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Quantitative assessment of a white seabass (*Atractoscion nobilis*) stock enhancement program in California: Post-release dispersal, growth and survival

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ABSTRACT

We evaluate post-release dispersal, growth and survival of hatchery-reared white seabass (*Atractoscion nobilis*) released as part of an experimental stock enhancement program in California. Releases of hatchery white seabass have been carried out since 1986, year round either directly from the hatchery or after acclimation in net pens. All released fish are implanted with coded wire tags. Post-release monitoring is carried out through a research gillnet fishery for juveniles, and tag returns from the commercial and recreational fisheries. Fish dispersed from the release sites at a diffusion rate D 795 km^2 year^{-1}, such that 50% of fish remained within 47 km and 95% within 135 km of the release site at the end their third year at large. The von Bertalanffy growth parameters for released hatchery fish were estimated at $L_\infty = 975$ mm SL and $K = 0.21$ year^{-1}. A set of alternative survival models accounting for dispersal and size- and time-dependent natural and fishing mortality patterns was confronted with the mark-recapture data using model selection based on the Akaike Information Criterion (AIC). The model that fit the data best accounted for short-term post-release mortality dependent on season and release method in addition to a long-term size-dependent mortality. Survival of released hatchery fish was highest in Spring, moderately lower in Summer and Autumn, but much lower in Winter releases. Acclimatisation in net pens had a substantial, positive effect on survival relative to direct releases. Survival of hatchery fish to legal minimum length (600 mm SL) in the fishery was estimated at 1.5% for a release size of 200 mm, rising to 13.8% for a release size of 400 mm, under optimal conditions (Spring releases with net pen acclimatisation). Mortality rates of hatchery white seabass under optimal release conditions were substantially below average for other hatchery fish released into the wild, but remained above those expected for wild fish in both, the short-term and long-term components.

1. Introduction

Many of the world's fisheries are fully exploited or over-exploited, as well as suffering from effects of aquatic habitat degradation. Global capture fisheries production is stagnant, a number of formerly productive stocks have collapsed with only limited evidence of recovery, and ecosystem-level impacts of biomass removal and fishing gear disturbance have become increasingly evident (Hutchings, 2000; Hilborn et al., 2003; Hilborn, 2007). Besides regulation of fishing effort and habitat restoration, aquaculture-based fisheries enhancement is the third principal means by which fisheries can be sustained and improved. Aquaculture-based enhancement is a set of fisheries management approaches involving the release of hatchery-reared juveniles to enhance or restore fish stock abundance and fisheries catches (Cowx, 1994; Lorenzen, 2008). Although widely used in inland and increasingly, coastal marine fisheries, few enhancement programmes have been assessed quantitatively for their contribution to fisheries management goals. Effective use of aquaculture-based enhancement in fisheries management is possible only under certain conditions and requires both the capacity to produce and release hatchery fish of a fitness in the wild akin to that of naturally recruited fish and appropriate management of the stocked or mixed (hatchery/wild) population (Lorenzen, 1995, 2005, 2008). The effectiveness of hatchery production and release strategies may be evaluated experimentally through post-release monitoring (Blankenship and Leber, 1995; Leber et al., 1996; Lorenzen, 2006). Population management strategies on the other hand are best evaluated using fisheries stock assessment models extended to capture the dynamics of enhanced fisheries (Walters and Martell, 2004; Lorenzen, 2005; Medley and Lorenzen, 2006). In the present paper, we use mark-recapture modelling to assess post-release dispersal, growth and survival of hatchery fish released as part of a long-running white seabass *Atractoscion nobilis* (Ayers, 1860)

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enhancement programme in California, USA. In doing so, we evaluate the efficacy of alternative release strategies, and also estimate key population parameters required to assess the contribution of enhancement to management goals for California white seabass fishery.

White seabass *A. nobilis* is a sciaenid (croaker) with a distribution that extends from Magdalena Bay, Baja California, Mexico, to Juneau, Alaska (Thomas, 1968). White seabass are considered to form a single breeding population, with a centre off central Baja California, Mexico (Moser et al., 1983; Vojkovich and Reed, 1983). White seabass are usually found associated with rocky headlands, sandy areas, and in and around kelp forests. Spawning occurs near shore during the spring and summer months peaking in June (Donohoe, 1997). White seabass grow to a maximum size of about 160 cm and reach sexual maturity at 42 cm SL in males and at 54 cm SL in females (Clark, 1930; Rivkin, 2008).

