Feasibility Study on the Ongrowing Potential for Periwinkles (*Littorina littorea*)

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Seafish Aquaculture

Marine Farming Unit, Ardtoe

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A report prepared for Highlands and Islands Enterprise.

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Summary

The periwinkle (*Littorina littorea* L.) fishery along the Scottish west coast is one of the largest in Europe and makes an important contribution to the local economy. There is concern, however, that the fishery may be under pressure, with a significant percentage of the hand gathered catch (5 - 20 % by volume) being too small for the market. There is at present no legal minimum landing size and animals below market size are either returned to areas on the shore which may be unfavourable for their survival, or discarded, constituting a waste of labour and resources.

Following enquiries from fishermen involved in gathering periwinkles, a three month study was conducted by Seafish Aquaculture to investigate the potential for ongrowing undersize animals and manipulating conditions to enhance growth rates. It became evident that benefits may also be gained from ongrowing commercial sized periwinkles and preliminary investigations were undertaken. The report summarises available information on growth rates, dietary requirements and culture conditions, together with observations on market sizes and seasonal price trends. Findings of some preliminary ongrowing experiments are also reported.

The growth rates on different dietary regimes, no supplementary feed, microalgae films, macroalgae and a combination of the last two diets, were measured at two periwinkle densities (600 m^{-2} and 1200 m^{-2}). The highest shell growth rates were achieved by feeding a seasonally abundant green seaweed (chlorophyte algae) *Ulva lactuca* (Sea Lettuce). However, it was found that growth also occurred without the provision of a supplementary feed, through grazing on microalgae which settled out from the natural seawater supply. The shell growth rates measured in the laboratory were higher than those reported in previous studies for wild populations and this was attributed to the opportunity for the periwinkles to feed continually, by being kept submerged throughout the trial, and the provision of an abundant food supply.

Large variations in individual growth rates, especially weight gain were found. These were considered to be related, in part, to differences between males and females and to individual spawning condition. Significantly greater shell length increments were achieved in segregated females and there was evidence to suggest that growth was reduced in mixed sex treatments. Consequently, population growth rates may be affected by manipulating sex ratios. Intra-specific competition (between individuals of the same species), parasitic infection and geographic population differences may also be important for determining individual growth rates

The growth rates obtained under the experimental conditions indicate the potential for ongrowing and manipulating environmental conditions to enhance the growth of periwinkles. However, a number of seasonal constraints, growth rate, market price, and availability of algae, have been identified and require further consideration before effective ongrowing strategies are developed.

Recommendations for future studies include trials investigating the growth rates of undersized, small and medium size grades of periwinkle on a pilot commercial scale over a twelve month period and elucidating the full significance of the seasonal factors identified above. Without further work, no substantive recommendations can be made to the industry.

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1.0 Introduction

1.1 General Biology

The periwinkle *Littorina littorea* (Linnaeus 1758) also known as the edible periwinkle or winkle, is one of the most abundant and widespread prosobranch molluscs on temperate shores. The adults of this species are easily identified by their smooth, opaque, predominantly spiralled, and relatively large shell, which can be black, brown-black, brown, grey, orange or white, the older whorls often erode to a light fawn or ash colour. (Fretter and Graham, 1980). Juveniles are more difficult to identify, having a crenulate shell, and are sometimes mistaken for the rough periwinkle *Littorina saxatalis*. They can, however, be distinguished by several characteristics, particularly the alternate light and dark banding on the outer lip of the shell (Fish and Fish, 1989).

On European shores, periwinkles are widespread extending from northern Spain to the White Sea (see Fretter and Graham, 1980 for a review). They are also distributed along the northeastern seaboard of North America, where they are generally found at higher densities than in European waters. Norton *et al* (1990) report that densities in excess of 200 m^{-2} are exceptional in the UK, while many estimates from across the Atlantic are in excess of 400 m^{-2} (Petraitis, 1987). This difference is thought to be a result of less competition from other species in North America , most notably limpets (Carlton, 1982).

Typically, they are most abundant on sheltered to moderately exposed, fractured rocky shores which have an abundance of algae, thereby providing areas which retain moisture. They also occur on sandy shores where conditions permit the firm attachment of seaweed and in brackish waters down to salinities of 10 $^{o}/_{oo}$ (ppt, parts per thousand) (Rosenberg and Rosenberg, 1973). The hight on the shore at which periwinkles may be found varies from area to area and is partly dependent upon shore exposure and weed cover

(Lubchenco, 1983). Their distribution centres on Mean Low Water Neap Tide (MLWNT), but can extend up the shore to High Water Spring Tide (HWST) on exposed coasts. At higher latitudes they are commonly found subtidally (Fretter and Graham, 1980).

Periwinkles are relatively long-lived (up to 20 years) and can spawn during most of their adult life. Maturity is thought to occur 12 to 18 months after settlement when a shell length of approximately 11 mm is attained. Breeding and spawning in UK populations occurs from January until June, peaking in April (Moore, 1937; Williams, 1964; Fish, 1972, 1979). The sexes are separate, and the males are identified during the spawning season by the presence of a penis on the right hand side of their body (Figures 1 and 2). Fertilisation of eggs is internal and females deposit them in pelagic capsules 1 - 2 hours after copulation. Upon release, the egg capsules swell osmotically and burst after 5 - 6 days, releasing planktonic veliger larvae which feed on the plankton for 4 - 7 weeks. Settlement on the shore takes place during the first six months of the year, mainly in early summer.

They are opportunistic herbivores, able to graze both macroalgae and microalgae on the surface of rock, mud and sand (Hylleberg and Christiansen, 1978; Watson and Norton, 1985a). They do, however, prefer to graze preferentially on some algal species, especially ephemeral fast growing ones such as *Ulva lactuca* (Sea Lettuce), *Porphyra umbilicalis* (Purple Laver) and *Enteromorpha* spp., all of which are easily digested and assimilated because they have a relatively poor capacity for chemical and mechanical defence (Watson and Norton, 1985b; Norton *et al*, 1990; Wilhelmsen and Reise, 1994). Brown algae, such as *Ascophyllum nodosum* (Knotted or Bubble Wrack) and perennial reds such as *Corallina officinalis* and *Mastocarpus stellatus* are either repellant or relatively indigestible and are avoided (Norton, 1986; Imrie *et al*, 1989). However, it has been shown that the certain parts of a plant, such as the frill margins of *Laminaria saccharina*, juvenile plants and sporelings of other brown algae may be more attractive to periwinkles than tougher, older material (Clokie and Boney, 1980; Lein, 1980, 1984; Lubchenco, 1978, 1983; Watson and Norton, 1985a; McKay and Fowler, 1996).

As generalist grazers (Norton *et al*, 1990) periwinkles have been used as a biological control to remove fouling organisms on oyster rearing trays (Enright *et al*, 1983). They may incidentally feed on sessile animals and egg masses (Frey, 1980). Davies *et al* (1992) also showed that the mucous trails they produce may be an important, but short-lived, source of food.

