FIRTA 84/93

Hatchery Production of Scallop Spat for Large Scale Reseeding Trials

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1988

DEPARTMENT OF SEA FISHERIES TASMANIA.
MARINE LABORATORIES
CRAYFISH POINT, TAROONA
TASMANIA
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CONTENTS

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ABSTRACT

Scallop fisheries throughout Australia have been characterized by fluctuating harvests. This reflects the boom and bust nature of scallop fisheries worldwide. Tasmanias' scallop fishery is currently at the bust or collapsed stage. This project hoped to provide some insight into the potential biological and economic viability of producing scallop spat in a hatchery, ongrowing it for several months and then reseeding it onto the seabed. No large scale hatchery production has been realised yet and no large scallop beds have been established, however private companies have now begun to develop scallop culture techniques based on research work carried out by this department.

INTRODUCTION

Research work conducted during FIRTA 83/52 "Feasibility assessment of commercial production of two important shellfish (abalone and scallops)" gave an indication of the potential of scallops for mid-water cage culture. Subsequently, FIRTA 84/93 "Hatchery production of scallop spat for large scale reseeding trials" commenced in 1984.

Hatchery rearing of scallops, which had initially been investigated by Dix and Sjardin (1975) at the Taroona Fisheries Laboratory, and more recently at Shellfish Culture Pty Ltd at Bicheno, was further investigated. Problems of suitable broodstock, larval rearing and settlement, intermediate culture and reseeding were addressed. These aspects formed the basis for the aims of the project 84/93 which were: (a) To produce large batches of scallop spat *Pecten fumatus* under commercial hatchery conditions; (b) Comparison of intermediate nursery production techniques; and (c) Establishment of large scale beds of hatchery produced juvenile commercial scallops.

As much of the research work can be treated in isolation and is, or has been written up as separate reports, it is presented here in six sections dealing with hatchery culture and costings, intermediate culture and reseeding.

Temperatures were recorded 3 times during the day and additional food was added near midday and also late afternoon.

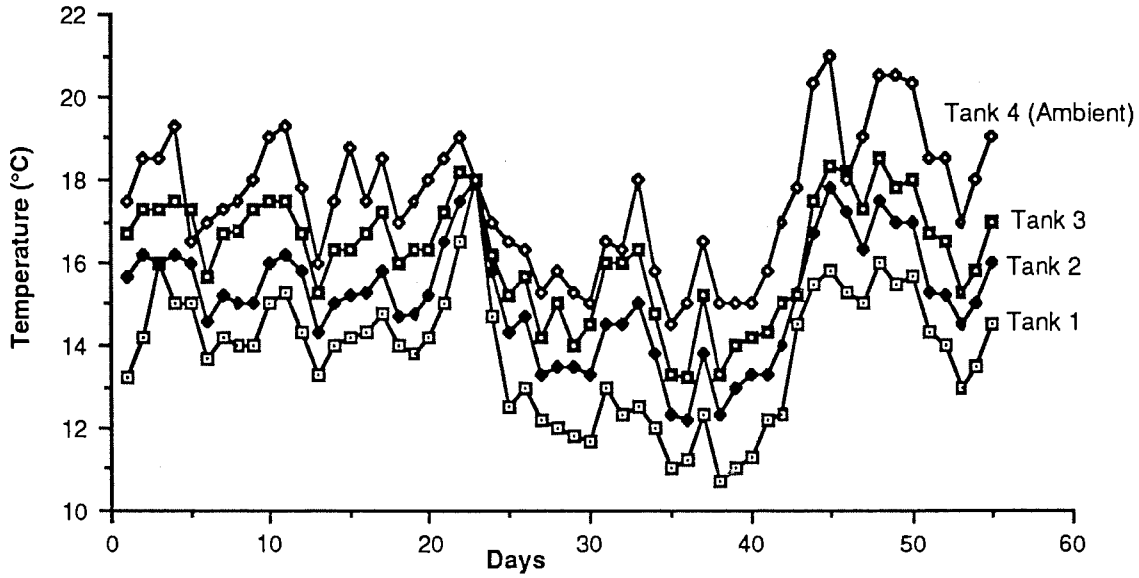

Figure 1. Water temperatures for broodstock, Experiment 1.

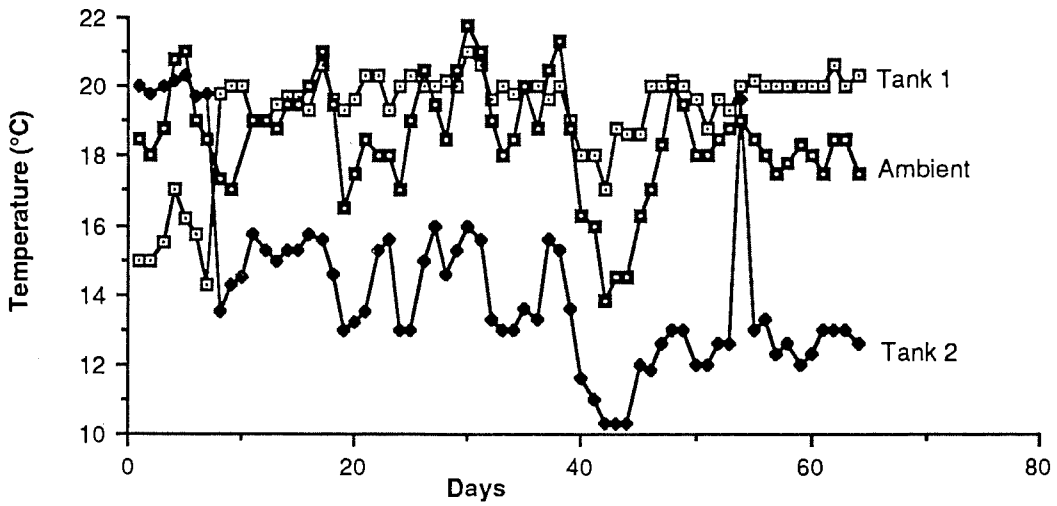

Figure 2. Water temperatures for broodstock, Experiment 2.

Gonad condition was scored each week by visual inspection of a sample of approximately 20 scallops (Tables 4a, b and c).
Macroscopic observations were supported by histological sections of

gonads - fixed in 10% seawater formalin, processed and stained using haematoxylin and eosin. **NB:** (Results to be appended)

RESULTS.

Temperature

Experimental and ambient temperatures are plotted in Figures 1 and 2, and summarised in Tables 1 and 2. Temperatures varied during the course of experiments although means were distinct (see also Day degrees).

Experimental temperatures maintained for scallop broodstock in Experiment 1 are shown in Table 1. Data are the mean of 3 readings taken each day.

Treatment	Mean	s.d.	s.d./x(%)Day	Day degrees
1	13.8	1.6	11.6	759
2	15.1	1.4	9.3	831
3	16.2	1.4	8.6	891
Ambient	17.5	1.6	9.1	963

Table 1. Water temperature in broodstock tanks, Experiment 1

Experimental temperatures for scallop broodstock in Experiment 2 are shown in Table 2 below. Data are the mean of 3 readings taken each day.

Treatment	Mean	s.d.	s.d./x(%)Day	Day degrees
1	19.2	1.4	7.3	1363.2
2	14.0	2.6	18.6	994
Ambient	18.2	1.8	9.9	1292.2

Table 2. Water temperature in broodstock tanks, Experiment 2

Scallop Survival and Condition

Considerable numbers died during the course of the experiments (Tables 3, 4a-c, Table 5a,b). Most mortalities (MORTS) occurred during the first month in the first experiment but not until after a month in the second. No clear reason for these mortalities was apparent but other observations suggest that the animals are not easy to maintain in conventional types of hatchery tanks, a feature which will have to be addressed in future work.

Experiment 1				Experiment 2		
WEEK	TANK 1	TANK 2	TANK 3	WEEK	TANK 1	TANK 2
1	13.3	11.7	15	1	2.3	1.9
2	26.8	15.5	26.8	2	4.7	5.8
3	40.1	21.4	35.7	3	4.7	9.9
4	45.2	23.5	35.7	4	14.5	12
5	47.9	25.6	35.7	5	19.9	14.2
6	50.7	29.9	38.1	6	22.8	16.4
7		32.2		7	31.6	16.4
				8	34.8	27.8
				9	51.5	30.4
				10	55.5	

Table 3. Cumulative mortality rates in scallop broodstock Experiments 1 and 2.

Table 4a: Gonad condition scores in Experiment 1, tank 1, low temperature

NO.	COND	MORTS	6/11	13/11	21/11	30/11	6/12	12/12	19/12	23/12
2916	4			4	F	4	4	4	5	5
2868	4						4	5		5
2803	1	Dead 4/12								
2930	5	Dead 15/11	5							
2854	1	Dead 5/12	2							
2547				3	1	1	1	1	1	1
2857	3	Dead 15/11	3	3						
2955										
2982	2	Dead 5/11								
2837	2	Dead 4/11								
2942	4		1	1	1	3	4	4	4	4
2845	2					1	3	3	4	4
2826	1					2	3		3	4
2804	2					3	3			4
2556	3	Dead 9/11								
2884	3		2			3		4	5	5
2911	1			2	2	1	3	3	4	3
2938	1	Dead 14/11								
2822	1	Dead								
2658	4			3	3	3				4
2936	1	Dead 5/11								
2847	2		1			3		2	2	3
2886	3		2	2	1	2			4	4
2925	1				3		3			4
2917	1				2	3				3
2956	7	Dead 23/11	4	2	3					
2844	3	Dead 15/11								
2856	1	Dead 12/11	1							
2973	1			2	1					1
2901	3		1	4	4	3	4	4	4	4
2881	1	Dead 23/11	1		1					
2843	1	Dead 18/11								
2820	1				2		2	3		4
2940	1			4	3	2	2		1	2
2834	1		1	3	3	2	4	2	5	4
2934	2			4		4	4	4	4	5
2952	3			3			4			4
2891	1	Dead 13/11	1							
2933	4	Dead 16/11		3						
2997	2			1	1			1		1
2811	4			4			4	4	5	5
2890	3				4	4	5	4	4	5
2980	1	Dead			1			Dead		
2922	3		2	4	4	5		5	5	5
2717	1	Dead 8/11								
2992	1	Dead 20/11								
2648	1	Dead 3/11								
2675	1	Dead 1/11								
2598	1		1					1	1	1
2557	3			2						2

2967	1		1				4			4
2651	2		3				3	4	4	4
2965	1	Dead 3/11								
2684	3			4	4	5		4		5
2570	1	Dead 6/11								
2915	1	Dead 12/11	1							
2948	1	Dead 1/11								
2534	3		2	3	3	4	4	3	4	4
3000	1	Dead 11/11								
2975	1		2			2	3	2	3	3
2995	Not listed	Dead 29/11/87								
		NUMBER	20	21	20	21	21	20	20	32
		TOTAL	37	61	47	60	71	66	72	116
		AVERAGE	1.85	2.9	2.35	2.86	3.38	3.3	3.6	3.63

Table 4b Gonad condition scores in Experiment 1 Tank 2, intermediate temperature

NO.	COND	MORTS	6/11	13/11	21/11	30/11	6/12	12/12	19/12	23/12
2985	1			3	3		4			5
2970	1							1		1
2880	1							1		2
2941	3			3		4	4			4
2686	3		3	4	3			3	5	5
2918	3		4	4	5	4	4		5	4
2878	3			3	4			4		4
2809	2	Dead 9/11								
2871	1				2		3	2		3
2999	3		2			3	4	4	5	4
2993	1			3		2		3		3
2818	3								5	4
2921	2		1	3	3			2	4	4
2902	5				5		4	4	5	5
2947	2			2	2			2		1
2988	1		1	1		1	4	1	1	1
2927	1		3			3		3	4	4
2850	4					4	4	4	4	5
2829	3						2	1		1
2855	1	Dead 2/11								
2693	3	Dead 4/11								
2711	3		4	2	4	3			4	4
2920	4			3		3	4			4
2882	1	Dead 8/12	1		1					
2833	1		1	2	3		3		4	3
2875	1			2				2		1
2945	2		1			3				3
2963	1	Dead 17/11	1	1						
2529	3		4		3	4	4	5	5	5
2949	1	Dead 23/11	2							
2904	3			3		4				5
2909	1									1
2986	1									1
2874	2					4			4	4
2873	2	Dead 14/12			1					
2987	1		1		1		3			4
2896	1				1	3			3	4
2501	3	Dead 3/11								
2563	1	Dead 30/10								
2550	2	Dead 8/11								
2532	2		1	4	3		3	3	4	4
2914	1	Dead 18/11								
2861	2		1							5
2840	1	Dead 2/11								
2966	1		2		3					4
2812	5									
2889	4						4		5	5
2801	3					5	4		5	5
2961	2							4		1
2615	3		2	3	4	4	4	4	5	5

2962	1				3		3	3	2
2670	3	Dead 31/10							
2545	1	Dead 11/12	1	2		1			
2705	3		4		3		3	3		3
2687	2			4			4		5	5
2990	3			3	3	3				4
2935	1						1	1		1
2907	1	Dead 17/11								
2596	1	Dead 30/11		2						
2575	2	Dead 6/11								
		NUMBER	20	21	20	18	19	22	20	42
		TOTAL	40	57	57	60	69	60	85	143
		AVERAGE	2	2.71	2.85	3.33	3.632	2.727	4.25	3.405

Table 4c. Gonad condition scores in Experiment 1, Tank 3 high temperature

NO.	COND	MORTS	6/11	13/11	21/11	30/11	6/12	12/12	19/12	23/12
2586	4					4	5	4		4
2548	3								4	4
2668		Dead 10/11	4							
2697	1			1	1		2		3	2
2943	1								4	4
2590	2			2	3	2	3			3
2860	1	Dead 10/11	1							
2906	2		4			3	4	4		4
2946	3							4		5
2533	1	Dead 6/11								
2828	3			4					5	5
2706	4					4		5	5	5
2950	1	Dead 18/11	1							
2932	1	Dead 20/11	1							
2939	4		5	4		4	4	4		5
2929	1	Dead 7/11								
2512	1			4	3	4		4	5	5
2815	1				1			1		1
2897	1		2	2					3	1
2953	1	Dead 6/11								
2872		Dead 4/11								
2599	3			4		3	4		5	5
2730	3			3	3	3		4		4
2569	1	Dead 15/11								
2677	3				4	3	4		5	5
2734	2	Dead 1/11								
2673	2		4		3	4	4	4		3
2643	1	Dead 2/11								
2864	1		2	3	2	3	4	4		4
2612	3			3	4	3		5	5	1
2628	1		1	1		1	3	1	1	1
2558	3									
2606	3	Dead 13/11		4						
2836	1		2		2					4
2676	4	Dead 4/11								
2923	1	Dead 10/11								
2919	5			4			4	5		5
2733	1	Dead 19/11								
2574	2		2						5	5
2659	1	Dead 3/11								
2572	1		4		4	4	4		5	4
2867	1		3	4	4		4			4
2732	1		1		1			1		1
2805	1			1	1				1	1
2702	4		3			3				4
2853	1		3		3	4	3	3	5	7
2515	2				2					
2682	1	Dead 2/11								
2672	2					4	4	4		4
2554	4		5	4		4	5	4	5	3

2996	1				1		3			3
2585	1				4	4	4	1	5	5
2848	4								4	5
2573	1	Dead 8/11								
2978	1		1	1	2		3	1	1	2
2523	3		4	4	4		4	4	5	5
2516	1	Dead 9/11								
2708	3			3						
2721	2			1						1
2622	2	Dead 10/12		1		2				
		NUMBER	20	21	20	20	20	20	20	37
		TOTAL	53	58	52	66	75	67	81	134
		AVERAGE	2.65	2.76	2.6	3.3	3.75	3.35	4.05	3.622

Table 5a. Gonad condition scores in broodstock Experiment 2 Tank 1, high temperature.

NO.	COND.	MORTS	9/2	16/2	23/2	2/3	16/3	23/3	30/3	6/4
3080		Dead 9/3	0	0	0	0	1			
3087			0	0			1	1	1	1
3100		Dead 28/3	0	0	1	1	1	1		
3088		Dead 4/3	1	0	1	0				
3125			0		1	0	1	1	1	1
3078			0	1	0	1	1	1	1	1
3079		Dead 4/3	0	0		0				
3081		Dead 10/4	0	0	2		1	1	2	3
3116		Dead 11/4	1	0	3	1	2		1	
3126			0		1	1	2	2	1	2
3115			0							
3113		Dead 5/2	0							
3097		Dead 12/4	0	0	1	0	1	1	1	1
3130		Dead 18/2	0				0			
3129		Dead 6/3	0	0		0				
3106		Dead 26/3	0							
3086		Dead 21/3	0	0	1	0	1			
3131			0							1
3103			0				2	2		
3109				0			1	1		2
3102		Dead 10/4		0				1	1	2
3089				0	0	0	1	1	1	1
3120				0						
3124				0	0	0		1	1	1
3107				1				1	1	2
3132				2	3		2		2	
3121		Dead 11/3			1	1				
3135		Dead 30/3			1	1	1			
3085					0	0	1	1	1	1
3096					0	0		1	1	0
3134					1	1				
3090					3	3		2		
3183		Dead 1/3			0					
3127						0		1		1
3101							3	3	3	1
3112							1	1	1	
3122		Dead 28/3					1	1		
3094		Dead 9/4							1	1
3119									1	
3117		Dead 5/4							1	
3111									1	1
3110										1
3095										1
		NUMBER	19	18	20	20	20	20	20	20
		TOTAL	2	4	20	10	25	25	24	25
		AVERAGE	0.11	0.22	1	0.5	1.25	1.25	1.2	1.25

Table 5b. Gonad condition scores in broodstock Experiment 2 Tank 2, Low temperature.

NO.	COND.	MORTS	9/2	16/2	23/3	2/3	16/3	23/3	30/3	6/4
3154			0			0				
2554		Dead 11/12	0							
2941			0		0		0		1	1
2852			0		0	0		1		
3160		Dead 30/3	0	0	0		1	1	1	
3108			0							2
3143		Dead 4/4	0							
3157			1	4					2	1
3168		Dead 5/4	0		1		2	2	1	
3171			0	3		0	1	1	1	2
3163			0		1				1	1
2512			0				1		1	
3137		Dead 29/3	1	3			2	2		
2962		Dead 26/2	0			0				
3158			1		0	1	2			1
3175			0				1			2
3139		Dead 11/3	0			0				
3177			0							
2996			0	0						2
2943		Dead 17/2	0	0			0			
3180		Dead 20/2		0		0				
3138				2	3	2				
3148				0	1		1			1
3170				0	1	1	1	1	1	
2867				0		1		1	1	2
2934				0				1		1
3173		Dead 21/3		0			1	1		
3091				0	1					
2946				0						1
3156				0					1	1
3141		Dead 5/3		0	0					
2560		Dead 31/3		5		5				
2901				0						
3147		Dead 30/3		0			1	1	1	
3145		Dead 24/2		0						
3181					1	0	1	1		
3172					1	1	1	1	2	1
3166					2	2		1	1	
3162					1			1	1	1
3146					0				2	
3142					2	2	2	2		
3150					0		1		2	
2711					0	1		1	1	1
3151						1		2	1	2
3136						1	1	1		1
3176						1		1		
2580						0	1	1		
2890							7			
3174									1	
3155									1	

3140 1
3165 2

NUMBER	20	21	19	20	20	20	20	20
TOTAL	3	17	15	19	28	24	24	27
AVERAGE	0.15	0.81	0.79	0.95	1.4	1.2	1.2	1.35

Scallops in Experiment 1 started with early developing and developing gonads in contrast to those in Experiment 2 where most of the stock were completely spawned (note: spawned animals were given a condition score of zero, not 7 as is done in some classifications - this allows better presentation of trends (Figs 3 and 4).

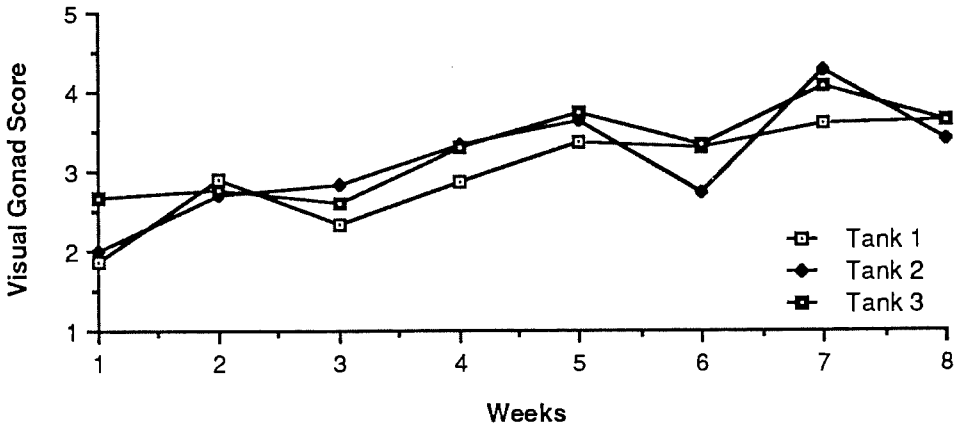

Figure 3. Mean gonad score, Experiment 1, October-December 1987.

Moderate improvement in condition occurred over the 8 weeks in Experiment 1 (Fig 3) and at the end of the experiment we were able to spawn from some of the stock (Table 6).

In neither experiment is there a clear trend with respect to temperature.

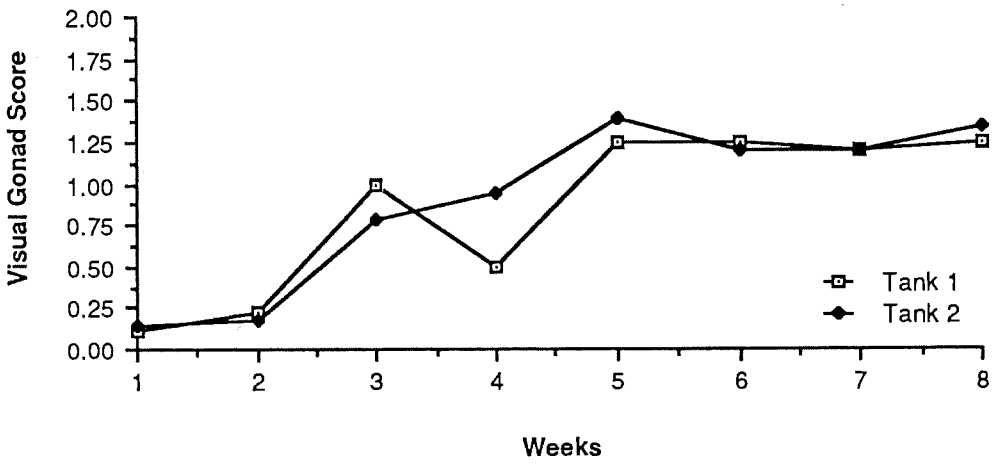

Figure 4. Mean gonad score, Experiment 2, February-April 1988.

DATE	NANO	T/SO	CHAETO	THAL	TOTAL
17/12/87	352.5				352.5
18/12/87	423				423
19/12/87	319.5				319.5
20/12/87	378				378
21/12/87	438				438
22/12/87			195		195
23/12/87			43.5		43.5

Table 8. Million cells added per day to broodstock Tank 1 and 2, Experiment 2.

