FISH and FISHERIES

Environmental improvement of seafood through certification and ecolabelling: theory and analysis

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Abstract

The study of environmental impacts of seafood production as a result of ecolabelling and certification is a young yet rapidly growing discipline that lacks theoretical models. Pieces of the model have been suggested in the literature, and these pieces are formalized here realizing the current operating parameters of the global seafood industry. The derived pull-threshold model assumes that if producers exceed the threshold, there is no incentive to improve while if too far below, improvement is most likely beyond technical or financial means. Thus, a single certification is only a marginal solution to the larger picture. Those producers immediately below the certification threshold are within range or 'pull' of the threshold to improve as a result of certification. Results from a single threshold model applied to compliance data indicated that a maximum improvement of 12.5%, achieved when the pull was the greatest and the threshold was at the lower end of the impact distribution. When impacts were continuous (e.g. escapes in aquaculture), greater improvement was observed with thresholds targeting the producers at the higher end of the impact distribution. In all cases, improvement was maximized with a triple threshold model, indicating that single threshold scenario will not drive the greatest movement towards environmental improvement throughout the industry. Innovation is potentially more important in reducing environmental impacts of seafood production and needs to be accounted for as the seafood certification or ecolabelling continues to mature.

Keywords Aquaculture, certification, environmental impacts, fisheries

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Introduction

Seafood (including marine and freshwater products) is an important global food commodity because developing countries depend on it as a protein source (Tacon and Metian 2008), developed countries accept it as a preferred protein (Pelletier *et al.* 2009), its importance for health and human evolution (Arts *et al.* 2001), and because it often represents an energy efficient, low environmental impact source of protein (Tyedmers 2004). However, for all of its benefits, there are a variety of concerns about the environmental impacts of global seafood production (Pauly 2009). The main concerns surrounding wild fisheries include the fact that many species are overfished (Myers and Worm 2003), harvested by methods detrimental to the ecosystem and other species within (Gislason *et al.* 2000), and that overfishing has led to even broader ecosystem impacts. Aquaculture also has its share of areas of concerns including habitat conversion or destruction (Boyd 2002), altering ecosystem processes (Neori *et al.* 2007), significant social impacts (Belton *et al.* 2009), loss of biodiversity (Diana 2009) and the use and volume of fish meal and oil derived from wild fisheries in this production process (Alder *et al.*, 2008, Naylor *et al.* 2009). Rather than providing a full review of this topic, the main point here is that for both wild fisheries and aquaculture production, there is growing concern that this is occurring in such a way that the benefits of biological efficiency are eroded because of a lack of adherence to sustainability principles and practices. To align protein production with a global environmental ethic, there is currently a great deal of emphasis placed on the development of environmentally responsible standards through certification and ecolabelling programmes (hereafter referred to as certification) for species harvested or produced for seafood (Ward and Phillips 2008). These programmes have an overall goal of using market-based mechanisms (such as retailer and consumer choice) to change current producer, sourcing and purchasing practices, moving the industry towards enhanced sustainability and environmental improvements (Ward 2008a, b; Parkes *et al.* 2009).

For all of the benefits that seafood certification potentially can provide, it is uncertain whether they are driving significant improvement on the water (Gardiner and Viswanathan 2004; Kaiser and Edwards-Jones 2006; Ward 2008b; Jacquet *et al.* 2009). One difficulty in evaluating progress is that the history of seafood certification is brief, spanning approximately a decade, and limited comprehensive data have been tabulated and analysed from such programmes (Ward 2008a). In addition, full assessments of the distribution curve of environmental impacts were not conducted prior to the implementation of many programmes. Furthermore, no models for understanding the improvement exist, although two have been conceptualized, but not formalized (Clay 2007, Parkes *et al.* 2009). Because a formalized model and the necessary data are lacking, any numerical assessment of real improvement as a result of certification is to date impossible. Therefore, this paper serves to formalize a conceptualized model for environmental improvements in seafood through implementation of certification. This will demonstrate parameters that are critical for maximizing the benefits of certification and will approximate the level of improvement that can be anticipated through implementation of a certification scheme.

