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NOTE

Drift algae: a contribution to near-shore habitat complexity in the pelagic environment and an attractant for fish

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ABSTRACT: Drifting macrophytic algae increased habitat complexity in coastal waters of California, USA, especially in convergence zones. Algae are large and abundant structures, especially drift *Macrocystis pyrifera* (0.2 to 20 m long), and have been ignored in historical models of the pelagic environment. Drift plants redistribute small fish and invertebrates, and their movement (by wind and oceanographic features) can provide insight to the movements of meroplankton. The drift of whole *M. pyrifera* plants is also relevant to understanding the demography of kelp forests, whilst the drogue-like qualities of plants can be used to study oceanographic features. The pelagic environment, therefore, is characterised by a hierarchy of structures (0.05 mm to >10 m, marine snow to drift algae) and plankton, of different sizes.

KEY WORDS: Drift algae · *Macrocytis pyrifera* · Fish · Pelagic environment

Historically, the pelagic environment has been viewed as a uniform environment characterised by a hierarchy of plankton of different sizes, from microbes and tiny plants to large scyphomedusae (Fenchel 1988). Recent research has identified important structures or aggregates, coined 'marine snow', that typically range in size from 50 µm to 10 cm (Silver et al. 1978, Barham 1979, Alldredge & Silver 1988). The discovery of marine snow and aggregates of plant cells (Alldredge & Silver 1982) has altered our understanding of the trophodynamics, primary production and nutrient recycling of pelagic environments as well as the transport of biotic material from the photic zone to the benthos (Alldredge & Silver 1988). In this paper I describe abundant large structures and increased habitat complexity in coastal waters of California, USA, primarily composed of drifting macrophytic algae *Macrocystis pyrifera*. Fish and invertebrates are attracted to drifting objects (e.g. Hunter & Mitchell 1967, Mitchell & Hunter 1970, Dooley 1972). With the exception of the Sargasso Sea (Dooley 1972), drifting macroalgae have been largely ignored as a significant structural component of pelagic habitats and there are few data on the abundance of floating drift algae on large (tens of kilometres) and small (tens of metres) spatial scales.

Materials and methods. I studied the large-scale distribution patterns of drift algae near to and away from land off the coast of Santa Barbara, California (Fig. 1). Clumps of algae were counted from a small airplane and the weight of clumps was estimated. This was based on experience I had from weighing algae collected in the small-scale component of the study. Counts were made on 3 occasions (Time 1: 21 September 1992; Time 2: 30 November 1992; Time 3: 15 December 1992) at an altitude of 100 m (airspeed 120 to 144 km h^{-1}). Algal clumps from the size of single laminae could be observed at this altitude. Counts were done along 2 transects (~40 km long) and at 5 locations, separated by 6 to 7 km, within each transect (Fig. 1). Algae were counted in 5 replicate transects at each location. Transect length was 960 m, determined by LORAN electronic position finder, and width estimated at 100 m by triangulation (based on viewing height to 45° from horizontal); transect size was 926 × 100 = 92600 m^2; data are expressed as number or weight per 10 ha.

The small-scale distribution patterns of drift algae were studied in San Pedro Channel, Catalina Island, off Los Angeles, California. The position of individual clumps of algae was plotted on a map of the study area from a small boat. Position was determined by compass bearing and proximity to rocks. The wet weight of clumps was measured using a spring balance. An understanding of the movements of drift algae will elucidate the importance of drift algae for the dispersal of associated organisms and the influence it has on recruitment to reefs. Movements of algae were examined experimentally on 3 occasions (2, 3 and 4 September 1992) by releasing algae and recording the time it

