Biochemical Systematics and Ecology, Vol. 21, No. 2, pp. 181–184, 1993.
Printed in Great Britain.
0305-1978/93 $6.00+0.00

Chitin Production by Krill

STEPHEN NICOL and GRAHAM W. HOSIE
Australian Antarctic Division, Channel Highway, Kingston, Tasmania 7050, Australia

Key Word Index—Chitin, krill, Antarctic krill, *Euphausia superba, Nyctiphanes australis*, production rates.

Abstract—The contributiion of krill to the oceanic production of chitin is re-examined using newly published data on the chitin content of Antarctic krill and on the production rate of chitin in the form of exuviae. Calculations suggest that earlier estimates of krill chitin production are likely to be overestimates. Krill are, however, among the major arthropod producers of chitin in the oceans and the Antarctic krill fishery at its current level is still a potential major source of chitin to industry.

Introduction

A recent paper by Jeuniaux and Voss-Foucart (1991) presented estimates for marine production of chitin. Included in their calculations were estimates for the production of chitin by krill and in particular, by Antarctic krill *Euphasia superba.* Since the publication of their article more comprehensive figures have become available for the chitin content of both whole Antarctic krill and for their exuviae (Nicol *et al.*, 1993). Because this species is the target of a large fishery (Nicol, 1989) and because this fishery has been cited as a potential commercial source of chitin (Anderson *et al.*, 1978) it is worth re-examining the potential production of chitin by Antarctic krill in the Southern Ocean.

Chitin production by Antarctic krill

The production of chitin by Antarctic krill is largely a function of their moulting rate. *E. superba* sheds its chitinous exoskeleton every 14–27 days, the inter-moult period being largely dependent on temperature (Nicol and Stolp, 1989). The chitin content of various species of krill, their cuticles and their cast exuviae have been estimated in a number of ways and expressed in a variety of formats (Table 1). There are obviously a wide range of values published for a number of different krill preparations. Chitin content is usually measured as the material stable to alkaline digestion procedures and this has potential sources of error. If relatively mild digestion procedures are used there is the possibility of not removing all other organic matter and therefore of over-estimating the amount of chitin present (Shimahara and Takiguchi, 1988). If, however, more rigorous digestion methods are employed then the risk of degradation of the chitin is greatly increased (BeMiller and Whistler, 1962). Other chitin assay methods such as the wheat germ agglutin assay may not be appropriate for intact exoskeletons or whole animal samples due to blocking or steric hindrance by other macromolecules (Montgomery *et al.*, 1990). Bacterial deproteinisation of krill cuticle still results in significant quantities of residual protein which would lead to an overestimate of chitin content by gravimetric methods (Shimahara *et al.*, 1984)

The figures used by Jeuniaux and Voss-Foucart (1991) for the chitin content of Antarctic krill are 7.08% of the dry weight for whole animals and 38.7% of the dry weight of the cuticle—these were obtained from a paper by Yanase (1975). A recent study (Nicol *et al.*, 1993) using orthophosphoric acid digestion followed by acetic acid analysis using HPLC yielded rapid and reliable results which, although potentially slightly conservative for chitin, were more likely to be accurate than the standard gravimetric methods. These results showed that the chitin content of whole Antarctic

(*Received* 27 *February* 1992)

TABLE 1. PUBLISHED ESTIMATES OF THE CHITIN CONTENT OF ANTARCTIC KRILL

Sample type	Chitin content	Notes	Chitin assay used	Reference
Dissected exoskeleton	7.08%	Expressed as fat-free dry wt	*N*-acetyl glocosamine Colorimetric	Yanase (1975)
Water cleaned exoskelton	40.2%	Expressed as fat-free dry wt	*N*-acetyl glocosamine Colorimetric	Yanase (1975)
Whole krill	3.2%	Expressed as % dry wt	NaOH+HCl Gravimetric	Anderson *et al.* (1978)
Krill processing waste	24%	Expressed as % dry wt	NaOH+HCl Gravimetric	Anderson *et al.* (1978)
Whole krill	2.11%	Expressed as % frozen wt	NaO+HCl Gravimetric	Clarke (1980)
Krill offal	40.2%	Expressed as % of dry de-proteinized shell	NaOH+HCl Gravimetric	Naczk *et al.* (1981)
Whole krill	2.7%a	a. mean % dry wt. from moult cycle	Orthophosphoric acid digestion/ acetic acid analysis by HPLC	Nicol *et al.* (1992)
	2.4%b	b. mean % dry wt from batched field sample		
Krill exuviae	13.7%	Expressed as % dry wt	,,	Nicol *et al.* (1992)

krill varies between 20 and 30 μg chitin mg^{-1} dry body weight during the moult cycle with a mean figure equivalent to 2.7% of the dry body weight. Chitin constitutes only 13.7% of the dry weight of cast exuviae of Antarctic krill and they lose 51.6% of their chitin at moulting (Nicol *et al.*, 1993); these are the first measurements of the loss of chitin through moulting in Antarctic krill. Since most of the chitin produced by krill is lost in the form of cast exuviae and since figures have only recently become available for the chitin content of krill moults, it is worth re-calculating the production rate of chitin by krill in the light of these new data.

