Available online at www.sciencedirect.com
ScienceDirect
Fisheries Research 90 (2008) 313–315
FISHERIES RESEARCH
www.elsevier.com/locate/fishres

Letter to the Editor

Estimating survival of discarded scallops in the Patagonian scallop fishery: Comment on "Survival of Patagonian scallop (*Zygochlamys patagonica*, King and Broderip, 1832) after the size selection process on commercial fishing vessels", by Bremec et al. 2004

Bremec et al. (2004) analyzed the results of a field experiment investigating the survival of Patagonian scallops (*Zygochlamys patagonica*, King and Broderip, 1832) after capture and passage through the size selection process onboard commercial fishing vessels. The size selection process in the commercial fishery is mechanical and retains commercial sized scallops (>55 mm shell height legal size) and discards undersized scallops and invertebrate by-catch. The experiment consisted of placing bags of scallops sampled from the unsorted catch (control) and scallops from the sorted catch (treatment) on the seabed. At the end of the experiment, bags were retrieved and the number of dead and live individuals was recorded. The experiment was conducted on four different occasions, each occasion retrieving bags after a different total number of days on the seabed, resulting in experimental durations of 5, 6.5, 8 and 12.5 days. Bremec et al. (2004) reported high scallop survival (mean = 96%) and no significant differences in scallop survival between control and treatment groups, concluding that the results justify a minimum size limit as a management tool in the Patagonian scallop fishery.

Bremec et al. (2004) provided size frequency distributions of scallops used in the survival experiment (Fig. 1) and reported that the mean size of scallops used in the controls was larger than in the treatment. Further inspection of scallop size distributions used in their experiment suggest that not only the scallops used in the control group were larger than scallops used in the treatment group at the onset of the experiment, but also larger scallops in the control were more likely to die at the end of the experiment (Fig. 1). Moreover, Bremec et al. (2004) did not distinguish between undersize (<55 mm) and legal size (>55 mm) scallops in their analysis of survival of discarded scallops. Indeed, the proportion of undersize scallops was significantly higher (80%) in the treatment group than in the control group (36%, $p < 0.001$, Fig. 2) at the onset of the experiment. Furthermore, the proportion of undersize dead scallops relative to the total dead in each experimental group was significantly higher in the treatment (82%) than in the control (7%, $p < 0.001$, Fig. 2). That is, legal size scallops not only constituted most of the control group scallops at the onset of the experiment but also most of the observed control deaths at the end of the experiments. However, survival of discarded scallops of legal size is almost irrelevant for management purposes since legal size scallops are retained by commercial fishing vessels and are rarely discarded (except for malfunctioning or limitations of the selection process). Therefore, analysis of survival of discarded scallops with management implications should focus on undersize scallops, which are actually discarded during fishing operations.

Bremec et al. (2004) analyzed scallop survival using a two-factor ANOVA with fixed effects (two levels: control and treatment) and random effects (four levels corresponding to each experiment date/duration). Even though the ANOVA showed no significant differences between the survival of treatment and control groups, it showed a significant effect for the experiment date/duration (Bremec et al., 2004, their Table 2) which is not discussed by the authors. The effects of experiment date and duration are confused in the experimental design since each experiment date resulted in different experimental durations, precluding formal testing of their relative effect. However, one would expect a priori that longer experiment durations would result in lower scallop survivals as a result of natural mortality or a combination of natural mortality and experiment effects. Therefore, the duration of the experiment should be incorporated in the analysis of scallop survival.

Here we present an alternative analysis of the experimental results presented by Bremec et al. (2004) by focusing on the survival of undersize discarded scallops and including the duration of the survival experiment. We also discuss potential implications of the new results for management of the Patagonian scallop fishery.