White seabass are fished commercially and recreationally. The commercial fishery started in the late 19th century and has dominated catches until very recently. The recreational fishery developed in the mid-20th century and has expanded to the point where its harvest exceeded that taken in the commercial fishery during the late 1990s and early 2000s (CDF&G, 2002; 2008). However current recreational landings have not exceeded more than about a quarter of the commercial landings. The white seabass population is believed to have declined substantially since the onset of the fishery, most severely between 1950 and 1980 (Thomas, 1968; Vojkovich and Reed, 1983). There are no regular quantitative assessments of the population, however. Two studies on historical fisheries and population trends have concluded that the population was moderately exploited but not depleted (MacCall et al., 1976; Dayton and MacCall, 1992). Fishing restrictions were introduced in 1931 and currently comprise a minimum landing size (71 cm TL, equivalent to 60 cm SL), closure during the spawning season (mid-March to mid-June), bag limits, and gear restrictions (Kent et al., 1995).

The Ocean Resource Enhancement & Hatchery Program (OREHP) under the direction of the California Department of Fish & Game (CDF&G) was established in 1983 by the California Legislature. White seabass was selected as a target species for an experimental stocking program due to its high commercial and recreational value, and the perception that the stock had declined to a historically low level (Vojkovich and Crooke, 2001). The white seabass stocking program released the first batch of cultured fish in 1986. White seabass juveniles are produced in a dedicated hatchery in Carlsbad, California, operated by Hubbs-SeaWorld Research Institute (HSWRI). A broodstock of 200 wild-caught fish, separated into four groups of 50 adults in equal sex ratios, is maintained and replenished by rotation with new wild stock. Broodstock are induced to spawn through photothermal manipulation in large holding tanks from which eggs are removed by filtration and incubated. Seabass were grown either exclusively in the hatchery or in the hatchery and then in net pens before being released. In the latter case, the fish spent approximately 130 days in the hatchery and an additional 160 days in the net pens before being released at an age of approximately 300 days and average size of 22 cm. In the case of direct hatchery releases, the fish were younger and smaller at approximately 200 days old and 16 cm, respectively. A total of 478 batches were released between 1986 and 2006, ranging in numbers from 27 to 17,448 juveniles. Releases were made throughout the year, at seventeen sites in the Southern California Bight.

2. Materials and methods

Mark-recapture modelling was used to assess dispersal, growth, and natural mortality of released hatchery fish. Our general approach follows that of Lorenzen (2006), but has been modified to account for (1) effects of dispersal on stock availability to fixed experimental fishing gear, (2) short-term post-release mortality, and (3) effects of release season and method.

2.1. Mark-recapture data

All hatchery white seabass are tagged prior to release and tag-recaptures monitored in the research, commercial and recreational fisheries. Tagging is carried out to identify release groups (batch marking), using coded wire tags inserted into the cheek muscle. Tagging is carried out at the hatchery, and tag retention is assessed prior to release. Experiments show an average tag loss of 4% within the first days after tagging, but negligible loss thereafter. Tags allow identification of a fish's release batch and thus, mean release size, date, site and release method.

Released fish may be recaptured in a research gillnet fishery, a commercial gillnet fishery, or a recreational line and spear fishery. In addition, released juveniles may be entrained in coastal power plant cooling water intakes as some plants have reported tag-recaptures. The research gillnet fishery targets juvenile fish and accounts for the bulk (over 85%) of tag recoveries. The commercial and recreational fisheries are subject to the same minimum landing size of 71 cm total length (equivalent to 60 cm standard length). In this study, we focus on analysing recapture data from the research fishery. However, we include recapture data from other fisheries in the estimation of growth parameters. We also use data from catches of wild white seabass in experimental gill nets to estimate gear selectivity. In both cases, using the additional data allows us to obtain more precise estimates of key relationships than would be possible with the research recaptures alone.