The standing stock of Antarctic krill is believed to exceed 500 million tonnes and estimates of its annual production range between 100–500 million tonnes per year (Ross and Quetin, 1988). Adult Antarctic krill moult regularly, casting off exuviae every 26–30 days at 0°C and the moult represents approximately 7.5% of the dry weight of the adult (Nicol and Stolp, 1989). A krill biomass of 500 million tonnes would represent a 3.1 million tonne standing stock of chitin. If this population were producing 13 exoskeletons a year, this would result in a chitin manufacturing rate of an additional 15.4 million tonnes per year. This is subject to some uncertainty because sub-adult krill may contain greater percentages of chitin since their surface area to volume ratio is likely to be higher and because small krill are known to moult at a greater rate than larger ones (Murano *et al.*, 1979). In comparison, total pelagic chitin production (including that of all species of krill) has been estimated to be as high as 1.9 billion tonnes per year (Jeuniaux and Voss-Foucart, 1991). If the biomass of krill is 1.08 g dry wt m^{-2} (22 mg chitin m^{-2}), a moult production of 1.053 g dry wt m^{-2} y^{-1} can be estimated (Nicol and Stolp, 1989) which is equivalent to 144 mg chitin m^{-2} y^{-1}. Jeuniaux and Voss-Foucart (1991) quote chitin production rates for species of krill other than *E. superba* which range from 12–1077 mg chitin m^{-2} y^{-1}.

A total of 357,538 tonnes of Antarctic krill were caught in the Southern Ocean during the 1990/91 reporting season (July–June) (Anon, 1991). Practical experience on Polish fishing vessels indicates that a recovery rate of only 150 kg of chitin per 5 tonnes of processed krill meat produced which corresponds to 25–30 tonnes of krill caught (Breski, 1982). Using this chitin recovery figure, the practical yield of chitin from the current krill catch is between 1788 and 2145 tonnes. In comparison, the production of chitin/chitosan in Japan, one of the major chitin/chitosan producing nations, in 1986 was 1,270 tonnes (Hirano, 1989). Therefore the krill fishery at its current level is still potentially a major supplier of chitin.

Chitin production by other species of krill

Some further figures for the production of chitin by other species of krill are available in addition to those presented by Jeuniaux and Voss-Foucart (1991). Hosie and Ritz (1983) showed that for the krill *Nyctiphanes australis*, in south-eastern Tasmanian waters, moulting rate was dependent on temperature. In winter months with water temperatures of 10°C production was 0.071 mg exuviae m^{-3} d^{-1}; in summer (15°C) production was 0.115 mg m^{-3} d^{-1}. Combining these values, annual production would be 33.897 mg exuviae m^{-3} (all figures in dry weight). Assuming that the chitin content of *N. australis* moults is the same as *E. superba*, (13.7%), annual production of chitin would be 4.64 mg m^{-3} d^{-1}. Integrating over an average water depth of 37 m gives a chitin production of 172 mg m^{-2} d^{-1}.

Sameoto (1976) estimated that dense concentrations of the North Atlantic krill *Meganyctiphanes norvegica* produced the equivalent of 0.52 mg chitin m^{-2} d^{-1} (converted from dry weight of moults using the chitin figure for *E. superba*) during their most productive three months. Annual moult production has also been estimated for the North Pacific krill *Euphausia pacifica* (Lasker, 1966) and converting these figures to chitin gives a figure of 205 mg chitin m^{-2} y^{-1}.

Conclusions

Annual chitin production by krill can be estimated either as a fraction of the total production of tissue based on the known percentage of chitin in whole animals or as that amount produced as exuviae plus a residual amount in the population at the end of the year. Treating exuviae production as additional to annual tissue production as Jeuniaux and Voss-Foucart (1991) appear to do would tend to greatly over-estimate chitin production. This may explain some of their higher figures (1077 mg chitin m^{-2} y^{-1}) for *N. australis*. Smaller species of krill, due to their smaller size, greater surface area to volume ratio, relatively greater chitin content and faster moult production rate are likely to have relatively higher chitin production rates than larger species such as *E. superba*.