We re-analyzed experimental results presented by Bremec et al. (2004) using a restricted data set, focusing only on undersized scallops (<55 mm) in order to estimate survival of scallops in the size range discarded by commercial fishing vessels. While Bremec et al. (2004) based their analysis on total survival we focused here on survival rates, the number of scallops surviving per unit time. We incorporated different mechanistic processes affecting scallop survival in the experiment by using four alternative competing models:

$$N_t = N_0 e^{-mt} \quad (1)$$

$$N_t = N_0 e^{-(m+s)t} \quad (2)$$

$$N_t = N_0 e^{-(mt+s(t-l))} \quad (3)$$

$$N_t = N_0 e^{-(m_d)t} \quad (4)$$

where N_t is the observed number of surviving scallops at the end of the experiment of duration t and N_0 is the observed num-

doi:10.1016/j.fishres.2007.10.004

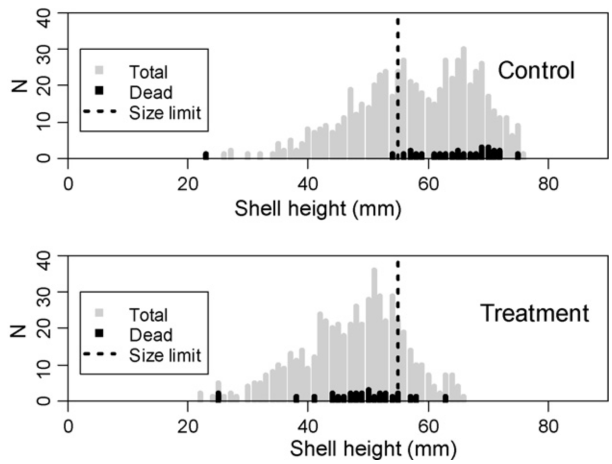

Fig. 1. Size frequency distributions (shell height) of scallops included in the survival experiments. Grey bars indicate total scallops, black bars indicate dead scallops, and the vertical dashed bar shows the minimum legal size. Modified from Fig. 1 in Bremec et al. (2004).

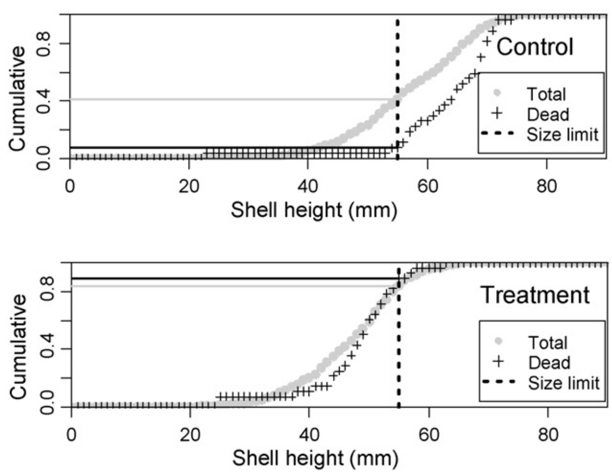

Fig. 2. Cumulative size frequency distributions (shell height) of scallops included in the survival experiments. Grey circles indicate total scallops, crosses indicate dead scallops, the vertical dashed bar shows the minimum legal size, and the horizontal lines show the fraction of total (grey) and dead (black) scallops below minimum legal size.

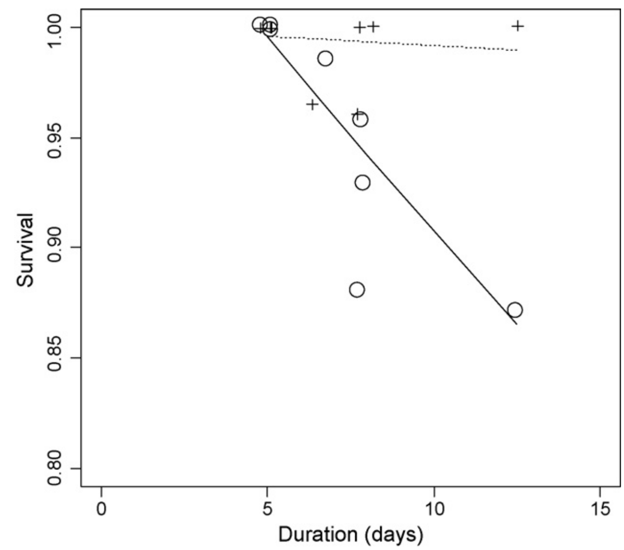

Fig. 3. Survival of Patagonian scallops in the control (crosses) and treatment (open circles) groups versus duration of survival experiment. Data points are jittered for better visualization of overlapping points. Dashed (control) and solid (treatment) lines represent best model fit.