DATE	NANNO	T/ISO	CHAETO	THAL	TOTAL
2/2/88	252				252
3/2/88	105				105
4/2/88	130.5				130.5
5/2/88	139.5				139.5
6/2/88	192				192
7/2/88	253.5				253.5
8/2/88	232.5				232.5
9/2/88	160.5				160.5
10/2/88	268.5				268.5
11/2/88					0
12/2/88	166.5				166.5
13/2/88	127.5				127.5
14/2/88	74				74
15/2/88	120				120
16/2/88	84				84
17/2/88	63				63
18/2/88	63.5				63.5
19/2/88	102				102
20/2/88	109.5				109.5
21/2/88	109.5				109.5
22/2/88	115.5				115.5
23/2/88	134.5				134.5
24/2/88	181.5				181.5
25/2/88	170.5				170.5
26/2/88	79.5				79.5
27/2/88	85.5				85.5
28/2/88	115.5				115.5
29/2/88	288				288
1/3/88	373.5				373.5
2/3/88	438				438
3/3/88	75				75
4/3/88	201				201
5/3/88	189				189
6/3/88	123				123
7/3/88	396				396
8/3/88	522				522
9/3/88	558				558
10/3/88	486				486
11/3/88	360				360
12/3/88	225				225
13/3/88	405				405
14/3/88	372				372
15/3/88	81				81
16/3/88	51				51
17/3/88	141				141
18/3/88	108				108
19/3/88	213				213
20/3/88	270				270

21/3/88	324		324
22/3/88	188.4		188.4
23/3/88	164.4		164.4
24/3/88	225		225
25/3/88	234		234
26/3/88	15		15
27/3/88	9		9
28/3/88	23.4		23.4
29/3/88	34		34
30/3/88	42		42
31/3/88	27	64.2	91.2
1/4/88	234		234
2/4/88		360	360
3/4/88	180		180
4/4/88	411		411
5/4/88	309		309
6/4/88	444		444
7/4/88	255		255
8/4/88	108		108
9/4/88	168		168
10/4/88	258		258
11/4/88	282		282
12/4/88	753		753

DISCUSSION.

Results are somewhat inconclusive although it is clear that broodstock can be brought into spawning condition by feeding in tanks as evidenced by Experiment 1.

Temperature per se appeared to have little effect on the conditioning process in either experiment. Some improvement was seen in the condition of animals in Experiment 2, but this was insufficient to produce scallops capable of spawning.

In contrast to the commercial scallop, conditioning protocols are well established for Pacific oyster (*Crassostrea gigas*) broodstock. These involve keeping the animals at approximately $20^{o}C$ for a period or a number of day degrees. Oyster experiences show that it is difficult to condition completely spawned animals in the hatchery. Instead normal practice is to condition partly developed oysters collected from farms.

A similar strategy may be required with scallops. Unfortunately animals inspected in the wild during the course of Experiment 2 also had spent gonads and thus conditioning of partly developed stock could not be tested at that time.

Temperature per se plays a role in scallop spawning as a temperature rise can be used to trigger spawning. The role of temperature in conditioning stock remains unclear as - in Tasmania - the commercial scallop may spawn in early spring as well as in summer.

Extended trials with animals at different stages of development at different times of the year will be required to further clarify factors involved in conditioning.

Hatchery Culture of Commercial Scallops (*Pecten fumatus*)

Derek A. Cropp

Aims

(1). To establish satisfactory procedures for all phases involved in rearing scallop larvae.

(2). To rear large numbers of scallop spat in the hatchery for ongrowing culture and ultimately for re-seeding onto the seabed.

(3). To improve production of larvae by artificial broodstock conditioning.

(4). To refine spawning techniques and the fertilization process.

(5). To increase the percentage of larvae settling from the swimming stage.

Introduction

In 1974 Dr. Trevor Dix, (then with the Fisheries Division, Dept. of Agriculture) produced a small number of scallop spat (*P. fumatus)* in a research hatchery at Taroona. These were the first scallops raised artificially in Tasmania and since then no real attempt has been made to scale up to a pilot commercial level until recently.

Research on rearing of larvae began at the Bicheno oyster hatchery, owned by Shellfish Culture Pty. Ltd., in 1982, with little success. Despite producing large batches of eggs (up to 100 x 10^6) no settled spat resulted. Initial problems with self-fertilization of eggs, over fertilization and non-ripe eggs were overcome and survival of larvae increased dramatically. More stringent controls on feeding rates of larvae and temperature regulation also increased the survival of larvae. Even so, only a small number of larvae reached the pedi-veliger stage and these could not be induced to settle. Time constraints upon the hatchery meant that oyster spat had to be produced over a certain period. This meant that scallop work at Bicheno had to be discontinued in 1985; research operation's were temporarily suspended while other facilities were investigated.

The new hatchery and nursery owned by the Tasmanian Shellfish Company at Dunalley then became available and work re-commenced there in late October 1985. Broodstock were obtained from the D'Entrecasteaux Channel and Bank's Strait. These were generally fed quantities of algae on a daily basis prior to spawning, in an effort to improve gonad condition. With the advent of new technology and experience gained over many years, three batches of larvae (in the first year) were successfully reared through to settlement and the early juvenile stage; the most crucial for success. Production was temporarily halted when the main hatchery at Dunalley burnt down, but this was re-built and another two larger batches were settled in spat collectors; the largest estimated at 500,000.

a pre-filled (with 45µm filtered water) 10-15,000 litre tank, heated to 17-18°C, at 2 eggs/ml and fed cultured algae daily after day 2; the amount depending on number of larvae and their size. A minimal amount of aeration is provided and the larvae tanks are heated with several 5kw immersion heaters. Larvae were drained from their tank and placed in a clean pre-filled and pre-heated tank on day 2, 5, 9 and 13 of the rearing phase. Accurate larvae counts can generally be performed on these water change days also. Unfortunately counts on other days may occasionally err when some of the larvae are not suspended in the water column, that is, they are on the floor of the tank. This occurs more often around the day 2 water change and hence counts at this time may be somewhat erratic. At other times counts may vary as healthy larvae tend to swim higher in the water column than unhealthy or weaker ones. In addition, the unhealthy or dying larvae accumulate on the tank floor and, if they are very weak, around the circumference of the tank, due to the water movement generated by aeration.

(ii) Settlement

When all larvae have developed to the eyed stage and some exhibit crawling activity, spat settlement is assumed to be imminent; this occurred on day 16. Conventional spat collectors (68 x 94 cm, 4 mm mesh) identical to those used for wild collections (Cropp, 1985), were then placed in the larval tank. Half the water in each larvae tank was changed on day 16 and a full water change was done gradually on day 18. All collectors can be transferred (dry) to a longline for ongrowing after they have been immersed in larvae tanks for about five days, ie. day 21.

More recently, different types of collector bags have been used to settle the spat on. Newer designs have an increased amount of internal mesh and/or a finer mesh external bag, with a subsequent increase in spat settlement (1,500-2,500 spat/collector). However, both these features quickly induce problems not encountered so soon in conventional collectors. The increase in internal mesh and reduction in size of external mesh, both cause a rapid build-up in fouling with growth checks and/or deformities becoming evident as the scallops grow. Thus these collectors must be sorted two to three months after settlement otherwise severe growth checks and high mortalities will occur.

Results

The number of live larvae and the growth rate is shown for the most recent batch. Spawning occurred at day 0 (21.01.88) while settlement began after day 16 (06.02.88), hence accurate size determination then became difficult. Algal concentrations refer to the amount of algae added daily and is composed of several species namely Tahitian *Isochrysis galbana*, *Chaetoceros calcitrans* and *Nannochloris atomus*. The composition of the daily diet is shown in Figure 6. Sufficient high quality (and preferably axenic) food for consumption by larvae was added at each water change, which occurred, as can be seen in Figure 5, every three-four days. Water for algae culture is

Methods

Various modifications and improvements were continually made to hatchery technology during the research programme. As a result of many trials, both at Bicheno and Dunalley, the following methodology was found to be the most successful overall and was used in rearing the February 1988 batch of scallop larvae.

(i) Spawning and Larval Development

Adult scallops were held in 1,000 litre tanks at Dunalley for up to eight weeks to condition the gonads. They were fed high quality, high density algae (8,000 cells/µl) on a regular basis and kept under subdued lighting and in cooled water (2-4°C below ambient, salinity 33-35ppth). When gonads were sufficiently developed the scallops were first scrubbed lightly to remove algae and encrusting organisms, aired for approximately half an hour, immersed in water, and then induced to spawn by thermal shock; the water temperature was raised approximately 4°C. This was aided by the introduction of large quantities of high density al food or phytoplankton, generally *Nannochloris atomus*. The adults were initially placed in large shallow spawning trays but as signs of spawning were detected (up to four hours later) they were transferred, in groups of two or three, to small, transparent plastic containers holding 5-10 litres of water. Sperm was generally released first and several spawning animals were left in the large trays to stimulate the release of eggs from other individuals. Male-female or female-male changes in the release of gametes have occurred as quickly as five to ten minutes apart but generally occur 20-30 minutes apart. Large females have produced as many as 12×10^6 eggs at one spawning.

Spawning scallops were placed in particular containers depending upon which gametes were being released at any time (males-white, females- orange). Water in these containers was regularly emptied into clean 20 litre buckets so that self-fertilization did not occur; eggs in one group of buckets and sperm in another. At this point it is beneficial to pour the eggs through a 120 x 120µm screen (to remove faeces and other rubbish) and then onto a 32 x 32µm screen and rinse them with clean saltwater (to remove possible sperm and algae cells). After checking the virility of the sperm and the condition of the eggs under a microscope, a pipette were used to carefully add several mls of the sperm solution to the egg buckets. The eggs and sperm were then gently mixed.

Approximately 20-30 mins. later, the eggs were examined under the microscope to assess the fertilization rate and the number of sperm per egg. If a significant percentage had 0-2 sperm around each egg then extra sperm would be added, provided that this ratio was kept below 10 and preferably between 1 and 5. A total count of eggs is carried out at this stage prior to pouring them from the buckets into the larvae tank.

The whole spawning/fertilization process can be repeated on the following day if the first spawning attempts are not successful. After a successful spawning, fertilized eggs are placed into

filtered to 1µm, placed in the respective flask or carboy and autoclaved prior to inoculation with algae. Algal food for larvae is generally produced in autoclavable polycarbonate carboys. This allows the food to be kept axenic and subsequently results in better growth rates of larvae.

The basic form of the two curves below (Figure 1) has been characteristic of larval culture to date, that is, high mortalities from day 0 to day 2, also common with various other molluscan species, and a relatively constant growth rate. Unfortunately, the particular batch plotted recorded an 'apparent' slowing of growth from day 13 to day 14 (2µm) but the increase then to day 15 (6.6µm) suggests it was probably a sampling error as subsequent high mortalities did not occur.

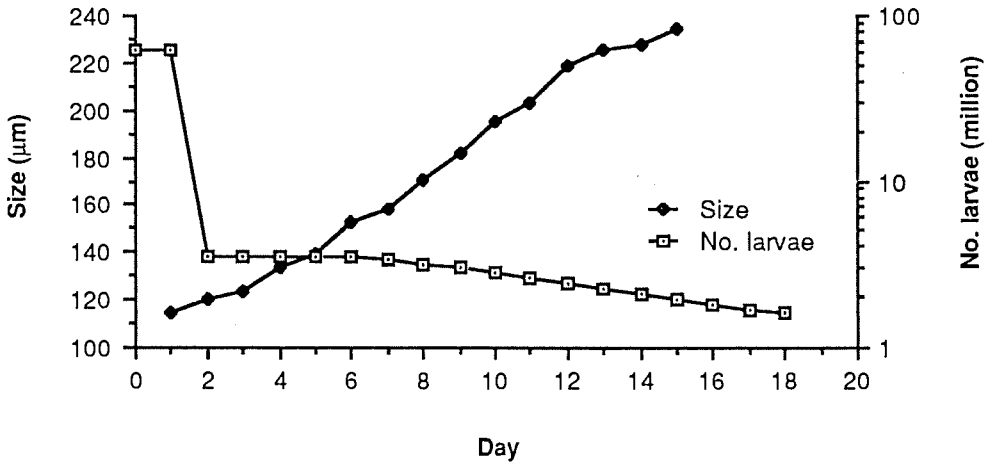

Figure 1. Number and growth of larvae, Jan-Feb 1988

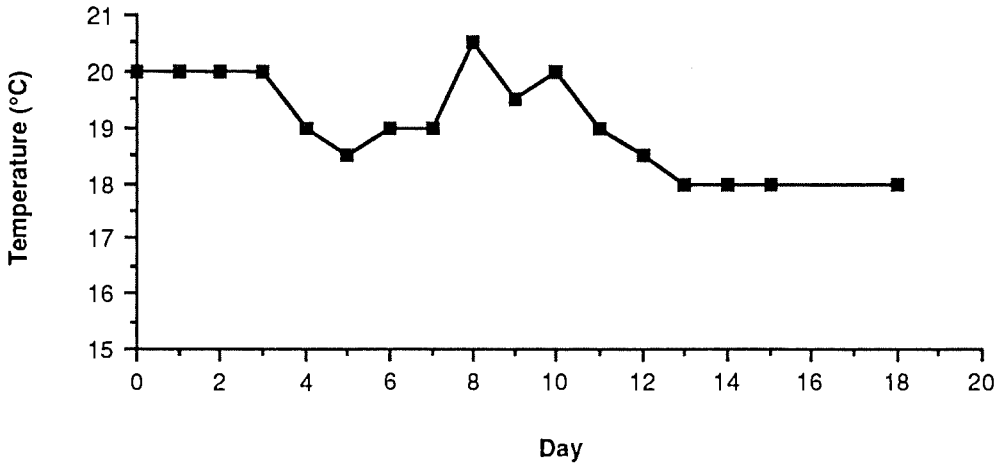

Figure 2. Larvae tank water temperature, Jan-Feb 1988

The water temperature in larvae tanks was maintained at approximately 19 ± 1°C which is stable enough for scallop larvae (Figure 2). Poorer results generally occurred when water temperatures fluctuated by more than 2°C, however larvae have been reared to settlement after encountering water temperatures as low as 13°C or as high as 22°C.

Algal food levels fluctuate daily as cells are consumed by the larvae. As can be seen in Fig. 3, food was added on a regular basis so that the residual level of algae in the tanks did not fall below a level where the larvae would have to expend a lot of energy and effort to encounter and consume algae cells; this can be referred to as the base volume. The peaks in algae concentration occur as a result of adding large amounts of algae when a water change has occurred; this procedure elevates the algae concentration to a level that will maintain food levels above the base volume even after the larvae have been consuming algae for a one day.

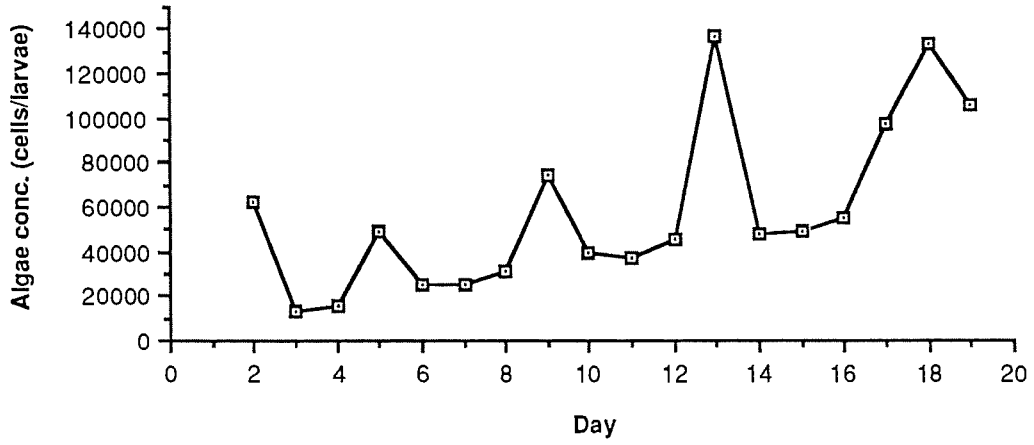

Figure 3. Number of algae cells/larvae, Jan-Feb 1988

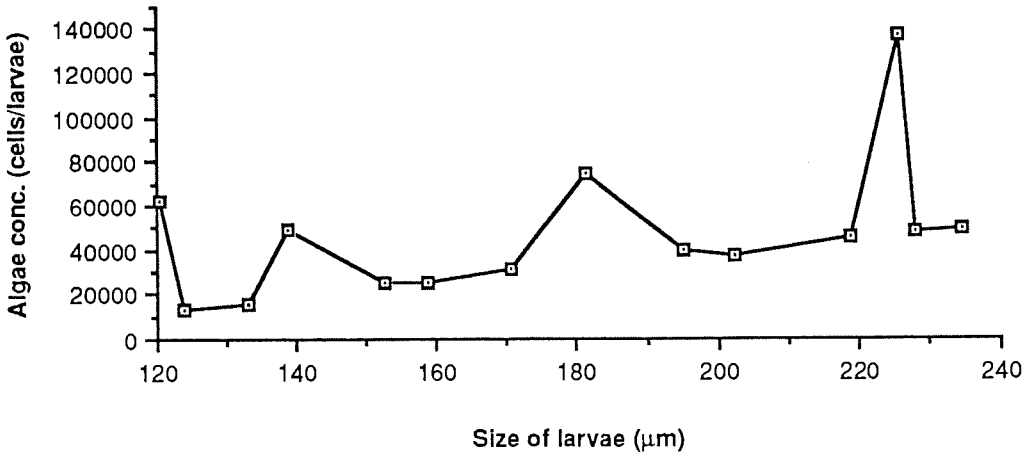

Figure 4. Daily number of algae cells against larvae size, Jan-Feb 1988.

The basic concentration of algae cells available to larvae needs to increase with larval size, as can be expected from an increasing food requirement (Figure 4). Daily fluctuations evident in Figure 3 are basically reflected in Figure 4. The concentration of algae cells per ml of tank water is not shown. Figure 5 illustrates the level of algae added daily and reflects the increased feeding of the larvae. The amount of algae added to maintain algae densities at a suitable level, sufficient for the projected growth is shown. As in Figure 3, the elevated peaks occur when large amounts of algae is added to the tank to restore a suitable food concentration after the larvae have been feeding.

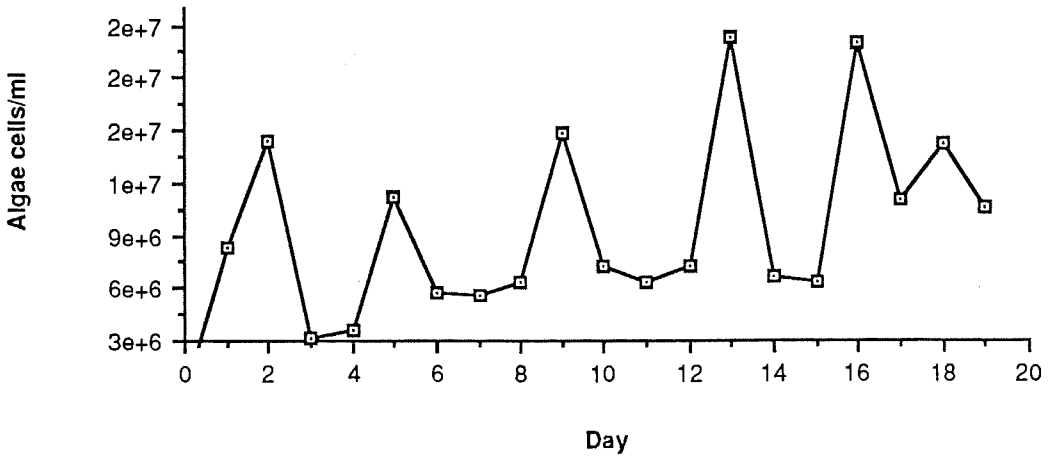

Figure 5. Number of algae cells per ml added daily to the larvae tank

NB: 1.00e+7 represents 1 x 10^7

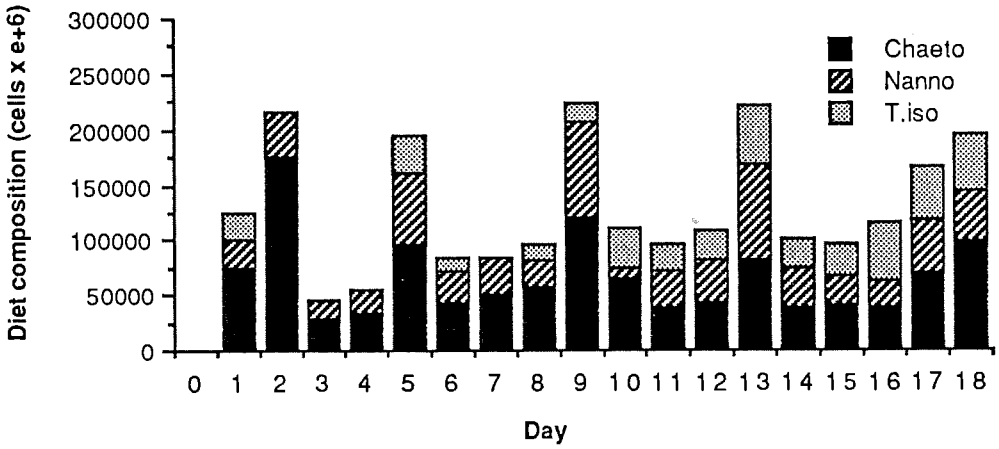

Figure 6. Composition of algae cells in the larval diet

In previous batches there has been survival as high as 28% from fertilized egg to 'D' larvae and then 7.5-10% from eyed larvae to settled spat; overall a survival of 1.2% from eggs to spat or 4.3% from 'D' larvae to spat. Unfortunately, in the January-February batch described here the respective survival figures were only 5.6% to 'D' larvae but 12.8% from eyed larvae to settled spat. Overall survival from eggs to spat was 0.4% , from 'D' larvae to spat it was 7.2% and from eggs to 10-15mm spat it was 0.12%.

The recent batch was produced at an unseasonal spawning time for scallops here and this may have had some effect on initial survival/development of eggs, even though the broodstock was artificially conditioned up to spawning. However, the survival from eyed larvae to settled spat is still encouraging. It is important to note that the amount of settled spat is difficult to determine precisely when mesh spat collector bags are used. This level of accuracy should improve if upwellers or downwellers are used in future to settle scallop spat on (eg. 50-80% from eyed larvae to spat in Canada; Thompson et al., 1985). In addition, Canadian research with the Japanese scallop *Patinopecten yessoensis* has shown a mean survival from fertilized eggs to 'D' larvae of 10%, and also 10% from 'D' larvae to metamorphosis.

Settlement success is dependent on the stored energy reserves of the larvae which enable it to metamorphose from eyed larvae to settled spat (Whyte, 1987). Poor quality food and stressful environmental conditions will result in low success rates. Also it is important not to disturb the larvae/spat until they are firmly attached to the settlement substrate as heavy losses can occur. Below is a table detailing the spat obtained from collectors removed from larvae tanks after 3, 5, 9

and 10 days immersion.

Days	Mean No.scallops/collector	s.d.	Mean scallop size (mm)	s.d.
* 3	958	95.4	2.50	0.044
5	1,534	393.4	3.03	0.015
9	213	40.8	2.64	0.139
10	78	10.5	2.82	0.121

Table 1. Number of spat settling against number of days in larvae tank

NB: * sampled 3 days before all other collectors, hence a slight size discrepancy would be induced cf the other collectors.

Early settling trials indicated that spat settlement may be increased by leaving collectors in the larvae tank with metamorphosing larvae for more than three days. Subsequently, the trial done with conventional collectors revealed that settlement apparently peaked at five days (Table 1). Problems with water cleanliness, circulation and feeding were encountered in the larvae tanks from day six onwards. In addition, collectors retained in the larvae tank for nine and ten days both contained spat which was marginally smaller than the five day collectors; thus it appears the growth rate of spat may have been slower in the larvae tank than in the sea. Overall, removal of the collectors from the larvae tanks after five days was the most sucessful procedure.

