromethane, revealed that 25% to 47% of the whole masses
86 of samples 1-3 collected from a Sperm whale in 1947 were dichloromethane-soluble (Table S1).
87 The insoluble material was not examined further. Clearly there is considerable compositional
88 variation, even within a single boulder of ambergris of known history. This is consistent with a
89 previous study (Baynes-Cope 1962). For instance, the present data can be compared with
90 those for ether-soluble portions, of what was probably the same boulder, which varied from 11-

91 96% (Laws, reported by Baynes-Cope 1962). Similarly, ether-soluble portions of an ambergris
92 boulder collected in 1953 (Clarke 1954) varied from 80-98% (Baynes-Cope 1962); wide
93 variations have also been reported for *ad hoc* pieces of unknown origin in the earlier literature.
94 Many of the older analyses of the lipid-soluble fractions of ambergris relied on chromatographic
95 isolation of ambrein and determination by melting point and gravimetry or rarely, infrared
96 spectroscopy (Hardwick and Laws 1951; Baynes-Cope 1962). FTIR spectra of whole extracts of
97 samples 1-3 obtained herein, were all broadly similar to each other (Figure S3) and exhibited
98 the following features: a broad transmittance at 3372 cm^{-1} was attributed to H-bonded hydroxyl
99 O-H stretching. A weak transmittance at $\sim 3067\text{ cm}^{-1}$ was indicative of unsaturation and
100 attributed to C-H stretch in an alkene. Transmittances at 2925 and 2863 cm^{-1} were attributed to
101 C-H stretching in methyl and methylene groups and those at 1461 and 1382 cm^{-1} to the
102 corresponding bending vibrations. Weak transmittances at 1711 - 1706 cm^{-1} were indicative of
103 ketonic carbonyl groups (C=O stretch). Transmittances at 1644 cm^{-1} were attributed to C=C
104 stretch and at 935 and 887 cm^{-1} to C-H out of plane bends in alkenes. The spectra were similar
105 in several aspects to that published by Governo et al. (1977) for a sample of ambrein (I) isolated
106 from ambergris: the presence of the transmittance attributed to the keto group in the latter was
107 not explained by those authors, but the other features are consistent with the known structure of
108 ambrein and with the spectrum of synthetic ambrein (I). Similar spectra were also recorded
109 herein for the archived perfumery samples 4-6 (Figure S3d-f) and suspected jetsam ambergris
110 samples 7-11 (Figure S4a-e) and a further ambergris sample from a beached Sperm whale
111 (sample 12).

112 Although previous attempts to form derivatives of ambrein proved problematic, in the late 1970s
113 it was reported (Governo et al. 1977) that after chromatographic isolation from ambergris,
114 ambrein could be converted to the trimethylsilyl (TMS) ether in the presence of 'Trisil Z'
115 (trimethylsilylimidazole in pyridine, 1 h). However, those authors did not publish either the mass
116 spectrum or the GC retention index of the derivatised products, thereby limiting the usefulness
117 of the GC-MS method for general use, even for isolated ambrein. That study also preceded
118 regular use of capillary GC (instead, less efficient Support Coated Open Tubular GC columns,
119 were used).

120 High temperature GC herein showed no high molecular weight components were present in the
121 dichloromethane-soluble fractions so we treated extracts of ambergris samples 1-3 with a Trisil
122 equivalent *N,O*-bis(trimethylsilyl)acetamide + trimethylchlorosilane + *N*-trimethylsilylimidazole
123 (3:2:3; 1 h) and examined the products by conventional capillary GC-MS (Figure 1). Each
124 sample contained at most five components (A1-D); the extracts were relatively simple (Figure

125 1). As expected, the most distinctive component was ambrein (Figure 1, I; peak D), which had
126 been converted efficiently to the TMS ether, as revealed, apparently for the first time herein, by
127 the mass spectrum of the ether (Figure 1). The spectrum was very similar in many respects, to
128 that of underivatized ambrein (Governo et al. 1977; Ueda et al. 2013) but notably and
129 importantly, unlike that of ambrein, contained low abundance but diagnostic ions, including a
130 molecular ion at m/z 500 (M^+) and an ion at m/z 485 (M^+ -methyl). A significant ion also
131 appeared at m/z 143, attributed to a mono-unsaturated, C_4H_6 -OTMS moiety. The retention
132 index on HP-5MS stationary phase was 3110; again this has not been reported previously to
133 our knowledge and should aid future assignments.

134 Component C (Figure 1) had a mass spectrum and retention index comparable to those of
135 epicoprostanol (III) TMS ether (available in a NIST mass spectral library) rather than
136 coprostanol, which is somewhat unusual, but consistent with many earlier reports (Lederer et al.
137 1946; Baynes-Cope 1962). A further underivatized minor component in these three samples,
138 was assigned to coprostanone (Figure 1, peak B, IV). The presence of the latter probably
139 explained the observation of a transmittance assigned to a keto group in the infra red spectra
140 (Figure S3). Probably, the presence of these steroids is due to the faecal nature of the origins of
141 ambergris, since such compounds are well known metabolites of cholesterol metabolism and
142 bacterial conversion of cholesterol metabolites. Interestingly, the proportions of steroids in
143 samples 1-3 varied considerably (Figure 1). Whereas the steroids dominated sample 1 (Figure
144 1; Table S2), the extract of the inner core (sample 3) comprised almost pure ambrein (Figure 1;
145 Table S2). Since this sample also had the highest proportion of dichloromethane-soluble
146 material of samples 1-3, this ambergris sample comprised almost 50% ambrein by mass.
147 Previous reports involving isolation and weighing of chromatographic fractions (Baynes-Cope
148 1962) showed ambrein contents of 14-40% in one boulder (collected 1953;
149 ambrein/epicoprostanol ratios of 0.8 to 4) and 1-28% in another (ambrein/epicoprostanol ratios
150 of 0.7 to 2.5). Two minor unknown isomers (Figure 1; peaks A1, A2) were also detected in each
151 of samples 1-3 (Figures S6 and S7).