ber of scallops at the beginning of each experiment. Model 1 describes the experimental results of both treatment and control groups as an exponential decay with a single mortality parameter *m*, which includes both natural mortality and any additional effects of experimental handling. Model 2 describes mortality as an exponential decay with parameter *m* for the control group mortality and a combination of *m* and *s*, a selection process mortality rate, for the treatment group. Model 3 adds a time lag in the effect of the selection process *s*. Model 4 describes scallop survival as the result of date specific mortality rates, m_d. Model selection was done using Akaike information criterion, AIC (Akaike, 1974).

Models with a selection process mortality rate for the treatment group were selected by AIC over models incorporating a single or date specific mortality rates (Table 1). Model 3, the model accounting for selection process mortality and a time lag on its effect is selected by AIC as the best model (Table 1, Fig. 3) followed by model 2 which also accounts for selection process mortality but no lagged effect. Daily mortality rate estimates (*m*) for the control group from models 2 and 3 (Table 1) are in the range of expected daily mortality rates based on annual natural mortality rate estimates obtained by an integrated modeling approach for the Patagonian scallop (0.0008 day^{-1}, 0.0006–0.0011 95% CI; Ernst and Valero, 2005). Daily mortality rates of the treatment group estimated by models 2 and 3 are 6–20 times higher than the control mortality rate estimates (Table 1). Since mortality rates were estimated over a short period of time caution should be taken in extrapolating these results beyond the duration of the experiment or using the results beyond the current comparison of competing models.

Table 1
Summary of competing models fitted to undersize scallop survival experimental results.

Model	*k*	−ln(*L*)	AIC	*m*	95% LCL	95% UCL	*s*	95% LCL	95% UCL
1	1	25.58	27.58	0.0050	0.0033	0.0071	–	–	–
2	2	20.79	24.79	0.0012	0.0002	0.0036	0.0058	0.0025	0.0093
3	3	14.67	20.67	0.0008	0.0002	0.0023	0.0179	0.0103	0.0271
4	4	18.55	26.55	–	–	–	–	–	–

k: number of model parameters, −ln(*L*): negative natural log likelihood, AIC: Akaike's information criterion value, *m*: natural mortality rate point estimate (day^{-1}), *s*: selection process mortality rate point estimate (day^{-1}), 95% LCL: respective 95% lower confidence limit and 95% UCL: respective upper confidence limit.

Bremec et al. (2004) reported high survival of scallop discards (mean = 96%) and no significant difference in survival of discarded scallops before or after the onboard selection process. However, no distinction was made between undersized and commercial sized scallops and the differing experimental durations were not included in the analysis of survival. The reanalysis presented here focuses on undersize scallops, which are in the size range discarded during fishing operations, and includes the duration of the experiment in the analysis of survival. We found that while scallops discarded before the selection process suffered mortalities similar to the ones reported in the literature for the Patagonian scallop (Ernst and Valero, 2005), scallops discarded after the selection process suffered mortality rates between 5 and 20 times higher. These mortality estimates should be considered with caution since the experiments were performed with undamaged individuals protected from predators (Schejter and Bremec, 2007) and the duration of the experiments was relatively short. Marked differences in mortality in relationship to shell damage have been described in other scallop species. Gruffydd (1972) found that mortality of damaged scallops was 5–13 times higher than that of undamaged scallops in the *Pecten maximus* dredge fishery. Repaired shell damage in the Patagonian scallop was reported by Lomovasky et al. (2005) and Schejter and Bremec (2007), however its relationship with fishing disturbance is still unclear. Further studies are needed to quantify the extent of shell damage as well as mantle disattachment in scallops prior to discarding and its effect on survival.