The research sampling program for juvenile white seabass was carried out by HSWRI and California State University, Northridge (CSUN). The sampling gear used were multiple mesh gillnets and a detailed description of this gear and deployment locations is provided in Allen et al. (2007). All sampling locations are associated with release points (each release point has at least one sampling location nearby) (Fig. 1). In a sampling month, the full set of research gillnets deployed in the nearshore coastal and embayment areas off southern California consists of 114 nets. Each net (Type I) was comprised of six, 7.6 m, panels with two panels for each of the stretch mesh sizes: 51, 76, and 100 mm. An additional 26 nets (Type II) were also deployed in the nearshore coastal areas but with three panels for each of the stretch mesh sizes: 51 and 76 mm. Research sampling effort and location varied greatly in the early part of the programme, but a consistent sampling schedule was employed through the period 1999–2004 and the analysis was limited to this period. A total of 720 tagged fish were recovered in the research fishery during this period with days at liberty ranging from 7 to 1084 (average 139 days).

2.2. Dispersal model

The dispersal of released fish from the release point is of innate interest to the enhancement program. It must also be accounted for in the analysis of post-release mortality because dispersal causes temporal variation in availability of the released stock to fishing gear deployed at fixed locations. We used a diffusion model to describe dispersal (Turchin, 1998). Diffusion theory predicts that the spatial density of dispersing animals is described by a normal distribution centred on the release point, with variance increasing linearly with time:

$$f_x(t_i) = \frac{1}{\sqrt{4\pi D(t_i - t_0)}} \exp\left(-\frac{{d_{xh}}^2}{4D(t_i - t_0)}\right) \qquad (1)$$

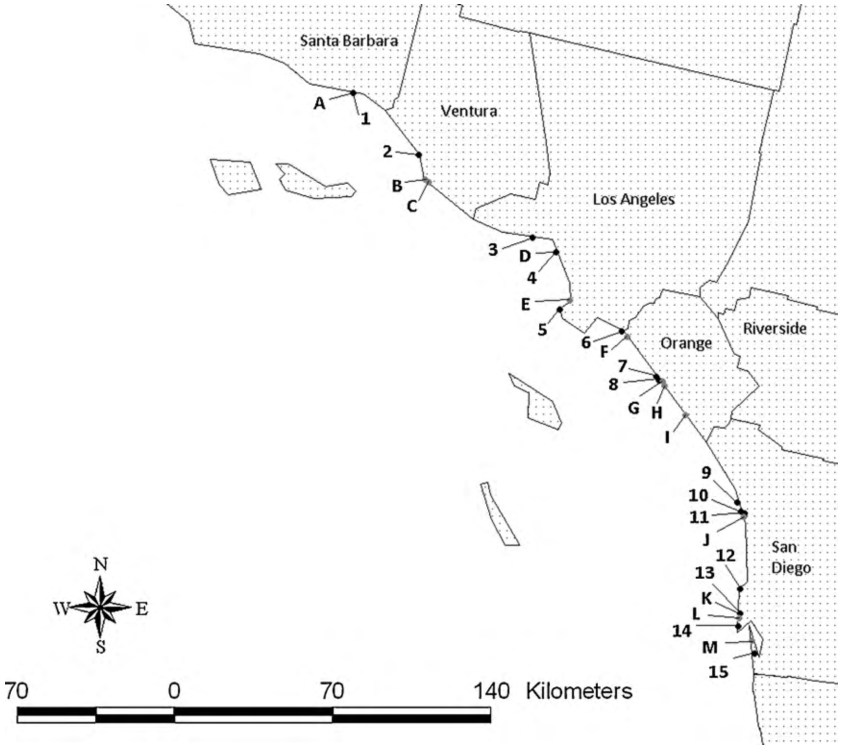

Fig. 1. Map of southern California showing release and experimental fishing (recapture) sites. Release sites are indicated by letters and recapture sites by numbers.

where $f_x(t_i)$ is the relative density at point x, d_{xh} is the distance of point x from the release site h, and D is the diffusion rate. The dispersal model was fitted to the observed spatial distributions of monthly recaptures for each release event using maximum likelihood estimation with binomial error structure.