Watson and Norton (1985a) report that periwinkles will selectively feed on preferred food items even when these are scarce, or when they are grazing upon cast-up flotsam. This behaviour has been directly related to enhanced feeding and growth rates (Watson and Norton, 1985a; Martinez, 1985).

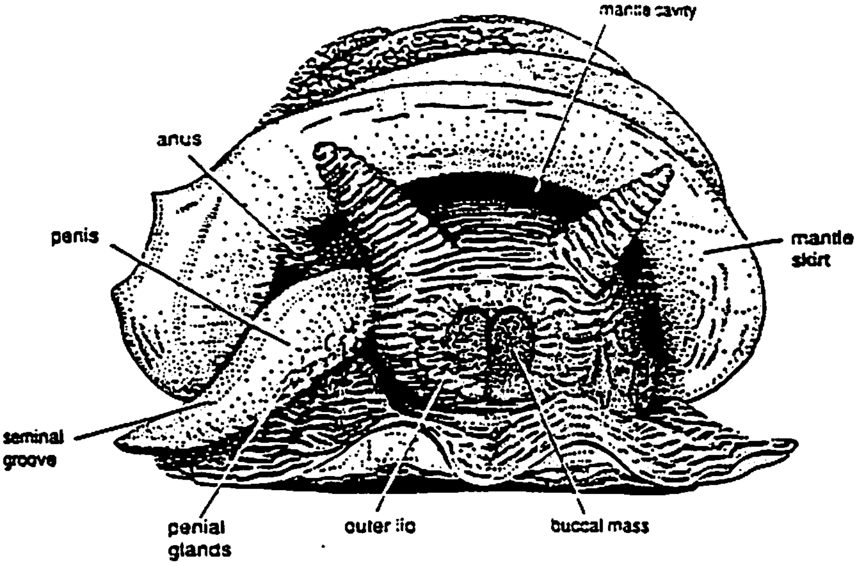


Figure 1 A male periwinkle viewed from the front (Taken from Fretter and Graham, 1962).

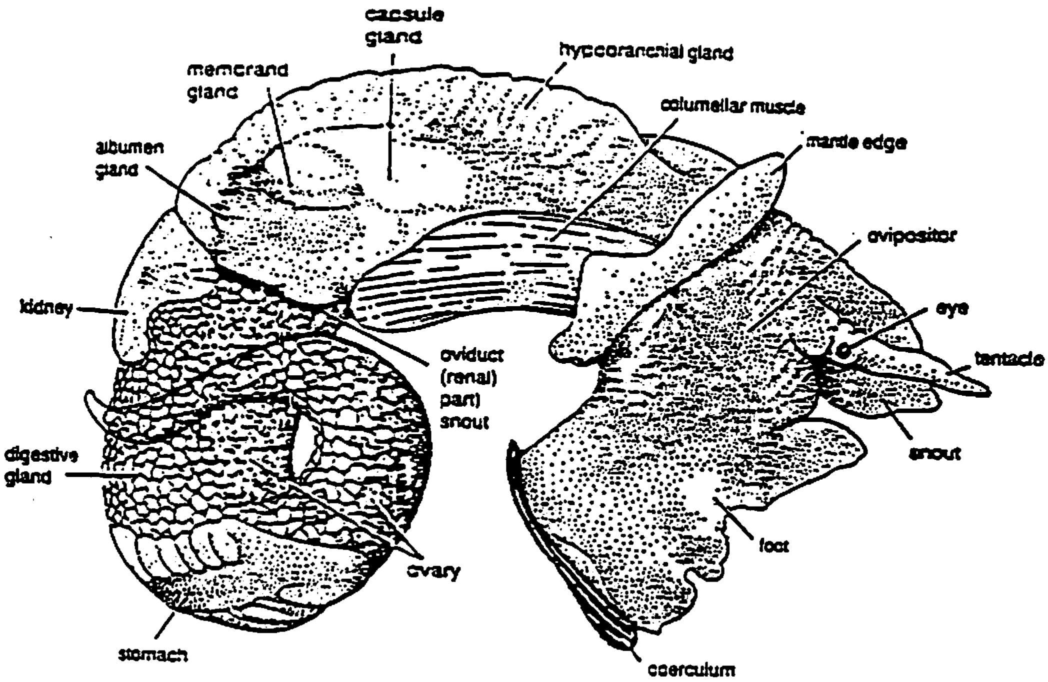


Figure 2 Female periwinkle with the shell removed and viewed from the right-hand side (Taken from Fretter and Graham, 1962).

Activity is greatly influenced by tidal cycle and season. They breed and feed when immersed, normally at high tide, or when damp conditions prevail (Little, 1989). They may, therefore, continue to feed for a short while following aerial exposure but eventually aggregate in pools and crevices to avoid desiccation (Newell *et al*, 1971). The grazing activity of populations at northerly latitudes is high during the summer and low during the winter months (Lein, 1984). Milder temperatures in more southerly areas of the UK are thought to allow continuous levels of grazing all year round (Norton *et al*, 1990). Grazing by periwinkles can have profound effects upon the abundance and diversity of algal species on the shore, especially in sheltered areas. Such activity has been considered during studies investigating the dynamics of rocky shore communities (Pertraitis, 1983; Hawkins and Hartnoll, 1983; Janke, 1990).

Littorina littorea populations acclimatise to prevailing local salinities (between the limits of 10 - 35 $^{o}/_{oo}$) but appear poorly adapted to withstand sudden osmotic shocks when placed in salinities to which they have not been previously exposed). They have a wide tolerance to temperature, which is greater in air than in water, with heat coma occurring after prolonged exposure to air temperatures greater than 32 °C and death occurring at 42 °C (Fretter and Graham, 1962; Arnold, 1972; Rosenberg and Rosenberg, 1973).

1.2 The Fishery

The earliest records of the existence of a periwinkle fishery in Scotland date back to the late 1800's, when they were marketed through Billingsgate in London. Today however, most are exported to markets on the continent; mainly those in France, Spain, Holland and Portugal (McKay and Fowler, 1996).

Periwinkles must meet the End Product Standards defined by the European Directive on Shellfish Hygiene (91/492/EEC), and wholesalers must obtain approval from the Environmental Health Department of the Local Authority before placing products onto the market. However, there is no requirement limiting collection to Classified Shellfish Harvesting Waters (79/923/EEC).

Gathering is unregulated, occurring throughout the year with the periwinkles typically sold to merchants who grade them by size and sell by weight.

The accuracy of official fishery statistics has been questioned. Figures presented in the 1995 Scottish Office Sea Fisheries Tables (SOAEFD, 1996) identify periwinkles as the sixth most important species in terms of tonnage and the seventh in terms of value within the whole Scottish fishery, but this is thought to be a gross under-estimate. McKay and Fowler (1996) estimated total landings in Scotland during 1995 to be around 4700 tonnes, more than twice the quantity officially reported. Data for the landings for the UK as a whole and the individual Scottish Fishery Districts, together with values for the catch, between 1991-1995 are shown in Tables I and II, respectively. It is evident that the largest fisheries are located along the Scottish west coast and around the Western Isles. However, McKay and Fowler (1996) present a more detailed analysis of the regional variations throughout Scotland, based largely on estimates, and it is apparent that the fishery is economically important in many other areas.

