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Spatial and temporal distribution of floating kelp in the channels and fjords of southern Chile

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ABSTRACT

Numerous studies suggest that floating macroalgae contribute to population connectivity of the algae themselves as well as of associated organisms. In order to evaluate the importance of floating macroalgae for population connectivity in southern Chile we analysed their spatial and temporal distributions. We estimated the abundance of floating kelp in the Interior Sea of Chiloé and the Los Chonos Archipelago via ship surveys conducted during austral spring (November) and winter (July) of the years 2002–2005. Highest densities of floating kelp (*Macrocystis pyrifera* and *Durvillaea antarctica*) were found during spring. Generally, the density of floating kelp was relatively low in areas with high supply of freshwater, and highest abundances were found in large channels opening to the open ocean. We suggest that this pattern is caused by the scarcity of natural kelp beds combined with rapid degradation of floating kelp in the interior fjords and by seaward surface outflow. The maximum densities of floating kelps were found in an area known to be an extensive convergence zone (i.e. estuarine front), which appears to act as a retention zone. In accordance with this distribution pattern, we propose that connectivity between local populations via floating kelp is higher in the outer channels with oceanic influence than in the inner fjords with high freshwater influx.

1. Introduction

The dispersal abilities of marine organisms are highly variable and depend on autonomous dispersal stages (e.g. planktonic larvae, Cowen and Sponaugle, 2009), capacity of adult movements, and rafting on floating substrata (Thiel and Gutow, 2005a,b). During the past two decades several studies have highlighted the importance of rafting as a transport mechanism for marine invertebrates and some fish species, possibly contributing to population connectivity and (re)colonization of habitats by these organisms (e.g. Johannesson, 1988; Castro et al., 2002; Colson and Hughes, 2004; Waters and Roy, 2004; Donald et al., 2005; Lourie et al., 2005; Thiel and Haye, 2006).

Floating algae have been suggested as one of the most important rafting substrata, which can be found in all major oceans. They often harbour a diverse assemblage of associated organisms (Helmuth et al., 1994; Ingólfsson, 1995; Hobday, 2000a; Thiel and Gutow, 2005a; Vandendriessche et al., 2006). Floating algae also provide food for travellers and complex ecological interactions may develop during extended journeys (e.g., Sano et al., 2003; Vandendriessche et al., 2007a). By directly consuming the floating algae associated organisms contribute to the demise of their rafts (Vandendriessche et al., 2007b; Rothäusler et al., 2009), which has direct implications for the persistence of algal rafts at the sea surface and potential dispersal distances. Several studies indicated that detached giant kelp *Macrocystis* continue growing (Rothäusler et al., 2009) and may remain afloat for more than 100 days (Hobday, 2000b; Hernández-Carmona et al., 2006). During these time periods floating kelp can be transported by currents over long distances and thereby contribute to population connectivity of kelps themselves and of associated marine organisms (Thiel and Haye, 2006; Waters, 2008; Fraser et al., 2009).

In order to evaluate whether floating algae may contribute to population connectivity in a particular geographic region it is necessary to identify their temporal and spatial distributions. Studies on the inter- and intra-annual variability in the abundance of floating algae suggest a seasonal tendency, driven mainly by the annual growth season of benthic algae. For example, in coastal areas of Japan the highest abundance of floating *Sargassum* spp. was reported during spring and summer (Hirata et al., 2001). Similarly, for a coastal area in NE New Zealand Kingsford (1992) reported very high densities of *Sargassum sinclairii* during austral spring and early summer (November to January). This author further indicated that

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species such as *Carpophyllum flexuosum*, *Carpophyllum angustifolium*, and *Cystophora* spp. reach high abundances after storms, suggesting that other factors (e.g. detachment events) may also play a role in the temporal dynamics of floating macroalgae (Kingsford, 1992). In contrast, no clear seasonal pattern in the abundance of large rafts *Macrocystis pyrifera* was observed in California, which was attributed to variable storm-induced supply from benthic sources (Hobday, 2000c).

Overall, there seems to be a global pattern of highest abundances of floating alga in temperate regions, i.e. between 20° and 50° in both hemispheres (Thiel and Gutow, 2005a). However, considerable differences in local abundance have been reported. For example, Kingsford (1995) found 1100 items km^{-2} of floating kelp *Macrocystis pyrifera* in the NE Pacific (34–35°N), while another study recorded only seven large kelp rafts km^{-2} for the same area (Hobday, 2000c). Both authors suggested that the abundance and distribution of floating kelp rafts is closely linked to their supply, persistence at the sea surface, and the local current regime. Some of the observed variability in raft abundance might also be caused by inter-annual variations in both supply and persistence of floating kelps in a particular area. Most previous studies have either examined the temporal abundance of floating kelps at specific sites or the spatial distribution during single sampling dates. While these data provide important insight in the geographic occurrence of floating kelps, little is revealed about the temporal variation in their abundance. Herein we examined the spatio-temporal distribution of floating kelps in an extensive area with abundant supply from benthic source populations (see e.g. Dayton, 1985).