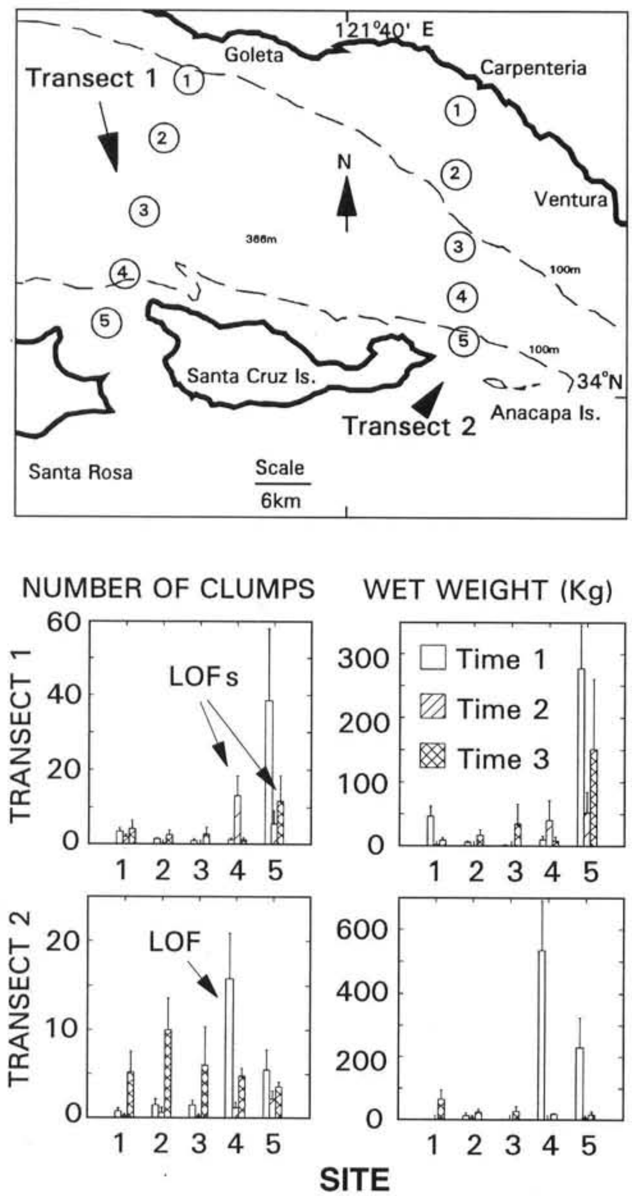

Fig. 1. Southern Californian Bight, USA, showing the location of sites sampled using an airplane along 2 transects extending from Goleta and Carpenteria towards Santa Cruz Island. The 100 m isobath is given. Abundances of drifting algae are presented as number of clumps and weight (kg) for transects 1 and 2; n = 5 replicates within each site (1 to 5), unit area per replicate = 10 ha mean ± 1 SE; LOF: Linear Oceanographic Feature (e.g. frontal convergence *sensu* Kingsford 1990)

took to drift 50 m downwind. Clumps of algae (2 kg) were placed 50 m (measured with a tape that floated behind the boat) upwind of a tethered float perpendicular to the long axis of the shore on 2 occasions (Times 1 & 2) in 216 to 306 m min^{-1} winds. On the third occasion (Time 3) algae were released in 93 to 154 m min^{-1} winds and surface waves (25 to 35 cm, trough to crest) running perpendicular to the wind; n = 5 clumps on each occasion. Wind direction was determined by compass. Wind speed and the size of surface waves was estimated by eye. The orientation of *Macrocystis pyrifera* in an adjacent kelp forest suggested it was not subjected to strong longshore currents at the time of sampling.

A 15 × 3 m plankton purse seine net (0.28 mm mesh) was used to seine fish around drift algae. The design of the net was modified from that of Kingsford & Choat (1985). Open water controls were taken on some dates. Visual observations of fish associated with kelp and number of holdfasts on clumps were taken, while snorkelling, on plants (n = 20 plants) in Santa Barbara Channel. I also attempted to document the movements of these plants by tagging them with 0.5 × 1 m sheets of orange plastic, to the west of Santa Cruz Island; an aerial search was made the following day, and the position of plants was recorded with LORAN. Distance moved was calculated as the shortest distance from the release point to the final position.