152 An extract of a small fragment (Sample 12) of ambergris obtained from a dead male Sperm
153 whale beached near Texel, Netherlands, was examined in the same manner to the above
154 analyses. The material was almost entirely soluble in dichloromethane (Table S1). GC-MS
155 revealed essentially the same components A1-D, but the chromatogram was dominated by
156 ambrein TMS ether (Figure 1), similar to sample 3. It is not known whether the fragment
157 originated from the core of the boulder.

158 Dissolution of three archived perfumery samples of ambergris (samples 4-6) in
159 dichloromethane, dissolved most of each sample (90-100%; Table S1). A similar treatment of
160 the dichloromethane extracts with derivatising reagent, followed by GC-MS, produced
161 chromatograms, which were similar to those of samples 1 and 2. GC-MS of the soluble portions
162 indicated that ambrein-TMS ether was present as the single largest component (Figure 1, peak
163 D). The steroids (Figure 1, peaks B, C, III, IV) were present (ambrein/epicoprostanol ratios >1 to
164 3). From the similarity of samples 4-6 with samples 1 and 2, the literature data and differences
165 to jetsam samples 7-11, we conclude that these ancient samples probably derived from whale
166 (rather than jetsam) ambergris.

167 We treated all five extracts of New Zealand jetsam samples 7-11 with derivatising reagent and
168 examined the products by GC-MS (Figure 1). These each contained ambrein-TMS as the
169 major constituent (ambrein/epicoprostanol about 6 to >30). The content of the steroids was very
170 low (Figure 1) similar to whale samples 3 and 12 (Table S2). Such data may well be typical for
171 jetsam ambergris; to our knowledge, no other similar data have been published.

172 **3. Conclusion**

173 As a result of the present analyses of 12 ambergris samples, we suggest that a reasonable
174 protocol for verification of jetsam ambergris is the deployment of GC-MS, ideally with cold on-
175 column injection, of organic extracts treated with a multiple silylation reagent (Governo et al
176 1977). Verification of the presence of ambrein-TMS ether as a major constituent, from the
177 retention index and mass spectral data published herein would allow confirmation of an
178 unknown jetsam sample as ambergris. The presence of epicoprostanol and cholestanone,
179 identifiable by mass spectral comparison with widely available library and literature data for the
180 TMS ethers, in addition to ambrein, might provide an estimate of the 'quality'; in the five jetsam
181 samples analysed herein these were only minor components.

182 **Acknowledgements** We are grateful to Richard Sabin and colleagues of the Natural History
183 Museum, London and Arthur Oosterbaan, curator of Ecomare Musuem, Texel, for access to
184 whale ambergris samples and to Dr. Tony Curtis (University of Plymouth) and Drs. Beverly
185 Bayne, Katie Aldridge and colleagues at CPL Aromas Ltd for supply of archived perfumery
186 samples of ambergris and the latter for authentic samples of ambrinol and Ambrox®. We thank
187 Professor Sato, Niigata University, Japan, for an authentic sample of ambrein and an
188 anonymous supplier for the samples of New Zealand jetsam ambergris.

189 **References**

This is a pre-publication copy of the article published in *Natural Product Research*. It is recommended that readers consult a copy of the final published article.

- 190 Awano K. Ishizaki S. Takazani O. Kitahara T. 2005. Analysis of ambergris tincture. *Flav Frag J.*
191 20:18-21.
- 192 Anderson RC. Sattar SA. Adam MS. 2012. Cetaceans in the Maldives: a review. *J Cetac Res*
193 *Manage.* 12:219-225.
- 194 Baynes-Cope AD. 1962. Analyses of samples of ambergris. *Nature.* 193:978-979.
- 195 Clarke R. 1954. A great haul of ambergris. *Nature.* 174:155-156.
- 196 Clarke R. 2006. The origin of ambergris. *LAJAM.* 5:7-21.
- 197 Governo TF. Alessandro RT. Pragger MJ. 1977. Gas-liquid chromatographic-mass
198 spectrometric detection and identification of ambergris. *J AOAC Int.*60:160-164.
- 199 Hardwick PJ. Laws EQ. 1951. The identification of ambergris. *Analyst.* 76:662-664.
- 200 Lambert JB. Shawl CE. Stearns JA. 2000. Nuclear magnetic resonance in archaeology. *Chem*
201 *Soc Rev.* 29:175-182.
- 202 Lederer E. Marx F. Mercier D. Perot G. 1946. Sur les constituants de l'ambre gris II. Ambreine
203 et coprostanone. *Helv Chim Acta.* 29:1354-1365.
- 204
- 205 Mookherjee B. Patel R. 1977. Isolation and identification of volatile constituents of tincture
206 ambergris. 7th International Congress of Essential Oils. 136:479-482.
- 207
- 208 Moniz GA. Hammond GB. 1996. Identification of ambergris from the New Bedford whaling
209 museum by nuclear magnetic resonance spectroscopy. *J AOAC Int.* 79:423-425.
- 210
- 211 NIST/MS <http://webbook.nist.gov/chemistry/> Accessed December 2016.
- 212
- 213 Oritani T. Yamashita K. Matsui M. 1970. Chemical studies of ambergris. Part IV. Configuration
214 of ambrein. *Agri Biol Chem.* 34:1244-1248.
- 215
- 216 Taha SA. 1989. Chemical investigation of the internal secretion of the sperm blue whale. *PJPS.*
217 2:105-110.
- 218 Taha SA. 1992. Studies on the mode of action of ambrein as a new antinociceptive compound.
219 *Jpn J Pharmacol.* 60:67-71.