Certifications are ‘designed and propagated to reduce ecological impacts and improve the ecological-friendliness of practices used in production, harvesting or growing of products, with a view ultimately increasing the sustainability of all products across the market’ (Ward and Phillips 2008). Thus, resultant seafood certification serve two purposes (TemaNord, 2008) – first, they identify those producers (wild fish stocks or aquaculture farms) that meet or exceed a threshold defined within a standards setting process (for a discussion of the appropriate governance and necessary procedures to create a standard, see Ward and Phillips 2008). This first purpose does not improve the overall sustainability of the seafood; rather, it serves to provide purchasers (retailers and consumers) with a degree of comfort regarding the product (Wessells 2000; Johnston *et al.* 2001). The second and main goal of seafood certification is to enhance sustainability and incentivize environmental improvement within a production sector. Ideally, a certification programme needs to offer the opportunity for improvement to be recognized and to get as many producers or as much product as possible to shift towards a threshold defining production scenarios with lower environmental impacts. This shift has previously been conceptualized as a complete translocation of the entire environmental impact distribution curve (Clay 2007), while Ward and Phillips (2008) discuss the importance of increasing sustainability of all products across the market. However, there has been no evaluation as to whether seafood certification can create large-scale improvements across an entire production segment, or only on narrower segments.

Parkes *et al.* (2009) offered that it is unlikely that any producer already meeting the criteria of a standard-based certification scheme (those above the threshold) would change practices to lessen their environmental impacts since there is no further incentive to improve. This leads to a second potential model, being that the direct effect of certification programmes result in improvement through their influence or 'pull' on the producers that are immediately below the threshold. Practical experience within the aquaculture realm suggests that those producers too far below the certification bar will be unlikely to be motivated to improve as the level of improvement needed to obtain certification is likely beyond their technical or financial means [J. Heerin and W. Moore, Global Aquaculture Alliance (GAA), personal communication]. The result of these two observations is a model that determines improvement through certification to occur primarily by pulling a fraction of the total distribution towards the threshold. In this case, the magnitude of the improvement may be dramatically lower than that expected if the entire curve were to be shifted (Fig. 1). Therefore, if only one threshold is to be utilized, it is important to place it properly to enable a maximum number of producers to improve. It has yet to be determined where the optimal placing of a threshold should occur.

Because both the theoretical and empirical knowledge base for improvement through certification of fisheries and aquaculture is lacking, here we adapted the ideas of curve translocation (Clay 2007) and zones of impact (Parkes *et al.* 2009) to develop a simple discrete model that could be used to determine parameters important in creating movement towards increased sustainability within the units of certification (stocks for fisheries and farms for aquaculture). For the purpose of this model, it is assumed that certification units will improve their overall score only if they are within the pull of the target threshold. In practical terms, a certification unit that exceeds the threshold is assumed not to make any improvement, as it has 'passed the bar'. Certification units that are just under the threshold will make improvements to become certified. Those too far below the threshold will not be compliant and will not alter their behaviour to span the 'gap' between their current status and the threshold (Ward and Phillips 2008).

This initial model is constructed for compliance data, where values are percentages indicating adherence to criteria, and range from 0 (maximum environmental impacts) to 100 (minimum environmental impacts). Improvement will come from those certification units just below the target threshold (T) that improve their performance in order to become certified. Therefore, the focus of this model is developing an understanding of the mathematical factors that determine how far a producer can be below T, yet still improve to become certified. The region below T in which producers are likely to improve to become certified is referred to as the pull (p) of certification. This model assesses the improvement of a seafood product as the result of certification with respect to the value of average score