Sorting of collectors several months later produced thousands of scallop spat and revealed that some collectors containing high numbers of spat (>1,000/collector) showed a corresponding reduction in size of the spat.

Discussion

During the period of research into hatchery culture techniques several important aspects of scallop reproduction were made clear, these are:

(1) Stresses for broodstock must be minimized to allow successful spawnings.

(2) There is no point forcing the broodstock to spawn if the gonads are not sufficiently developed.

(3) Producing very large numbers of eggs does not necesarily guarantee success, high mortalities are often experienced.

(4) Self and over-fertilization appear to be problem areas and should be avoided. Past results suggest that they both produce very poor results.

(5) Density of eggs and larvae should be kept at low levels, ~2-3/ml, ie. lower than for Pacific oysters.

(6) Water and food quality must be maintained at a high level, oceanic water and axenic food appears to be most suitable for rearing larvae.

(7) Mesh spat collecting bags should be immersed for five-seven days prior to use as a substrate for spat to settle on.

(8) Spat losses appear to be heavy when transferring spat collectors from larvae tanks to longlines for ongrowing.

(9) Use of upwellers or downwellers as a setting medium for spat is potentially much more effective than using spat collecting bags.

(10) Spat in collectors at high densities must be sorted sooner than collectors containing low densities, otherwise fouling will induce severe growth checks, deformities and mortalities.

In summary it is clear that considerable planning and effort is neccesary to establish an efficient scallop culture system. The commercial scallop *P. fumatus* does not have a hardy larval stage and is very susceptible to poor handling conditions or food. If growth rates as low as 1-3µm are seen at any stage of larval life then mortalities would be expected to occur soon after. Satisfactory growth rates have been about 5-8µm per day as early larvae and then in excess of 9µr per day just prior to settlement. For the saucer scallop *Amusium balloti*, Rose et al. (1988) recorded a growth of 5.2µm per day up to the umbonal veliger stage and then 6.3µm per day until the pediveliger stage. In general, a satisfactory growth rate for healthy bivalve larvae has been suggested as being a minimum of 5µm per two days (Chanley, 1981).

Research in Canada with the Japanese scallop *P. yessoensis* has shown that an acceptable growth rate averages 4.3µm per day while larval feeding rates increase from 10,000 (at 110µm) tc 50,000 cells per 250µm larvae (Thompson et al, 1985). As was shown in Figure 4, the base volume of of algae (fed to *P. fumatus*) maintained the density at approximately 20,000 cells per larvae, at 120µm in size, and up to 50,000 cells per larvae prior to settlement (size ~230µm).

It is apparent from this work and other trials not mentioned here that under-feeding of larvae is just as detrimental to growth as over-feeding. In Tasmania, the gradual improvement of food quality and feeding techniques has resulted in increased growth and survival rates of larvae. Subsequently, improved culture conditions have shown that settled spat can be obtained in less than 20 days and that an 'eye'spot is visible prior to metamorphosis. In comparison, early trials in hatchery culture resulted in pre-metamorphosis larvae without a notable 'eye' spot , culture at 13-15°C, and settlement 31 days after fertilization of the eggs (Dix and Sjardin, 1975). Also, a 5-10°C rise in water temperature to initiate spawning has been revised to 4-6°C which does not stress the animals as much.

The great improvement in survival of larvae, reduction of larval life and settlement in collecting bags, as a result of our new methodology, has shown clear promise for the future. The ability of these factors to reduce hatchery operating costs is also of great economic importance and is an integral part of assessing the viability of large scale scallop spat production (Cropp, 1988).

Growth and Survival of the Commercial Scallop (*Pecten fumatus*) in Intermediate Culture

Derek A. Cropp

ABSTRACT

Several different methods of nursery/intermediate culture were used to grow scallops from the early spat or juvenile stage to at least five months of age, a crucial phase with regard to survival. Scallops were either left in collectors for the whole period or sorted from spat collectors soon after settlement and split into size groups. These were divided between Japanese lantern cages (at low densities) and conventional upwellers (at high densities) for ongrowing. Another group was placed in compartments of a floating upweller (FLUPSY). Although the various methods generally produced high survival rates, growth in cages was markedly higher than in spat collectors, upwellers or the FLUPSY.

1. INTRODUCTION

The success of cage or mid-water culture of scallops has been extensive in Japan (Ventilla,1982; Maru,1985). Their annual yield has increased from 15,000 tonnes (live weight) in 1969 to over 200,000 tonnes in 1986, with more than 60,000 tonnes produced by hanging culture alone. Initial work in Tasmania looked at the suitability of using *Pecten fumatus* (previously referred to as *P. meridionalis*) for cage culturing (Dix,1981; Cropp,1985; Cropp and Hortle, in press). Although successful, growth rates were somewhat marred by high mortalities. Even so, the trials were still indicative of a potential for this form of culture. Results suggested that the scallops would attain 75mm. in height at 18-20 months of age.

Both the presence of food (phytoplankton) and its availability to the scallops is important in any form of culture. Kirby-Smith and Barber (1974) proposed that "normal variations in phytoplankton concentration do not influence the growth rate of scallops in their natural habitat" but that unnaturally low levels of phytoplankton did decrease the growth rates. However, Wallace and Reinsnes (1985) showed that the growth of Icelandic scallops can be significantly increased by suspending them mid-water in hanging culture where nutrition is higher than on the seabed. They also found that growth in hanging culture was higher still, just under the sea surface, compared with deeper down in the water column.

Under suitable conditions it may be possible to culture scallops at high densities and record good growth and survival rates. In this situation it is imperative that the natural

available level of food is enhanced either by, culturing algae and feeding it to the scallops at high density (which is expensive), or pumping large volumes of seawater containing natural levels of algae (which is also expensive). Hence, for either method to be successful it must be cost effective, and to be cost effective for scallops it must have a large quantity of output . This report details some primary investigations carried out by the Tasmanian Department of Sea Fisheries (DSF) between 1984 and 1987 and funded by the Fishing Industry Research Trust Account (FIRTA).

2. MATERIALS AND METHODS

2.1 SPAT GROWTH IN COLLECTORS

Artificial scallop spat collectors (Cropp, 1985) were deployed on a sub-surface longline placed in Mercury Passage near Maria Island (Figure 1). The structure of the longline is shown in Figure 2. The longline was placed in position in 30 m of water in August 1985, by the DSF research vessel 'Challenger'. The spat collectors were then attached to the longline during the following ten days. Regular monitoring was carried out with divers removing collectors from various depths over a period of months. For further information see Hortle and Cropp, 1987.

2.2 SPAT GROWTH IN THE FLUPSY

The collecting site for the juveniles (Mercury Passage) is shown in Figure 1. Juvenile scallops were sorted from collectors taken off the Maria Is. longline in when. These were transferred directly by vessel, in water, to the Floating Upweller System (FLUPSY) which was moored at the Tasmanian Shellfish Company's wharf in Boomer Bay, near Dunalley (also see Fig. 1). For further information see separate FLUPSY report.

2.3 SPAT GROWTH IN MID-WATER CAGES AND UPWELLERS

Approximately 1,800 juvenile scallops were sorted from spat collectors in Mercury Passage, near Maria Is. (Figure 1), in late November 1983. These spat collectors, or mesh bags, loosely filled with shark mesh netting (Cropp, 1985) were attached to sub-surface longlines placed near Maria Is. in August-September 1983 (Hortle and Cropp,1987).

After removing the juvenile scallops from the collectors, they were transferred, by sea, immersed in circulating water. They were then graded for size and divided between the two ongrowing sites, i.e. Waub's Bay and the Bicheno upweller, so that direct size related comparisons were possible.

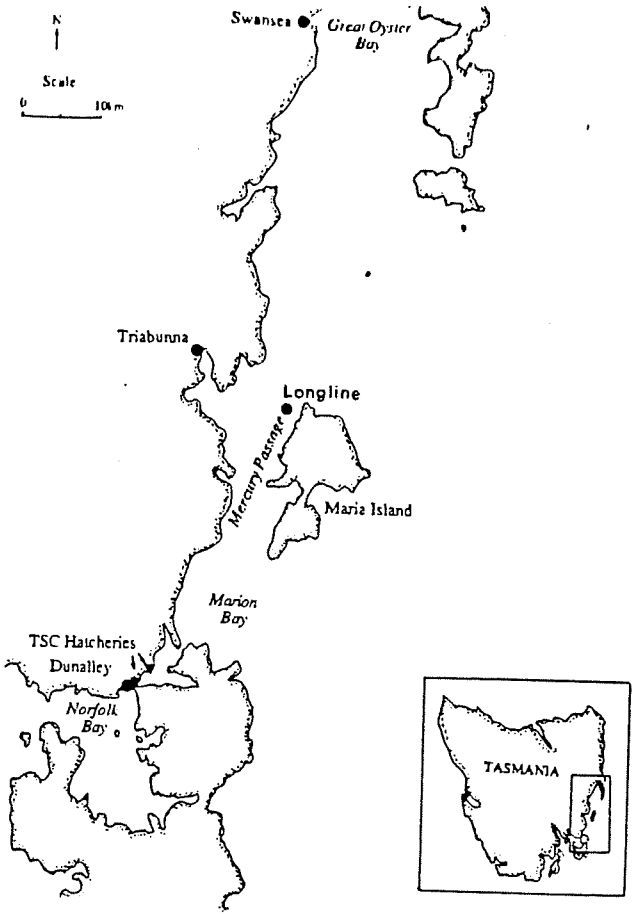

Figure 1. Maria Island and Dunalley sites.

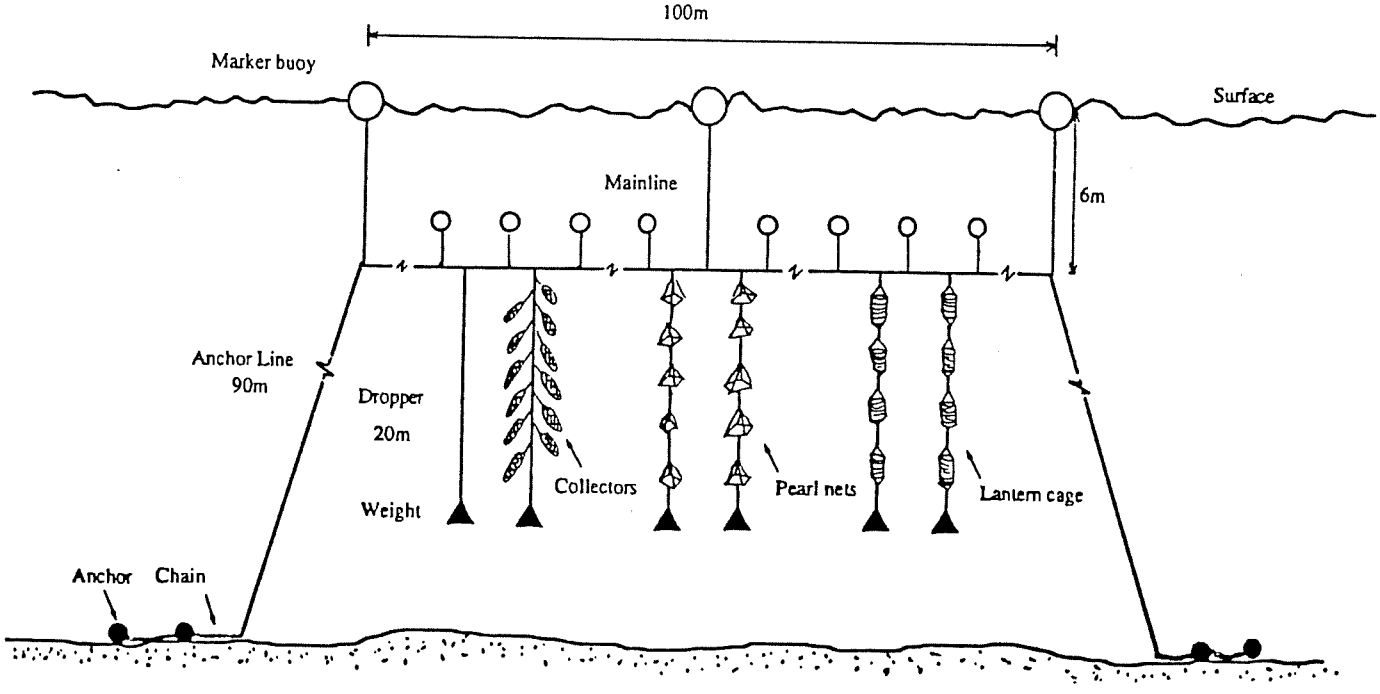

Figure 2. Subsurface longline used at Maria Is.

In Waub's Bay (30nm north of the Maria Is. site), a longline was anchored to the bottom. Cages were attached at the bottom and stretched vertically upwards by a cluster of three 200mm polystyrene buoys, so that the cages were suspended in mid-water.

At the Bicheno site an upweller measuring 470 x 633mm. and divided into three compartments of 470 x 108mm. (containing group 1 scallops), 470 x 240mm. (containing group 2)and 470 x 285mm. (containing group 3) respectively, was constructed. This was placed in water within a 4m. diameter, fibreglass pond with the water flow directed up through each compartment, prior to draining from the pond.

The scallops in cages and upwellers were regularly measured and dead animals removed; surface water temperatures were also taken. In Waub's Bay, densities had to be periodically altered to remain within recommended densities for this form of culture (Taguchi and Walford,1976). Consequently, changes in the type of cage also had to be made as the scallops grew.

The use of upwellers had not been investigated, prior to this, in relation to Tasmanian scallop aquaculture. Hence, numbers were not reduced to alter densities for this trial. The amount of unoccupied space within the upwellers therefore decreased as the scallops grew.

3. RESULTS

3.1 SPAT GROWTH IN COLLECTORS

Growth rates of up to 1.5mm/week were achieved for scallops up to 40mm in size, or 7-8 months of age. Results of previous years work was also included as similarities occur from year to year. See Hortle and Cropp, 1987 for details.

3.2 SPAT GROWTH IN THE FLUPSY

Growth of spat under high density conditions was poor but survival for most of the monitoring period was also high. For further information see separate FLUPSY report.

3.3 SPAT GROWTH IN MID-WATER CAGES AND UPWELLERS

The comparative growth of the various size groups (1,2 and 3) are shown in Figures 3, 4 and 5. There is a clear and significant difference in growth rates between those scallops cultured in cages and those in upwellers. Table 1 shows the variation in surface water temperatures at the two sites.

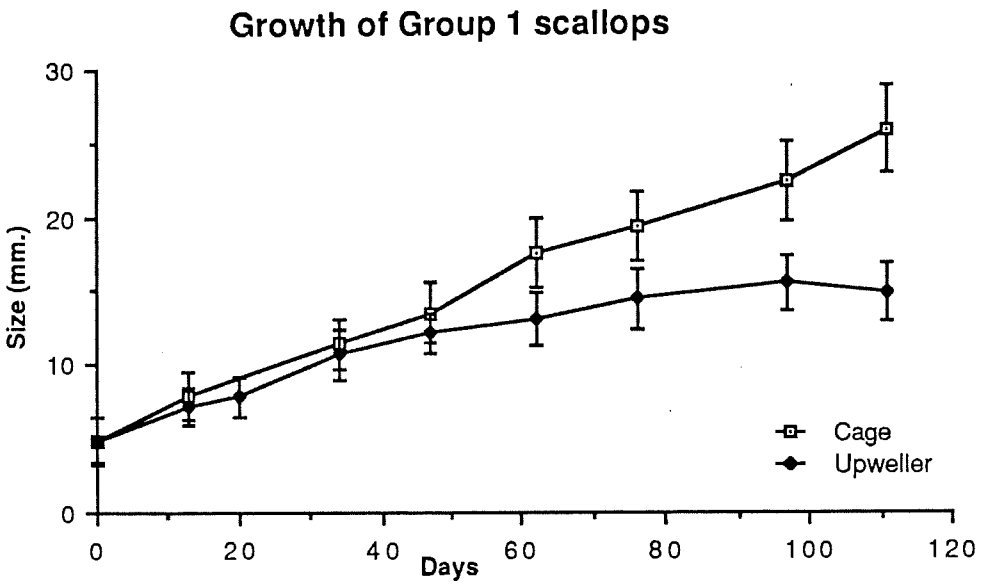

Figure 3. Growth of group 1 scallops at Bicheno

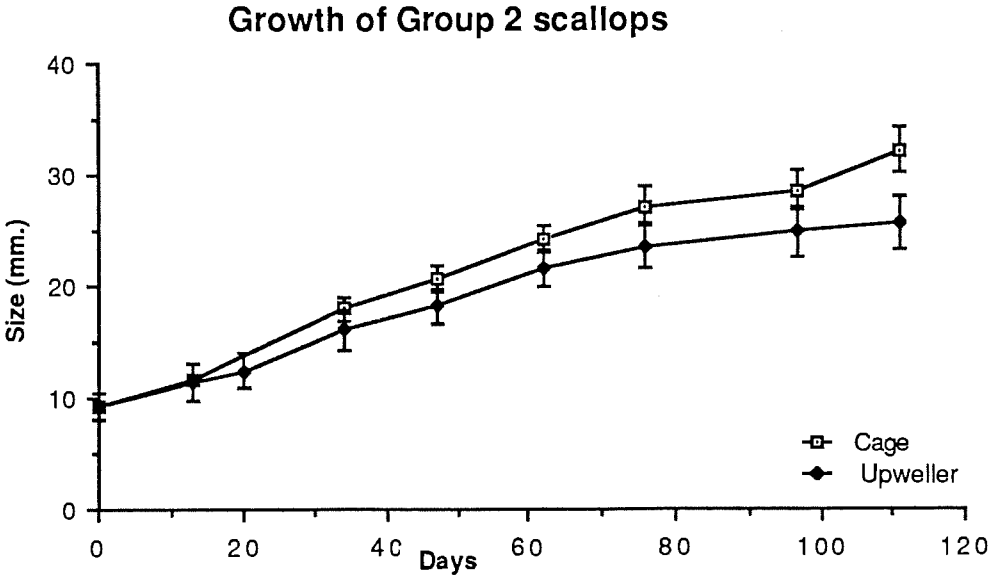

Figure 4. Growth of group 2 scallops at Bicheno

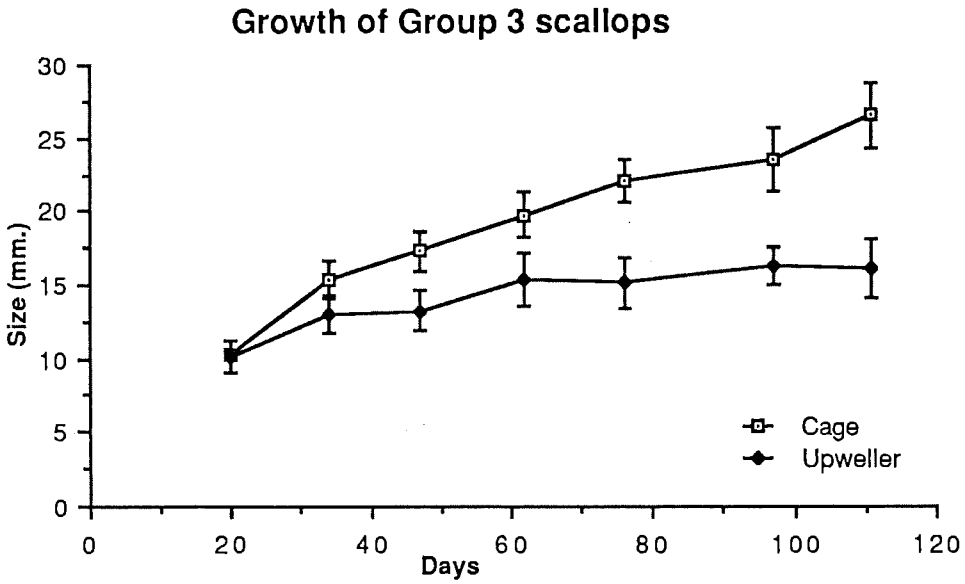

Figure 5. Growth of group 3 scallops at Bicheno

Day	Date	Waub's Bay (°C)	Bicheno (°C)
0	30/11/83	12.8	13.4
13	13/12/83	15.2	17.0
20	20/12/83	17.2	17.5
34	05/01/84	17.9	18.0
47	18/01/84	17.0	17.0
62	02/02/84	17.4	18.7
76	16/02/84	18.8	19.3
97	08/03/84	17.5	16.7
111	22/03/84	17.5	19.0

Table 1. Surface Water Temperatures at the two Sites

Group No.	Initial Density (% occup.)	Final Density (% occup.)	Av. Density (% occup.)	Growth Rate (microns/day)
1	36	93	64	232
1	93	193	143	166
1	86	118	102	164
1	59	99	79	265
1	99	121	110	133
1	58	78	68	147
1	47	63	55	247
2	11	18	15	192
2	18	42	30	299
2	42	56	49	206
2	56	76	66	237
2	76	95	86	211
2	95	104	99	69
2	63	79	71	253
3	32	72	52	372
3	72	90	81	141
3	54	71	63	168
3	71	88	80	162
3	88	100	94	69
3	29	37	33	214
Mean	59	85	72	197
s.d.	26	37	30	73

Table 2. Density and growth rate in mid-water cages

Section 1 Day	Number of scallops	Average height (mm)	Area occupied (cm^2)	% occupancy	Growth rate (µm/day)
0	750	4.9	141	28	-
13	747	7.2	304	60	179
20	740	7.9	363	71	95
34	740	10.7	665	131	202
47	732	12.1	856	169	124
62	730	13.2	999	197	68
76	728	14.5	1 219	240	96
97	725	15.6	1 404	277	52
111	723	14.9	1 278	252	-47

Table 3. Growth of group 1 scallops in upwellers at Bicheno.

Section 2 Day	Number of scallops	Average height (mm)	Area occupied (cm^2)	% occupancy	Growth rate (µm/day)
0	150	9.3	102	9	-
13	149	11.4	155	13	164
20	148	12.5	182	16	150
34	146	16.2	301	27	260
47	144	18.2	379	34	163
62	143	21.6	524	46	364
76	142	23.6	621	55	146
97	135	24.9	663	59	60
111	128	25.8	669	59	61

Table 4. Growth of group 2 scallops in upwellers at Bicheno.

Section 3 Day	Number of scallops	Average height (mm)	Area occupied (cm^2)	% occupancy	Growth rate (µm/day)
22	1750	10.1	1423	106	-
34	1748	13.0	2356	175	237
47	1740	13.3	2418	180	19
62	1738	15.3	3237	241	137
76	1711	15.1	3104	231	0
97	1670	16.3	3527	263	58
111	1668	16.1	3438	257	0

Table 5. Growth of group 3 scallops in upwellers at Bicheno.

4. DISCUSSION

It is apparent that scallops are susceptible to growth retardation in high density situations. This may be overcome by the addition of supplementary food (phytoplankton) or by simply increasing the water flow through the upwellers. Survival in both cages and upwellers was high but growth was clearly higher in the cages. Water flow through the cages was lower than in the upwellers but lower densities produced good results. In a situation where animals are competing for a limited food resource (natural seawater through upwellers or FLUPSY) increasing density has a detrimental effect on growth rates. Similar or even higher density situations in an open water location can maintain better growth rates for longer periods. Growth rates in lantern cages can be higher than those seen in collectors, however both are density dependent. In this comparison, the amount of fouling on the underwater cage/collector is also very influential in determining growth rates of enclosed scallops.