This is a pre-publication copy of the article published in *Natural Product Research*. It is recommended that readers consult a copy of the final published article.

220 Ueda D. Hoshino T. Sato T. 2013. Cyclisation of squalene from both termini: identification of an
221 onoceroid synthase and enzymatic synthesis of ambrein. *J Am Chem Soc.* 135:18335-18338.

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244 **SUPPLEMENTARY MATERIAL**

245

246 **Chromatographic and spectral studies of jetsam and archived ambergris**

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248 Steven J. Rowland* and Paul A. Sutton

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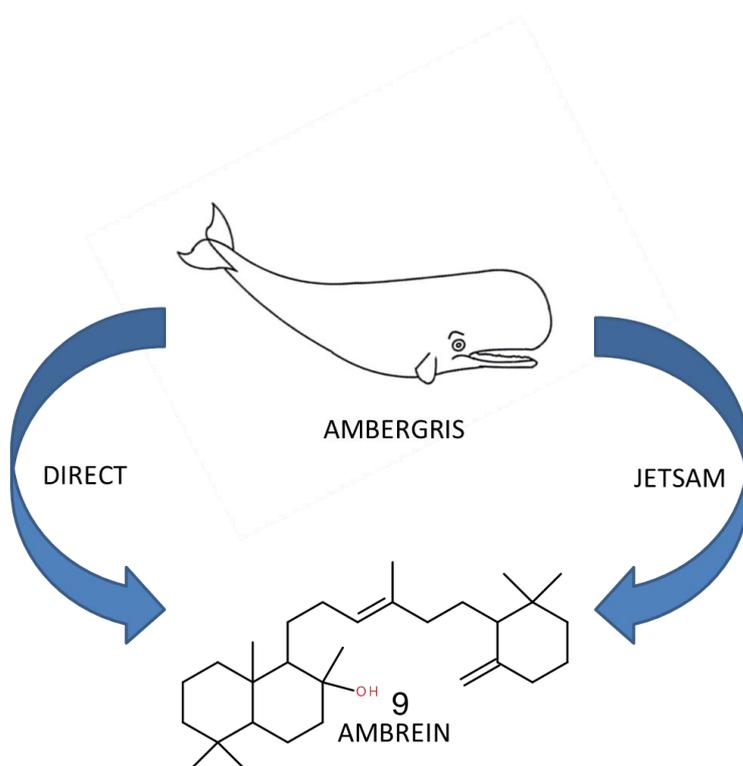
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266 Abstract

267 We describe determination of the dichloromethane-soluble components of 12 samples of the
268 natural product, ambergris, using capillary gas chromatography-mass spectrometry (GC-MS).
269 Ambergris is produced *in vivo* in about 1% of Sperm whales and is used in perfumery and for
270 odour fixation. Whilst descriptions of ambergris chemistry appeared until about 40 years ago,
271 few accounts of analyses of whole extracts of multiple samples of ambergris by GC-MS have
272 been published before. As expected, our analyses revealed that the major component (up to
273 97% of the dichloromethane-soluble material) was ambrein, with co-occurring, variable
274 proportions of steroids. Moreover, we report apparently for the first time, mass spectra and
275 retention indices of derivatised ambrein. These data should now allow reliable, rapid
276 confirmation of even small amounts of jetsam, archived museum and customs samples of
277 ambergris and an assessment of ambergris 'quality'.

278 **Keywords:** Ambergris, Ambrein, Ambrox[®], GC, GC-MS, Sperm whale.

279

280 **Experimental**

281 **Materials**

282 Sample descriptions are shown in Table 1. A boulder of ambergris weighing 155 kg taken from
283 a 16 m male Sperm whale on board Floating Factory ship *Southern Harvester* in 55°59'S,
284 03°02'E on 21 November 1947 by Clarke [Clarke, 2006 shows a photograph taken at the time],
285 portions of which are archived by the Natural History Museum, London, were sub-sampled by
286 one of the present authors (SJR) on 14 June 2016. Small pieces were taken from an odorous
287 black fragment with a smell similar to that of synthetic Ambrox[®] (II), covered in white crystals
288 (Figure S1a; Sample 1); two further sub-samples were taken from the black outer laminae and
289 the golden brown inner core of a further odorous piece (Figure S1b; Samples 2 and 3).
290 Evidence of black shiny fragments, of what were assumed to be squid beaks, was visible in the
291 outer part of the latter piece (Figure S1b). Samples were taken from the outer (Sample 2) and
292 inner (Sample 3) parts of this piece (Figure S1b). These pieces are thus similar to those
293 designated A-C by Laws, for which (non-GCMS) data (obtained by the method of Hardwick and
294 Laws 1951) were reported by Baynes-Cope (1962).

