Formation and Potential Trophic Significance of Marine Foam near Kelp Beds in the Benguela Upwelling System

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Abstract

The present study investigates the importance of foam in nearshore waters on the west coast of the Cape Peninsula (South Africa) as a possible food resource for consumer organisms. A bacterial density of $3.45 \times 10^9$ cells m$^{-1}$ foam suspension was recorded. Calorific values of up to 15.39 kJ g$^{-1}$ ash-free dry weight were noted, and a biochemical analysis of the drained foam suspension gave a composition of 22.85% protein, 10.76% lipid and 3.07% carbohydrates. Field data showed a correlation between peaks of phytoplankton up to 510 mg C m$^{-3}$ water temperature and days of intense foam formation during periods of strong onshore winds. Experimental foam formation in the laboratory indicates that kelp mucilage and phytoplankton contain surfactant agents. An additional feature of kelp mucilage is its capability to improve foam stability. The comparison of the chemical composition of 12 and 120 h-old foam suspension indicates a loss of easily metabolizable components such as trichloroacetic-acid precipitated protein and neutral lipid with time. It is hypothesised that the losses are due to utilisation of these components by consumers.

Introduction

The binding of energy in the form of dissolved organic matter (DOM) and subsequent energy transfer in the marine environment is a subject of much controversy and ecological importance. According to Mann (1972), over 90% of the production of marine macrophytes enters the food chain as dissolved or particulate organic matter (POM), and the problem arises of identifying the mechanisms and processes which make these resources available to consumers. Theories about the transfer of DOM to POM were put forward by Baylor et al. (1962), Baylor and Sutcliffe (1963) and Riley (1963) after discovering that particles could be formed on the surface-water layer by bubbling air through seawater. Reports on the enrichment and concentration of particulate matter in water layers, especially surface-water layers, are numerous (Riley et al., 1965; Williams, 1967; Riley 1970; Nishizawa and Nakajima, 1971; Wangersky, 1976, 1977). Amongst the mechanisms believed to be responsible for this enrichment are internal waves, vertical water movement, i.e., Langmuir circulation (Sutcliffe et al., 1963) and the action of breaking waves in creating air bubbles which scavenge on particles and DOM in the water column (Riley, 1963). A characteristic feature of the surface-water layer, or more specifically the surface microlayer, is its potential to form foam due to surfactant agents (MacIntyre, 1974). The ecological importance of foam depends on the extent to which foam formation can contribute to the transfer of energy to the consumer level. Most foams have been reported to be rich in particulate organic matter, and the concept of foam as an ecological habitat was put forward by Maynard (1968).

Heavy foam formation is frequently observed in the nearshore waters of the West Coast of the Cape Peninsula (South Africa), mostly under strong westerly winds accompanied by large breakers, and in the vicinity of extensive kelp beds (Field et al., 1977; Velimirov et al., 1977). The foam is stable for periods of up to 2 days in nearshore waters after the cessation of onshore winds, or may be blown out to sea by offshore south-east winds.

Most studies on foam, froth, or surface slicks are of a physical (Abe, 1955a, b; MacIntyre, 1968, 1974) or a chemical (Skopincev, 1938; La Fond and Bhavanarayana, 1959; Sutcliffe et al., 1963; Garett, 1965, 1967; Wilson and Collier, 1972) nature. This paper discusses the results of a preliminary study dealing with foam formation on the west coast of the Cape Peninsula and
Materials and Methods

Foam samples were collected in the vicinity of the main kelp beds at Oudekraal. Samples were collected 12 h after the start of foam formation and, if the foam buildup continued, 110 h later. The samples were collected in 1 and 2 l PVC tubes that could be capped at both ends by means of tight-fitting rubber lids. Samples were taken between the intertidal zone and a maximum of 15 m offshore. They were kept in cooling bags and immediately taken back to the laboratory.

By keeping the tubes in an upright position, complete drainage (= total foam collapse) of the foam was accomplished in 2 to 4 h. The resulting particle/liquid suspension was processed immediately, or kept in a deep-freezer until further use.