Results from the reanalysis presented here suggest that the duration of the experiment was not sufficient to identify protracted mortality since there are indications of a time lagged effect of the selection process mortality as well as a significant declining trend in the survival of scallops discarded after sorting with no signs of a plateau over the duration of the experiments (Fig. 3). Although the specific causes of indirect mortality in Patagonian scallops are unknown, protracted mortality has been addressed in recent studies (Broadhurst et al., 2006). Most of the work on protracted indirect fishing mortality has been done on fin-fish species and a few invertebrate species (see Broadhurst et al., 2006; Orensanz et al., 2006). Ramsay et al. (2001) found protracted mortality of starfishes discarded by otter trawlers during more than 3 weeks. Protracted indirect mortality was also found for the *Pecten fumatus* Australian scallop fishery resulting in death of most scallops 8 months after fishing ceased (McLoughlin et al., 1991).

Given the poor selectivity of the current fishing gear in the Patagonian scallop fishery and the negative effects of onboard selection on survival of discarded scallops, additional research on improving gear performance and processing efficiency is needed. Evaluation of square mesh codends such as those used in the Queensland's saucer scallop and prawn fisheries (Broadhurst et al., 2006) could improve the poor selectivity of the current gear and reduce mortality associated with the current onboard selection process. Current management measures for the Patagonian scallop fishery include permanent reserves, a minimum size limit, and a quota based on a fraction of the commercial biomass. Given the significant negative effects of the sorting process on the survival of undersized discarded scallops and the uncertainty on the duration and magnitude of protracted discard mortality alternative management measures and strategies should be evaluated in the Patagonian scallop fishery.

Acknowledgements

We thank D. Hernandez and C. Bremec for discussions prior to the submission of this letter. We also thank M. Haltuch, A. Punt, A. Hicks, L. Conquest and J. Skalski for discussions that improved this letter.

References

Akaike, H., 1974. A new look at the statistical model identification. IEEE Trans. Automat. Control 19, 716–723.

Bremec, C.S., Lasta, M.L., Hernandez, D., 2004. Survival of Patagonian scallop (*Zygochlamys patagonica*, King and Broderip, 1832) after the size selection process on commercial fishing vessels. Fish. Res. 66, 49–52.

Broadhurst, M.K., Suuronen, P., Hulme, A., 2006. Estimating collateral mortality from towed fishing gear. Fish Fish. 7, 180–218.

Ernst, B.G., Valero, J.L., 2005. Are equilibrium-derived estimators good for stock assessment in data poor situations? In: Assessment and Management of New and Developed Fisheries in Data-Limited Situations, Alaska Sea Grant, UAF, Alaska, pp. 715–735, AK-SG-05-02.

Gruffydd, L.L.D., 1972. Mortality of scallops on a Manx scallop bed due to fishing. J. Mar. Biol. Assoc. U.K. 52, 449–455.

Lomovasky, B., Lasta, M., Campodonico, S., Iribarne, O., 2005. Relationship between repaired shell damage and fishing disturbance in the Patagonian scallop *Zygochlamys patagonica*. J. Shellfish. Res. 25, 289–290.

McLoughlin, R., Young, P.C., Martin, R.B., Parslow, J., 1991. The Australian scallop dredge: estimates of catching efficiency and associated indirect fishing mortality. Fish. Res. 11, 1–24.

Orensanz (Lobo), J.M., Parma, A.M., Turk, T., Valero, J.L., 2006. Dynamics, assessment and management of exploited natural populations. In: Shumway, S. (Ed.), Scallops: Biology, Ecology and Aquaculture, second ed. Elsevier, pp. 765–868.

Ramsay, K., Bergmann, M., Veale, L.O., Richardson, C.A., Kaiser, M.J., Vize, S.J., Feist, S.W., 2001. Damage, autotomy and arm regeneration in starfish caught by towed demersal fishing gears. Mar. Biol. 138, 527–536.

Schejter, L., Bremec, C., 2007. Repaired shell damage in the commercial scallop *Zygochlamys patagonica* (King and Broderip, 1832), Argentine Sea. J. Sea Res. 58, 156–162.

Juan Luis Valero*

School of Aquatic and Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195, USA

Mario Lasta

Instituto Nacional de Investigación y Desarrollo Pesquero, Mar del Plata B7602HSA, Argentina

* Corresponding author. Tel.: +1 206 685 3609; fax: +1 206 685 7471.

E-mail address: juan@u.washington.edu (J.L. Valero)