295 Three, non-odorous, ancient archived samples of suspected ambergris were donated by
296 sources from the perfumery industry (samples 4-6). Five samples of brown to white, slightly
297 odorous suspected jetsam ambergris were provided from beaches from undisclosed locations in
298 New Zealand (samples 7-11). An extract of a small fragment (sample 12) of over 83 kg of
299 ambergris obtained from a dead male Sperm whale beached on 15 December 2012 at Razende
300 Bol near Texel, Netherlands and archived by the Ecomare Museum, Texel was also provided by
301 the museum. An authentic sample of ambrein was obtained from Ueda et al., (2013) and
302 samples of ambrinol and ambroxan were supplied by a perfumery company. *N,O*-
303 bis(trimethylsilyl)acetamide + trimethylchlorosilane BSTFA/TMCS (99:1) and *N,O*-
304 bis(trimethylsilyl)acetamide+ trimethylchlorosilane + N-trimethylsilylimidazole; BSA +
305 TMCS+TMSI (3:2:3) reagents were supplied by Sigma-Aldrich (Poole, UK).

306 **Methods**

307 Samples were taken from specimens of ambergris using an acetone rinsed scalpel blade and
308 spatula and digested by sonication (2 x 5 min) in dichloromethane at a nominal concentration of
309 10 mg mL⁻¹ prior to analysis using Fourier transform infrared spectroscopy (FTIR). Aliquots of

310 the digest were taken and diluted for direct analysis of the underivatised sample, or dried under
311 a gentle stream of nitrogen (40 °C) and derivatised to their trimethylsilylated derivatives with
312 BSTFA/1% TMCS (TMS; 50 µL; 70 °C; 1 h) or with BSA/TMCS/TMSI (3:2:3; 'TRISIL'; 100 µL;
313 70°C; 1 h) and reconstitution in solvent, prior to analysis.

314 FTIR spectroscopy was undertaken using a Bruker Alpha Platinum ATR (Bruker (UK) Ltd.,
315 Coventry, UK) instrument in transmittance mode (32 background and sample scans; resolution
316 4 cm⁻¹) and data were collected from 4000 to 375 cm⁻¹.

317 GC-MS was carried out using an Agilent GC-MSD (Agilent Technologies, Wilmington, DE,
318 USA). This comprised a 7890A gas chromatograph fitted with a 7683B Series autosampler and
319 a 5975A quadrupole mass selective detector operated at 70eV ionisation voltage. The column
320 was a HP-5MS fused silica capillary column (30 m x 0.25 mm i.d. x 0.25 µm film thickness).
321 The carrier gas was helium at a constant flow of 1.0 mL min⁻¹. A 1.0 µL sample was injected
322 into a 250 °C splitless injector. The oven temperature was programmed from 40 to 300° C at
323 10 °C min⁻¹ and held for 10 min.

324 HTGC-FID was carried out using an Agilent 6890 gas chromatograph fitted with cool-on-column
325 inlet (0.5 µL manual injection; +3 °C track oven mode), high temperature FID jet (435 °C) and
326 Agilent VF-5ht Ultimetall column (15 m x 0.25 mm i.d. x 0.1 µm; constant flow mode, helium
327 carrier gas at 1 mL min⁻¹). The oven was programmed from 40 - 430 °C at 10 °C min⁻¹ with 10
328 min hold. Samples were heated in a heater block (70 °C, 1 h) prior to hot injection.

329 High temperature (HT) GC-MS was carried out using a BenchTOF-dx™ reflectron time-of-flight
330 mass spectrometer (Almsco International, Llantrisant, UK) interfaced with an Agilent 6890 gas
331 chromatograph (set up in the same manner as HTGC-FID with an Agilent VF-5ht Ultimetall
332 column (15 m x 0.25 mm i.d. x 0.1 µm; constant flow mode, helium carrier gas at 2.5 mL min⁻¹),
333 via an in-line Siltite™ mini-union and HT-deactivated silica tubing (2 m x 0.18 mm id ;
334 Phenomenex, Macclesfield, UK). General operating conditions were: helium carrier gas; oven
335 programmed from 40 - 430 °C at 20 °C min⁻¹, 5 min hold; transfer line and ion source at 350 °C;
336 mass spectrometer in EI mode (70 eV or 10 eV) recording mass range *m/z* 50 -1350. The
337 chromatograph was controlled through Agilent MSD Chemstation (VE.02.01) and the
338 spectrometer through ProtoTOF™(V 1.1.1) software. Data processing software included dx-
339 Connect™ and TargetView™ with library matching via NIST/MS Search. Prior to operation,
340 air/water background, signal optimisation and mass calibration (PFTBA) were performed using
341 auto-routines (ProtoTOF software).