Table I Periwinkle Landings in the UK

	Quantity ('000 Tonnes)					Value (£ million)				
	1991	1992	1993	1994	1995	1991	1992	1993	1994	1995
UK	2.3	2.0	1.9	2.3	2.4	1.2	1.2	1.1	1.6	2.0
England & Wales	0.1	0.1	0.1	0.1	0.2	-	-	-	0.1	0.1
N. Ireland	0.1	0.1	0.1	0.1	0.1	-	0.1	-	-	0.1
Scotland	2.1	1.8	1.7	2.1	2.1	1.2	1.1	1.1	1.5	1.8

The state of the Scottish fishery is poorly defined with the majority of the official information being anecdotal. While there appears to be mixed opinion on whether specific periwinkle populations are being recruitment over-fished, there is general evidence to suggest that they are being growth over-fished, with a greater percentage of small animals appearing in the catch. A solution to regulate the fishery would be to introduce a legal minimum landing size, but this is not currently proposed by the regulatory bodies (McKay and Fowler, 1996). The market exercises the only control mechanism; periwinkles of less than 13 mm shell height have no economic value, hence they are either not collected or discarded at grading.

1.3 Potential Benefits of Ongrowing

Interest in ongrowing gathered periwinkles before sale is relatively recent. Historically, the animals commanded a relatively low value and were found in abundance throughout Scotland, sustaining small-scale local exploitation. However, the fishery has expanded greatly with a resultant limitation of supply. Consequently, the benefits to be gained from ongrowing may now provide an incentive for developing a commercial system.

McKay and Fowler (1996) raised concerns about the impact that this practice may have upon the future sustainability of the wild fishery given that undersized periwinkles are thought to make a significant contribution to stock recruitment (Robson and Williams, 1971). However, the act of dumping vast quantities of periwinkles discarded after grading could have a detrimental effect upon the environment and may not allow the survival of

Table II Periwinkle landings in Scotland by Fishery District: quantity and value of landings (From: Scottish Sea Fisheries Statistical Tables 1995. Crown copyright.).

District	Quantity (tonnes)					Value (£'000)				
	1991	1992	1993	1994	1995	1991	1992	1993	1994	1995
Eyemouth	192	128	162	115	121	84.8	55.6	73.0	62.5	60.7
Pittenween	66	39	133	94	90	25.8	14.0	43.3	46.4	51.8
Arbroath	52	39	61	59	-	23.9	19.1	30.1	28.3	-
Aberdeen	-	-	-	-	-	-	-	-	-	-
Peterhead	-	6	6	-	1	-	1.2	1.1	-	-
Fraserburgh	-	-	-	-	-	-	-	-	-	-
Macduff	1	3	-	-	-	0.3	1.2	-	-	-
Buckie	2	-	-	-	12	0.6	-	-	-	5.9
Lossiemouth	20	5	-	-	-	10.1	2.3	-	-	-
Wick	22	7	-	--	-	11.2	3.5	-	-	-
Orkney	8	14	14	23	29	4.0	1.5	6.7	13.1	18.8
Shetland	18	4	13	12	9	7.0	1.8	5.1	4.9	4.3
Stornaway	301	244	265	298	500	206.9	167.1	203.5	241.7	516.8
Kinlochbervie	3	-	-	-	-	1.6	-	-	-	-
Lochinver	5	1	-	-	-	2.2	1.0	-	-	-
Ullapool	20	8	-	-	71	10.3	5.2	-	-	54.0
Mallaig	378	418	416	451	551	274.9	312.4	305.5	348.1	414.0
Oban	306	214	150	502	464	130.7	99.8	93.3	428.7	435.8
Campbeltown	267	353	249	308	102	165.1	205.5	168.9	163.3	85.3
Ayr	391	354	239	190	188	217.1	195.1	139.9	119.9	136.0

the stock (Lubchenco, 1978; Lein, 1980, 1984; Pertraitis, 1983, 1987; Hawkins and Hartnoll, 1983; Bertness, 1984; Norton et al, 1990). Refusal to buy small animals from pickers has not, however, completely prevented their collection. Potentially, this constitutes a significant waste of labour and harvest resources unless they can be ongrown or restocked in favourable areas.

Seasonal fluctuations in market price and differences in the value of size grades are other important factors in considering the feasibility of commercial ongrowing. Periwinkles command a low value during certain periods of the year and there is interest in retaining them until they can be sold at a premium. Additional benefits gained as a result of ongrowing are that certain larger grades command a higher price and a greater biomass of animals should be generated.

Information on growth rates, dietary requirements and suitable ongrowing conditions, along with market sizes and seasonal trends in price, are required to determine the economic feasibility of ongrowing enterprises. This report presents preliminary findings regarding the above and discusses future options for the ongrowing of the species.

2.0 Determining Target Growth Rates

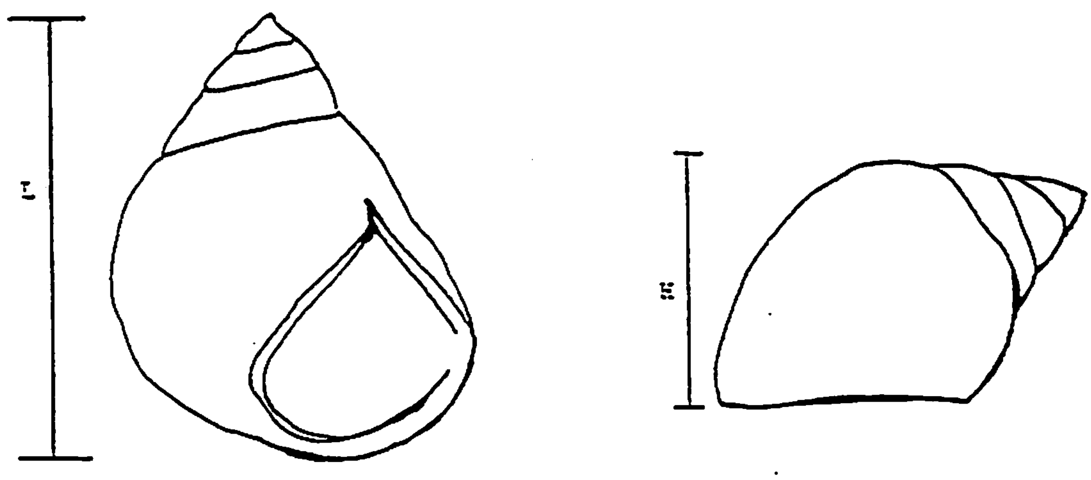
2.1 Introduction

Commercial grading operations typically produce up to five size classes of periwinkles; undersize, small, medium, large and extra large. Markets do not exist for either the undersize or extra large animals, in the latter case due to the high shell to body weight ratio. If commercial benefits are to be gained by ongrowing periwinkles there is a need to determine the relative size range of individuals within each graded class and the growth required to optimise the economic return.