ACKNOWLEDGEMENTS

George Sumner and Leigh Oates are to be thanked for their assistance with gear construction and monitoring. Thanks are also extended to Shellfish Culture Pty Ltd for use of their outdoor pond and pumps and help when required.

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Internal Report

Cost Comparison of Hatchery and Natural Scallop Spat

Derek A Cropp and Ken R Frankish

1988

DEPARTMENT OF SEA FISHERIES TASMANIA
MARINE LABORATORIES
CRAYFISH POINT
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CONTENTS

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ABSTRACT

The dramatic decline in Tasmanian catches of commercial scallops (*Pecten fumatus*) has resulted in rapid price rises. The current high market value of scallops has markedly increased the potential for scallop culture to become economically viable. However, catching naturally occurring scallop spat in Tasmanian coastal waters is currently difficult due to low broodstock numbers. An alternative method of obtaining spat for ongrowing is necessary. Recent advances in hatchery technology has resulted in the production of small quantities of commercial scallops. An assessment of the costs involved in this work has been used to produce an economic analysis for a projected production of 15 million eyed scallop larvae which could be settled onto spat collectors and then ongrown. By comparison, scallop spat obtained from collectors placed at sea is more expensive at present given the low catch rate per collector, but wild spat collection in close proximity to an established scallop population may well be economically viable. If the high market value of scallops continues, then hatchery produced spat will enhance the establishment of scallop culture and may remain as an alternative to the irregular availability of natural spat.

1. INTRODUCTION

The Tasmanian commercial scallop *Pecten fumatus* is hermaphroditic and generally spawns as a result of increasing water temperature. Egg production is up to 10 million per individual (Dix and Sjardin, 1975). Fertilized eggs develop into trochophores and then straight -hinged (or D-shaped) veligers (larvae) after 2 - 3 days at 17°C. The larvae grow at a rate of about six microns (μm) per day up to the eyed larvae stage at age 17 - 21 days, when they have attained a size of 220-240μm. Metamorphosis and settlement occurs soon thereafter and the scallops are then referred to as 'spat'.

Initial research into hatchery rearing of scallop larvae began in Tasmania in 1974 when Dr Trevor Dix produced a small number of commercial scallop spat at the Taroona Fisheries Research Laboratory. Hatchery work on commercial scallops then lapsed until the early 1980s when research resumed at the Bicheno oyster hatchery operated by Shellfish Culture Pty Ltd. This was a joint project between the Tasmanian Fisheries Development Authority (now Department of Sea Fisheries, DSF) and Shellfish Culture Pty Ltd.

Work at Bicheno continued intermittently and with limited success until 1985 when

operations were transferred to the larger facilities of the Tasmanian Shellfish Company (TSC) at Dunalley. With the implementation of new technology and experience gained over several years, five batches of larvae were successfully reared through metamorphosis to settlement (the most crucial period). The most recent and largest of the five batches was reared in February 1988 and produced 400-500 000 spat at settlement. During the research at TSC significant improvements were made: increased survival rate of larvae; reduction in the length of larval life and an increased percentage of eyed larvae setting. These are all important factors in reducing the end cost of scallop spat.

An analysis of the costs of large scale hatchery production of scallops was part of a scallop research project undertaken by the DSF and funded by the Fishing Industry Research Trust Account (FIRTA 1984/93 : *Hatchery production of scallop spat for large scale reseeding trials*) and the Rural Credits Development Fund (RCDF) (MISC/8558 : *Enhancement of Scallop Fisheries*). Work for this project was conducted at commercial oyster hatcheries in south-east Tasmania under contract to DSF.

The potential of collecting naturally occurring scallop spat in Tasmanian waters was investigated in the 1970s by Dix (1981) using technology adapted from Japan. Although only a low level of success was recorded, his work was still encouraging. Subsequent work from 1982-86 (Hortle and Cropp, 1987) proved to be highly successful considering the low numbers of breeding adults in the collection area near Maria Island. A maximum catch of 1,120 scallops was obtained in one collector with an average (assessed in March/April) of approximately 400 per collector in 1984, 1985 and 1986. Unfortunately, the catch averaged only 159 scallops per collector in 1987 and 178 in 1988 (DSF unpublished data). Even so, it is expected that the spat catch will improve in future years as the local scallop population increases, much as it did in Mutsu Bay, Japan (Ito *et al.*, 1975) where catches rose from 200 per collector to 44 000 per collector in 6 years.

Longline design and structure used at Maria Island has improved each year. Gear and techniques now employed are described here, both for hatchery reared and natural spat. The collectors used for settlement of spat are the same in both situations and have been described by Cropp, 1985. Funds for recent spat collection work were provided by DSF, FIRTA and the RCDF.

Figures on growth rates, settlement rates, mortalities and costings have been extrapolated from research work to date and these are used as **assumptions** for the purposes of this report. Application of the figures to future developments should be done with caution as they can vary markedly without predictability. In assessing the viability of scallop culture, those people intending future involvement are advised to consider worst-case situations illustrated here.

2. HATCHERY CULTURE

2.1 General Description of Proposed Hatchery

Techniques and equipment detailed in this report have all be trialled during hatchery research. The largest artificial spawning of scallops in Tasmania produced 125 x 10^6 eggs but no hatchery in Australia has yet produced more than 500 000 settled spat from one batch of larvae. This report details the methodology and costs necessary to produce 15 x 10^6 larvae, up to the setting or eyed stage; growth, mortality and settlement rates are all **predictions** based upon previous culture of small numbers of larvae and spat. It is anticipated that 100 x 10^6 fertilized eggs would need to be produced per spawning (day 0), from a minimum of 30 broodstock (greater than 70mm in height), conditioned and spawned on-site, to have 15 x 10^6 eyed larvae remaining at day 19 (assuming a mortality of 85%).

Algae would be cultured in carboys (autoclavable transparent polycarbonate flasks with a small mouth) to feed the larvae and in bags for the broodstock. It is intended that the polyethylene mesh bags for spat collecting (Cropp, 1985) would be placed in the larvae tanks as a settlement substrate for the scallops. After a settlement period of up to 7 days the collectors would then be transferred to an offshore longline for ongrowing.

Figure 1 shows a schematic diagram for the layout of a hatchery. Its design has been based on previous scallop hatchery work at both Bicheno and Dunalley and encompasses various ideas developed as a result.

The proposed scallop hatchery would need to be located with a water intake that was virtually unaffected by freshwater year-round, maintaining a salinity greater than 30 ppth but preferably between 34-35 ppth.

All labour in the hatchery has been evaluated using a wage of $12 per hr. The contract labour used for construction of collectors and longline is costed at $10 per hr. Both wage scales assume a normal working day of nine hours.

2.2 Costs of the Proposed Hatchery

It is assumed that the hatchery would be erected on flat, cleared land near the sea. The building proposed is the minimum size required to give the intended production. Capital costs are detailed in Appendix 1. For the purposes of this report we can assume that an established and operational hatchery is available for lease to carry out scallop spat production. The lease cost of the facility is assumed to be $2 000 per month or $65.75 per day.

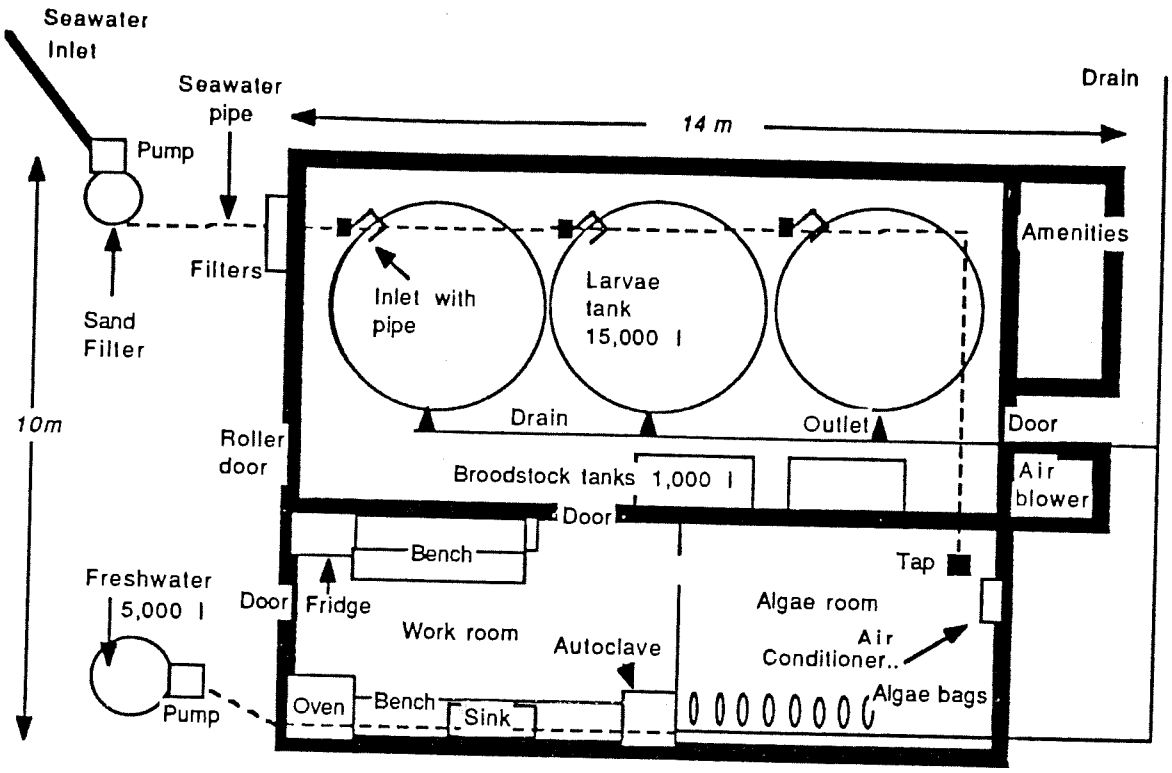


Figure 1. Proposed scallop hatchery layout

2.3 Algae Culture

2.3.1 Algae start-up

Axenic starter cultures are necessary for initiating the growth of algae. These were available free from the CSIRO Division of Fisheries in Hobart, but now cost in the vicinity of $30 per 250ml inoculum. The costs shown in Table 1 include the purchase of four algae cultures plus postage. The diatom algal species that would preferably be used are *Chaetoceros calcitrans* (*C.c.*) and *Thalassiosira pseudonana* (*3H*). Two other preferred species are the golden brown flagellate Tahitian *Isochrysis* aff. *galbana* (*T. iso.*), and the green unicellular *Nannochloris atomus* (*Nanno.*). Several of these cultures should be held in reserve in case they are required at a later date. Satisfactory cell counts in carboys are : *T. iso.*, 8 000 cells/µl ; *Nanno.*, 25 000 cells/µl ; *C.c.*, 20 000 cells/µl and *3H* , 15 000 cells/µl. When the algae have attained their respective densities they can be fed to the larvae (or broodstock if necessary).

The nutritional value of the algae is dependant on age and varies between species, (Whyte, 1987; Helm and Laing, 1987) and is an important factor affecting the growth and survival of the larvae (Laing, 1987). Maximum benefit is obtained if algae is fed to the larvae when it has a high nutritional value -as well, this often corresponds to a low level of bacteria. Older algae can be fed to juvenile or adult scallops.

Large scale algae culture should begin when the broodstock are approaching spawning condition, that is about two weeks prior to the projected spawning date. As algae culture is expensive, wastage of algae needs to be minimized. Algae preparation (start-up) costs are detailed in Table 1 with all labour in the hatchery evaluated using a wage of $12 per hour and, for this report, assume a normal working day of nine hours. The labour component in Table 1 includes: washing up, preparation for autoclaving, subculturing and inoculations, preparation of media and nutrients (Guillard, 1972) in bulk, (Guillard's "f/2" nutrient mix; see Appendix 3), microscopic examinations and cell density counts. Regular backflushing and maintenance of the sand filter is essential but is included as a labour cost at other stages.

The algae room of the proposed hatchery has a capacity of 8 x 420 litre bags. One bag of usable algae can be produced each day provided all operations proceed as planned; this is sufficient for scallop culture as detailed. Provision has been made for an electric blower to provide aeration throughout the hatchery.

2.3.2 Algae culture prior to broodstock conditioning (day 0-18)

For conditioning of broodstock, two algal species (in bag culture) should be sufficient, one flagellate and one diatom. The time (labour) required to prepare the algae system is 18 days (after the cultures are received) at two and a half hours per day. It is

necessary to start preparations for algae culture approximately 79 days before the first anticipated spawning day (ie. day zero for larvae, L0). This allows enough time for the algae system to be set up and for the cultures to attain satisfactory densities for feeding.

Four species of algae will be cultured in stages in 250 ml, 500 ml and 5 litre flasks, of which only three of the species will be selected to be grown through to the 23 litre carboys. The selection will depend on the relative condition and growth rates of the cultures. When bag culture of algae is initiated it is necessary to use a 5 litre flask to inoculate each bag.

The time line (Figure 2) shows that the first two 5 litre flasks are inoculated on day 5 and thereafter at a rate of two flasks per day, with the first bag being inoculated on day 12. This procedure allows a choice of algae for inoculation into bags and also as a back up in case of algal failures. Normal procedure (for a hatchery of this size) is that three new carboys containing Guillard's "f/2" solution, trace metals and vitamins are innoculated each day after all mediums have been autoclaved. Each algae requires five to seven days of growth in the bag before it is usable as a high density culture.

To initiate bag culture, heavy duty plastic bags are inserted into holding frames and filled with filtered air and then filtered seawater. Overnight sterilization of each bag is accomplished by adding a sodium hypochlorite solution to the bag. This is neutralized the following day with a solution of sodium thiosulphate before nutrients are added. The bag is subsequently inoculated with a 5 litre flask of healthy algae. Daily checks and cell counts are all that is then required before the algae is fed out. The bags can be refilled repeatedly (for up to several weeks) with sterililized and filtered seawater after each food volume has been removed ($^1/_4$-$^1/_2$ of the bag per day), provided the algae remains healthy and continues to grow. This procedure of semi-continuous bag culture also serves to reduce costs. Food hygiene is not crucial for the adults but the plastic bags are not re-used once the algae they contain is deemed to be unsuitable as food (for larvae, spat or adults).

The conditioning of the first batch of broodstock begins on day 19 (in tank A of 1 000 litres) and ends on day 79 when they are induced to spawn. The spawning day may occur sooner but this reduces costs in accordance with reduced conditioning time. The costs shown in Table 1 are for the 18 days of culture, up to the start of broodstock conditioning when feeding commences.

2.3.3 Algal culture during broodstock conditioning (day 19-64)

It is expected that by day 19 bag cultured algae would be ready for feeding to the adult scallops and the conditioning period would begin. Satisfactory algal densities in bags would be as follows: *T. iso.*, 2 000—4 000 cells/µl; *Nanno.*, 4 000—8 000 cells/µl;

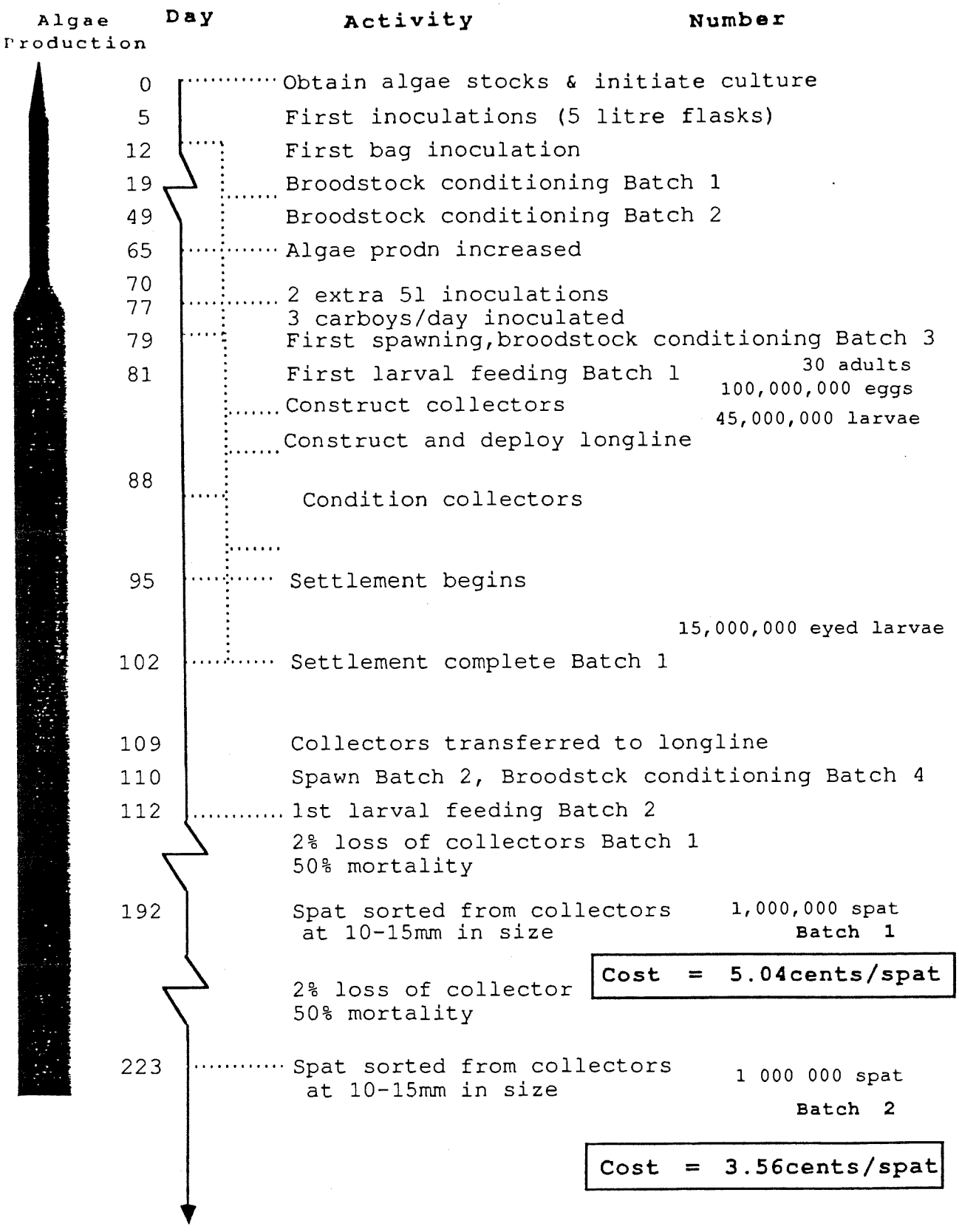


Figure 2. Timeline for hatchery operations

Item		Cost ($)
Labour (2.5 hrs/day for 18 days at $12/hr)		540
Electricity for:	-pumping	1
	-aeration	46
	-lighting	16
	-air conditioning	20
	-autoclave	5
Starter cultures (4)		150
Nutrients		8
Plastic bags		21
Filters		30
Carbon dioxide (CO_2)		32
Miscellaneous		20
	Total	$889

Table 1. Algae preparation costs

Labour (2.5 hrs/day for 18 days at $12/hr)		30.00
Electricity for:	-pumping	0.10
	-aeration	2.56
	-lighting	2.82
	-air conditioning	1.08
	-autoclave	0.32
Nutrients		1.12
Heavy duty plastic bag		3.00
Sterilization of bags, overnight chlorination and then neutralization		0.20
55 mls of standard 12% Sodium Hypochlorite and 20 mls of 1M Sodium Thiosulphate		
Filters (one per day)		1.00
Carbon dioxide (CO_2)		2.50
Miscellaneous		0.30
	Total per day	$45.00
	Total for 46 days	$2 070.00

Table 2. Algae culture costs during broodstock conditioning

C.c., 4 000—8 000 cells/µl; *3H.*, 3 500—6 000 cells/µl. On day 49 the second batch of broodstock would be placed in the conditioning system (1 000 litre tank, Tank B). At this point sufficient algae is already being produced to condition the 200 broodstock being held.

2.3.4 Algae for broodstock conditioning and larval feeding (day 65-109)

It is intended that only algae from 23 litre carboys is used as larval food since food quality is most critical at this stage. By day 65 algae production is increased so there would be sufficient cultures of the four algae species to allow the inoculation of four 5 litre flasks (from day 70 onwards). Three of these 5 litre flasks are used to inoculate the three carboys (from day 77 onwards) and the remaining one can be used for inoculating a bag for broodstock. Labour includes: microscopic examination and cell counts of algae, food calculations and feeding. Food consumption is assessed by cell counts of remaining food in each larvae tank and then additional food is added each day to increase this to a suitable level for the number and size of the larvae. An extra 1.5 hours is required to complete the additional tasks from Table 2. The table below shows the costs for algae culture, over and above those incurred during conditioning only.

Item		Cost ($)/day
Labour (1.5hrs extra per day)		18.00
Electricity for:	- pumping	0.00
	- lighting	1.50
	- aeration	0.00
	- autoclave 4 extra loads per day	2.00
	- air conditioning	negligible
Nutrients		0.20
Filters, 2 per day		2.00
Carbon dioxide		0.00
	Total	$23.20

Table 3. Additional costs during broodstock conditioning and larval feeding

Total cost per day during the above period = $45.00 + $23.20 = $68.20, therefore, the total cost for this period (of 45 days) would be $3 069.00.

The total cost represents the cost of culturing 420 litres of algae each day. However, if allowance is made for bag cultures that prove unsuitable for feeding (assume one out of every three bags), then only 280 litres per day will be available for use. The average count

is 4 000 cells per µl and the algae fed to broodstock would be composed of at least 50% diatoms. The method of conditioning broodstock is described in section 2.4.

Feeding of the batch 1 larvae would commence on day 81 and cease on day 102, ie. after 21 days. This includes a settlement period which may be as long as seven days.

2.4 Conditioning of Broodstock

If wild broodstock are available they could be collected by divers or dredge and transported to the hatchery. However, this is only likely to occur over very restricted periods of the year. A safer alternative is to artificially condition adult scallops held in the hatchery.

It is assumed that 100 adult scallops are held at 16-17°C (thermostat regulated) in two 1 000 litre tanks where the water is changed once per day. Each tank is fed 70 litres of algae twice per day at a cell count of 4 000 cells per µl for up to 60 days. Food costs are based upon a predicted feeding rate. However, recent research has suggested that the actual requirement may be a smaller daily volume than anticipated, hence the cost may be reduced significantly in the future. Regular cleaning of the tanks must be done but care should be taken to reduce the disturbance to the scallops during this period.

Table 4 details the overall costs for conditioning broodstock in one tank which is sufficient to produce one batch of 15 million eyed larvae.

Item	Cost ($)	
	per day	for 60 days
Pumping of water: 0.7 kw x 0.5 hrs x 0.0821 $/kw/hr unit	0.03	1.72
Heating: initially for 1,000 l requires 10 kw x 1.33 hrs		
10 x 1.33 x 0.0425 $/kw/hr = $0.57/day	0.57	34.20
: maintenance of temperature:		
5 kw x 8 hr. x 0.0425 $/kw/hr = $0.50/day	0.50	30.00
Food: accounted for in algae production costs	0.00	0.00
Aeration: accounted for in algae production costs	0.00	0.00
Labour: 0.5 hr/day x $12/hr	6.00	360.00
Total	$7.10	$425.92

Table 4. Total costs for broodstock conditioning

2.5 Spawning of Broodstock

Heated water and algae are used to stimulate the ripe broodstock to spawn. The first

batch would be stimulated to spawn on day 79. Approximately 30 adults, out of 50 put in the spawning tray, will need to fully spawn to yield the required 100 x 10^6 fertilized eggs. This would generally take place over a period of several hours (this may need to be repeated over 2-3 days if unsuccessful initially) and requires about 20 litres of high density algae (>8 000 cells/µl) and running water at 18 - 21°C. Heated water is available at that time as it is used to fill the larvae tanks, hence the cost of warm water for spawning is assumed to be negligible. The remaining 50 scallops could be used if initial spawnings are unsuccessful or if additional conditioning is required.