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Sample number	Origin	Date of collection (receipt)	% dichloromethane-soluble
1	Piece of ambergris from a boulder weighing 155 kg ex 16 m male Sperm whale Floating Factory ship Southern Harvester 55°59'S, 03°02'E 21 November by Clarke (2006). Black outer (Figure S1a).	1947	25
2	Piece of ambergris from a boulder weighing 155 kg ex 16m male Sperm whale Floating Factory ship Southern Harvester 55°59'S, 03°02'E 21 November by Clarke (2006). Black outer of inner core (Figure S1b).	1947	37
3	Piece of ambergris from a boulder weighing 155 kg ex 16m male Sperm whale Floating Factory ship Southern Harvester 55°59'S, 03°02'E 21 November by Clarke (2006). Golden brown inner core (Figure S1b).	1947	47

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4	Archived perfumery sample (T Curtis).	(2016)	100
5	Archived perfumery sample (T Curtis).	(2016)	93
6	Archived perfumery sample (CPL).	(2016)	90
7	Jetsam sample New Zealand (White).	(2016)	93
8	Jetsam sample New Zealand (Sweet/woody).	(2016)	99
9	Jetsam sample New Zealand (Dark).	(2016)	103
10	Jetsam sample New Zealand (White-gold).	(2016)	99
11	Jetsam sample New Zealand (Silver)	(2016)	101
12	Small fragment of 83 kg of ambergris obtained from dead male Sperm whale beached on 15 December at Razende Bol near Texel, Netherlands, archived by Ecomare Museum, Texel.	2012 (2016)	93

345 **Table S1** Sample descriptions and % dichloromethane-soluble material.

346

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Sample	A1	A2	B	C	D
1	6	2	18	47	26
2	3	1	6	22	68
3	1	<1	3	8	87
4	3	2	6	25	64
5	3	2	5	46	45
6	2	1	5	37	55
7	<1	<1	<1	5	95
8	1	1	<1	3	95
9	1	1	4	8	85
10	2	1	1	12	85
11	<1	<1	<1	2	97
12	1	1	2	3	93

348

349 **Table S2** Relative percentage compositions of components A1-D in dichloromethane soluble
350 portions of ambergris samples 1-12. The proportions of dichloromethane extractable material in
351 samples 1-12 are given in Table S1. A1,2=unknowns; B=coprostanone; C=epicoprostanol;
352 D=ambrein.

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355 **Figure S1a.** Piece (sample 1) of ambergris from a boulder of ambergris weighing 155 kg taken
356 from a 16 m male Sperm whale on board *Southern Harvester* in 55°59'S, 03°02'E on 21
357 November 1947 (Clarke 2006).

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372 **Figure S1b.** Piece (samples 2 & 3) of ambergris from a boulder of ambergris weighing 155 kg
373 taken from a 16 m male Sperm whale on board *Southern Harvester* in 55°59'S, 03°02'E on 21
374 November 1947 (Clarke 2006).

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382 **Figure S2** Five samples of white to silver jetsam ambergris collected from beaches from
383 undisclosed beach locations in New Zealand (samples 7-11).

Sample 7 White		Hard, brown material with white surface coating
Sample 8 Sweet/woody		Hard, brown material
Sample 9 Dark		Hard, dark brown material with white surface mottle
Sample 10 White-gold		Hard, white exterior with gold/brown core