2.2 Materials and Methods

Thirty periwinkles from each of the five graded size classes were sampled from a merchant's stock sourced from throughout Scotland. Vernier calipers were used to measure both shell length (from the apex of the shell to the anterior margin of the aperture) and height (from the dorsal point of the body whorl to the base of the snail) to the nearest 0.1 mm (Figure 3). Length is the main criterion used for measuring growth in wild populations while height is ultimately the criterion used for commercial grading. Individual wet weights were measured to the nearest 0.01 g and used to determine the number of animals per kg wet weight. The data were used to calculate the mean size range for each parameter and hence the increment required to ongrow periwinkles to the next size grade. The additional gross wet weight gained by ongrowing was also determined. The assessment of seasonal market trends was undertaken through collation of data supplied by shellfish merchants for the period June 96 - July 97.

Figure 3 Shell length (L) and shell height (H) measurements taken for each graded size class



2.3 Results

The mean and range for all parameters within each size class measured are presented in Table III. The data clearly show the smallest shell dimension in all grades to be height, the minima being 9 mm for undersize, 13 mm for small, 15 mm for medium, 16 mm for large, and 17 mm for extra large. The range of sizes indicate a considerable overlap between classes and large variations in individual shell size (both height and length) and wet weight within each grade.

Table III Mean (+/- SD) (n = 30) and range of wet weight, shell length and shell height for periwinkles from each graded size class.

Grade	Wet Weight (g)		Shell Length (mm)		Shell Height (mm)	
	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
Undersized	2.76(0.63)	1.47-3.97	18.4(1.7)	14.0-21.1	12.5(1.2)	9.1-14.8
Small	4.15(0.52)	3.31-5.18	21.5(1.2)	19.0-23.6	14.0(0.8)	12.8-15.7
Medium	6.02(0.13)	4.31-9.81	25.1(2.3)	22.2-30.4	16.0(1.0)	14.9-18.7
Large	8.32(1.40)	5.92-11.83	28.6(2.0)	24.0-33.1	17.9(1.1)	16.3-21.1
Extra large	12.11(3.05)	7.69-21.10	32.9(2.8)	27.4-41.0	20.3(2.1)	16.8-24.8

The mean individual growth increments in wet weight, shell length and shell height required to raise periwinkles to the next graded size were calculated using the mean values (Table IV). The requirements generally increase with increasing size grade. However, due to the decreasing number of individuals per kg as their size increases, the gain in gross weight reduces in comparison with the smaller grades.

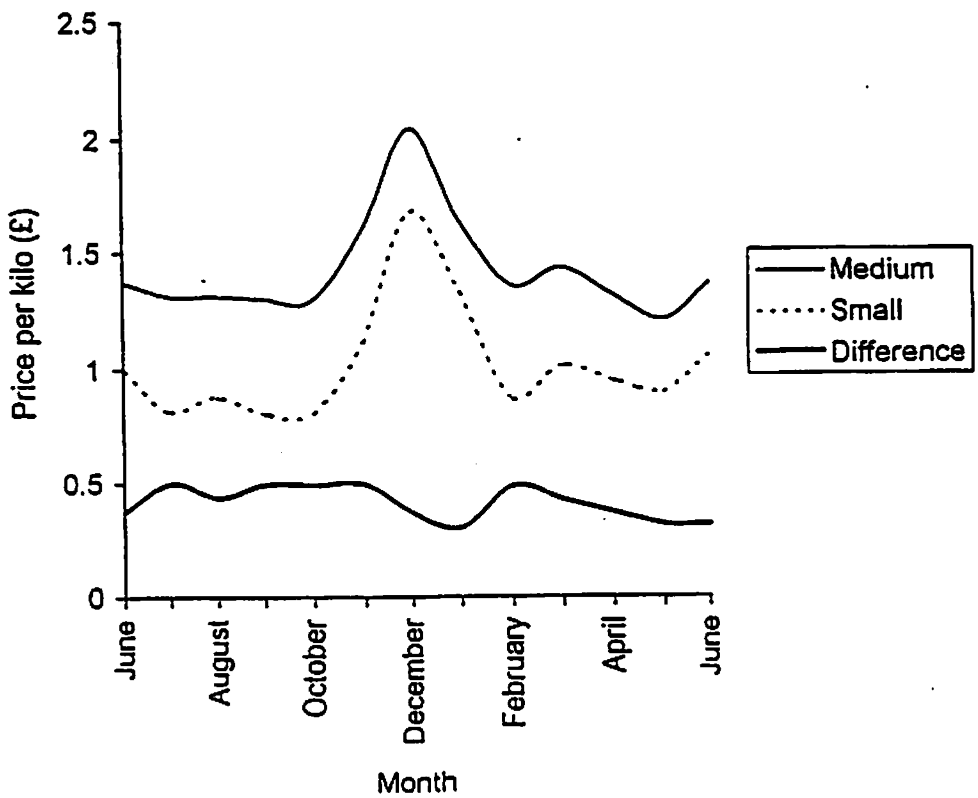
The average price of periwinkles during 1995 based on official statistics (SOAEFD, 1996) was £ 857 per tonne. These do not however, reflect differences in price between size grades and seasonal price fluctuations. Figure 4 indicates the seasonal trends in value for small and medium sized animals during 1996/1997 and the relative price difference between them. Both groups follow a similar seasonal pattern, increasing rapidly during the autumn to a peak in December and falling through the spring to a fairly stable baseline over the summer. The price differential between grades is greatest during the late summer and autumn and decreases around Christmas, when the demand for periwinkles is at its peak.

Table IV Mean individual wet weight and shell growth increments required to grow undersize, small and medium periwinkles to the next larger size grade. The corresponding gross weight increase based on an initial wet weight of 1 kg of periwinkles is also presented.

Grade at start and finish	Individual Growth Increments			Gross Weight Increment (kg)
	Wet weight (g)	Shell length (mm)	Shell height(mm)	
Undersize to small 360*	1.39	3.1	1.5	0.500
Small to medium 240*	1.87	3.6	2.0	0.449
Medium to large 167*	2.30	3.5	1.9	0.384

* Initial number of periwinkles in 1 kg

Figure 4 Seasonal trends in value for small and medium size grades of periwinkle during 1996/97 and the relative price difference (£ kg^{-1}).



3.0 Optimising conditions for growth

3.1 Introduction

Many studies have shown that periwinkle growth rates are strongly influenced by habitat and environmental conditions. This has been demonstrated by transplanting animals from geographically separated populations to common sites and obtaining similar figures (Frey, 1980; Behrens Yamada, 1987). These findings have important implications for ongrowing since stock is collected from many areas throughout Scotland. However, these regional variations should not restrict potential operations provided suitable environmental conditions can be supplied.