The Interior Sea of Chiloé and Los Chonos Archipelago in southern Chile consist of a highly fragmented landscape with large kelp beds of *Macrocystis pyrifera* and *Durvillaea antarctica*. Bull kelp *D. antarctica* only grows on exposed hard bottoms (Westermeier et al., 1994), but *M. pyrifera* can be found in moderately exposed bays on the outer coast and also in more protected areas of the inner channels and fjords (Dayton, 1985; Westermeier and Möller, 1990; Buschmann et al., 2004, 2006; Graham et al., 2007). Furthermore, *D. antarctica* is limited to the intertidal and shallow subtidal zone, while *M. pyrifera* occurs from the intertidal zone down to about 20 m water depths (Dayton, 1985; Hoffmann and Santelices, 1997). Populations of *D. antarctica* decrease during the winter months (Westermeier et al., 1994). Similarly, entire kelp beds of *M. pyrifera* disappear during winter in the interior channels and bays but redevelop during the following spring (Buschmann et al., 2006). Based on this information, it was hypothesised that the populations of floating kelp show a seasonal pattern with high abundances in winter when benthic populations decrease in abundance.

The Interior Sea of Chiloé and Los Chonos Achipelago is characterized by complex oceanographic processes (e.g. Cáceres et al., 2003; Valle-Levinson and Blanco, 2004; Sievers and Silva, 2006; Valle-Levinson et al., 2007), usually with strong surface currents (>40 cm s^{-1}, Salinas and Hormazabal, 2004; Cáceres et al., 2006). Furthermore, a recent review (Sievers and Silva, 2006) indicated that net surface currents in seaward direction are supported by freshwater influx from continental sources (see also Cáceres et al., 2002; Castillo et al., 2006; Valle-Levinson et al., 2007). This suggests that floating kelps can be rapidly transported over relatively large distances. The general current patterns, in combination with strong westerly winds, may lead to the accumulations of floating kelps in certain areas, possibly near the opening of channels and fjords. This could have important consequences for the population connectivity of organisms that depend on rafting on floating kelps for dispersal.

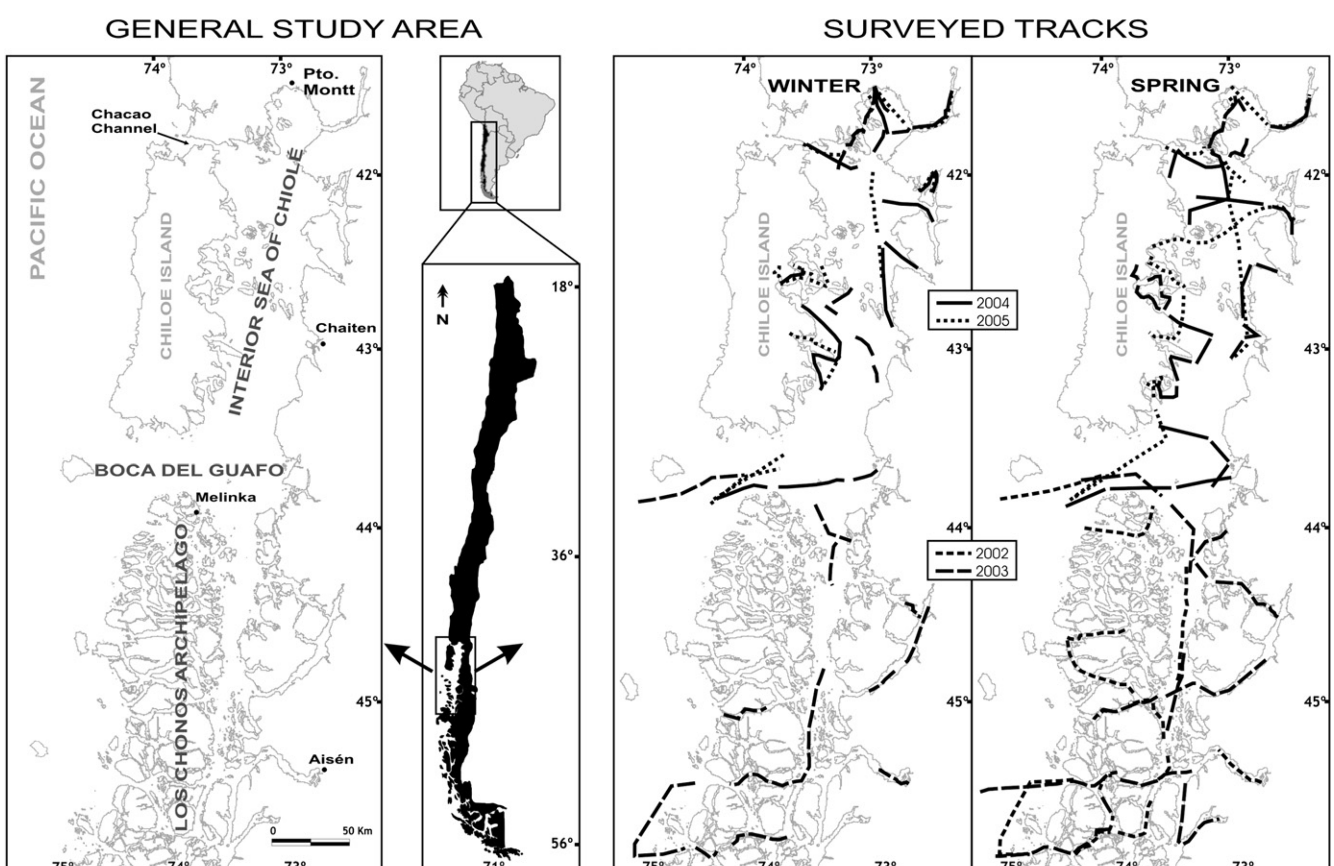

Fig. 1. General study area in southern Chile and surveyed tracks during austral winter and spring in each year.