As soon as the first batch spawns (day 79) the third batch of scallop broodstock would be placed in the conditioning system to replace the first batch. On day 110 the second batch of broodstock would be spawned and the fourth batch placed in the conditioning system.

Item		Cost ($)
Algae: 20 litre		$1.40
Labour: 8 man/hrs x $12/hr		$96.00
	Total	**$97.40**

Table 5. Cost for broodstock during spawning.

Additional spawnings will require a further three days of algae culture just for broodstock conditioning (at $45 per day), 28 days of algae culture for broodstock and larvae ($68.20 per day) prior to larval feeding commencing. That is, a cost of 3 x 45 + 28 x $68.20 = **$2 044.60** (Table 7b).

2.6 Larvae Culture

After spawning, two larvae tanks are to be used to hold the eggs at a density of 3.3 per ml, and from day 2-3 two larvae tanks (with larvae at a low density of 1 per ml) are still required (assuming 30% survival). The full duration of the larval period is 23 days at which point larval settlement is theoretically complete. (NB: L= Larval age in days)

The proposed schedule for the larvae is to begin water changes whenlarvae is at day two or three (L2-3) and continue them every 2-4 days (assume 2 days) up until day L16-19 (depending on developmental stage of the larvae). Settlement generally occurs during day L19-23. The 15 x 10^6 eyed larvae would be divided into three tanks, 5 x 10^6 per tank, prior to settlement. However, the spat collectors should be left undisturbed in

the larvae tanks for another seven days to ensure that byssal thread attachment is firm and the spat do not fall off the mesh when transferred to the longline for ongrowing. Water changes in each tank should be performed daily using a very low flow rate for the incoming water.

The labour component includes sizing, counts and microscopic examination of larvae, tank cleaning, food calculations, feeding and draining of tanks.

Item		Cost ($)
1. Pumping with an overall head of 8 m. Rate is 2 l/sec or 7200 l/hr		
Pump draws 0.7 kw and runs for 2 hrs/day, ie	0.7 x 2 x $0.0821 x 23	2.64
2. Heating: water is changed in each larvae tank 9 times during the 23 day cycle. Ambient temperature is assumed to be 8°C. The required temperature is 17°C. It takes 6 x 5 kw immersion heaters 0.67 hrs to raise the water temperature 1°C. Hence it will take approximately 6 hrs to raise the water temperature to a satisfactory level.		
	180 kw/hr x 9 x $0.0323 x 2	104.65
Maintenance of water temperature for 23 days, assuming a loss of 3°C/day, will require one 5 kw heater operating for 12 hrs/day.	60 x 23 x $0.0425 x 2	117.30
3. Aeration for algae and larvae, accounted for previously		0.00
4. Labour for larvae 2.5 hrs/day x 23 days x $12/man/hr		690.00
	Total Cost	**$914.59**

Table 6. Cost of culturing 15 x 10^6 eyed larvae

2.7 Summary of Hatchery Operating Costs

Initial startup costs as well as the operating costs have been combined here to assess the overall cost of algae culture, conditioning of broodstock, spawning broodstock to obtain 100 x 10^6 fertilized eggs, and culture of the surviving larvae up to the eyed stage when only 15 x 10^6 are expected to remain (Table 7a). Capital costs have not been included but are available for information in Appendix 1.

During a normal production season several batches of larvae would be reared. The cost of producing subsequent batches would decrease as the algae system would already be operational and conditioned broodstock would be available (continued feeding and maintenance of the broodstock would still be neccesary). Costs of producing further batches is detailed in Table 7b.

Item		Cost ($)
Lease of hatchery for 109 days at $65.75/day		7 166.75
Algae -Preparation (Table 1)		889.00
-Broodstock conditioning & Larval Food (Table 2 & 3) x 45 days		3 069.00
Broodstock Conditioning (Table 4)		425.92
Spawning (Table 5)		97.40
Larval Culture (Table 6)		914.59
	Total cost	$12 562.66
		0.0838 cents/larvae

Table 7a. Total hatchery costs to produce 15 x 10^6 eyed scallop larvae (Batch 1).

NB: Food is provided during settlement but these costs may be reduced by using flow through of partly-filtered water.

Item		Cost ($)
Lease of hatchery for 31 days at $65.75/day		2 038.25
Algae -Preparation (Table 1)		0.00
-Broodstock conditioning & Larval Food (Table 2 & 3) x 28 days		1 909.60
-Broodstock conditioning (Table 2) x 3 days		135.00
Broodstock Conditioning (Table 4)		213.00
Spawning (Table 5)		97.40
Larval Culture (Table 6)		914.59
	Total cost	$5 307.84
		0.0354 cents/larvae

Table 7b. Total hatchery costs to produce 15 x 10^6 eyed scallop larvae (Batch 2).

NB: Food is provided during settlement but these costs may be reduced by using flow through of partly-filtered water.

2.8 Spat Settlement

For larval settlement to occur it is imperative that a suitable substrate is provided in the tanks prior to metamorphosis beginning. Mesh bags (called collectors) filled with old

monofilament shark netting (Cropp, 1985) or the common mussel ('Christmas tree') rope can be used. These are attached to droppers (without the weight) and should be conditioned in seawater for several days before placing them in the larvae tanks. A total of 500 spat collectors would be divided into three equal groups and tied onto a total of 50 droppers (10 collectors per dropper). Each group of droppers (16-17 droppers) would be placed in one of the larvae tanks. Approximately one week after the larvae have settled, the droppers with the collecting bags can be transferred carefully to longlines for ongrowing.

The hatchery described has the capacity to produce 15 million scallop larvae from each batch of eggs spawned. The unit cost per spat depends on the percentage of eyed larvae which set; this cost has been determined at day L30 for a range of setting percentages, (seven days after settlement begins) and is shown in Table10. The cost also includes the collectors (and droppers they are attached to), on which the spat settle (Table 8). Some savings may be made by not feeding out cultured food after settlement is complete; a flow through system of partly or semi- filtered water could be provided to the tanks.

On day L30 (overall day 109) the droppers, with spat collectors and weights attached, are transferred to a longline for ongrowing; this point signifies the end of the hatchery phase of culture.

Item	Number	Type	Length (m)	Unit cost	Total cost ($)
onion bags	500			$0.66	330.00
shark mesh		used	10 000	$0.00	0.00
twine		3mm pp*	100	$0.07	7.00
dropper	50	8mm pp*	10	$0.21	105.00
labour for construction				8.5 mandays @ $10/hr	765.00
				Total	**$1 207.00**

pp* = polypropylene rope

Table 8. Cost of collectors for settlement of hatchery spat

The cost of spat collector materials and construction is added to the cost of producing 15 x 10^6 eyed larvae to obtain the cost of settled spat at the end of the hatchery stage of culture. This total cost using 500 collectors is shown in Table 9 and is **$13 769.66** for batch 1 and **$6 514.84** for batch 2. The cost per spat is assessed in Table 10 below and varies according to the percentage of eyed larvae which actually settle.

Item	Batch 1	Batch 2
Eyed larvae cost	$12 562.66	$5 307.84
Collector cost	$ 1 207.00	$1 207.00
Total	$13 769.66	$6 514.84

Table 9. Total hatchery spat cost at day 30

% Set	Number of Spat	No. spat/collector	Cost(cents/spat)	
			Batch 1	Batch 2
3.3	0.5×10^6	1 000	2.7539	1.3030
6.7	1×10^6	2 000	1.3770	0.6515
13.3	2×10^6	4 000	0.6885	0.3257
26.7	4×10^6	8 000	0.3442	0.1629
40.0	6×10^6	12 000	0.2295	0.1086

Table 10. Cost of hatchery produced spat at day 30

2.9 Ongrowing

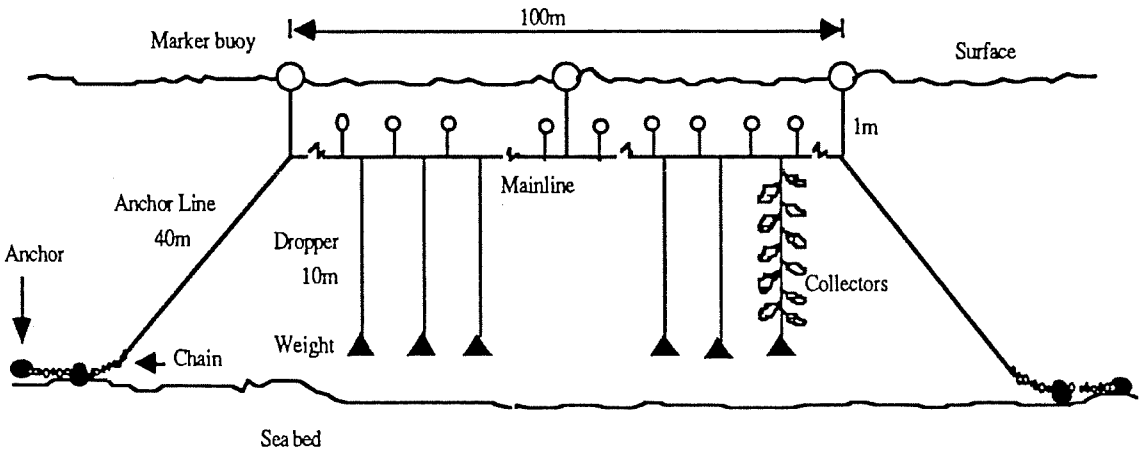
The cost and construction of a suitable settlement substrate for scallops has been outlined in Cropp, 1987. The equipment design has been slightly modified to allow placement of the longline, used to hold the collectors, at a site where the water depth is only 13m. The collecting bags are attached in pairs at intervals of 0.75m on the rope droppers, 20 bags per dropper.

If we assume that settlement of larvae results in 1×10^6 spat then 1 000, 500 or 200 collectors would be required. Any of these can be held on 50 droppers which will fully occupy 1 x 100m longline at an inshore semi-protected site. The basic structure of this longline is shown in Figure 3. This type of site is chosen so that regular monitoring is easy (and cheap) and virtually the whole water column can be used to hang collectors in. Sea conditions at offshore deepwater sites are generally too rough for scallop collectors placed anywhere within 6m of the surface whereas at an inshore site as mentioned, the collectors can be placed from 1.5m below the surface to 4m above the bottom at high tide.

As mentioned, with a settlement of 1×10^6 spat assumed, the cost varies depending on how many collectors are used and subsequently the number of spat that settle in each collector. For simplicity we can assume that the same basic longline and dropper arrangement is used to hold all the collectors. That is, a 100m longline with droppers supporting 20 collectors each. Obviously the batch resulting in 5 000 spat per collector

(requiring 200 collectors) will only need 10 droppers. Collectors from subsequent batches could be attached at a later date, further reducing the cost per spat.

Figure 3. Inshore longline design (Not to scale)



Item	Number	Type	Length (m)	Unit cost	Total cost
main line	1	24mm pp*	100	$1.57	$157.00
anchor line	2	24mm pp*	40	$1.57	$125.60
thimbles	4	25mm galv		$4.00	$16.00
anchor chain	4	9mm black	20	$3.29	$263.20
anchor weights	4	bogey wheel		$27.50	$110.00
shackles	12	12mm black		$3.30	$39.60
floats	3	250 litre		$110.00	$330.00
floats	10	14 litre		$7.15	$71.00
		Basic Longline Cost			**$1 112.40**

onion bags	1 000		-	$0.66	$660.00
shark mesh		used	10 000	$0.00	$0.00
twine		3mm pp*	100	$0.07	$7.00
droppers	50	8mm pp*	10	$0.21	$105.00
dropper wts	50	steel		$1.10	$55.00
		Collector Cost			**$827.00**
TOTAL					**$1 939.40**

pp* = polypropylene rope

Table 11. Longline and spat collector materials for hatchery spat.

Item	Cost ($) No. of collectors 1000	500	200
Deployment of longline and spat collecting equipment (Barge)	400.00	400	400
Monthly check on equipment (3 trips, small runabout)	450.00	450	450
Labour for retrieval of spat collectors and sorting	1,800.00	900	360
Vessel for retrieving spat collectors and longline	6,000.00	2400	1200
Total	$8,650.00	$4,150	$2,410

Table 12. Costs of deploying, retrieving and monitoring spat collecting equipment

Item	No. spat/collector	1 000*	2 000	5 000
	No. of collectors	1 000	500	200
Basic cost of Longline		$1 112.40	$1 112.40	$1 112.40
Cost of collectors:-				
Twine		$7.00	$7.00	$7.00
Onion bags		$660.00	$330.00	$132.00
Droppers		$105.00	$52.50	$42.00
Dropper weights		$55.00	$27.50	$11.00
Total material cost		$1 939.40	$1 529.40	$1 304.40
Labour to construct longline (1 manday at $10.00/hr)		$90.00	$90.00	$90.00
Labour to construct collectors and droppers		$1 440.00	$765.00	$450.00
Cost of deploying/retrieving, monitoring equipment and sorting collectors (see Table 11)		$8 650.00	$4 150.00	$2 410.00
Total cost of Labour		$10 180.00	$5 005.00	$2 950.00
Total cost (Materials and Labour)		$12 119.40	$6 534.40	$4 254.40

* 1 000 spat per collector implies that 1 000 collectors would be required. These would not fit inside the larvae tanks as described, thus larger tanks would be neccesary.

Table 13. Spat settlement and ongowing costs for 1 x 10^6 spat at selected densities.

The ongrowing methodology described is one of three options after the spat are contained within collectors. Three months after settling they can be transferred into pearl nets for the first stage of hanging cage culture, they can have their ears drilled and be tied (or glued) onto droppers, or they can be left in collectors and sorted from them once they have attained a suitable size (then reseeded). It has been **assumed** that 2% of the collectors would be lost due to bad weather or construction deficiencies and there would be a 50%

mortality of the spat during the 3 months of ongrowing.

2.10 Hatchery Spat Cost

The total cost per spat from the hatchery has been assessed on a 6.7% settlement rate of eyed larvae. The subsequent 1 x 10^6 spat are settled in conventional spat collectors at varying densities of 1 000, 2 000 and 5 000 spat per collector. As the number of collectors used decreases, the amount of spat settling in each collector increases at a corresponding rate. High numbers of spat per collector result in increased mortalities but to economise, spat would be removed from collectors early and hence would be smaller than originally planned. For this example we can assume an ongrowing period of 3 months, after which the spat are sorted from the collectors at a size of 10-15mm. Mortality of the spat during ongrowing and total loss of collectors needs to be included in costings and as mentioned previously, this is expected to be 50% and 2% respectively. Overall figures are shown in Table 14. Costs clearly fluctuate based on how many batches of larvae/spat are produced.

Item	No. spat/collector	1 000	2 000	5 000
	No. of collectors	1 000	500	200
Cost of producing	Batch 1	$12 562.66	$12 562.66	$12 562.66
eyed larvae	Batch 2	$5 307.84	$5 307.84	$5 307.84
Ongrowing costs		$12 119.40	$6 534.40	$4 254.40
Total	Batch 1	$24 682.06	$19 097.06	$16 817.06
	Batch 2	$17 427.24	$11 842.24	$9 562.24
Cost/spat (Excluding	Batch 1	2.47c	1.91c	1.68c
collector and spat losses)	Batch 2	1.74c	1.18c	0.96c
But assuming 2% loss of collectors and 50% mortality in collectors, leaving 490 000 scallops				
Cost/spat	**Batch 1**	**5.04c**	**3.90c**	**3.43c**
	Batch 2	**3.56c**	**2.42c**	**1.95c**

Table 14. Summary of costs for hatchery reared scallops at 10-15mm in size

The flow diagram below illustrates how the various figures were derived and also gives the three price alternatives for buying eyed larvae, 30 day old settled spat or 10-15mm spat.

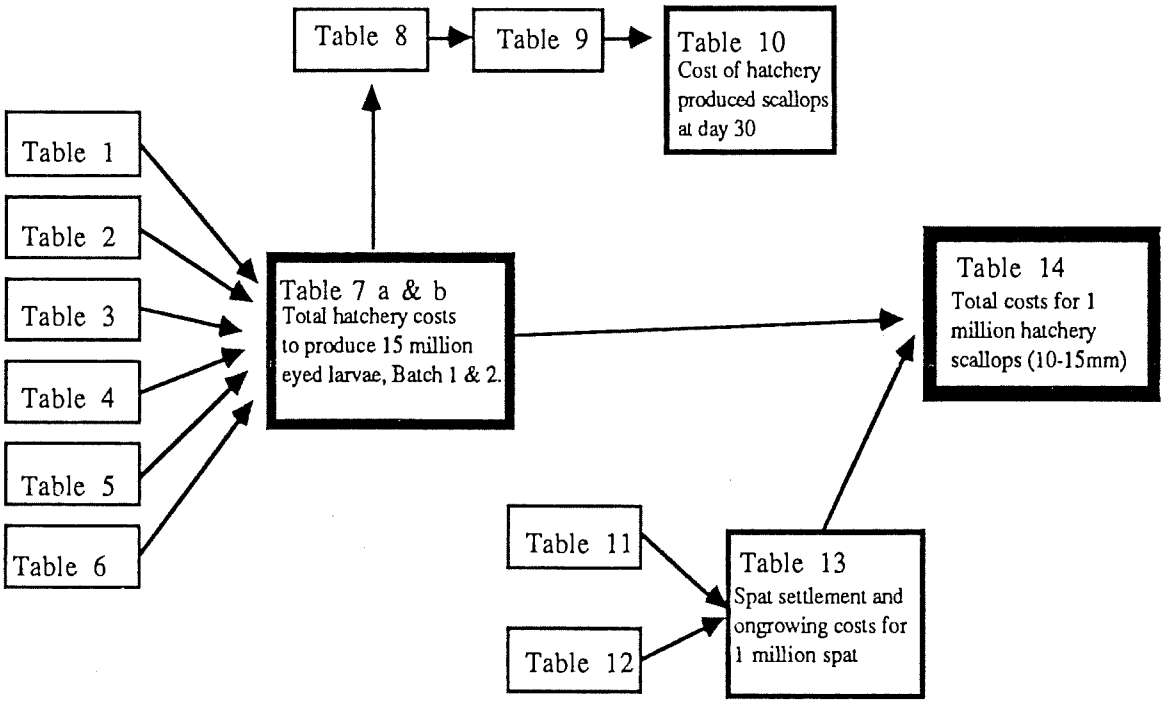


Figure 4. Flowchart for hatchery costings

3. COLLECTION OF NATURAL SPAT

3.1 Methodology

The method of collecting scallop spat, derived from the natural spawning of adult scallops at sea, has been adapted from techniques used in Japan for many years. Many diffent types of equipment have been tested over a number of years at a research site off Maria Island. A suitable longline and collector arrangement has now been determined. This design can be modified to withstand rougher weather than that experienced at Maria Island. For example, the three 250 litre surface floats would be replaced by 14 litre floats (buoys) and several more 14 litre floats would be added to the mainline to provide sufficient buoyancy. Modifications are also possible for calmer conditions incurred at shallow water sites (see Figure 3)

The longline detailed in Table 15 is for a semi-sheltered oceanic site where the water depth is 30m; it is shown schematically in Figure 6. A total of 2 000 collectors are attached to droppers (40 per dropper) so that they span the depths between 7 and 27m when they

are hung vertically from the mainline. The schedule of major operations is shown on a timeline (Figure 5).

Item	Number	Type	Length (m)	Unit cost ($)	Total cost($)
main line	1	24mm pp*	100	1.57	157.00
anchor line	2	24mm pp*	90	1.57	282.60
thimbles	4	25mm galv		4.00	16.00
anchor chain	4	9mm black	20	3.29	263.20
anchor weights	4	bogey wheel		27.50	110.00
shackles	12	12mm black		3.30	39.60
floats	3	250 litre		110.00	330.00
floats	10	14 litre		7.15	71.00
droppers	50	8mm pp*	20	0.21	210.00
dropper wts	50	steel		1.10	55.00
onion bags	2 000			0.66	1 320.00
shark mesh		used	10 000	0.00	0.00
twine		3mm pp*	100	0.07	7.00
TOTAL					**$2 861.40**

pp* = polypropylene rope

Table 15. Longline and spat collector materials

Item	Number	Mandays	Cost($)
Construct longline	1	1	90.00
Construct collectors	2 000	21	1 890.00
Construct droppers	50	8	720.00
TOTAL		**30**	**$2 700.00**

NB: Labour cost is $10/hr @ 9 hrs/day.

Table 16. Cost of labour required to construct longline and spat collectors

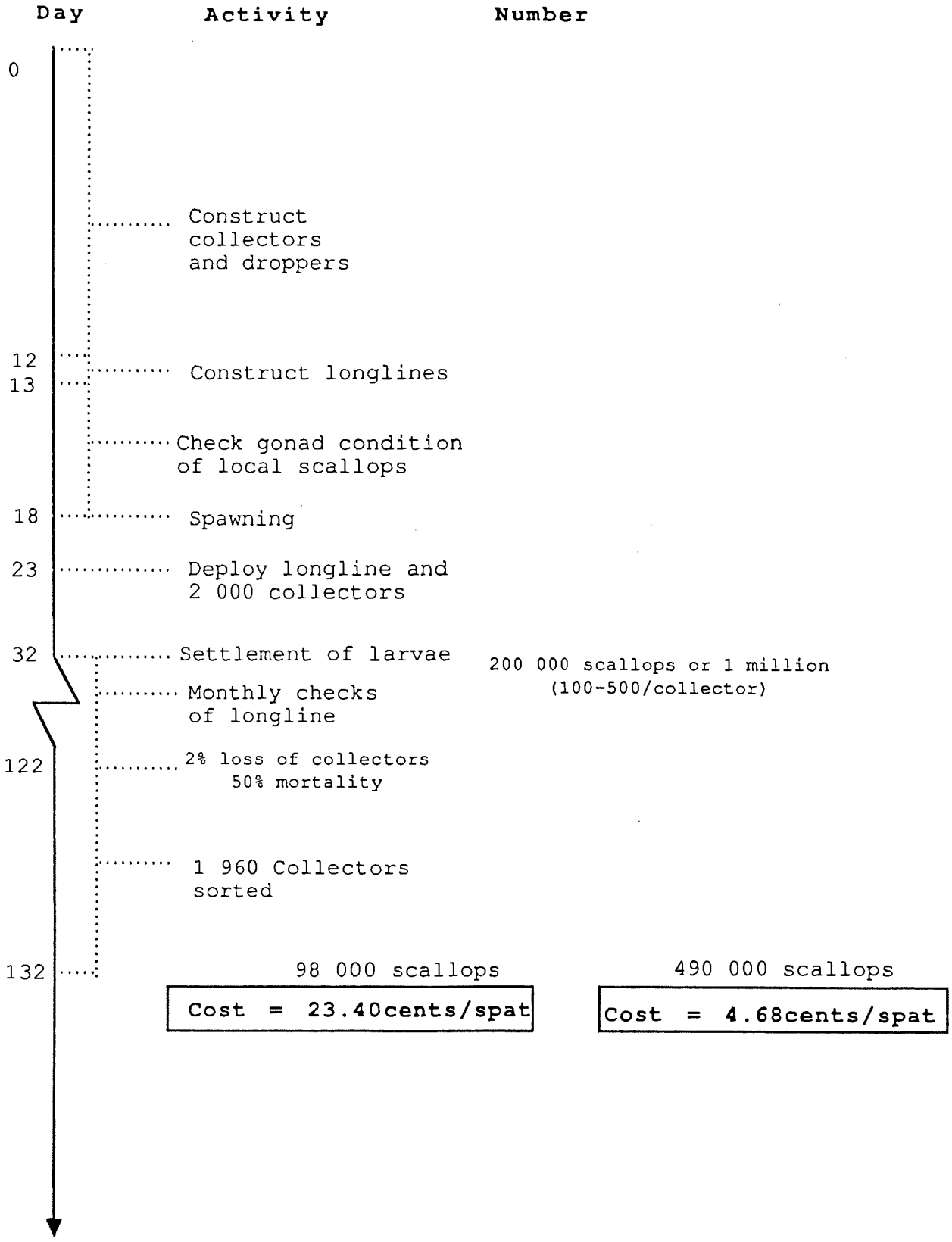


Figure 5. Timeline for natural spat collection

Labour requirements for construction of equipment have been conservatively over-estimated so that the work could be completed by inexperienced staff within the time frame shown. Obviously, as staff develop more expertise this labour cost would decrease.