Species of krill are found in almost all oceanic waters (Mauchline and Fisher, 1969) and in several areas can dominate the pelagic community but much of the chitin production that occurs in the oceans may be associated with the smaller crustacean zooplankton such as copepods. It is the vast population size and fisheries potential of Antarctic krill which have focused attention on this species as a potential source of chitin rather than their contribution to the global production of chitin.

Acknowledgements—We would like to thank O. Nordstrom of the Australian Government Analytical Laboratory for specialist advice on chitin analysis.

References

Anderson, C. G., de Pablo, N. and Romo, C. R. (1978) *Proceed. First Internat. Conf. Chitin/Chitosan* (Muzzarelli, R. A. A. and Parsier, E. R. eds), MIT Sea Grant Report **78-7**, 54–63.

Anon. (1991) *CCAMLR Newsletter* CCAMLR, Hobart, **13**, 4pp.

BeMiller, J. N. and Whistler, R. L. (1962) Alkaline degradation of amino sugars. *J. Org. Chem.* **27**, 1161–1164.

Breski, M. M. (1989) Production and application of chitin and chitosan in Poland. In *Chitin and Chitosan* (Skjak-Braek, G., Anthosen, T. and Sandford, P., eds), pp. 161–170, Elsevier, London.

Clarke, A. (1980) The biochemical composition of krill, *Euphasia superba* Dana, from South Georgia. *J. Exp. Mar. Biol. Ecol.* **43**, 221–236.

Hirano, S. (1989) Production and application of chitin and chitosan in Japan *Chitin and Chitosan* (Skjak-Braek, G., Anthonsen, T. and Sandford, P. eds), pp. 37–44, Elsevier, London.

Hosie, G. W. and Ritz, D. A. (1983) Contribution of moulting and eggs to secondary production in *Nyctiphanes australis* (Crustacea: Euphausiaceae). *Mar. Biol.* **77**, 215–220.

Jeuniaux, C. and Voss-Foucart, M. F. (1991) Chitin biomass and production in the marine environment. *Biochem. Syst. Ecol.* **19**, 347–356.

Lasker, R. (1966) Feeding, growth respiration and carbon utilisation of a euphausiid crustacean. *J. Fish. Res. Bd. Can.* **23**, 1291–1317.

Mauchline, J. and Fisher, L. R. (1969) The biology of euphausiids. *Adv. Mar. Biol.* **7**, 1–454.

Montgomery, M. T., Welschmeyer, N. A. and Kirchman, D. L. (1990) A simple assay for chitin: application to sediment trap samples from the subarctic Pacific. *Mar. Ecol. Prog. Ser.* **64**, 301–308.

Murano, M., Segawa, S. and Kato, M. (1979) Molt and growth of the Antarctic krill *Trans. Tokyo Univ. Fish.* **3**, 99–106.

Naczk, M., Synowiecki, J. and Sikorski, Z. E. (1981) The gross chemical composition of Antarctic krill waste. *Food Chem.* **7**, 175–179.

Nicol, S. (1989) Who's counting on krill. *New Scientist* **1690**, 38–42.

Nicol, S. and Stolp, M. (1989) Sinking rates of cast exoskeletons of Antarctic krill (*Euphausia superba* Dana) and their role in the vertical flux of particulate matter and fluoride in the Southern Ocean. *Deep Sea Res.* **36**, 1753–1762.

Nicol, S., Stolp, M. and Nordstrom, O. (1993) Change in the gross biochemistry and mineral content accompanying the moult cycle in the Antarctic krill *Euphausia superba. Mar. Biol.* (in press).

Ross, R. M. and Quentin, L. B. (1988) *Euphausia superba*: a critical review of annual production. *Comp. Biochem. Physiol.* **90B**, 499–505.

Sameoto, D. D. (1976) Respiration rates, energy budgets, and moulting frequencies of three species of euphausiids found in the Gulf of St. Lawrence. *J. Fish. Res. Bd. Can.* **33**, 2568–2576.

Shimahara, K. and Takiguchi, Y. (1988) Preparation of crustacean chitin. *Meth. Enzym.* **161**, 417–423.

Shimahara, K., Takiguchi, Y., Ohkouchi, K., Kitamura, K. and Okada, O. (1984) Chemical composition and some properties of crustacean chitin prepared by use of proteolytic activity of *Pseudomonas maltophillia* LC102. In *Chitin, Chitosan and Related Enzymes* (Zikakis, J. P., ed.), pp. 239–255. Academic Press, Florida.

Yanase, M. (1975) Chemical composition of the exoskeleton of Antarctic krill. *Bull. Tokai Reg. Fish. Res. Lab.* **83**, 1–6.