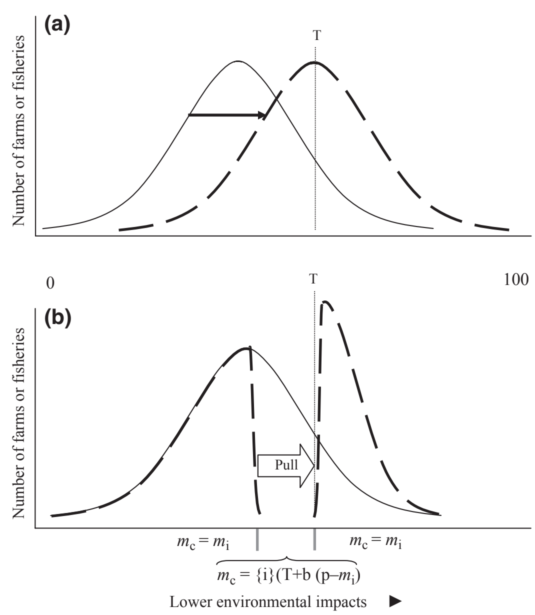

Figure 1 Two potential models of how certification will alter an environmental impact curve. The distribution of impact values (in this case a scale of 0 to 100, with 100 indicating the least environmental impacts) pre-certification distribution is solid, the post-certification distribution, dotted, and the vertical stippled line indicates the threshold (T). The top figure (a) refers to the Clay (2007) model in which the entire distribution translocates. The lower figure (b) represents the model presented within this manuscript. When the score is above or below the pull, the post-certification metric will equal that of the pre-certification metric ($m_c = m_i$). For those producers within the pull of the threshold, improvement will be made dependent upon the probability of improving ($\{i\}$), the result of the improvement (b), and the overall amount of the pull (p) determined by a proportion of the standard deviation.

pre-certification, variation and shape of the response curve, and the capacity for the standard to pull (influenced by the probability of improvement). This model is initially conducted with a single threshold. However, multiple thresholds are added to address how this may increase the impact of certification on the performance fishery or aquaculture units.

To explore how the model results compare to numerical data, the number of salmon escapes in Norway (www.bellona.org/aquaculture/tema_aquaculture/Escapes) was assessed. These data are similar to many of the environmental impact metrics in that a value of 0 indicates the best production scenario and minimum environmental impact. In this case, distributional data were determined for three different datasets representing the number of escapees per event from individual farms for the years 2006–2008. This provided data that varied in distribution and mean value and allowed for a determination of how applying a certification would result in a change in the measurable impact on the water, namely fewer fish escaping.

Model development

The 'pull-threshold' model developed here assumes that there is a limited range of the impact distribution curve on which a threshold will have impact. This model is a deterministic function that assumes a known continuous distribution of metrics as the input. For the initial purpose of model development, the 'metric' is a compliance index (from 0 to 100) which is a continuous distribution of environmental performance and would be derived as the summary score each farm or fishery would receive from a certification audit. Each extant fishery and aquaculture certification programme [e.g. GAA-Best Aquaculture Practice, GlobalGap, Marine Stewardship Council (MSC)] have different methods and targets to determine whether the certification unit passes or fails (see Ward and Phillips 2008). However, all certification programmes typically use a variety of data types such as the metric and compliance data examined (see WWF Switzerland and Norway 2007). Either data type can be tabulated in a manner that allows for determination of the overall performance and change in performance of the certification unit. For example, the MSC has three principles, with 23 criteria and 80–100 performance indicators (Howes 2008). For a fishery to be certified, the average score of the three principles needs to exceed 80, and no one principle can be <60 (Potts and Haward 2007). Thus, an average MSC scores (the average of the three principles) can then be characterized with traditional distributional statistics, including the average value, the variation of the scores, and a determination of the distribution of the scores.

For the initial development of the model, it was assumed that a score of 100 indicated full compliance with standards criteria indicating the lowest environmental impacts. Six initial distributions were created, against which improvement through certification was assessed. Both normal and skewed distributions were assessed. Normal distributions with $\bar{X} = 50$ or 70 were created with low and medium variation ($\sigma = 6$, or 12) while a distribution of $\bar{X} = 50$ and high variation ($\sigma = 18$) was also created (the high variation distribution could not be created when $\bar{X} = 70$). The last distribution consisted of a single skewed distribution ($\gamma_1 = 0.83$) with $\bar{X} = 50$ and medium variation ($\sigma = 12$) indicating a longer right tail of the distribution.

From these different distributions, the model proceeds by first resolving if each individual producer (fishery or farm) will improve as a result of certification, applies that improvement to the metric of the producer and then calculates the subsequent population average accounting for the improvement (Equation 1). This model proceeds to first resolve whether each individual producer will or will not improve their metric (m_i) as a result of certification. The model assumes that the only producers that will improve their scores are those in which ($T - \mathrm{p} \leq m_i \leq T$), where T is the certification threshold, and p is the pull of the certification. For the purpose of this model, three values of T were assessed, 80, 50 and 20, representing ecolabel programmes that promote an upper tier (80), a median (50) or remove the worst actors (20). The pull (p) is defined as ($a\sigma$) where a is a constant (0.5 or 1.0) determining whether a full or half standard deviation will be pulled and hence improved through certification.

$$\bar{X}_{m_c} = \frac{\sum_{m_i<T-p} m_i + \left(\sum_{m_i \geq T-p}^{m_i=T} (\{i\}(T + b(p - m_i))) \right) + \sum_{m_i>T} m_i}{f_t} \quad (1)$$