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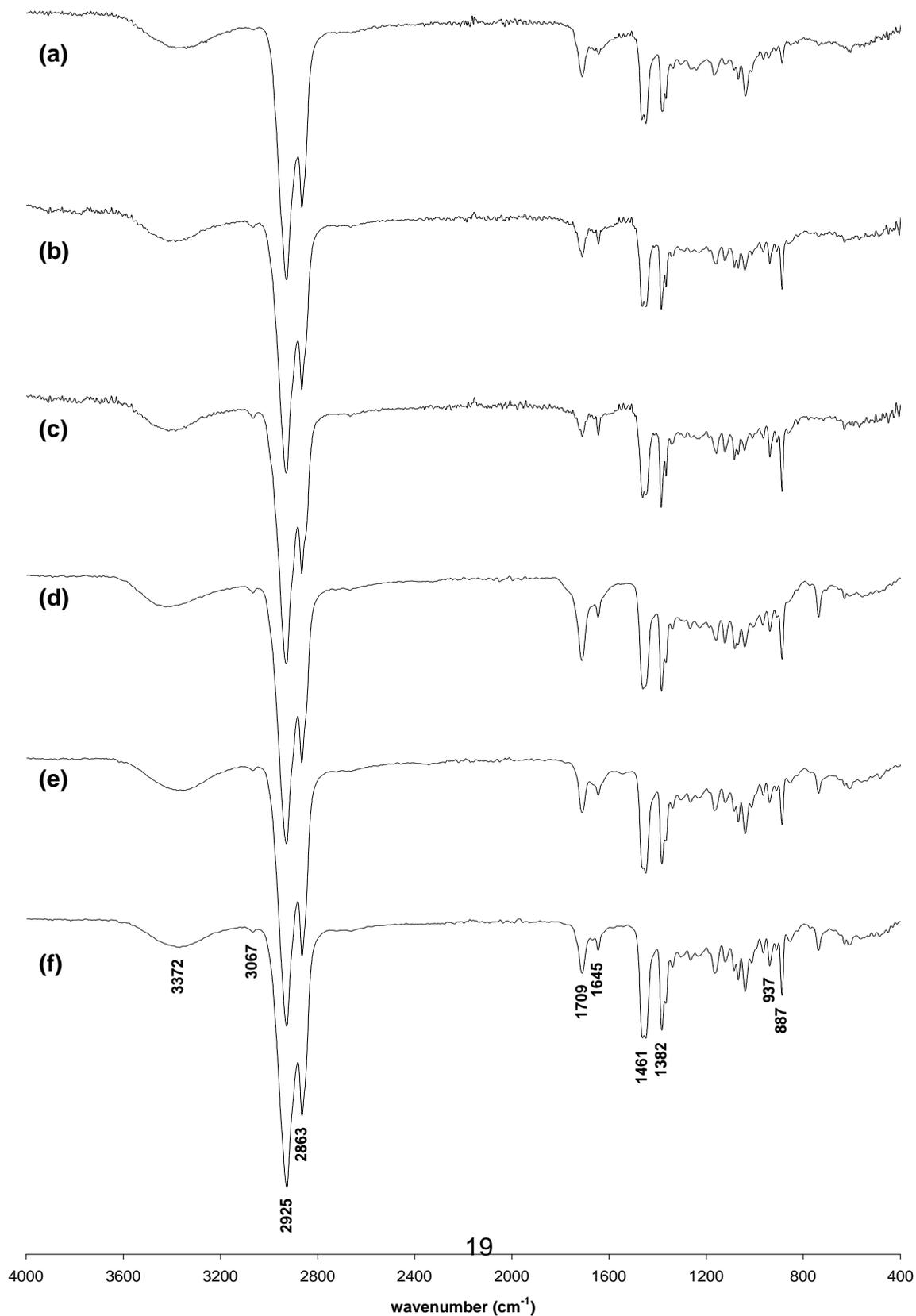
<p>Sample 11 Silver</p>		<p>Hard, white</p>
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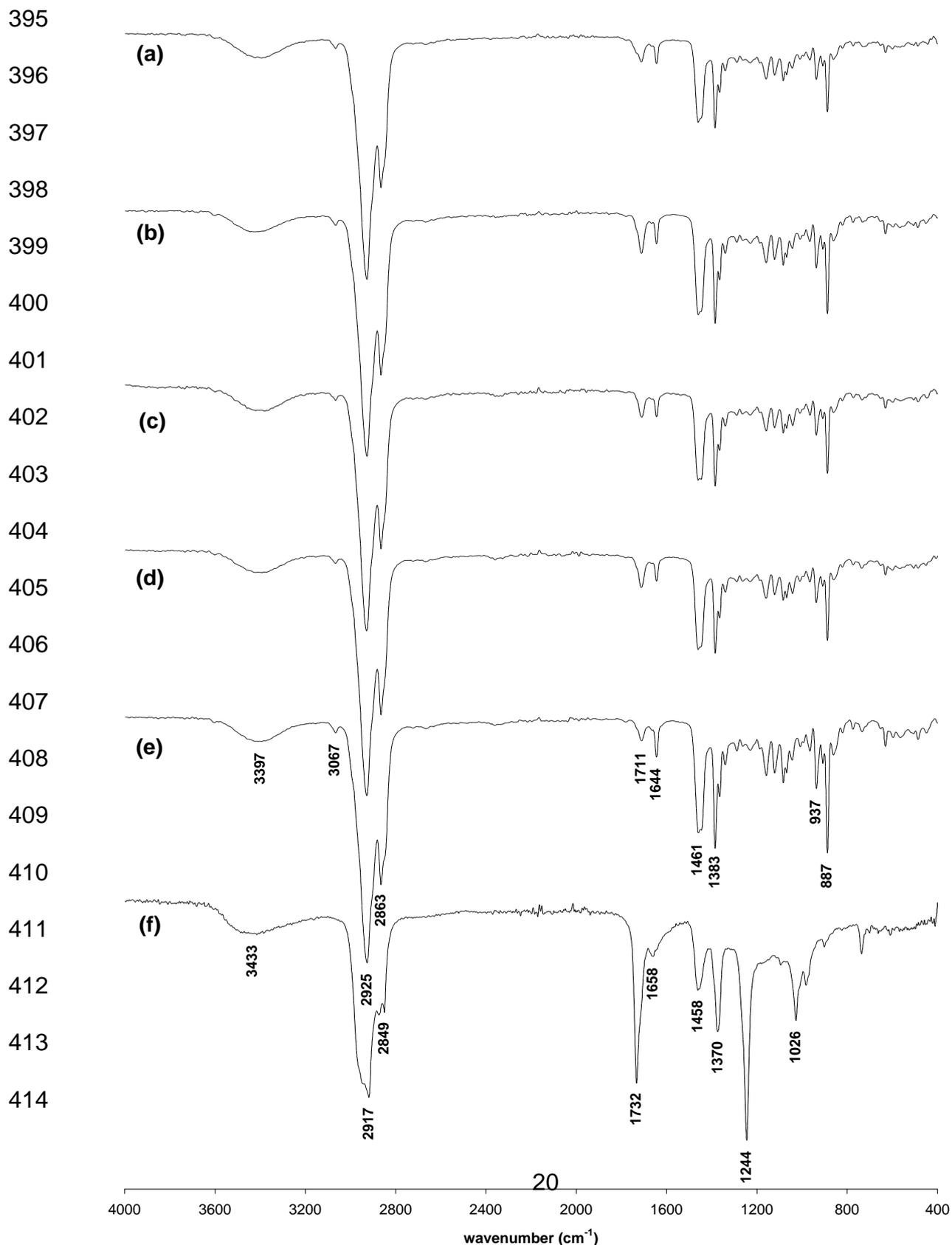
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386 **Figure S3.** FTIR spectra of (a-c) extracts of samples 1-3 from a boulder of ambergris weighing
387 155 kg taken from a 16 m male Sperm whale on board Floating Factory *Southern Harvester* in
388 55°59'S, 03°02'E on 21 November 1947 by Clarke (2006); (d-f) archived perfumery samples
389 (Samples 4-6) of suspect ambergris.