2.3. Growth model

A von Bertalanffy model was used to predict mean length $L(t_i)$ at time t_i:

$$L(t_i) = L_\infty - (L_\infty - \bar{L}(t_0))e^{(-K(t_i - t_0))} \tag{2}$$

Here $\bar{L}(t_0)$ is the mean length at release. Maximum likelihood estimation with normal error structure was used to estimate model parameters from mark-recapture data.

2.4. Survival and recapture model

A mortality and recapture model was developed to predict the survival of released fish over time and their recapture in the experimental fishery. The model accounts for size-dependent natural and fishing mortality patterns, as well as for the influence of dispersal on the availability of fish to research gear.

2.4.1. Natural mortality

Natural mortality was described by a set of four alternative, size- and time-dependent mortality models that were confronted with the mark-recapture data by means of model selection using the Akaike Information Criterion corrected for overdispersion (QAIC, Burnham and Anderson, 2002). The models are extensions of a length-inverse natural mortality model which has been shown to provide a good description of size-dependent mortality in wild and released hatchery fish (Lorenzen, 1996, 2000; Coggins et al., 2006), The extended models allow for long- or short-term season and release method effects on motality rates.

The simplest model is the basic length-inverse mortality model without season or release method effects (Mortality Model 1):

$$M(t_i) = \left(\frac{L(t_i)}{L_r}\right) M_r \tag{3}$$

where $M(t_i)$ is the natural mortality rate at time t_i, M_r is the natural mortality rate at reference length L. This model can be expanded to allow for long-term effects of season and release size (Mortality Model 2):

$$M(t_i) = \left(\frac{L(t_i)}{L_r}\right) (M_{r,season} + JM_{r,direct}) \tag{4}$$

where $M_{r,season}$ is a mortality rate dependent on the release season, $M_{r,direct}$ is an additional mortality rate suffered by fish released directly (without acclimatisation in net pens), and J is a dummy variable indicating release method ($I = 1$ for direct releases, $I = 0$ for net pen releases).

An alternative set of models can be formulated assuming that fish suffer a short-term post-release mortality additional to the long-term size-inverse mortality. Applying the additional short-term mortality to the first month post-release only results in (Mortality Model 3):

$$M(t_i) = \begin{cases} \left(\frac{L(t_i)}{L_r}\right)(M_r + M_s) & \text{for} \quad i = 1 \\ \left(\frac{L(t_i)}{L_r}\right) M_r & \text{for} \quad i > 1 \end{cases} \tag{5}$$

where M_s is the additional short-term mortality rate. Finally, allowing short-term mortality to vary with release season and method leads to (Mortality Model 4):

$$M(t_i) = \begin{cases} \left(\frac{L(t_i)}{L_r}\right)(M_r + M_{s,season} + JM_{s,direct}) & \text{for} \quad i = 1 \\ \left(\frac{L(t_i)}{L_r}\right) M_r & \text{for} \quad i > 1 \end{cases} \tag{6}$$

Table 1
Parameter values estimated or assumed.

	Parameters	Value [95% CI]	Source
D	Diffusion rate of dispersal model	795 [709, 900] km^2 year^{-1}	Dispersal model
L_∞	Asymptotic length	975 [934, 996] mm	Growth model
K	Growth rate	0.21 [(0.20, 0.23] year^{-1}	Growth model
L_r	Reference length	10 mm	Arbitrary value
L_{ma}	Optimum length – 51 mm mesh	293.1 mm	Gillnet selectivity
L_{mb}	Optimum length – 76 mm mesh	436.8 mm	Gillnet selectivity
L_{mc}	Optimum length – 100 mm mesh	574.7 mm	Gillnet selectivity
s^2	Variance for selectivity	5234.7	Gillnet selectivity

2.4.2. *Fishing mortality*

The fishing mortality rate $F(t_i)$ on released fish at time t after release is given by

$$F(t_i) = F_b E(t_i) S_g(t_i) S_s(t_i) \tag{7}$$

where F_b is a baseline fishing mortality rate modified by effort $E(t_i)$, the size selectivity of fishing gear $S_g(t_i)$ and the spatial availability $S_s(t_i)$. Experimental fishing effort $E(t_i)$ was expressed as the proportion of time in each monthly interval during which the sampling gear was deployed.