The familiar green seaweeds, *Ulva lactuca* and *Enteromorpha* spp., are widely distributed and proliferate in areas of high nutrient availability during the spring and summer. Both are preferentially grazed by periwinkles, but *Ulva lactuca* appears to be the best candidate as an on-growing diet; it is readily available and easily manipulated by the animals. In addition, enhanced rates of feed consumption have been achieved in abalone (*Haliotis discus*) by feeding *Ulva* spp. alone (Harada and Kawasaki, 1982).

Population density has been shown to affect growth rates in natural populations, with competition for resources acting to limit growth at higher values (Sherreli, 1981). High densities can also prevent the re-settlement of a food source, for example areas of *Enteromorpha* can be completely cleared from the shore (Pertraitis, 1983) in comparison to lower densities where a sustainable supply of the food is maintained (Sherrelli, 1981). Consequently, there is a need to determine optimum on-growing densities in relation to feeding regime and competition between individuals.

Growth is also influenced by the time available for feeding. Increased growth rates found in animals lower down the shore have been attributed to there being an opportunity for longer feeding periods when submerged (Behrens Yamada and Mansour, 1987; Pertraitis, 1987; Janke, 1990), although greater food availability may also be a factor.

The actual rate of food consumption (feeding rate) also affects the growth rate. This in turn is influenced by position on the shore and by temperature. Individuals further up the shore consume food quicker than those lower down (Petraitis and Sayigh 1987), which may serve to compensate for shorter periods of immersion, and the rate of feeding at 5 °C has been shown to be 50% of that recorded at 15 °C (Barker and Chapman, 1990).

Given the various factors which influence the growth rates, there is a need to determine optimal feeding regimes and ongrowing conditions. For the purposes of this preliminary study, it was decided that dietary requirement was the most important factor and consequently trials were conducted to determine the effects of different dietary regimes upon growth.

3.2 Materials and Methods

A typical mixture of undersized, small and medium periwinkles (50 %, 48 % and 2 % respectively) were obtained from a merchant and the shell dimensions and wet weights measured. They were placed in Northwest Plastic Trays ™ (6 mm mesh size, 0.25 m^{-2} floor area), stacked four high, with an additional empty tray on top which served as a lid, in a raceway tank (5 m x 0.75 m x 1.5 m) supplied with seawater at ambient temperature (7.9 - 11.8 °C). The experiment was conducted from 7 th May until 28 th May 1997 (21 days). Two densities were tested on four types of food regime with two replicates for each combination. The densities were 600 m^{-2} (150 animals per tray or 0.5 kg wet weight per tray) and 1200 m^{-2} (300 animals $tray^{-1}$ or 1.0 kg wet weight $tray^{-1}$) and the four feeding regimes were:

a) No supplementary feed - 'No food'
It was assumed that the periwinkles would be restricted to grazing upon water borne organisms which settled on to the tray or shells.

b) Micro-algal diet - 'Film only'
Heavily (1 mm thick) algal fouled tray replaced once per week.

c) Macro-algal diet - '*Ulva* only'
Fresh *Ulva lactuca* fed at 150 g (wet weight) per week.

d) Macro/Micro-algal diet - '*Ulva* and Film'
150 g of fresh *Ulva lactuca* fed per week in a heavily algal fouled tray which was replaced once per week (as above).

The full 150 g ration of *Ulva* was added at the beginning of each week, with any remaining food being removed and weighed before fresh seaweed was added.

After 21 days, 25 periwinkles were sampled from each replicate treatment and shell length and wet weight measured. Mean growth increments were calculated for each replicate and these were pooled to give a population mean for each treatment. Data were analysed statistically by one-way analysis of variance, and when significant differences were shown, Tukeys test. Samples were also graded according to market size criteria and the percentage composition of each class was calculated for each treatment.

3.3 Results

The initial mean shell length and wet weight of the animals at the beginning of the experiment were 19.3 mm and 3.2 g respectively.

Table V shows the mean wet weight (g) of macro-algae eaten by the replicates for both density treatments (600 m^{-2}, 0.5 kg per tray and 1200 m^{-2}, 1.0 kg per tray) in which the supplementary feed was provided ('*Ulva* only' and '*Ulva* and Film'). The amount of algae eaten varied from week to week with the higher density stocks consuming the entire ration on several occasions.

Table V Mean weight (g wet weight) of algae, *Ulva lactuca*, consumed in feed treatments at two densities.

Treatment	Week 1	Week 2	Week 3
Ulva only, 600 m^{-2}	86	145	105
Ulva only, 1200 m^{-2}	127	150	148
Ulva and Film, 600 m^{-2}	72	132	123
Ulva and Film, 1200 m^{-2}	150	150	150

Figures 5 and 6 show, respectively, the mean shell length and wet weight increments after 21 days for each density and diet treatment. Large variations in growth increment, especially increase in wet weight, were observed as illustrated by the length of the standard error bars for some of the population means. Statistical analysis showed that at the higher density, the shell length increment in the 'No Food' treatment was significantly smaller ($P < 0.005$) than those in the other diet treatments.

Tables VI shows the percentage composition of each graded size class at the start of the experiment and the results for each diet and density after 21 days. In all treatments there was an increase in the percentage of small and medium sized periwinkles over those recorded at the start, with the *Ulva* fed treatments at the higher density showing the highest percentage of medium sized animals.

Figure 5 Mean (+/- SE) shell length increments (mm) after 21 days for periwinkles in different density and dietary treatments.

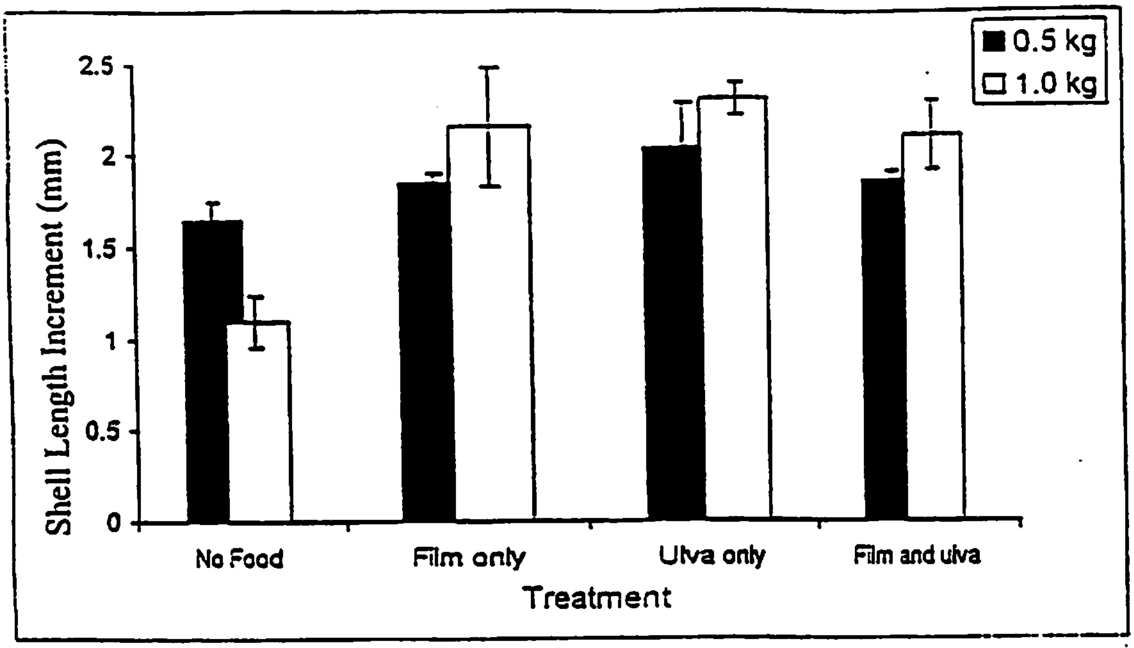


Figure 6 Mean (+/- SE) wet weight increment (g) after 21 days for periwinkles in different density and dietary treatments.