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391 **Figure S4.** FTIR spectra of (a-e) extracts of jetsam ambergris collected from beaches in New
392 Zealand (samples 7-11); (f) sample of suspect jetsam ambergris bequeathed in Natural History
393 Museum London in 1928 collected from Tanna Island, South Pacific (probably collected 1875).
394 The latter is not ambergris.



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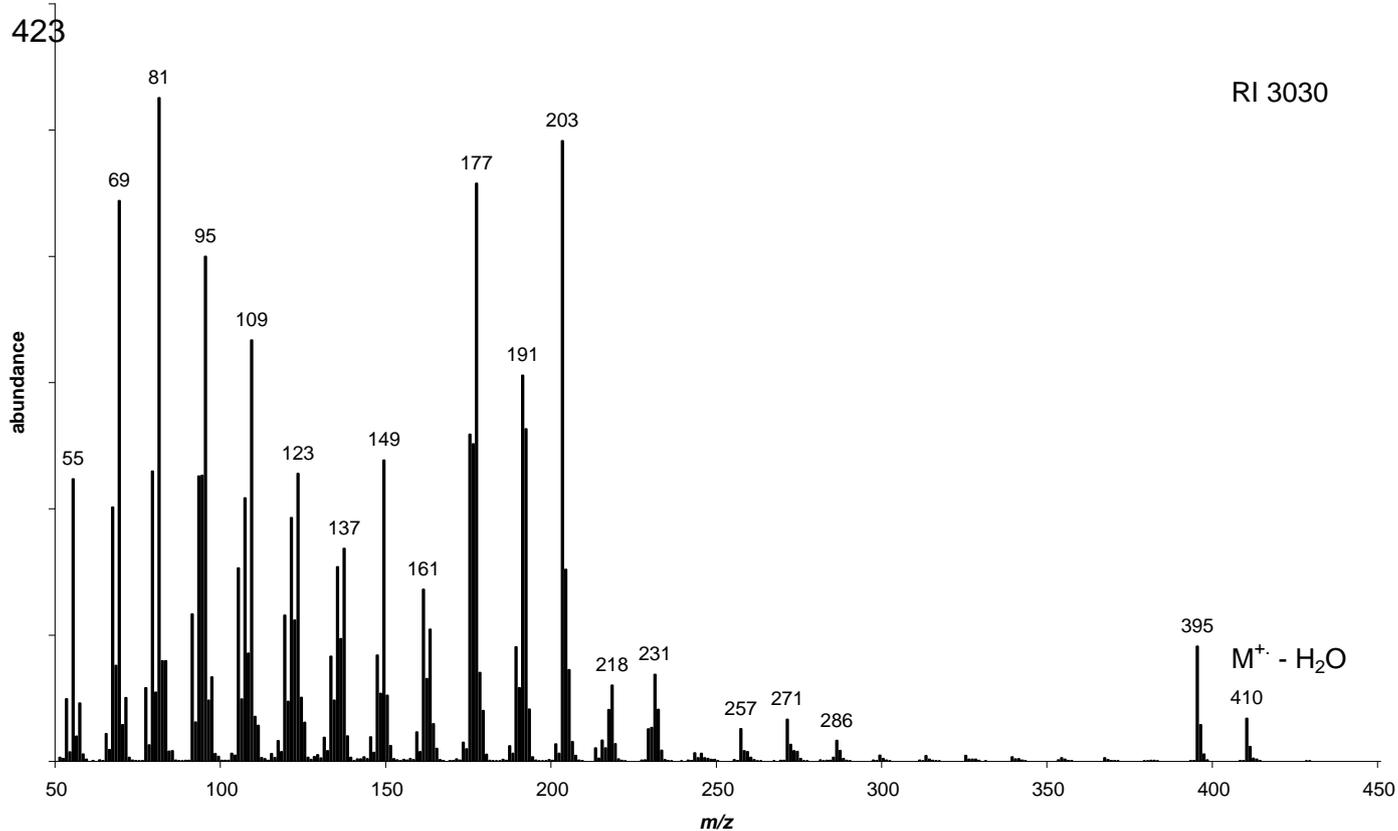
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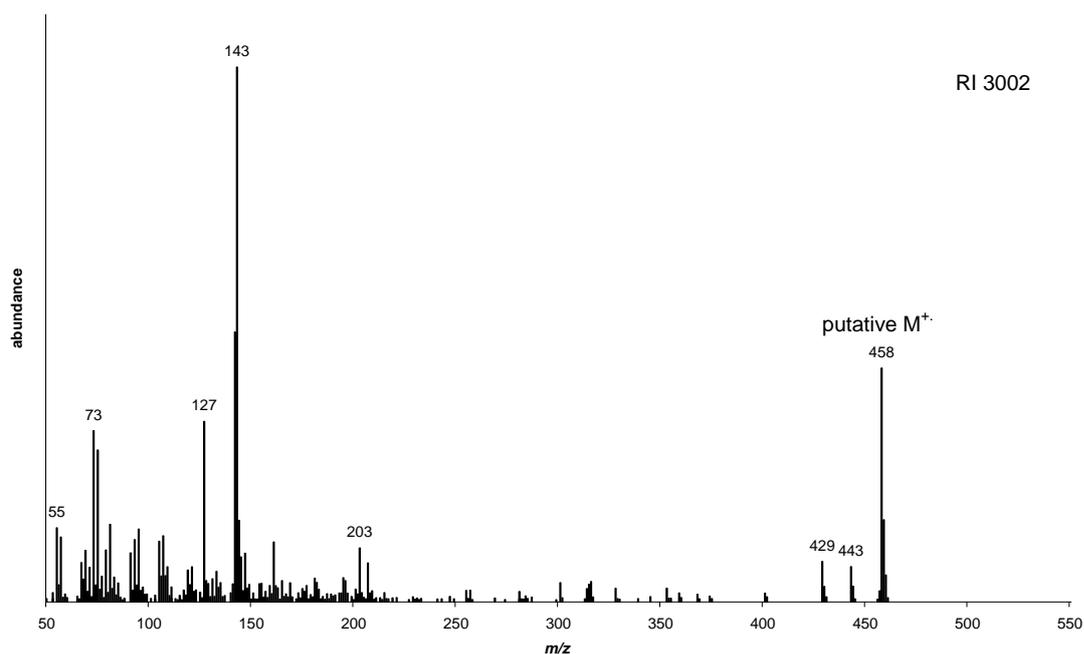
420 **Figure S5** Mass spectrum of underivatised ambrein (70eV, GC-MS). When derivatised this is

