The effects of the environment on the reproduction and early performance of the habitat-forming kelp *Ecklonia radiata* (C. Agardh) J. Agardh

Abstract

Many organisms display patterns in the intensity, frequency and synchrony of reproduction, which are influenced by the physical environment. Knowledge of how these environmental factors underpin reproduction and early life-stage ecology is critical to assessing the persistence of populations and the ecosystem services they provide. In marine systems, some of the major factors which are known to influence the reproduction of ecologically important seaweeds are sea temperature, light, nutrients and wave action. Kelps (Order: Laminariales) are the major habitat forming species on warm-temperate to polar subtidal reefs. Kelps have a biphasic, diplohaplontic, heteromorphic life cycle. Most kelp studies have focused on the ecology of the macroscopic sporophyte while comparatively little is known about their reproductive ecology and the ecology of the microscopic gametophyte stage. However, an understanding of the ecology of all life stages is required to understand the dynamics and persistence of populations. *Ecklonia radiata* is the major habitat-forming kelp in temperate Australia where it plays a pivotal role in structuring shallow, inshore communities, by providing habitat and energy to higher trophic levels. Little is known about the reproduction of this ecologically significant species in Australia, and the role the environment plays in controlling it. Thus, the aim of this thesis was to determine spatial and temporal patterns in the reproduction of *E. radiata*, and to examine the possible role of environmental drivers of zoospore production and release, and early gametophyte growth and survival.

In order to study the early phase of the kelp life cycle it is necessary to collect zoospores for experimentation. World-wide there are 122 species, in 33 genera of kelps, and research has been undertaken to investigate the early life stages of many of these. The first chapter in this thesis aimed to review and compare zoospore release methods in order to advise on effective techniques. Literature from around the world was synthesised, and it was found that methodologies were disparate and highly variable. Various popular methods for spore release were selected and tested on *E. radiata*, establishing an effective protocol for this thesis. This chapter not only stands as a methodological chapter for this thesis, but highlights the importance of method standardisation in phycological research.

A particular knowledge gap exists in Australia concerning the timing of reproduction and possible synchrony of zoospore production in *E. radiata* populations. Reproduction is sensitive to fluctuations in the environment and alterations in the physiology of individuals. The main aim of the third chapter of this thesis was to identify patterns in reproductive timing of *E. radiata* and potential relationships with prevailing environmental conditions. This was achieved through the collection and quantification of zoospore release from sporophytes collected over a range of temporal and spatial scales. *E. radiata* exhibited strong seasonal periodicity, reproducing from mid-summer to the end of autumn, with synchronous production of zoospores in populations across spatial scales from 100's meters to 10's kilometers. The timing of reproduction coincided with increasing local sea temperature and wave exposure, and was related to thallus size. From the results of this chapter it was concluded that *E. radiata* undergoes synchronous reproduction which can be linked to its annual growth cycle and natural environmental fluctuations, so that propagules are released under favourable conditions for growth and survival.

Natural fluctuations in ambient environmental conditions influence the intrinsic characteristics of gametes, which define their ability to tolerate varied conditions. Thus, the aim of chapter four was to document temporal patterns in zoospore production, settlement densities, and gametophyte growth and survival across the period of reproduction, and to investigate whether these patterns related to environmental variables. Zoospores were collected every fortnight for 3.5 months and cultured in a range of temperatures, and gametophyte performance was assessed over this time. Survival and growth of gametophytes was compared to natural fluctuations in environmental conditions; such as sea temperature, day-length, light intensity, wave action and lunar cycle. Over the period of reproduction, *E. radiata* gametophytes revealed distinct patterns in performance. Growth rates of gametophytes were positively related to day-length, with the fastest growing recruits released when days were longest. Gametophytes consistently survived best in the lowest temperatures, yet exhibited optimum growth in higher culture temperatures. Since the season for reproduction occurred when *in situ* sea temperatures are at the highest for the year, it appears that an ecological trade-off is occurring. This trade-off gives priority to growth over survival, perhaps so that *E. radiata* can out-compete other species for space and quickly replenish populations.

Temperature influences the physiology and ecological performance of organisms, and since *E. radiata* in Australia has a broad distribution which spans a large temperature range it is likely that it has adapted or acclimatised depending on its biogeography. Therefore the aim of chapter five was to test the effects of temperature on *E. radiata* gametophytes to compare populations from warm- and cool-climatic conditions. Gametophytes were collected from three locations around temperate Australia (Western Australia, South Australia and Tasmania) and cultured over a temperature gradient to determine the thermal optima for survival and growth. There were differences in gametophyte growth and survival over the distribution of this species and the thermal tolerance of gametophytes could be related to patterns in local sea temperature. Gametophytes from warmer-climate populations tolerated a temperature range one degree higher than cool-water populations; however, cool-climate gametophytes grew considerably faster than those from northern populations. It is likely that *E. radiata* populations have acclimatised to the surrounding environment and may possess some ability to adapt to gradual changes in sea temperature.

In conclusion, this thesis has demonstrated that *E. radiata* undergoes synchronous reproduction, which is temporally aligned with *in situ* environmental conditions and varies only slightly over a range of spatial scales. When conditions were ideal, *E. radiata* commenced reproduction to ensure new sporophytes were ready to recruit into an environment favourable for growth and productivity. Increasing temperature appeared to be a driver for the onset of reproduction, and since *E. radiata* kelp beds are found in warmer waters than most other kelp communities, reproduction occurs outside the thermal optima for other kelp. The timing of reproduction was also linked with the onset of winter storms, and it is plausible that zoospores are scoured from plants at a time which allows for maximum dispersal. *E. radiata* gametophytes were also released when days were longest, so they were exposed to light for longer periods promoting increased photosynthesis and better growth and survival. *E. radiata* is reproductive at a time when environmental conditions support optimum dispersal, germination, and growth and survival of gametophytes and sporophytes, suggesting that the reproduction of this species is seasonally controlled. Future changes in the environment, such as those induced by human activities, have the potential to influence *E. radiata* through changes in reproductive synchrony and recruitment; however, in this research *E. radiata* displayed some ability for acclimation to changing thermal conditions.