The length-dependent selectivity curve of research gillnets was described by normal distributions with different means, but the same variance for each mesh size. The combined length selectivity $S_g(L)$ was then described by

$$S_g(t_i) = \frac{1}{H}\sum_{n} m_{gj}\ \exp\left(-\frac{\left(L(t_i) - L_{gj}\right)^2}{2s^2}\right) \tag{8}$$

Here, m_{gj} is the number of nets set of mesh size j, L_{gj} is corresponding mean (peak) selection length, s^2 is the variance, and H is a scaling factor used to normalize the combined distribution so that the maximum selectivity is 1. The selectivity parameters were estimated using Holt's method (Sparre and Venema, 1998), from catch length distributions based on 1596 wild white seabass caught in the Type I research gillnets deployed at the coastal sites from 1997 to 2004.

The availability of fish to fishing gear is given by

$$S_s(t_i) = \frac{1}{U}\sum_{x} f_x(t_i) \tag{9}$$

where $f_x(t_i)$ is the relative density of fish at sampling location x as determined from the dispersal model (Eq. (1)) and U is a scaling factor used to normalize the availability with respect to the highest availability value found in any release batch.

2.4.3. *Combined mortality model*

Using the natural and fishing mortality models defined above, the probability $Q(t_i)$ of a tagged fish surviving to time t_i can be calculated from $Q(t_{i-1})$ by:

$$Q(t_i) = Q(t_{i-1})\exp(-(M(t_i) + F(t_i))\Delta t) \tag{10}$$

This model assumes that all captured fish are retained rather than re-released, as is the case in most commercial fisheries. The probability $P(t_i)$ of a tagged fish being recaptured and reported in period t_{i-1} to t_i is given by:

$$P(t_i) = Q(t_{i-1})\left(\frac{F(t_i)}{M(t_i) + F(t_i)}\right)(1 - \exp(-(M(t_i) + F(t_i))\Delta t)) \tag{11}$$

Using this model it is possible to predict the probability of a tag being reported for all periods monitored. In line with the experimental results mentioned earlier and the fact that all recaptures analysed are from a research fishery, we assume that tag loss is negligible after the initial 4% loss (which is accounted for) and that all recovered tags are reported.

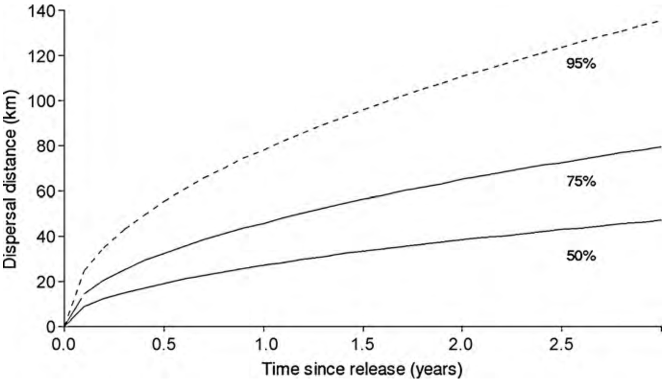

Fig. 2. Dispersal of fish from the release site, estimated using the model in Eq. (1). Curves show the envelope within which 50%, 75% and 95% of fish can be found during the first three years after release.

2.4.4. *Parameter estimation*

Parameters are estimated by maximum likelihood estimation using binomial error structure. The negative log likelihood is calculated for each release batch as follows:

$$L = -\sum_{i=1}^{i_{\max}} C(t_i)\ln(P(t_i)) - \left[\left(R - \sum_{i=1}^{i_{\max}} C(t_i)_{obs}\right)\ln\left(1 - \sum_{i=1}^{i_{\max}} P(t_i)\right)\right] \tag{12}$$

where R is the number released in the batch. Negative log likelihoods calculated for different batches are combined additively to provide a negative log likelihood for the full experiment.