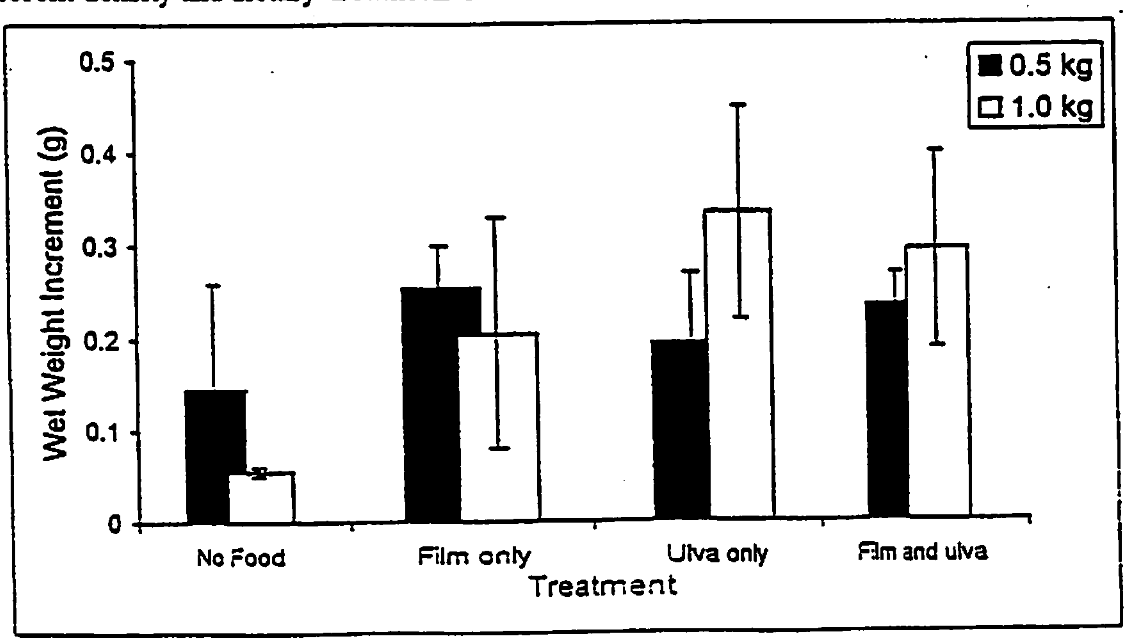


Table VI Percentage composition of each graded size class (n= 50) at the start of the experiment and after three weeks in the low (600 m^{-2}) and high density (1200 m^{-2}) diet treatments.

Treatment	Undersized	Small	Medium	Large
Initial Composition (%)	50.00	48.0	2.0	0.0
Final composition (%) Low density (600 m^{-2})				
No food	12.0	82.0	6.0	0.0
Film only	14.0	78.0	8.0	0.0
Ulva only	12.0	72.0	16.0	0.0
Ulva and Film	10.0	80.0	10.0	0.0
High density (1200 m^{-2})				
No food	18.0	80.0	2.0	0.0
Film only	8.0	82.0	10.0	0.0
Ulva only	8.0	70.0	22.0	0.0
Ulva and Film	10.0	74.0	16.0	0.0

4.0 Determining the Potential for Growth

4.1 Introduction

Periwinkles are graded by size and sold by weight. Growth rate data are therefore required to determine the optimum period to ongrow periwinkles to a larger size and net weight gain. While the rates of increase of both parameters are a function of environmental conditions, periwinkle density and food abundance, there are several studies which have shown that there are also associated seasonal patterns (Moore, 1937; Williams, 1964). Differences in absolute growth rate between males and females have been measured and attributed to changes in the energy budget at the onset of sexual maturity and during spawning and non-spawning periods (Moore, 1937; Grahame, 1973a and 1973b).

Most studies of cohorts (year classes) in wild populations have assessed annual growth rates in terms of shell length. Table VII shows estimates of annual shell length increments for different ages of periwinkle from several areas. While there is considerable variation in the data for size at age, all have reported a reduced rate of shell growth at sexual maturity. All sizes collected by the fishery, including those which are undersized, are likely to be sexually mature and therefore the amount of energy expended in reproduction may be an important consideration when assessing the potential for enhanced growth.

Table VII Annual shell length increment (mm) in wild populations of periwinkles from different locations.

Age				Reference
Year 1	Year 2	Year 3	Year 4	
9.5	6.0	1.0		Cousin (1975), Normandy
14.0	3.5	5.0	2.5	Moore, (1937) Plymouth
8.5	5.0	2.5	1.5	Williams (1964), Cardigan Bay
13.5	5.5			Robson and Williams (1971), Yorkshire

Annual growth rates recorded for sexually mature periwinkles (12 - 18 months old) do not appear encouraging when considering the potential for on-growing. However, a number of studies have shown that most of the annual growth in these individuals occurs during the 4 - 5 months (July - November) when they are not breeding or spawning. Higher temperatures and a greater abundance of food at this time of year are also thought to contribute to this period of maximum growth (Williams, 1964; Ekaratne and Crisp, 1984).

There is a seasonal variation in periwinkle flesh weight (body mass) to the shell size ratio. During late winter, prior to spawning, they achieve their highest body mass relative to the shell size, and are at their heaviest individual weight. This occurs due to energy being diverted to the development of gonads and the production of eggs and sperm at the expense of shell growth. During spawning in spring this weight is lost and the animals drop to their lowest body mass, and lightest individual weight, despite there being continued but slow tissue and shell growth. Both sexes show similar cyclical weight gain and loss throughout the year, but males generally have a lower body mass relative to their shell size than females. This pattern of weight increase and decrease could have implications for commercial returns, in terms of the gross weight marketed, at certain times of the year.

It has also been shown that the pattern of growth varies between the sexes. Moore (1937), examining three populations in Plymouth, reported similar, but slow, growth rates in males and females during the spawning season but found that females grew twice as fast as males when they were not spawning.

The current trials were conducted from March to May, and were therefore restricted to a period of the year when body tissue and shell growth was limited. It was also likely that tissue weight would be lost as a result of spawning.