421 component D.

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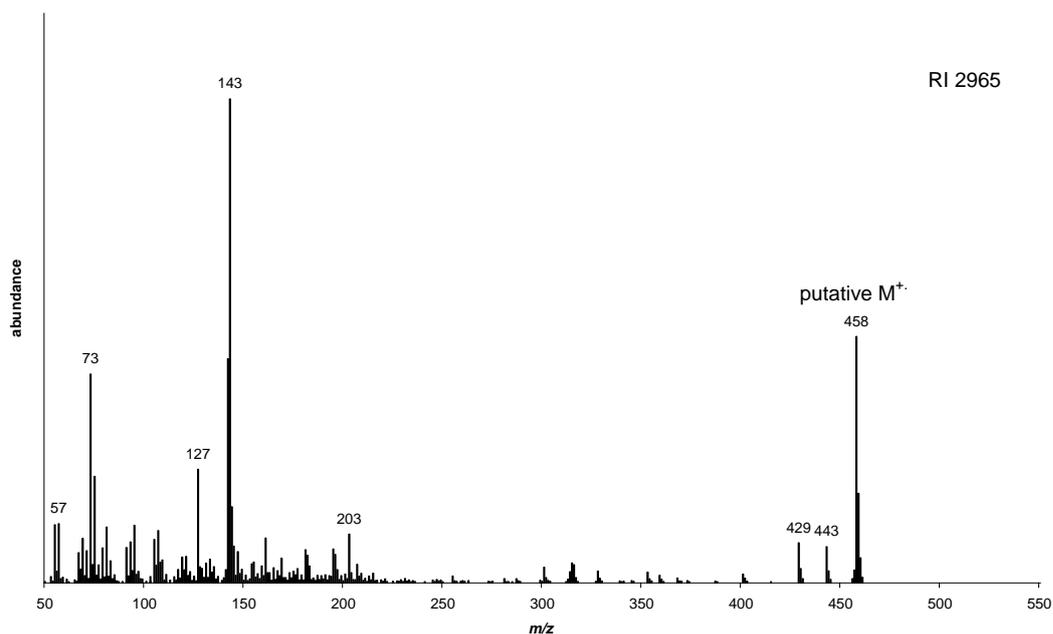


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426 **Figure S6.** Mass spectrum of unknown component A1 (as shown in Figure 1)



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428 **Figure S7.** Mass spectrum of unknown component A2 (as shown in Figure 1)

429 We are grateful to Deniz Koseoglu (University of Plymouth) for supplying an original signed
430 copy of the previously reportedly partially mis-translated, Russian book, 'Cachalot' by A.A.
431 Berzin (1971) and for re-translating pages 320-324 on the composition of ambergris, into
432 English.

433

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434 **Figure 1.** Structures (**I-IV**) of chemicals discussed in the text; total ion current GC-MS
435 chromatograms of silylated ambergris dichloromethane whole extracts (samples 1-3
436 and 12 from Sperm whales; samples 4-6 from archived perfumery sources and samples
437 7-11 jetsam ambergris from New Zealand beaches). Components A1,2 are unknowns;
438 component B is coprostanone; Component C is epicoprostanol TMS ether and
439 Component D is ambrein TMS ether; electron impact mass spectrum of ambrein-
440 trimethylsilyl ether.

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