To account for overdispersion (extra-binomial variation) in the data, negative log likelihood was corrected using an overdispersion factor $\hat{c}$ calculated for the best fitting model

$$L_c = \frac{L}{\hat{c}} \tag{13}$$

where

$$\hat{c} = \frac{\chi^2}{df} \tag{14}$$

Empirical support for the alternative natural mortality models was assessed using the Quasi Akaike Information Criterion and Akaike weights (Burnham and Anderson, 2002).

3. Results

3.1. *Dispersal*

The diffusion coefficient D was estimated as 795 km^2 year^{-1} (Table 1). This implies relatively moderate dispersal, with 50% of fish remaining within 47 km and 95% within 135 km of the release site at the end their third year at large (Fig. 2).

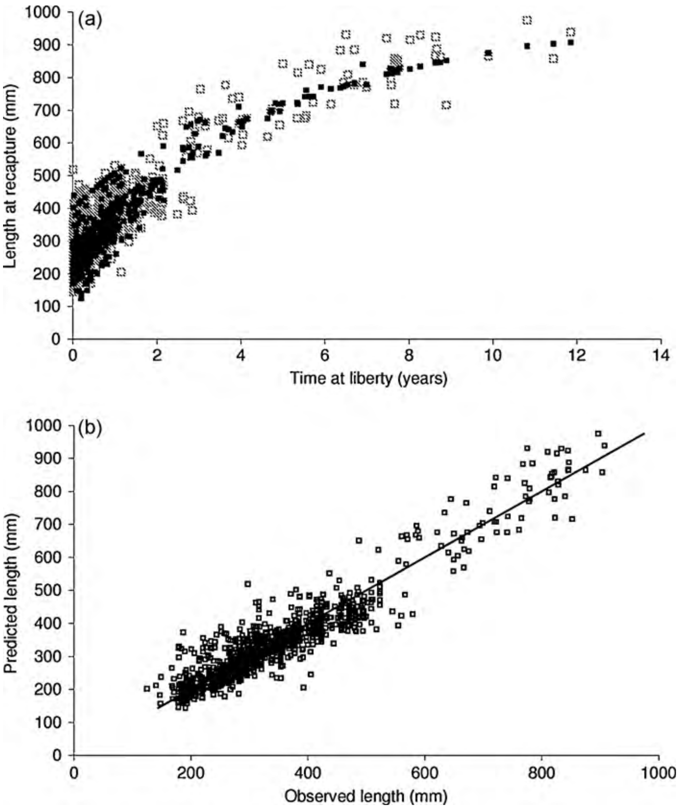

Fig. 3. Von Bertalanffy growth model for released white seabass. (a) Observed and predicted recapture lengths over time. Note that fish have been released at different sizes, and this variability is reflected in the predicted lengths at recapture. (b) Predicted vs. observed lengths at recapture.

3.2. Growth

The von Bertalanffy growth parameters of released white seabass were estimated as $L_\infty = 975$ mm (95% CI [934,996]) and $K = 0.21$ year^{-1} (95% CI [0.20, 0.23]). The model has excellent predictive power (Fig. 3). A length–weight relationship was also estimated, as $W = 1.57 \times 10^{-5} L^{2.97}$ for standard length.

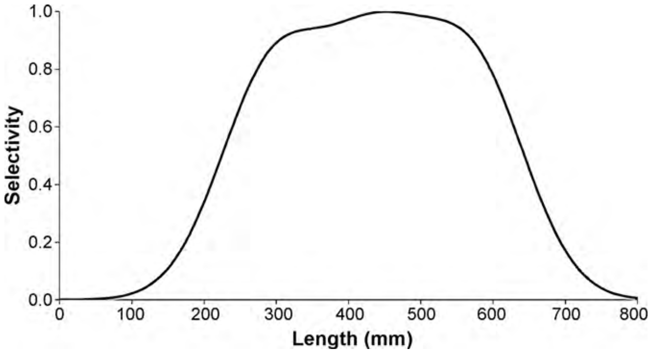

Fig. 4. Selectivity pattern of the research gill net fishery. The combined selectivity curve results from the combination of gill nets with three mesh sizes.