In order to investigate the relative differences in growth rate between males and females and in comparison to a mixed sex population, on-growing trials were undertaken with the sexes separated. It was recognised that it would not be commercially viable to on-grow the sexes separately, but the results might be applied to wild populations with differing sex ratios and may also assist in the interpretation of whole population growth data.

Grahame (1994) has demonstrated enhanced growth rates during single sex on-growing in a closely related north European littorinid, *Lacuna vincta,* the Banded Chink Shell.

4.2 Materials and Methods

The experiment comprised three treatments, females only, males only and 'mixed' (1:1 ratio male:female) with each replicated twice. Animals were sexed by separating copulating pairs and microscopic examination (Saur, 1990). Each replicate was allocated 1 kg of periwinkles (approximately 300 animals) and was maintained in the conditions described in Section 3. The food ration was 150 g (wet weight) of *Ulva lactuca* per week. The wet weights and shell lengths in a sample of thirty periwinkles per replicate treatment were measured at the start of the trial and after 28 days (May 1st -

May 28th). Mean population growth increments and the size class composition were determined. Statistical analysis was completed as previously described (section 3).

4.3 Results

Analysis of initial shell length and wet weight data showed that there were no significant differences between treatments or between males and females at the beginning of the experiment ($P > 0.05$ for each criteria).

Mean population shell length and wet weight increments obtained after 28 days in each treatment are shown in figures 7 and 8 respectively. Statistical tests showed that the mean shell growth increment in the female only group was significantly greater than those for male only and mixed sex treatments, having grown 3.5 mm in shell length in comparison to 2.5 mm and 2.6 mm respectively ($P < 0.001$). It was also shown that the shell growth increment in the mixed sex group was less than the predicted value (derived from mean data for the female and male only treatments), indicating slower growth. This trend was also reflected in the percentage composition of each graded size in the different treatments (Table VIII).

Data for wet weight increase showed the same significant trend as that for shell length increment ($P < 0.005$, Figure 8). However, there were larger variations about the means for all groups and there was an apparent disparity between wet weight gain and shell length increment. The shell length increment reached the calculated target figure to on-grow the periwinkles to the next graded size class (see Table V), but the increase in wet weight was very much below its target value.

Table VIII Percentage composition of each graded size class (n = 30) in each treatment at the start of the experiment and after four weeks.

Treatment	Undersized	Small	Medium	Large
Initial composition (%)	40	55	5	0
Composition after four weeks (%)				
Females only	7	39	52	2
Males only	12	56	32	0
Males and Females	10	54	36	0

Figure 7 Mean (+/- SE) shell length increments (mm) after 28 days in single sex and mixed sex treatments, and the calculated shell length increment (mm) for the mixed sex treatment derived from the means of the single sex groups.

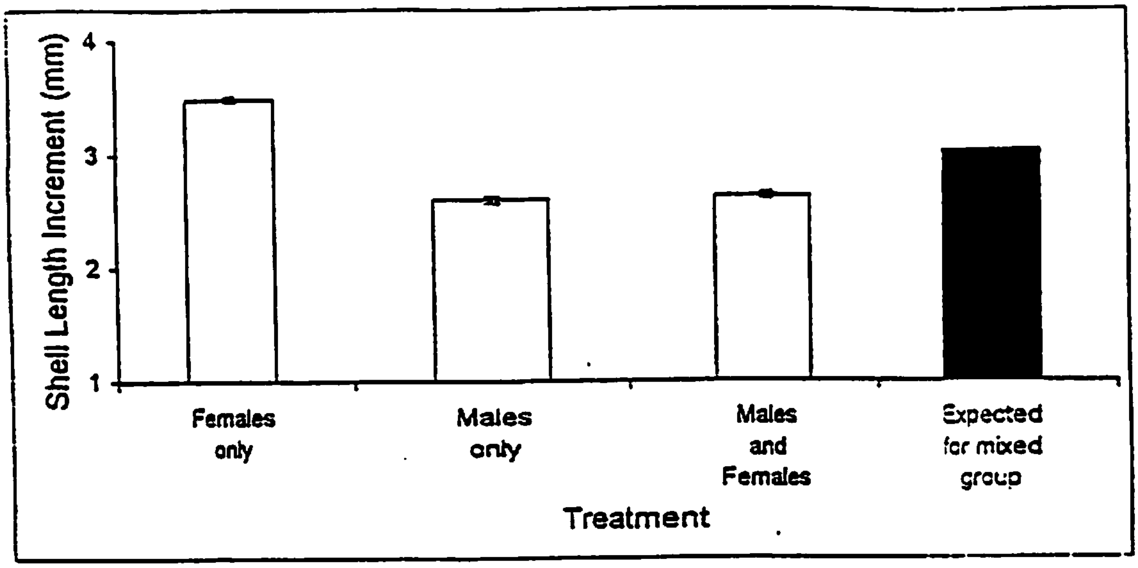
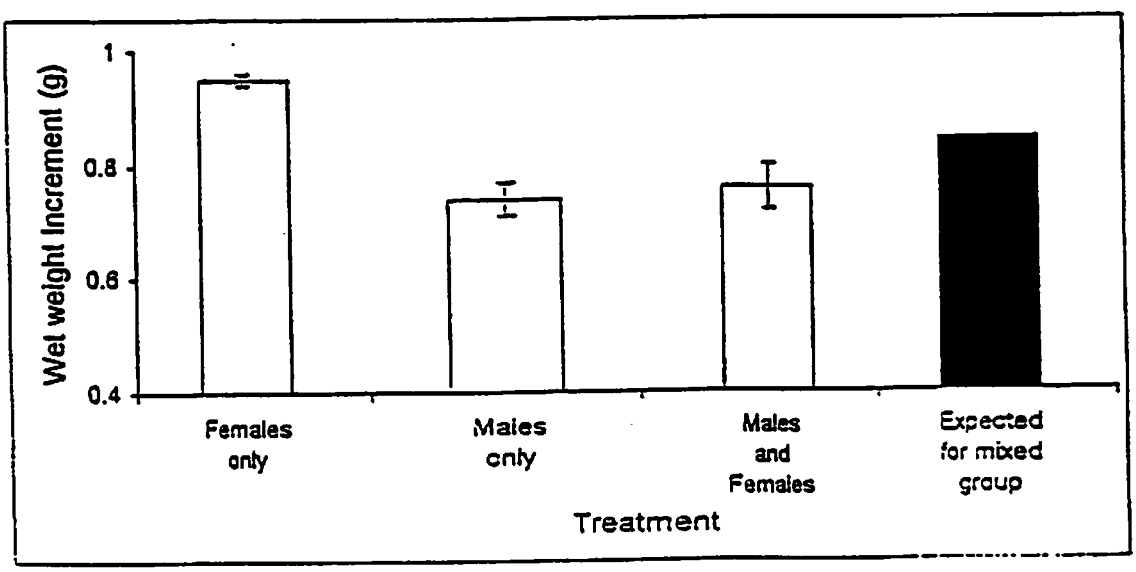


Figure 8 Mean (+/-SE) wet weight increments (g) after 28 days in single sex and mixed sex treatments, and the calculated wet weight gain (g) for the mixed sex treatment derived from the means of the single sex groups.