Results and discussion. Drift algae (mostly *Macrocystis pyrifera*) were found near to and away from land in aerial surveys over the Santa Barbara Channel to Santa Cruz Island (Fig. 1). Large numbers of clumps and high biomasses of algae were found at some sites (e.g. mean weight >150 kg per 10 ha). Proximity to land and potential 'source kelp forests' was not a good predictor of abundance of drifting kelp. Although drifting algae were often most abundant within 10 km of Santa Cruz (Sites 4 & 5, both transects) this was not always the case. Rank abundance and weight of algae at each site varied among observations, probably due to the movements of the algae by currents, wind and a variable supply of plants from kelp forests. Algae were at times concentrated in a front located within 4.3 km of Santa Cruz Island [Fig. 1; this front was also observed from a boat (14 December 1992) and may be a topographic shear front located at the shelf slope]. High numbers and biomass of drift algae were consistently found at the western end of Santa Cruz (Transect 1, Site 5) and appeared to be due to oceanographic features that facilitated the retention of algae in this area. Hence, the presence of these oceanographic features are remotely apparent when delimited by algae. Although general patterns of oceanography are described for the southern Californian Shelf (e.g. Winant 1983), current patterns are complex (Browne 1993) and small-scale circulations (<10 km) in the vicinity of the Channel Islands are poorly known. Persistent aggregations of algae should provide greater focus for oceanographic and biological investigations. The distribution and behaviour of zooplankters, particularly small fish, will be influenced in retention areas and convergences by the presence of abundant large structures (i.e. *M. pyrifera*). Highest densities of kelp in single transects reached 110 clumps per 10 ha and 104 kg ha^{-1}, at distances of 4 km or more from land. This illustrates how habitat complexity can be increased greatly by drift algae in localised areas. The rate of detachment of plants from kelp beds and the subsequent input of drift to coastal waters will vary according to the seasonality of storms, particularly during unusually large storms (Dayton et al. 1992) such as those that occur during El Niño events (Tegner & Dayton 1991).

Drift algae were also abundant within an 1.4 × 0.8 km area, 1 to 2 km from Catalina Island (250 to 400 kg within the mapped area, Times 1 & 2, Fig. 2), and clearly constituted increased habitat complexity of coastal waters. Mapping of clumps revealed that algae were patchily distributed throughout the study area, and that the spatial patterns changed between observations. Clumps ranged in size from 20 g (single frond) to 75 kg (whole plants) and averaged 1.7 kg. All of these plants were within 1 km of kelp forests. This raises 2 points: (1) drift kelp increased the complexity of pelagic habitats within 1 km of kelp forests, and (2) although nearby kelp forests may be the source of some local drift, many clumps undoubtedly came from further afield, their movements influenced by wind and currents.

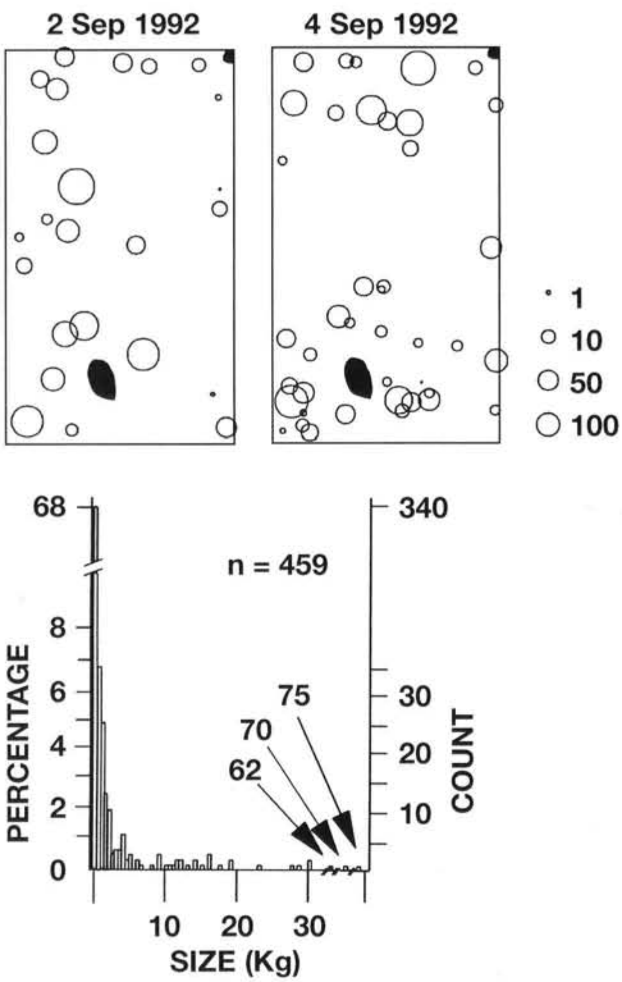

Fig. 2. Small-scale distribution patterns of drift algae within a 1.4 × 0.8 km area in San Pedro Channel, Catalina Island, off Los Angeles, California, USA. Filled-in areas: Ship Rock (upper) and Bird Rock (lower). Symbol sizes for bubble plots are $\ln(x+1)$-transformations of the wet weight of algae (kg); bubbles often represented more than 1 clump of drift in a small area (~10 × 10 m). Size frequency of algal clumps in 0.5 kg size classes. Note broken axes: weight of large clumps indicated with arrows. Rank abundance of algal types by weight: *Macrocystis pyrifera* (97.5%), *Egregia menziesii* (2%), *Cystoseira* spp. (0.49%) and *Pelvetia* spp. (0.001%)