3.3. Survival

The combined selectivity curve estimated for the research gill nets is shown in Fig. 4. The research gillnets were selective for fish from about 100 to 750 mm standard length (SL) but were most effective at sizes between about 300 and 500 mm SL. All parameter values estimated independently and 'fixed' in the survival model are shown in Table 1.

The survival model provided a good fit to observed recaptures in the research fishery, with an overdispersion parameter of $\hat{c} = 1.67$. Results of the model selection (Table 2) show very strong support for Model (4) and thus, the occurrence of short-term post-release mortality dependent on season and release method in addition to a long-term length-inverse mortality pattern independent of release season or method.

Survival of released hatchery fish was highest in Spring, moderately lower in Summer and Autumn, but much lower in Winter releases (Fig. 5). Acclimatisation in net pens had a substantial, positive effect on survival relative to direct releases. Survival of hatchery fish to legal minimum length (600 mm) in the fishery was estimated at 1.5% for a release size of 200 mm, rising to 13.8% for a release size of 400 mm, under optimal conditions (Spring releases with net pen acclimatisation).

4. Discussion

Analysis of tag-recapture data from the long-running enhancement and experimental fishing programme for California white

Table 2
Results of the model selection and parameter values.

Model	Parameter	Value	95% CI	L	m	QAIC	Δ	W
Model 1	M_r	66.3	[55.8, 77.3]	1724.9	2	1728.9	30.7	0.00
	F	0.013	[0.011, 0.016]					
Model 2	$M_{r,Winter}$	85.1	[62.8, 112.7]	1701.7	6	1713.7	15.5	0.00
	$M_{r,Spring}$	24.7	[5.2, 46.9]					
	$M_{r,Summer}$	48.2	[33.6, 65.8]					
	$M_{r,Autumn}$	41.5	[28.9, 56,1]					
	$M_{r,direct}$	41.7	[24.7, 60.1]					
	F	0.013	[0.011, 0.016]					
Model 3	M_r	36.9	[25.2, 49.5]	1701	3	1707	8.8	0.01
	M_s	576	[418, 732]					
	F	0.051	[0.035, 0.072]					
Model 4	M_r	34.1	[21.6, 46.8]	1684.2	7	1698.2	0	0.99
	$M_{s,Winter}$	737	[487, 984]					
	$M_{s,Spring}$	295	[86, 493]					
	$M_{s,Summer}$	421	[208, 636]					
	$M_{s,Autumn}$	410	[202, 621]					
	$M_{s,direct}$	166	[53, 276]					
	F	0.037	[0.022, 0.053]					

L is the negative log likelihood, m the number of parameters estimated, QAIC the quasi Akaike Information Criterion, Δ the difference in model QAIC to the lowest QAIC in the set, and W the Akaike weight (an approximate probability of the model being the best model in the set).

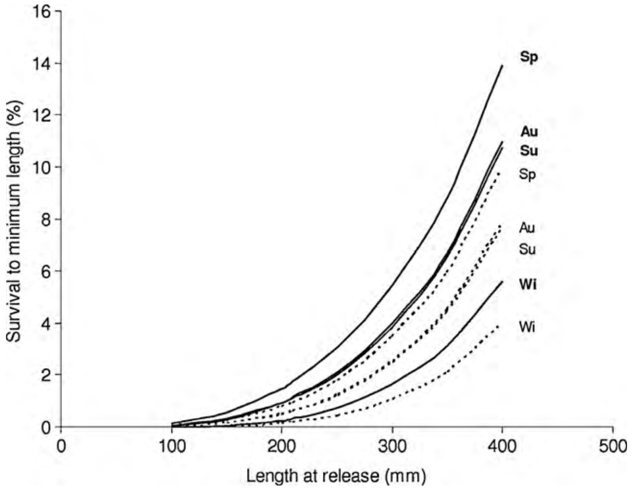

Fig. 5. Predicted proportion of released hatchery white seabass surviving to the legal minimum length as a function of release size, for Spring (Sp), Summer (Su), Autumn (Au) and Winter (Wi) releases and net pen acclimatisation (solid lines) or direct release (dashed lines).

seabass has provided new insights of generic interest to stock enhancement programmes as well as specific information pertinent to improving the white seabass release strategy. The extensive data set allowed testing of alternative natural mortality models, showing that survival of hatchery fish was best described by a mortality model that included components of both, long-term size-dependent mortality and an additional short-term post-release mortality dependent on release season and method. This model extends the basic size-dependent model of Lorenzen (2000, 2006).