The drained foam was dried to constant weight at 95 °C, and carbon and nitrogen values were obtained using a CHN Analyser (Hewlett Packard Model 185 B) with integrator (Model 3580-A), and were calibrated with cystine. Ash weight was obtained by ashing subsamples in a muffle furnace using porcelain crucibles at 550 °C for 5 h. Calorific values were determined with a Gallenkamp Ballistic Bomb Calorimeter, samples being ignited under 25 atm O₂, mixed with benzoic acid. The values obtained were repeatedly checked with a Phillipson Microbomb Calorimeter.

Volume determination of fresh foam drainage was followed by filtration of the suspension through a Whatman I filter paper using a vacuum pump (12 kg cm⁻² pressure). The volume of the filtrate was obtained using a 2 l graduated measuring cylinder, and the residue was weighed.

Protein, carbohydrates and lipid values for the residue and filtrate were obtained following the methods of Holland and Gabbott (1971) and Holland and Hannant (1973), using a Beckman spectrophotometer. Bacterial density was estimated in the foam suspension as well as the water underlying the foam. The water samples from the surface water (first 3 cm under the foam) and the water layer (10 cm under the surface water) were collected using flat medical flasks. These additional samples as well as subsamples of the foam were fixed during collection with 5% formalin and kept at 5 °C in the dark for microscopic observation. Counts of bacteria were made by the epifluorescent microscopic technique (Jones, 1974) using 0.45 μm pore-size black Nuclepore membrane filters. Twenty fields were counted for each filter at 1000x magnification on a Zeiss microscope equipped with an ultraviolet vertical illuminator. Ten replicates of samples from each source (foam drainage = foam suspension, surface water, water layer) were counted.

Surface-water temperature was measured twice daily from the boat; wind direction and speed were noted using the Beaufort scale. One liter water samples were collected daily in the vicinity of the kelp bed at the surface by means of National Institute of Oceanography water samplers, between 11.00 and 13.00 hrs.

Water samples were filtered through 0.45 μm pore-size acetate filter papers, and phytoplankton pigments were extracted according to the method of Strickland and Parsons (1972). Chlorophyll a concentrations were determined according to equations recommended by UNESCO (1966), and converted into carbon concentration after Andrews et al (1980). The values were verified with a Beckman Total Organic Carbon Analyser (Model 915 A).

To produce foam under laboratory conditions, plastic tanks of similar volume (4 l) were set up in pairs and filled with filtered (0.45 μm) and unfiltered fresh seawater. To one tank of each pair, the same weight (fresh weight = 150 g) of kelp fronds (Ecklonia maxima) or phytoplankton concentration was added. Phytoplankton for experimental use was collected during periods of onshore wind near the kelp beds by towing a plankton net (200 μm mesh size) a distance of 500 to 1000 m. The sample was then filtered through a 100 μm mesh-size net and the concentration of the obtained filtrate determined as above. After microscopic inspection, the filtrate was stored in the deep-freezer or used immediately. Each tank was supplied with air bubbles at a constant rate and approximately constant bubble size. Foam formation, stability and decay times were recorded each day. Decay time was defined as the period of time from the cessation of air supply to the appearance of an area without foam bubbles on the surface of the medium (Wilson and Collier, 1972), foam being defined as a measurable, stable, honeycomb structure of air cells whose walls consist of a thin liquid film. The air supply was interrupted 3 h after foam formation was observed.

Results

Particulate and Bacterial Components of Foam

Data on drained suspension and residue (or particle load) for foam 12 and 120 h old are given in Table 1; mean values for drainage, filtrate and residue show no significant differences with time. Only half of the drained suspension volume is filtrate, averaging 5.24 and 4.78 ml l⁻¹ for fresh and old foam, respectively. The rest of the volume represents the particle load, with mean dry weight values of 1.18 and 1.64 g, respectively.

Observations of bacteria in the drained suspension showed that 95% of all foam bacteria were rod-shaped.