Experimental algal clumps (1 to 2 kg) moved downwind at a rate of 3.3 to 5.4 m min^{-1} (216 to 309 m min^{-1} winds, Times 1 & 2) and onshore winds generally caused the accumulation of natural drift near shore (pers. obs.). Hence, larvae of fish (e.g. *Paralabrax clathratus*, *Chromis punctipinnis* and *Sebastes* spp.; Table 1) that colonise algae drifting in coastal waters may be advected onshore by wind as well as by oceanographic features such as internal waves (e.g. Kingsford & Choat 1986) and coastal currents (e.g. Winant 1983). Thus, the accumulation of algae nearshore may indicate an important recruitment event (e.g. Kingsford 1992), as transported early life-history stages settle into nearshore habitats. In low winds (93 to 154 m min^{-1}) on one occasion, algae were transported downwind at 2 (SE = 0.15) m min^{-1}. Surface waves that were propagating perpendicular to the wind transported algae at 1.7 (SE = 0.1) m min^{-1}. Hence, surface waves may also be important for transport (Broche & Forget 1992). Algae can drift considerable distances. I only observed 2 tagged clumps out of 20 after 24 h, in which time they had moved a minimum of 10 to 12 km. One plant was observed twice on the day of sampling and had moved 0.8 km in 2 h.

Many algal clumps extended well below the surface of the water column because the heavy holdfasts were still attached. Some clumps had algae that hung down to depths of 1 m or more (maximum of 9 m). Those drifting within 4 to 10 km of Santa Cruz Island had a mean of 3.1 holdfasts per clump (n = 20 clumps, 8 to 230 kg). Large plants act more like current-indicating drogues than small clumps because they are less prone to transport by light winds (<460 m min^{-1}; pers. obs.). Because coastal waters off southern California are subject to prolonged periods of winds less than 460 m min^{-1}, the drogue-like properties of algal clumps will reveal coastal retention areas, mainstream currents (Harrold & Lisin 1989) and surface convergences such as internal waves (Kingsford & Choat 1986) and Langmuir circulations (Faller & Woodcock 1964).

Drifting macrophytes contribute to habitat complexity in surface waters. Perceptions of the pelagic

Table 1. Fish associated with drift algae off the coast of southern California (see also Hunter & Mitchell 1967, Mitchell & Hunter 1970, Boehlert 1977). Fish were collected using a plankton mesh purse seine net (Kingsford & Choat 1985). Values are the mean (SE in parentheses). % occ.: percentage occurrence; size ranges are total length. Open water seines (n = 3 seines) did not capture any of the species below on 4 July 1991 or 5 September 1992. Developmental stages (terminology according to Leis & Rennis 1983) are J: juvenile; P: postflexion larva; PR: preflexion larva

Location & date Species (stage)	Number per clump	Number per kg	% occ.	Size range (mm)
5.6 to 7.4 km off Goleta (n = 6 clumps, 0.25 to 14.5 kg), 4 July 1991				
Anoplopoma fimbria (J)	42 (33)	5.4 (4)	66	80–100
Sebastes serriceps (J)	1.7 (0.9)	0.9 (0.09)	50	19–40
Sebastes diploproa (J)	3.1 (1.6)	0.3 (0.12)	66	14–25.5
Sebastes sp. (J)	0.5 (0.3)	0.05 (0.04)	33	12–17.5
Scorpaenichthys marmoratus (J)	0.2 (0.2)	0.01 (0.01)	15	38.7
Atherinidae (PR, P)	0.2 (0.2)	0.01 (0.01)	15	18
Clinidae (P)	1.8 (0.6)	1.7 (1.3)	83	11–21.5
Sygnathidae (J)	0.8 (0.5)	0.08 (0.05)	33	140–170
Cottidae (PR)	0.2 (0.2)	0.01 (0.01)	15	7.4
Unknown	0.7 (0.3)	0.8 (0.6)	50	8.7–12
San Pedro Channel, Catalina Is. (n = 6 clumps, 0.82 to 12.5 kg), 3 September 1992				
Medialuna californiensis (J)	16 (9)	13 (8)	66	32–44
Chromis punctipinnis (J)	6 (4.5)	1.7 (0.7)	83	10–23
Paralabrax clathratus (P, J)	3.8 (2.7)	1 (0.4)	66	7.8–19
Seriola lalandi (J)	0.3 (0.2)	0.3 (0.2)	33	33–64
Unknown preflexion	0.2 (0.2)	0.2 (0.2)	15	4
San Pedro Channel, Catalina Is. (n = 6 clumps, 1 to 6 kg), 5 September 1992				
Chromis punctipinnis (P, J)	2.5 (2)	0.8 (0.7)	33	11–22
Paralabrax clathratus (P, J)	3.8 (0.8)	1.3 (0.2)	100	8.7–18.1
Sardinops sargax (J)	0.2 (0.2)	0.05 (0.05)	15	85
1.9 to 9.3 km north off Santa Cruz Is. (n = 20 clumps, 8 to 230 kg), 14 December 1992[a]				
Medialuna californiensis (J)	11 (4)	0.2 (0.08)	45	70–130
Chromis punctipinnis (J)	4.5 (3.2)	0.1 (0.08)	10	8–25
Sebastes serriceps (J)	0.2 (0.2)	0.005	5	30–40