5.0 Discussion

The size range (wet weight, shell length and shell height) of each graded size class determined from the samples obtained from a local merchant closely resembled those previously reported for other areas (Burnell, 1996). However, large variations in all three measurements within each class and some overlap between the different grades were noted. It was also evident during the course of several visits that variations in size distribution within the graded size classes occurred in different deliveries of periwinkles. This may reflect the geographic area of collection and the method of grading. Such variation in size within each size class has important implications for on-growing periwinkles; some will require only a small increment of shell growth to reach the next graded size status, but others will require more substantial growth. An option to reduce the on-growing period, or increase its efficiency, may be to grade animals by shell size prior to and during on-growing. In this way, the suppression of growth of smaller individuals by competition from larger ones may be reduced and the harvesting of stock which have attained the target size would be permitted. However, the benefits which might be gained have yet to be evaluated and may be constrained by the large quantities of periwinkles required for commercial production.

Seasonal price fluctuations and the differential in value between graded sizes require consideration when determining the time of year which will confer the greatest benefits from ongrowing. At this early stage of the work, it is difficult to determine both the timing and which size class should be targeted; currently there are insufficient data relating to seasonal growth patterns and rates for the different sized animals.

Shell growth rates measured for undersized and small periwinkles during these trials were greater than those previously reported in field studies. Significant increments in shell growth were obtained after 3 - 4 weeks of intensive culture. Further increases in the rate of growth under similar conditions might be expected during the summer, when the majority of the stock are not breeding or spawning, ambient seawater temperatures are higher and food abundance is increased. The relatively high shell growth rates recorded may be attributed to the on-growing conditions, where continual immersion provided conditions for unrestricted feeding, and the provision of supplementary food. It was also found that periwinkles gained weight during the experiment, this contrasts with previous studies which reported weight loss during this time of year (Moore, 1937; Grahame, 1975). However, large variations in weight increment were seen and these may be explained either by differences in spawning stage of the animals or difficulties in consistently measuring individual wet weights. Taken together, these results demonstrate the potential for enhancing the growth of periwinkles by manipulating conditions and provide encouragement for commercial on-growing.

Results from the density and diet treatments are less clear. They suggest, however, that while the provision of food can increase shell growth rates, there is less benefit to be gained in terms of individual weight increment. For these trials, this may be attributed to the spawning state of the animals. Any increase in growth rate derived from supplementary feeding requires further evaluation to determine whether, and when, it is viable.

The quantity of algae eaten varied from week to week, with the higher density (1200 m^{-2}) replicates consuming the entire ration on several occasions. Whilst it was projected that 150 g of *Ulva lactuca* was sufficient to feed 1 kg of periwinkles for one week (15 % wet body weight), it is possible that the ration size was insufficient to support maximal growth on those occasions. This assertion is supported by the lower density stocks (600 m^{-2}) which consistently consumed proportionately more of the ration (ie > 50 %), averaging 73.7 % removal (minimum 48 %, maximum 97 %). Thus, increasing the amount of algae offered at the higher density may have further increased growth.

Ulva lactuca was shown to be a suitable food for enhancing growth rates in periwinkles. This algae is abundant on the shore, but only seasonally available. Work is required to determine whether it can be harvested during the summer, when it is abundant, and stored for use out of season.

The Northwest Plastic trays used for retaining the animals were ideal for ongrowing, providing a large surface area for grazing and an effective means of retainment. Further work will be needed, however, to develop the basic design for use on a commercial scale, where extensive on-growing may be required. Units which have been developed for the catching and extensive on-growing of juvenile spiny lobsters may provide some guidance (Jernakoff, 1993; Phillips and Booth, 1994; Reimers and Branden, 1994).

In general, good growth rates were achieved, but there was evidence of large variations in individual growth. This variance may have been the result of intraspecific competition. Understanding the effects of competition for food resources and the interaction between periwinkles of different sizes upon individual growth rates may have important implications for obtaining consistently high growth, by additional grading, in all sizes of animals and for developing optimal feeding regimes.

Differences in growth rates bought about by reproductive state and those apparent between males and females also require consideration. The implications of the indication that females grow faster than males and that this can be enhanced if the sexes are segregated during the spawning season should be investigated further. It is unlikely that sorting periwinkles by sex would be economically viable on a commercial scale, but the results show the additional benefit which might be gained by separating the sexes.

Parasitism by digenean flatworms could affect individual rates of growth (Robson and Williams, 1971). The literature, however, is contradictory. For example, Moore (1937) attributed accelerated growth in parasitized periwinkles to necrosis of reproductive tissues, but Huxham *et al* (1993) reported retarded growth in parasitized animals. Further, the level of infection is thought to increase exponentially with size and can vary between areas (Robson and Williams, 1971).

At present, the organisms can only be detected by detailed microscopic investigation of the soft tissues. Work is, therefore, required to develop a quick and reliable method for identifying parasitized periwinkles and to determine the significance of parasite infection for on-growing.

It should be noted, however, that parasitism is a natural feature of wild populations and has no implications for human health. Ongrowing stock will have no impact on the level or extent of such infection.

6.0 Conclusions and Recommendations

The growth rates demonstrated by these trials have indicated the potential for ongrowing periwinkles. However, there are a number of seasonal constraints to be considered before effective strategies for each graded size class can be developed for the industry, namely growth rate, algal food availability and price. At present, it would appear that the greatest benefit would accrue by on-growing from August through to November. This would allow the period of highest growth rate to be exploited and the best price obtained on harvest at the beginning of December. A full evaluation, however, would necessitate small commercial scale growth trials using undersized, small and medium sized animals over a twelve month period.

The variations in growth increment observed during the study indicate several factors which will have to be individually assessed to determine their implications for on-growing (i.e. competition, reproductive state, parasitic infection). In addition, while these trial conditions appeared favourable, optimum conditions, or the most cost effective methods of ongrowing, have yet to be determined. Further development of the facilities will be required to meet the needs and resources of the industry, which will have to on-grow on a much larger scale.

Recommendations for further work to determine the potential for pilot scale commercial development:

Primary

- Investigate the dietary requirements of periwinkles, determine the benefits of providing supplementary feed and examine feeding regimes.
- Investigate the effects of parasitism and intraspecific competition upon individual growth rates and determine optimum stocking densities.
- Determine seasonal patterns in growth for undersized, small and medium sized animals and evaluate the potential returns over a twelve month period to determine when during the year the greatest benefits accrue.
- Compare the shell morphology, dietary preferences and growth rate of geographically separated periwinkle populations to determine whether differences exist and their implications for on-growing different stocks.

Secondary

- Develop methods for harvesting and storing *Ulva lactuca*, and possibly *Enteromorpha* spp.

to ensure the availability of feed outside the summer season.

- Develop facilities suitable for commercial scale extensive ongrowing.

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