3.2 Deployment of Spat Collectors

Once the equipment has been constructed it will need to be conveyed to a vessel that will then transfer it to the longline site and deploy it. Monthly inspections of the equipment should be carried out to ensure that floatation is sufficient as fouling accumulates, and that no damage has occurred as a result of shipping, algae or weather conditions.

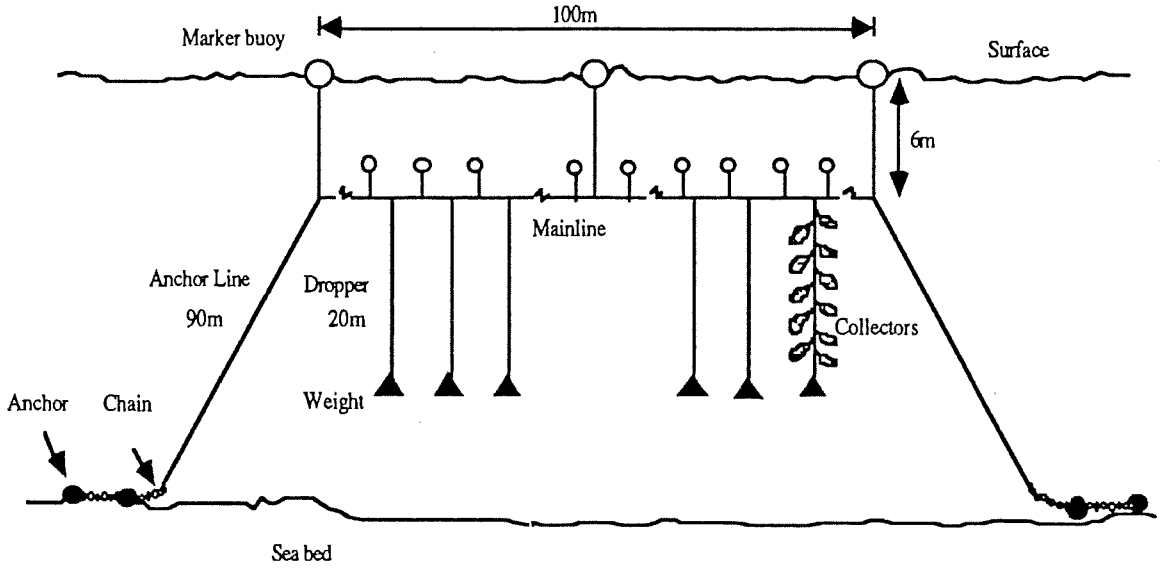
Item	Cost ($)
Transport of equipment to vessel (including labour)	200.00
Deployment of longline and spat collecting equipment (large vessel)	1 200.00
Monthly check on equipment (3 trips, small runabout)	375.00
Labour for retrieval of spat collectors and sorting (40 mandays x $90/man/day)	3 600.00
Vessel for retrieving spat collectors and longline (10 days)	8 000.00
Total	**$13 375.00**

Table 17. Costs of deploying, retrieving and monitoring the equipment.

3.3 Natural Spat Costs

The sorting of 1 960 spat collectors (assuming a 2% loss) three months after their deployment should produce from 2×10^5 to 1×10^6 juvenile scallops ranging in size from 10 to 15mm with 100 to 500 per collector. The cost per scallop will vary depending on the catch rates as shown in Table 19 below. These are calculated by using the total cost figure (Table 18) of obtaining spat from the wild (at sea).

Figure 6. Offshore longline design (Not to scale)



Item	Cost($)
Cost of materials	2 861.40
Labour costs of constructing longline equipment	2 700.00
Costs of deploying/retrieving and monitoring equipment	13 375.00
Total	**$22 9 3 6 . 4 0**

Table 18. Total labour and materials for natural spat collection

At the present time it is expected that there would be 100 scallops settling initially per collector. If there is a 50% mortality and loss of these scallops up to the time of sorting, the cost becomes 23.40 cents per scallop (Table 19). If the number of scallops per collector was to increase in future years there would be a marked reduction in the cost per scallop (as much as 20 cents per scallop).

Item	Number of spat per Collector		
	100	500	1000
Total cost	$22 936.40	$22 936.40	$22 936.40
Number of scallops initially	200 000	1 000 000	2 000 000
Cost/spat (cents) (Excluding collector and spat losses)	11.47	2.30	1.15
Assuming 2% loss of collectors and 50% spat mortality			
Number of scallops	98 000	490 000	980 000
Cost/spat (cents)	23.40	4.68	2.34

Table 19. Summary of natural collecting costs for 0.10-1.0 x 10^6 scallops

4. DISCUSSION

The establishment cost of the hatchery has been detailed (Appendix 1), but the capital amount has not been included in assessing the cost per spat. However, if the hatchery is to be built and used solely for producing scallops then it would need to be taken into consideration. For the analysis conducted here the leasing cost of an established hatchery has been used. Basic administration and staff costs such as superannuation, workers compensation, leave loading etc. have not been included. Although this type of arrangement may be possible in some instances, Tasmania is somewhat restricted at present (as are other parts of Australia) by having only three hatcheries capable of culturing bivalve molluscs. For the purposes of this report it is assumed that staff would be payed on an hourly basis.

Realistically, most hatcheries are designed at cultivating multi-species and hence preliminary work for the culture of scallop larvae (ie. broodstock conditioning) could be carried out whilst the hatchery is actually culturing another bivalve species. In this manner, algae culture would probably be already established and producing. As long as potential broodstock is available, conditioning of gonads can be scheduled such that the

hatchery transforms its operations from one bivalve species to another (in this case scallops) without passing through a non-productive changeover period.

Producing algae as food for bivalves is clearly an expensive operation as it is in many shellfish hatcheries (Laing, 1985) and it is important to schedule the various cycles of culture in conjunction with the changing requirements of the scallops so that uneccessary production and/or wastage of algae is avoided. As well, quality or nutritional value of the algae is a major concern and again, it is necessary to plan algal production so that harvesting of algae occurs at the optimum time (Lewis *et al.*, 1986 and Whyte, 1987).

The study here shows that eyed scallop larvae **could** be produced for less than 0.1 cents each. However the crucial stage is metamorphosis of the eyed larvae and survival rates during metamorphosis have a significant effect on the cost per spat. Settlement of the spat onto a suitable substrate also involves additional costs. If 1×10^6 settled spat (day L30) are obtained then the cost would be 0.1-2.8 cents per spat. Investigations are already underway to assess the viability of settling spat in a downwelling system (Dao, Cameron, 1988, pers. comm.) or an upwelling system similar to that used in settlement of Pacific oyster spat (John, 1988 pers. comm.). Handling of the spat at this stage should be kept to a minimum as they are very small and fragile and large amounts can easily be damaged or lost. Losses incurred during settlement of larvae onto collectors would thereby be avoided.

Once the spat have been ongrown to 10-15mm in size and removed from the collectors, the cost is then 2-5 cents each. In addition, it is important to note that the cost of rearing scallop spat decreases considerably after the first batch. In this report, the full costs of algae preparation and broodstock conditioning are included in the cost of producing the first batch of spat; however the actual cost of producing batch 2 is approximately 40% of the batch 1 cost. This illustrates that if operating costs were to be spread over a culture season or over a large number of batches of spat then the cost per spat would decrease markedly, down to 2-3.6 cents per 10-15mm spat. **NB:** (No profit margin is included at any stage in this report).

Overall it seems likely that being able to produce scallop spat for a cost of between $0.02 and $0.04 (2-4 cents) each could be profitable given that the value of two year old scallops of 8-9 cm in size is currently about $0.23 each (assuming a meat weight of 70 scallops/kg; range 60-80; price: $16/kg meat weight). The economics of ongrowing scallops in hanging cages or trays up to this size has previously been examined in Cropp, D.A. (1984 , 85) and Cropp, R. A. (1987).

In Tasmania it appears that the collection of natural spat at sea is presently too costly due to the low catch rate per collector, itself a result of very low numbers of adult scallops

in the catch areas. At this stage, a catch of natural spat in excess of 500 per collector would be required before it could become economically viable. As vessel costs are a major component in obtaining natural spat, the reduction of the rate from $1 200 per day to $800 per day would result in spat costing 3.9 cents each (instead of 4.7 cents) at 500 per collector. This component is not so influential for hatchery reared spat as the vessel is costed at $600 per day. Overall, hatchery reared spat is **currently** the most economically viable method of obtaining large numbers of scallop spat.

ACKNOWLEDGEMENTS

We wish to thank the Tasmanian Shellfish Company (Manager: Ian Cameron) and Shellfish Culture Pty Ltd (Manager: Malcolm Fraser) for allowing the hatchery work to be carried out at Dunalley and Bicheno respectively. Dr. Trevor Dix is thanked for his involvement and advice on the project and his criticisms of this report. Roger Cropp helped compile data and information. Ivor Growns is thanked for his help in final preparation and Ann Gschwendtner provided assistance with technical details. Dr. Ian Woodward and Dick Friend reviewed the manuscript.

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Appendix 1. Capital costs of the proposed hatchery.

Item		Cost ($)
Building	- superstructure (10 x 12m)	26 000
	- concrete slab and drains	11 700
	- internal laboratory and algae room	11 700
Amenities block		5 500
Electrical	- switchboard, internal wiring, etc.	15 600
PVC pipes and fittings		2 500
Algae lights (32 units)		2 900
Steel mesh bag holders (8)		640
Air conditioning unit		1 040
Autoclave (manual)		8 800
Refrigerator (secondhand)		250
Oven		250
Larvae tanks (3 x 15 000 litre)		13 500
Sand filter		690
Pump		1 400
Rainwater tank (5 000 litre) and pressure pump		2 300
Airblower		5 400
Titanium heaters (12 x 5kw)		2 900
Larvae screens, spawning trays, buckets, etc.		1 800
Hot water system		280
Laboratory equipment - glassware, carboys, microscope, algae stands, haemocytometer, volumetric flasks, balance, etc.		13 000
Contingency		6 000
	Total	**$134 150**
plus labour for construction, estimated at		$25 000
	Grand Total	**$159 150**

Appendix 2. Cost of chemicals required for the Guillard's "f/2" medium

Chemical	Minimum amount available	Cost
$FeCl_3.6H_2O$	500g	$13.50
	5kg	$56.00
$MnCl_2.4H_2O$	500g	$32.60
EDTA	500g	$53.00
	5kg	$300.00
$NaH_2PO_4.2H_2O$	500g	$22.40
	3kg	$80.00
$NaNo_3$	5kg	$88.00
	50kg	$650.00
$ZnCl_2$	250g	$18.00
$CoCl_2.6H_2O$	100g	$39.00
	500g	$130.00
$(NH_4)6Mo_7O_{24}.4H_2O$	100g	$27.95
	500g	$86.00
$CuSO_4.5H_2O$	500g	$24.00
	3kg	$135.00
Conc HCl	2.5l	$24.40
Biotin	100mg	$9.50
	500mg	$21.50
	1g	$37.00
	5g	$175.00
Cyanocobalamin (B_{12})	100mg	$12.00
	5g	$242.00
Thiamin HCl (B_1)	5g	$9.00
	1kg	$215.00
$Na_2SiO_3.5H_2O$	500g	$12.50
Sodium Hypochlorite	30l (12%)	$30.00

APPENDIX 3.Guillard's "f/2" Algae culture medium

Composition of enrichment "f/2"

Major nutrients		Cost (cents)
$NaNo_3$	75 mg (883 µM)	0.13
$NaH_2PO_4.H_2O$	5 mg (36.3 µM)	0.02
$Na_2SiO_3.9H_2O$	15-30 mg (1.5-3 mg Si or 54-107 µM)	0.08
Trace Metals		
Na_2.EDTA+	4.36 mg (ca 11.7 µM)	0.05
$FeCl_3.6H_2O$	3.15 mg (0.65 µg Fe or ca 11.7 µM)	0.01
$CuSO_4.5H_2O$	0.01 mg (2.5 µg Cu or ca 0.04 µM)	0.01
$ZnCl_2$	0.022 mg (5 µg Zn or ca 0.08 µM)	0.01
$CoCl_2.6H_2O$	0.01mg (2.5 µg Co or ca o.05 µM)	0.01
$MnCl_2.4H_2O$	0.18 mg (0.05 µg Mn or ca 0.9 µM)	0.01
$(NH_4)_6Mo_7O_{24}.4H_2O$	0.006 mg (2.5 µg Mo or ca 0.03 µM)	0.01
Vitamins		
Thiamin.HCl	0.1 mg	0.01
Biotin	0.5 µg	0.01
Cyanocolalamin (B_{12})	0.5 µg	0.01
Seawater	to one litre	
Total cost		0.37

Notes : Silicate may be omitted for organisms other than diatoms.

(mixture from Holliday, 1985)

Tables:

Growth and survival of Tasmanian commercial scallops *Pecten fumatus* in an underwater enclosure.

Derek A. Cropp, Marine Biologist, Department of Sea Fisheries, Research and Resource Section, Crayfish Point, Taroona.

Abstract

A circular 1.8m high underwater fence was constructed and positioned on the seabed in 10m. of water off Tasmania's east coast. Nylex mesh of internal diagonal 33.5mm. was used to confine the scallops. Two groups of 1,000 scallops averaging 37.4mm and 37.2mm in height (or length) were placed inside and outside the fence respectively. Monitoring was regularly carried out to ascertain seasonal growth and survival rates in a situation where movement was only possible, for some, in a confined area. Growth rates between the two groups were comparible for 230 days, after which the outside scallops dispersed and measurements could not be taken from this group. Rapid growth rates were recorded for the enclosed group up to an age of 829 days. The muscle and gonads recovered from these scallops after processing averaged 19% of live weight.

Introduction

There are two main methods used worldwide for artificially culturing scallops. They can be either sown, as spat, on scallop beds to grow to adult size under natural conditions (re-seeding) or they can be reared by means of hanging cages suspended in the water column. Of these two methods re-seeding has the advantage that it requires virtually no capital for equipment or labour during ongrowing.

There have been few studies (outside Japan) carried out on the re-seeding of scallops (eg. Dao and Didou, 1982 Castagna, 1975). However, in Japan it has been studied and developed for many years (Ito *et al.*, 1975; Ventilla 1982). In previous years spat were sown at a size of 17-20mm at a density of 6 spat per square metre (Ito *et al.*, 1975). They were left for 2-3 years before they were harvested. More recently, spat have been ongrown to 50mm (Sasaki, pers. comm.) prior to reseeding and are left for up to 4 years before harvesting.

In situ studies of the Tasmanian commercial scallop (*Pecten fumatus*) have been very limited (Olsen, 1953,1955), as have experiments to monitor the natural growth and mortality of scallops on the seabed (Tubb, 1964) . More extensive work has recently been completed on the culture of

caged commercial scallops (Dix, 1981; Hortle, 1983; Cropp and Hortle, in press, and Cropp, 1985). Preliminary work has now been done on the growth and survival of wild scallop spat released onto the seabed.

Methods

The experiment was carried out at Promise Bay in Great Oyster Bay on the east coast of Tasmania (Fig.1). A 1.8m. high fence was constructed using 50mm. diameter P.V.C. plumbing pipe. Two rings of pipe were joined by vertical uprights 1.75m. long producing a fence with a diameter of 5.2m., a circumference of 16.3m. and an enclosed area of 21.2m.^{2}. Black nylex mesh (maximum internal diagonal; 33.5mm.) was strapped to the outside of the frame using plastic cable ties. The whole structure was anchored using 4 x 50kg. weights tied to the outside vertical uprights. Supporting ropes were tied across the top of the structure to increase the rigidity. The seabed inside and outside the fence (a total of 100m^2) was checked and cleared of any potential predators (eg. starfish or hermit crabs). An adjacent area to the cage was marked out as a control.

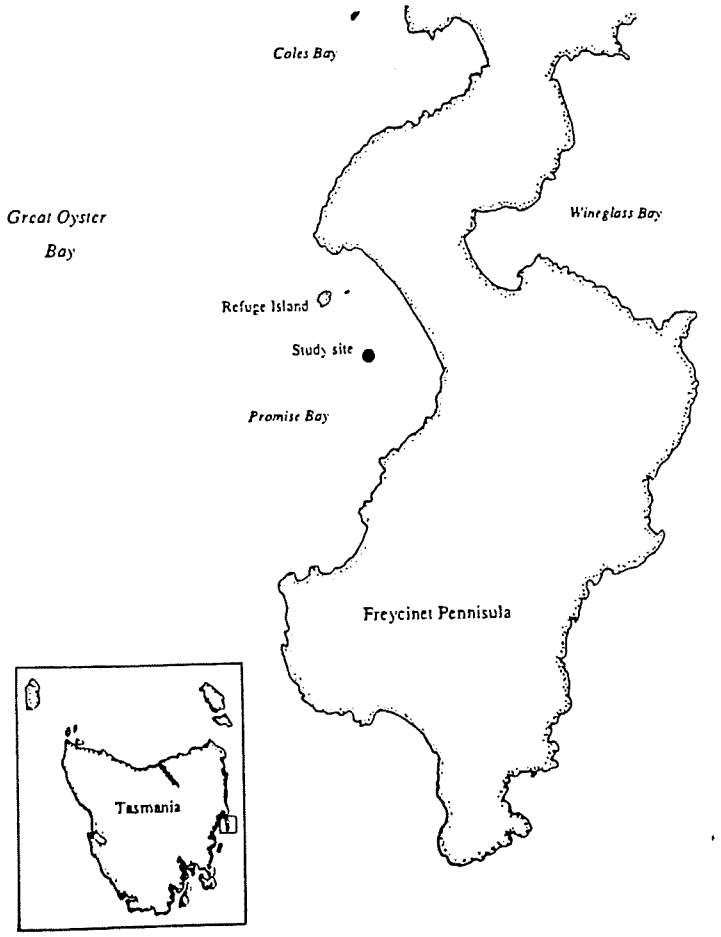

Figure 1. Research site in Promise Bay.

Juvenile scallops were obtained from mesh spat collectors attached to a sub-surface longline in Mercury Passage near Maria Island, approximately 25nm from the research site in Promise Bay (Hortle and Cropp, 1987). These collectors were put in the water in August- September, 1984 and scallops removed from them in June, 1985. Only scallops greater than 33.5mm in diameter were utilized for the release experiment and these were assessed as being approximately 299 days old at that stage.

From the range of spat obtained, 2,000 juvenile scallops were graded using a 33.5mm mesh seive. Of these, 1,000 were put inside the fence and the other 1,000 in the adjacent control area. The height (the distance from the umbo to the margin of the shell) of fifty scallops, from each group was measured prior to their release. The scallops were measured underwater at various intervals after release and dead shells or potential predators were cleaned out of the cage and control enclosure during these times. On the 25/6/86 and 19/9/86 a number of scallops were taken for processing. The remaining scallops were collected on the 4/12/86 and the experiment discontinued due to storm damage to the cage.

Shell height is used to describe scallop size in this study, but as width is commonly used as the legal measurement in the scallop fishery, a graph showing the relationship between the two, as obtained in this experiment, is presented in Figure 2.

Results

The height - width comparison is necessary when considering the various results of this study. Figure 2 shows the relationship produced from measurements of all live scallops processed at the end of the study detailed here.

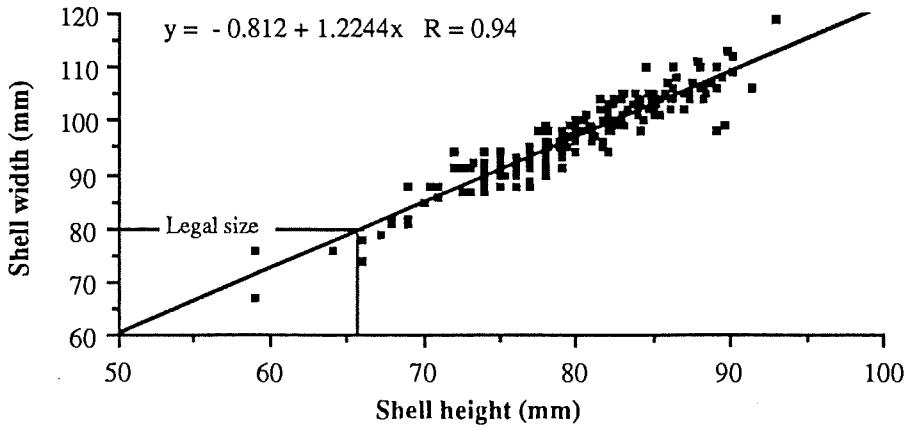

Figure 2. Linear relationship between shell width and height

The scallops in the enclosure reached legal size (66mm in height, 80mm in width) when they were approximately 550 days old, after 251 days on the sea bed (Fig 3). At the end of the experiment they averaged 79mm in height and 93mm in width although in the previous sampling they averaged 87 mm in height. There were no scallops left in the control area after 7 months. They had either been preyed upon or swam away.

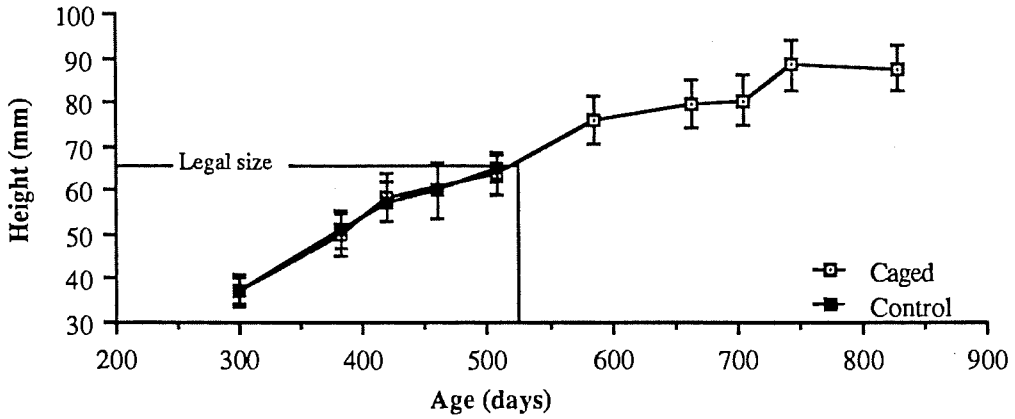

Figure 3. Growth of scallops released onto the seabed

At the end of the experiment 82 scallops were found alive, 118 scallops had been taken for processing and 443 dead shells had been collected. The fate of the remaining 353 scallops is unknown, however they could have either swum away after the cage was damaged or been consumed whole at a small size by transient predators. It is assumed that the 118 scallops that had been removed for processing would have survived till the end of the experiment.