[a] Visual counts only

environment, therefore, should include a hierarchy of natural structures as well as plankters (Fenchel 1988), ranging from small aggregates and plant cells to large clumps of drift algae (especially laminariales and fucales) and other flotsam (Kingsford 1993). Although drift algae may represent a relatively small percentage cover of the ocean surface (estimated at ≤2% of the sea surface in transects where individual clumps in aerial surveys were estimated to average 3 × 3 m), this would give little indication of their importance in surface waters. Algae hang down and by moving through the water effectively 'fish' a volume that is much greater than their surface area would suggest. Aerial photography or video transects are potential methods for monitoring changes in the abundance of drift algae, but ground verification is required.

Drift algae provide a substratum that may be utilised by the early life-history stages of invertebrates (e.g. Highsmith 1985) and fish (e.g. Mitchell & Hunter 1970, Kingsford & Choat 1985). Abundant drift algae facilitate the redistribution of organisms in the pelagic environment and may influence the survivorship of species which depend upon drift algae for shelter and food. The distribution and movement of algae will influence that of associated larvae. Studies of drift algae may lead to insights into the processes affecting the recruitment of the associated presettlement larvae and juveniles, e.g. do quantities of drift affect the magnitude of recruitment on small (<1 km) and large (>10 km) spatial scales? Invertebrates and fish that brood or bear live young may have increased dispersal by rafting on drift algae (e.g. Highsmith 1985, Kingsford 1992). Others (e.g. juvenile *Medialuna californiensis*, Table 1) may treat drift algae as a nursery habitat and the presettlement or 'larval phase' of some fish may be extended.

Due to the drogue-like properties of large macrophytes, oceanographic questions can be addressed as well. Habitat complexity can be greatly increased by drifting algae in convergences and retention areas.

Drift algae can also contribute to the dispersal of algal propagules. Algal spores may normally travel short distances (<10 m), but dispersal of spores increases during storms (Reed et al. 1988). Drift macrophytes that still have sporangia on the holdfast may have an important role in the dispersal of spores (Dayton 1985) at times.

Drift algae which lose their floats sink, and like marine snow (Alldredge & Silver 1988) may provide an important input to the benthos within tens of kilometres from the mainland (Harrold & Lisin 1989). Drifting algae probably lose their floats after 7 to 10 d (Harrold & Lisin 1989). If persistent oceanographic features concentrate the drift, then the benthos beneath the features may receive a higher input of carbon, accordingly drift algae that sinks may influence benthic assemblages. Other drifting algae may sink into reef environments (Dayton et al. 1992) or be washed up surf beaches as 'wrack'. With the exception of Harrold & Lisin's (1989) work where kelp was tracked from kelp forests and up to 50 km from Monterey Peninsula, the fate of individual plants and the frequency of deposition in different environments is poorly known.

Drifting macrophytes are often abundant, constitute important structures and increase habitat complexity in the surface waters off California, and probably other parts of world where laminarian and fucoid algae with floats are abundant (Schiel & Foster 1986). With the exception of the Sargasso Sea, drift algae should be most abundant in coastal waters. The presence of abundant large algae in pelagic environments contrasts with historical views that emphasise microscopic algae (i.e. phytoplankton). Contemporary views of the pelagic environment should include a hierarchy of structures from marine snow to drifting macrophytes.

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