The long-term size-dependent mortality rate estimated for hatchery white seabass ($M_r = 34.1\ \text{year}^{-1}$ at $L_r = 10\ \text{mm}$) is well below the median for released hatchery fish ($M_r = 67.5\ \text{year}^{-1}$) but higher than the median for wild fish ($M_r = 16.5\ \text{year}^{-1}$) (Lorenzen, 2006). In addition, the fish suffered varying levels of short-term post-release mortality. This indicates that hatchery rearing has both short- and long-term effects on survival in the wild and that short-term effects in particular are strongly influenced by release season and method. Long-term mortality patterns are likely to reflect genetic and developmental influences of hatchery rearing that can be minimized through appropriate husbandry but may be difficult to eliminate completely. The California white seabass hatchery programme employs comparatively advanced broodstock management and juvenile rearing protocols and this is reflected in a comparatively low level of long-term mortality (Kent et al., 1995).

From 1986 to 2006 just over 1.13 million cultured white seabass were released into coastal waters of southern California. During this period fish were released opportunistically year round and at different lengths. Applying the seasonal and release method mortality parameter estimates from Model 4 results in about 27,000 or 2.4% of these fish being recruited into the fishery.

Grow-out pen release methods are the most favourable option for better survival compared to direct releases. This is probably a result of the acclimatisation period the fish go through before being released into the wild habitat. Investigators have observed increases in survival with short acclimation periods (<7 days) for stocked fish (Cresswell and Williams, 1983; Jonssonn et al., 1999; Brennan et al., 2006). Fish released from grow-out pens in this study where held for an average of 160 days (range 14–837 days). While the range of days that fish were held in grow-out pens was highly variable, no analysis was conducted to determine if survival rates varied with acclimatisation time. In addition, the mean size at release varied with release method. Fish released directly averaged 162 mm SL, whereas those released from grow-out pens were 224 mm SL. Despite the release method, size-dependent mortality would result in fewer fish surviving to recruit to the fishery when released at smaller sizes. Further investigation into these acclimation conditions and duration is warranted to understand how it influences post-release mortality.

Additional investigations should be carried out to better understand how possible seasonality and site effects in dispersal affect mortality rates. The research sampling in this study was disproportionate in that effort only occurred in four months (April, June, August, October). Fish that were released in late fall and Winter had more time to disperse prior to the next sampling in April. While this effect was accounted for by modelling how dispersal affects availability to fishing gear, dispersal itself was assumed to be independent of season and release site. In order to better understand how seasonal dispersal patterns may affect these mortality estimates, sampling during winter months, shortly after releases, would be beneficial. Additional sampling would also allow estimating release site effects in dispersal and mortality rates.

This study represents one of the most comprehensive evaluations of a marine stock enhancement program conducted to date, especially for a highly mobile, coastal pelagic species. As an outcome of this quantitative assessment, the release strategies of the program are currently being modified to the fullest extent practicable. That is, every effort will be made to release juveniles from net pens in the spring, summer and autumn. Achieving this goal will likely require modifications to current production plans, including broodstock management, as well as an increase in net pen capacity. This assessment has also provided the ability to perform sensitivity analyses on variables such as size at release, and release method and season, to estimate the number of fish recruiting to the fishery under different scenarios. This modeling tool will be used to set enhancement targets for the next phase of the program that can then be empirically tested through additional mark and recapture efforts. When using the model to evaluate options for up-scaling the enhancement program, it is important to bear in mind that compensatory density-dependence in post-release mortality rates is likely to occur when release numbers are increased substantially and that the strength of compensatory density-dependence is likely to vary with release size (Lorenzen, 2005). It is therefore important to adopt an experimental approach to up-scaling, with continued monitoring and assessment (Walters and Martell, 2004; Lorenzen, 2005).

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