If the 353 scallops (unaccounted for) are assumed to have been alive, a maximum of 55.7% of the scallops would have survived till the end of the experiment. However, the catch rate by the end of the experiment was only 20.4 %. If the cage had not been damaged the survival rate of the scallops is likely to have been very high. Up until the 18/9/86 (Day 748) only 360 of the original 1000 scallops had been confirmed dead i.e. a survival of 64% (Fig. 4).

The anomaly between the last two sampling dates is a sampling error induced by divers apparently measuring the most visible scallops underwater, ie the largest. Visibilty was at times down to 0.25 metres which made underwater measuring very difficult. The large sample at the completion of the experiment is a more accurate indication of scallop sizes.

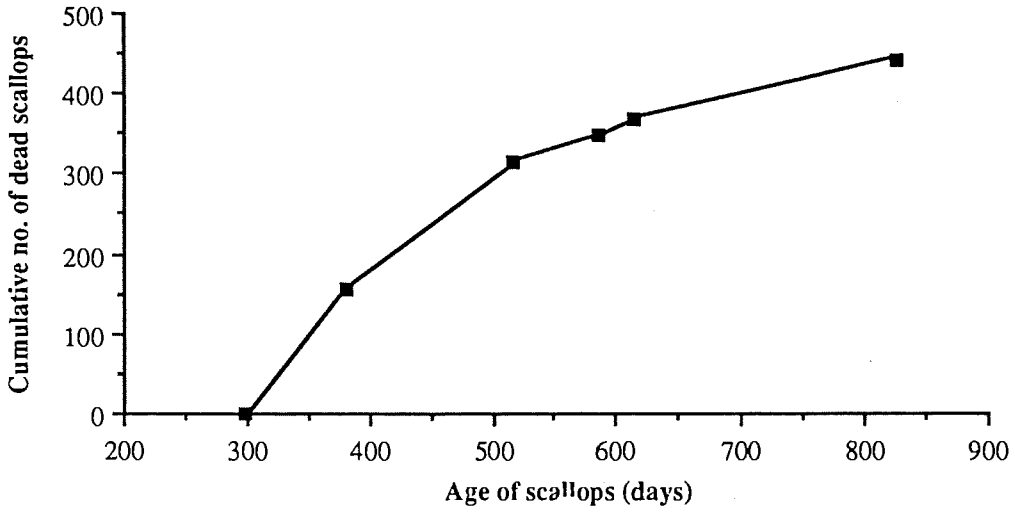

Figure 4. Cumulative mortality of the scallops during the experiment

It is important to note that on a macroscopic gonad condition score (Harrison, 1961; Sause et al., 1988) the June processing sample had a mean condition of 4.3. This improved up to a condition of 5.4 in September after which stage spawning apparently occurred as the condition in December was only 4.5. This is supported by the increase in gonad weight from 4.3 $\pm$ 1.16 in June (mean $\pm$ s.d.) up to 7.5 $\pm$ 3.00 in September and the subsequent decrease down to 3.9 $\pm$ 0.77 in December. The occurrence of spent gonads between September and December was confirmed visually by divers.

Final processing from the day 829 harvesting produced 18.8 $\pm$ 0.3g ($\mu \pm$ S.E.) of meat and gonad per scallop, representing an average recovery of 20.6%. The scallops sampled on the 18/986 also show similar weights. The total weight and meat weight both show a logarithmic relationship with shell height (Fig. 5), while the meat weight of the scallops shows a linear relationship with the total weight (Fig. 6).

$$\text{a)}\quad y = .001\, x^{2.63} \quad r = 0.92$$

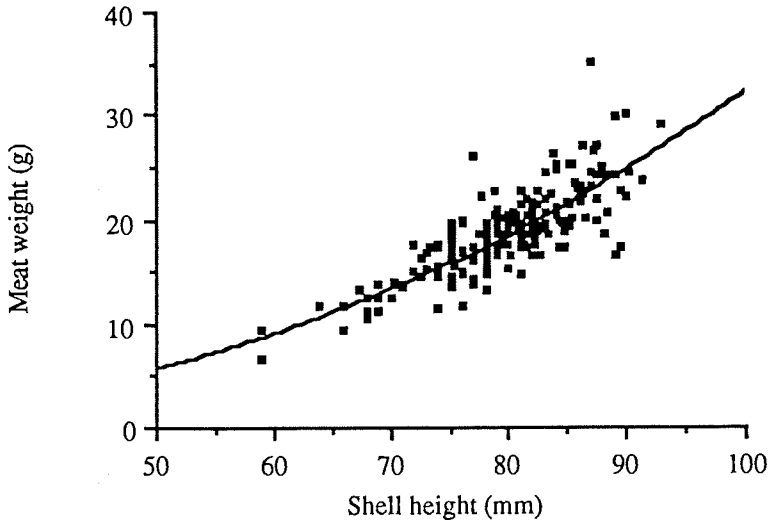

Figure 5a. Logarithmic relationship between meat weight and shell height

b) $y = .0003\, x^{2.48}$ r = 0.84

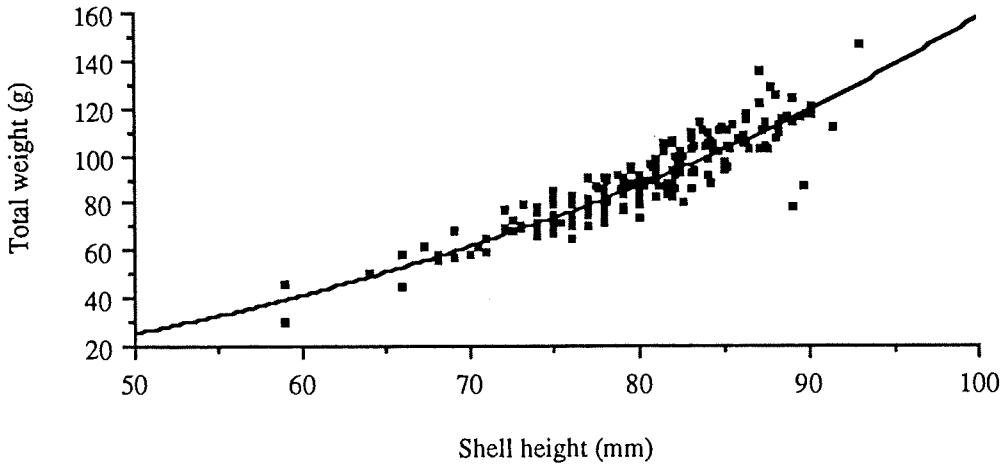

Figure 5b. Logarithmic relationship between total weight and shell height

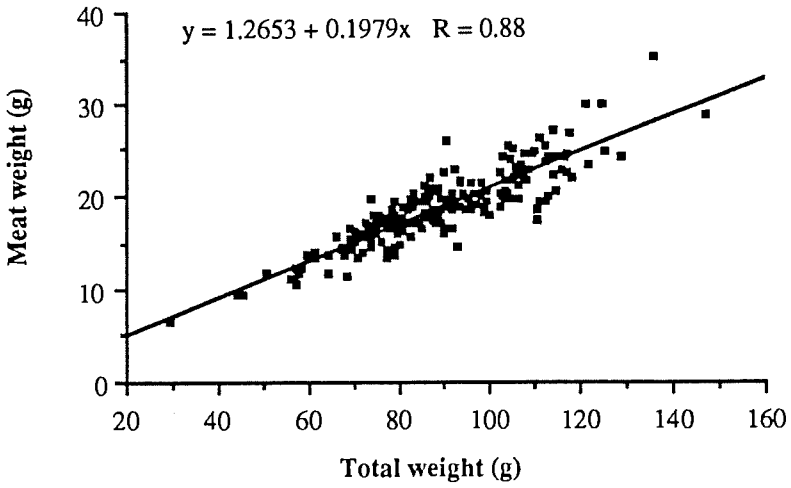

Figure 6. Relationship between meat and total weight of reseeded scallops

Overall a total of 210 starfish (*C. calamaria*) were removed from inside and around the cage (Figure 7). Both adults and juveniles were found throughout the experiment but juveniles were in larger numbers. Other potential predators such as hermit crabs were also found but starfish were clearly the dominant predator and during monitoring were occasionally observed eating scallops.

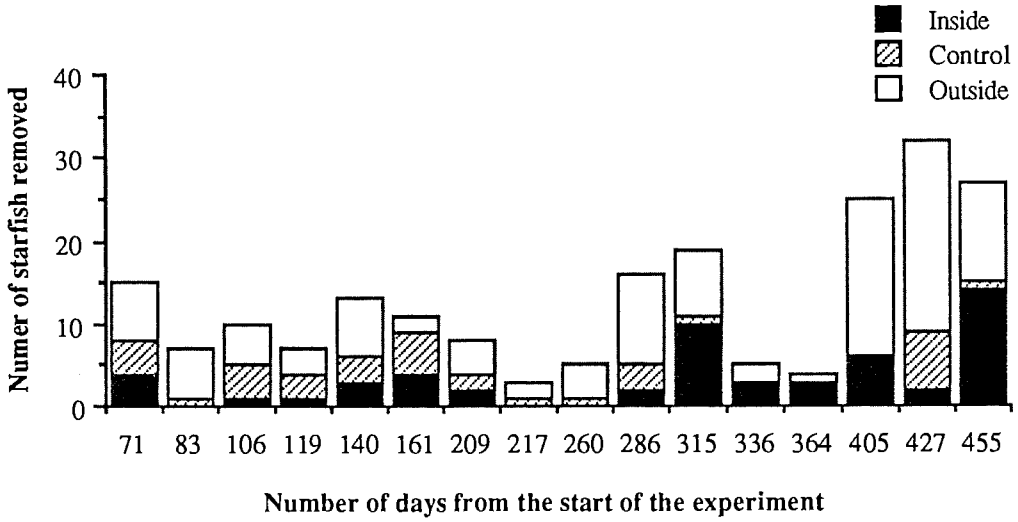

Figure 7. Number of starfish removed around and in the underwater enclosure

Discussion

This study has shown that scallops can be successfully cultivated at economically viable densities on the seabed and can be reared to legal commercial size within two years. However in this experiment regular predator removal was carried out to ensure the survival of scallops. If the predator *C. calamaria* could be totally excluded or removed from the area then survival would be higher than the 31.5% obtained in this trial. Even so this figure is encouraging for future work on re-seeding and is comparable with similar projects overseas, (Hayashi, pers.comm; Bull, pers.comm.). It is probable that if the starfish had not been removed on a regular basis that survival of the scallops would have been zero. Other factors which may have influenced survival such as predation by transient predators like flathead, skates, sharks and stringrays, clearly requires further investigation.

The high recoveries obtained also suggests that the economic return from these scallops is likely to at least as high as the natural fishery figure. Natural scallops dredged up nearby (in previous years) revealed meat weights considerably lower (Harris, 1979) than those resulting from the reseeded scallops. It is possible therefore, that these scallops could be harvested before they attain 90 mm in width, and still return an acceptable income per unit.

Acknowledgements

I would like to thank Ken Silk, Phil Pyke, John Spaulding (Tasmania Police, Marine Division), the master and crew of R. V. "Challenger", Roger Cropp,Wendy Perrin and Will Zacharin for assistance with field work. Ivor Growns is especially thanked for data presentation and assistance with the preparation of this paper. John Thomson reviewed the manuscript.

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Predation of Reseeded Commercial Scallops

Derek A. Cropp and Andrew T. Davidson

Introduction

Initial experiments in releasing juvenile commercial scallops (*Pecten fumatus*) onto the seabed suggested that predation was high immediately after reseeding had occurred. Subsequently, trials were undertaken to try and assess the extent of predation, the species involved and the fate of any non-predated individuals. Overall, the aim was to investigate the rate of predation on reseeded wild caught and hatchery reared *Pecten fumatus* (commercial scallop) spat.

Methods

Three 200m x 200m square experimental plots were established in Promise Bay (Fig. 1). Two plots (T1 and T2) were trawled to remove the majority of potential scallop predators and a third plot left untrawled(U). Two of these plots, one trawled (T1) and one untrawled (U), were each reseeded with 40,000 *P. fumatus* spat of 30mm shell height. Both plots were reseeded by surface distribution of scallop spat within a 50m radius of the centre, giving a reseeded area of 7,850m^2 and reseeding density of 5 spat / m^2. Numbers of potential predators were assessed in each of the plots over a period up to six weeks after reseeding was finished. Results were recorded in relation to the reseeding area, positioned between 50 and 150m on the transect line.

In T1 this left a 50m trawled perimeter around the reseeded scallops. Four 200m transects were then established in each plot as diameters at intervals of ~45° of arc. Hatchery scallops were released in one plot nearby without any intensive monitoring. Details of this work are minimal as no time or manpower was available to carry out regular sampling.

Predator numbers were recorded in a 6m wide area at every 10m interval along the 200m transect lines at the same time as scallop predation was assessed. The mean predator occurrence for all the transect lines was computed for each sample time and the summed predator occurrence at each distance on the four transect lines was then ranked "Above" or "Below" the mean. The data was then analysed using the Wold-Wolfowitz Runs Test for each experimental plot at each sample time.

Results

The trawling showed the abundance of potential predators to be vary between plots. T1 contained significantly greater numbers of *Coscinasterias calamaria* (eleven armed starfish) adults and juveniles, flathead and leatherjackets than did T2, the latter containing more skates and rays.

Elasmobranchs (skates and rays) occurred in greater numbers in T1 than any other despite trawling showing that this area initially had less than T2. The occurrence of skates and rays

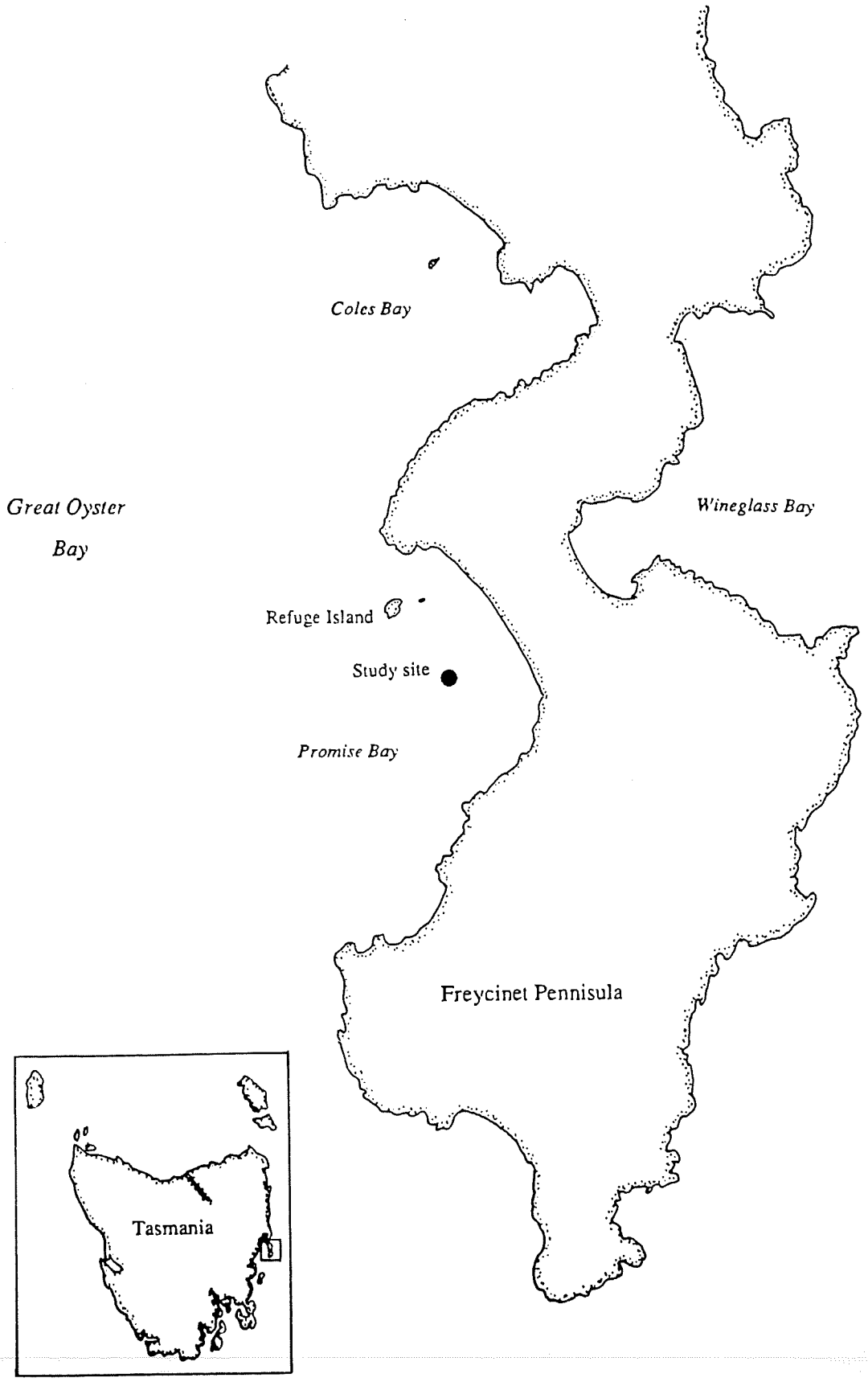

Figure 1. Research area in Promise Bay, Tasmania.

in the remaining two plots were similar despite one of these plots having not been reseeded with scallops. Thus it is possible that these potential predators were attracted by both the scallops reseeded into the area and the disturbance associated with the trawling.

CATCH		TOTAL NUMBERS (from 40,000m^2)	
Common name	Species	Trawled and Not Reseeded Plot (T2)	Trawled and Reseeded Plot (T1)
Eleven armed starfish	*C. calamaria* (Adults)	29	119
Eleven armed starfish	*C. calamaria* (Juveniles)	14	257
Other Starfish sp.		3	2
Ascidians	*Polycarpa sp*	>1000	≈750
Leatherjackets(Tooth brush)	*Penicipelta vittiger*	29	95
(Brown Striped)	*& Meuschenia australis*		
Flathead (Sand)	*Platycephalus bassensis*	25	242
(Tiger)	*& Platycephalus richardsoni*		
Flounder (Greenback)	*Rhombosolea tapirina*	1	6
(Andrew's)	*Arnoglossus andrewsi*		
Butterfly Gurnard	*Lepidotrigla vanessa*	8	15
Spider Crabs		2	10
Stingaree (Banded)	*Urolophus cruciatus*	105	87
(Sparsely-spotted)	*Urolophus paucimaculatus*		
Whitley's Skate	*Raja whitleyi*	1	1
Barred Toadfish	*Contusus richei*	9	0
Porcupine Fish	*Diodon nicthemerus*	10	32
Hermit Crabs		3	5
Sea Urchin	*Heliocidaris erythrogramma*	30	37
Octopus	*Octopus* sp.	3	1
Southern Calamary	*Septioteuthis australis*	1	4
Soldierfish	*Gymnapistes marmoratus*	0	1
Silverbelly	*Parequula melbournensis*	0	29
Shaw's Cowfish	*Aracana aurita*	0	42

Table 1. Catch analysis of trawled plots, May 5 and 6, 1987.

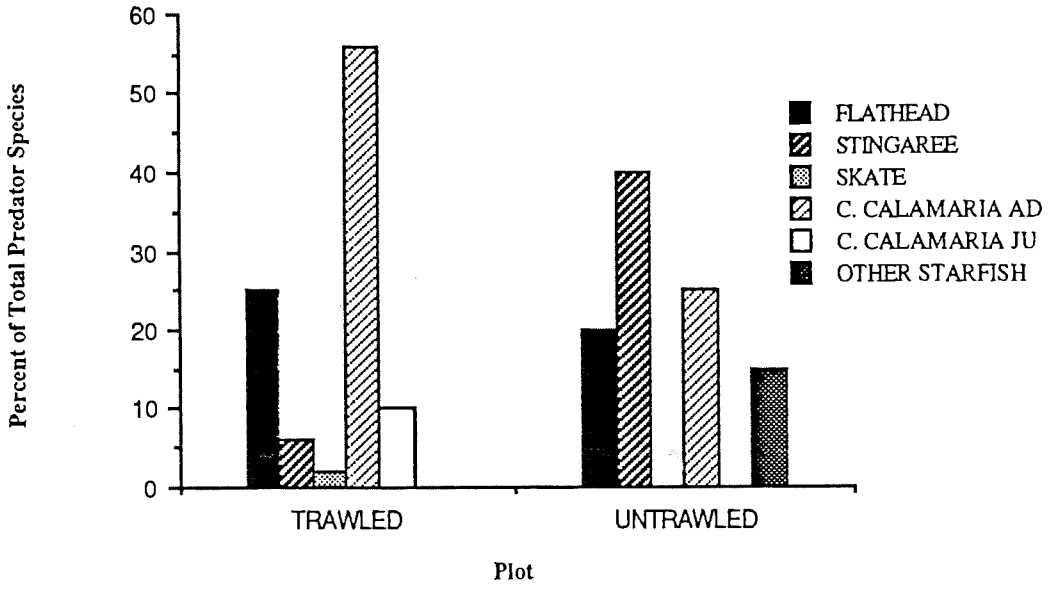

Figure 2. Predator species present in the research plots

The results of the Wold-Wolfowitz Runs Test on mean predator occurrence in the various plots are presented below.

Plot	Week	Z Value	Probability
Trawled and Reseeded, T1	1	2.479	0.014*
	2	1.621	0.107
	6	0.595	0.549
Not Trawled and Reseeded, U	1	1.236	0.215
	2	0.085	0.928
	3	0.011	0.992
	6	0.817	0.418
Trawled and Not Reseeded, T2	1	0.438	0.660
	2	0.817	0.412
	6	0.908	0.363

* Probability significant at the 5% level

Table 2. Predator Occurrence Values

The occurrence of predators within the reseeded plots was only non-random in T1 in week 1 (see Table 2 and Fig. 6). This contrasts with all other predator occurrences where

distributions were purely stochastic (See Fig. 7).

Only half of the scallops reseeded into U and two thirds in T1 were to be found after six days. This initial loss of scallops may have been due to currents carrying them out of the plot during the reseeding or active movement after the reseeding. However, were this the case, they would probably have appeared in the 50m perimeter and there was no indication of them in this region; although they may have moved further afield. Predators which swallow their prey whole (such as flathead) may also have accounted for this spat loss but this predation only occurred to any extent during the first six days. The fate of reseeded scallops is shown in Figure 3 and 4 below.

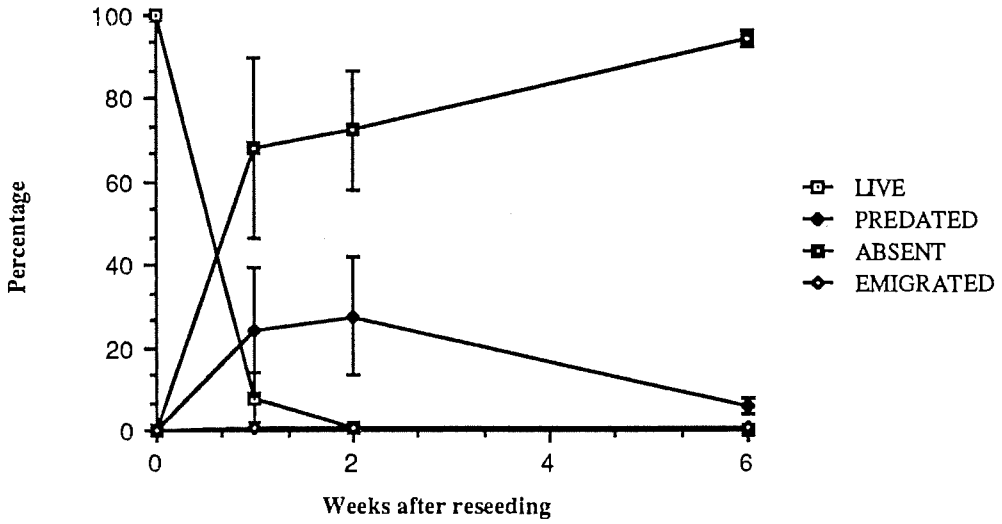

Figure 3. Fate of reseeded scallops in T1

Of the scallop spat remaining, there was approximately 80% mortality in U after 20 days. This contrasted with T1 where the mortality was 75% after 6 days and 98.7% after 13 days. This may have been in response to the observed patchiness of predator distribution.

49% of dead scallops in T1 existed as clappers. This proportion of the mortality could be due to either natural mortality or starfish predation. In U only 25-31% of predation left the dead scallops as clappers. The higher percentage of clappers in T1 probably reflects the fact that between 5 and 8 times more *C. calamaria* remained in this plot after trawling than were present in U. This was despite 376 *C. calamaria* individuals being removed from the 40,000 m^2 plot by trawling.

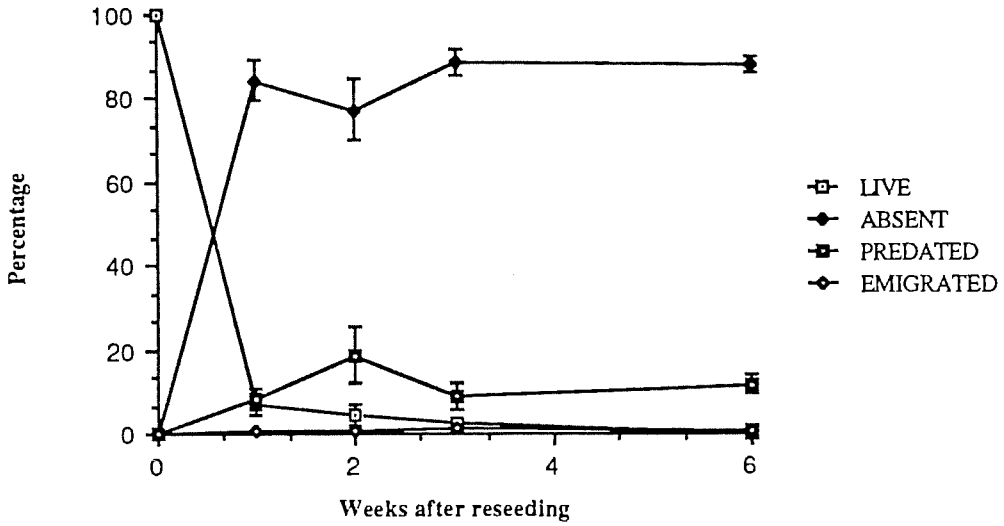

Figure 4. Fate of reseeded scallops in U

Both reseeded plots (T1 and U) had approximately one third of the scallops fragmented by the predator. Starfish could not be responsible for this predation, suggesting that skates, rays, flathead, leatherjackets and crabs are also preying on the reseeded scallops (Figure 45. Thus, starfish proved responsible for only part of the predation. The remainder of the predation left the scallops as single valves, death being of undetermined cause.

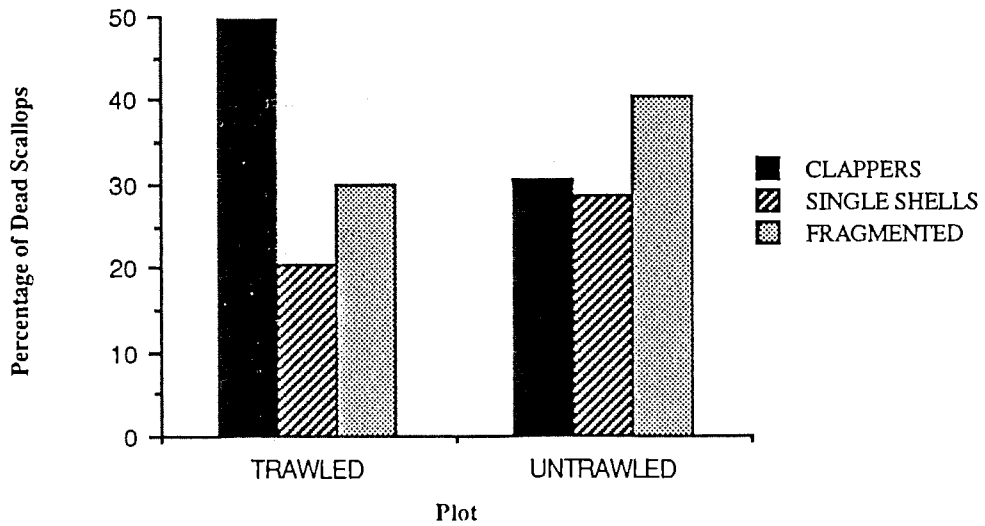

Figure 5. Percentage composition of dead scallop shells

The shell height of spat released into the experimental plots ranged from 14.50mm to 52.60mm. However, no significant difference existed between the mean size of live spat and those

which had been predated (mean live height = 30.26 ± 5.62, n=36; mean dead height = 29.65 ± 8.54, n=31). Thus, for this range in shell height and given a variety of predators, the rate of predation was independent of spat size.

Results of the weekly assessment of predator numbers are shown in Figures 6, 7 and 8.

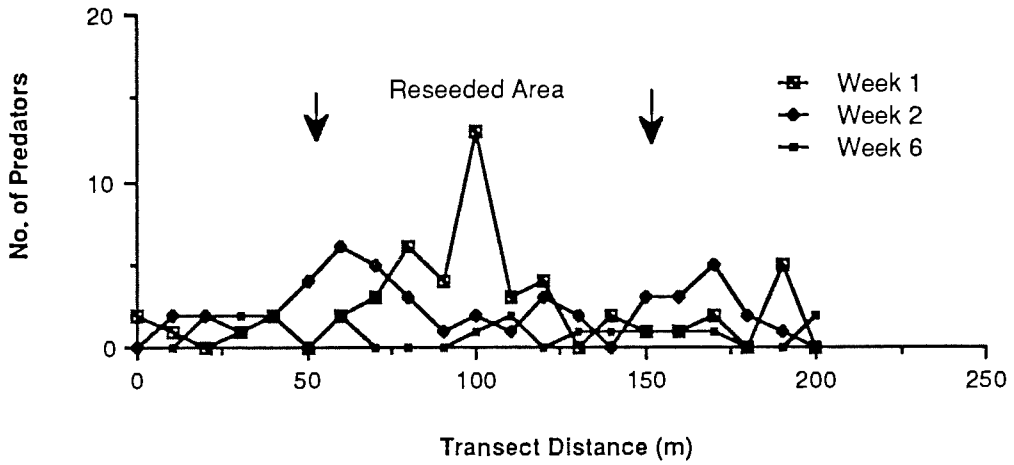

Figure 6. Predator assessment in plot T1 after reseeding

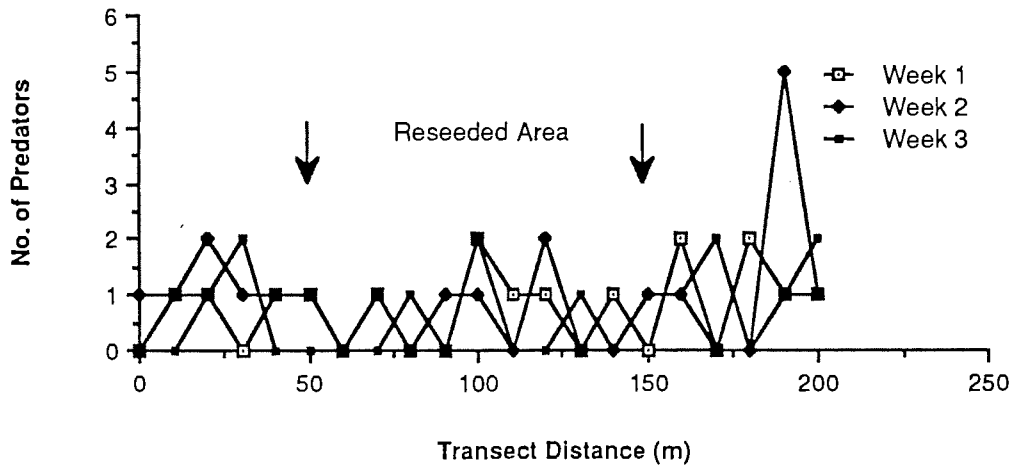

Figure 7. Predator assessment in plot U after reseeding

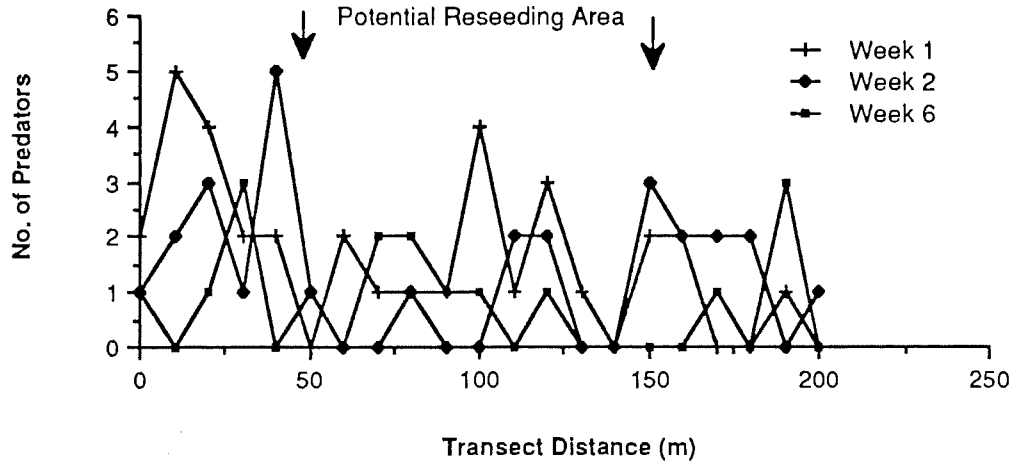

Figure 8. Predator assessment in plot T2 1,2 and 6 weeks after reseeding of plots T1 and U

Discussion

Hatchery spat (~10,000) released near the experimental area suffered a similar rate of predation to that within the plots T1, T2 and U. Sufficient time and manpower was not available to do a repeat of the monitoring exercise outlined here for wild spat. However the overall assessment gave similar results to those provided indicating that the origin of the spat made no difference to the rate of predation. Further work is planned to carefully examine comparative survival of hatchery reared and natural scallop spat.

In conclusion, the results of this experiment suggest extremely high predation upon scallops reseeded in small numbers in Promise Bay. Promise Bay was chosen for this experiment because it is known to support large populations of starfish, hitherto accepted as the main scallop predator. In this respect it indicates a worst case option. However, it has also indicated that highly mobile fish species are probably preying on the reseeded spat. Furthermore, the majority of the reseeded spat are simply disappearing. The fate of these scallops is unknown. Research into whether these spat are predated whole or move out of the reseeded area is neccessary to quantify the potential success or otherwise of the reseeding option as a method of ongrowing scallops to a marketable size. The magnitude of the predation problem in other sites is at present unknown but if similar to that in Promise Bay it means that a serious approach to predator control is required to make scallop reseeding viable in Tasmania.

Reseeding trial using the commercial scallop *Pecten fumatus*

Introduction

Several groups of juvenile scallops were released onto the seabed over a period of time. These juvenile scallops or spat were obtained from mesh spat collecting bags suspended in Mercury Passage near Maria Is (Figure 1). The collectors were normally deployed on sub-surface longlines at this site during September of each year. Collectors were lifted from the water and spat removed in February-March of the following year when they had attained 15-25mm in size. Various research plots were marked out on the seabed in Promise Bay (Figure 2) prior to release of any spat. The seabed at this site consisted of firm muddy sand with abundant bottom dwelling ascidians. Water depth was 10-12m and a slight current (less than 0.2 knots) travelling north to south was evident.

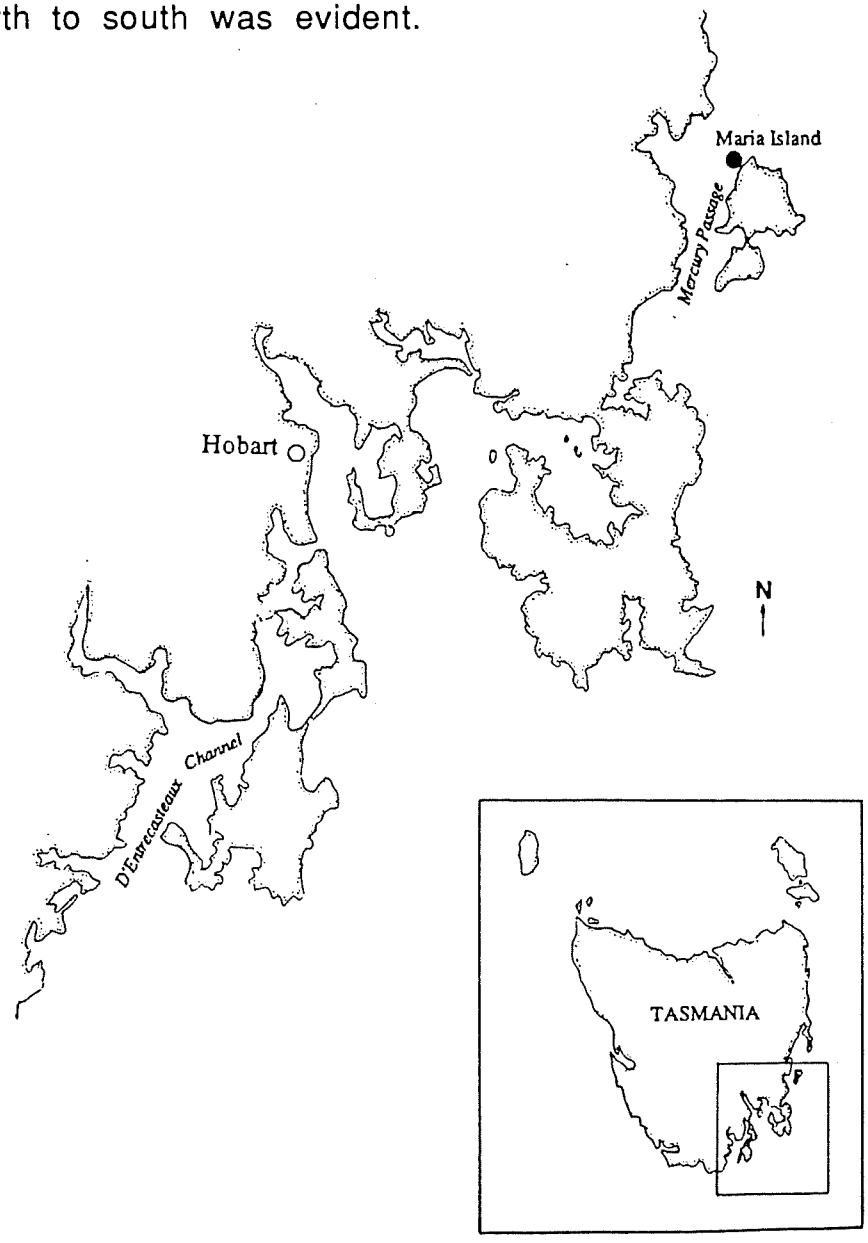

Figure 1. Maria Island site

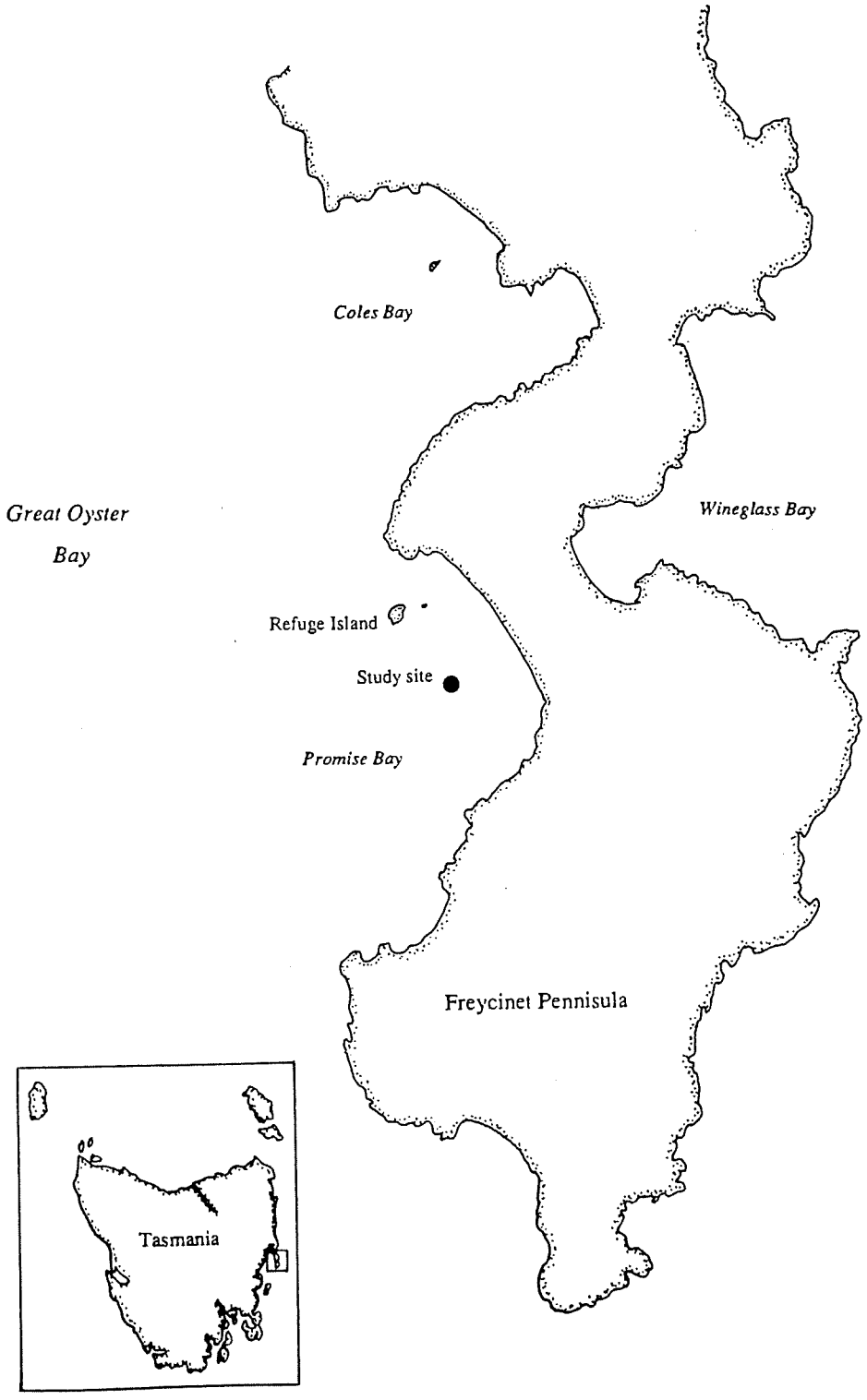

Figure 2. Promise Bay Site

Plot 1.

A 50 x 50m plot was established for the release of scallops greater than 13.5mm and less than 20.4mm in size. The experiment was a long term release trial to assess the effect of reseeding spat on starfish *Coscinasterias calamaria* numbers in the area. The area was known to support a quantity of starfish. Over a period of approximately two and a half years, spat (in the size group mentioned) were released on this plot in varying numbers (Figure 3). In addition divers removed all starfish in this plot at intervals (shown on Figure 3) during the monitoring period.

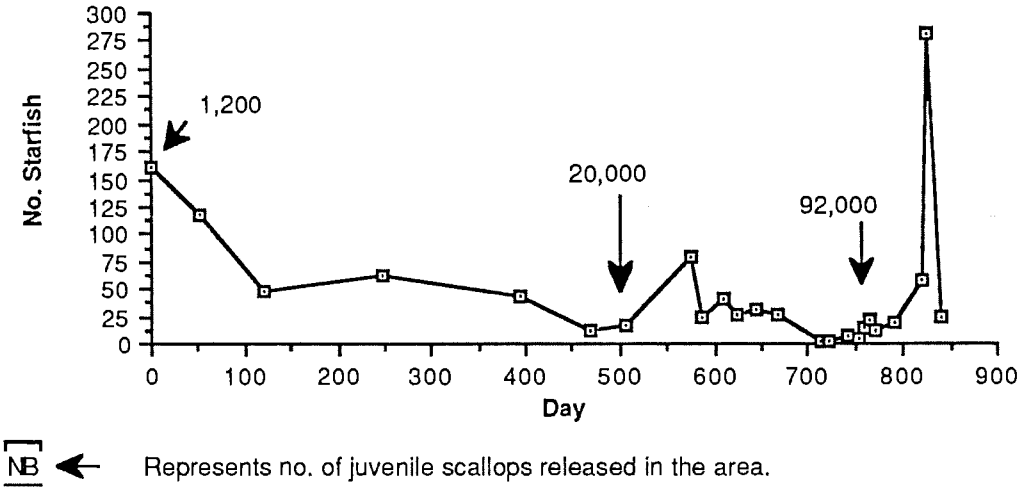

Figure 3. Starfish removal from Plot 1, Promise Bay.

Figure 3 shows that starfish are clearly attracted to an area by the presence of juvenile scallops. The distance that they are attracted from may be considerable given the starfish removal that was occurring regularly. Whether it is live or dead scallops that is the attractant is yet to be determined. It is inevitable that some reseeded scallops will die after being released due to handling procedures and this could be the initial stimulant.

A diver survey of scallops in Plot 1 was conducted at the completion of the trial. No live scallops were found inside the plot or in a 20m band around the plot. As only relatively low numbers of dead shell was found (<4,000 scallops) it can be assumed that either the scallops were consumed whole by predators or they moved totally out of the research area. Dredging nearby still failed to locate any trace of these scallops. Results of the underwater cage experiment tend to support the second hypothesis.

DISCUSSION OF ALL REPORTS

Rearing of commercial scallop larvae has shown to be a difficult and risky exercise with condition of broodstock, quality of algal food, larval treatment and settlement procedures all being important in ensuring the production of large quantities of spat. Technology now is almost sufficiently developed to allow hatcheries to produce millions of spat. It is expected that by mid 1989 in excess of four million scallop spat will have been produced by private mollusc hatcheries within Tasmania. As the economic comparison report shows, the cost of obtaining scallop spat at sea is currently much higher than it is for hatchery produced spat. Thus it appears that we are on the verge of large scale hatchery scallop production becoming a commercial reality.

Many forms of intermediate culture are presently available in Tasmania and, biologically, most provide satisfactory results. Economically, the situation for some has been unfeasible until recently (Cropp, 1987), but the lack of natural scallops and subsequent price rises has changed this situation. A hanging or mid-water cage culture scallop industry now seems set to develop rapidly and many private companies are already deeply involved or committed to scallop culture.

Reseeding of juvenile scallops clearly is an operation that needs to involve careful site selection with regard to bottom sediments, water currents and predator density. In addition bottom management (biological and legal) is critical to ensure a viable and sustainable fishery can be established.

ACKNOWLEDGEMENTS

I wish to thank the following people who helped with fieldwork, construction, maintenance and cleaning of equipment during the project:
Roger Cropp, Andy Gregory, Judy Marshal, Leigh Oates, Tim Peters, Ken Silk, Phil Pyke and the master and crew of R. V. "Challenger, namely Geoff Darcey, Brian Boyce and Jack Cooper.

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