The scores for the individual certification units are then adjusted either to the threshold T ($b = 0$ in

Equation 1) or to a value of $m_i + p$ ($b = 1$ in Equation 1), dependent upon the probability of improvement $\{i\}$. It is unknown whether certification units will improve by merely meeting the threshold, or whether they will improve beyond it, thus each case is modelled here. As for the probability of improvement $\{i\}$, Volpe (2001) hypothesized that improvements in aquaculture will follow a diminishing return curve. The closer a certification unit gets to zero impacts, the more difficult it will be to make additional improvements. For the purpose of the model, the probability of improvement is either a constant ($\{i\} = 1$) or shows a constant decay function, $\{i\} = (f_t - f_i)/(f_t - 1)$, where f_t is the total number of farms or fisheries, and f_i is the ranked order count, least to greatest. The overall average after certification ($\bar{X}_{\mathrm{m_c}}$) is then calculated based on these adjustments to metrics and compared to the average prior to certification (m_i).

This model was run for single thresholds ($T = 20$, 50 and 80), the paired parameter states of $\{i\}$, a and b for each of six distributions (normal $\bar{X} = 50$ [$\sigma = 6$, 12, 18], $\bar{X} = 70$ [6, 12] or skewed $\bar{X} = 50$, [12]) yielding a total of 144 runs. From these runs, the combination of variables leading to the greatest improvement was identified. Using these best parameter states, the model was then run utilizing multiple thresholds. The relative improvement using paired (80:50, 80:20 and 50:20) or tripled (80:50:20) thresholds was compared to the best improvement from the single threshold model.

A number of certification schemes also used metric-based data (e.g. escapes, effluent, antibiotics) where the goal is to reduce the metric towards a limit of 0. To assess this type of data, Atlantic salmon escape data from Norway were analysed for individual escape events from individual farms for three discrete years (2006–2008) (www.bellona.org/aquaculture/tema_aquaculture/Escapes, accessed 1 May, 2009). This provided three data sets of a continuous variable each with a different average, 30 523 ($n = 32$), 11 855 ($n = 23$) and 3996 ($n = 15$). For each of these data sets, the coefficient of variation (c.v., σ/μ) was large, with values of 1.95, 2.3 and 2.4 for the three consecutive years. Because of this, a pull of ½ or 1 standard deviation could not be utilized. To normalize the data, the values for the farm-level reported escapes were log-normal transformed, which reduced the c.v. to 0.37, 0.47 and 0.35 respectively. The model was then run, with three single threshold models (20, 50 and 80) applied with a pull = 1 σ. Both a constant and decreasing probability of improvement were assessed, but improvement increased only to the threshold ($b = 0$). Results were back-transformed through an exponent function, and the change in values post-model application was calculated as both the per cent change and the decrease in the realized number of escapes. The pull-threshold model was implemented for this continuous data as it was for the compliance data examined above with the difference that movement towards a 0 value indicated environmental improvement. Therefore, the pull was determined as being greater than the threshold ($T + p$), compared to ($T - p$) as described for compliance data and within Equation 1.

Model results

Compliance data

Each of the model runs increased the overall population average, indicating an improvement in scores through the certification process. However, the average improvement for all 144 runs was 2.13 ± 0.2% ($\bar{X} \pm 1$ σ). The maximum improvement offered by a single threshold model was 12.9% (Fig. 2) and occurred with the parameters $\bar{X} = 50$, $\sigma = 18$, $T = 80$ and a and $b = 1$. In this case, the increase in the average scores as a result of the model came only through the improvement in metrics by those producers that were within range (the pull) of the threshold value of the certification. Thus, factors that increase the pull factor are critical to improvement. This maximal improvement occurred when the pull was largest (1 σ compared to 0.5 σ) and came about under conditions where the probability of improvement $\{i\}$ was constant, and the scores were improved by the pull factor ($T + p$), not just to the target.

The importance of the pull factor was also indicated by the fact that larger improvement through certification occurred when the population variation was larger, although the improvement was nominal. When considering each distribution, the per cent increase as a result of the model was statistically significantly different between the different distribution – mean – variation combinations ($F_{5,138} = 5.54$, $P < 0.001$). The distributed data with $\bar{X} = 50$ and $\sigma = 18$ (N50[18]) were significantly greater than the N70[6], N70[12] and N50[6] distributions (Tukey's Multiple Comparison

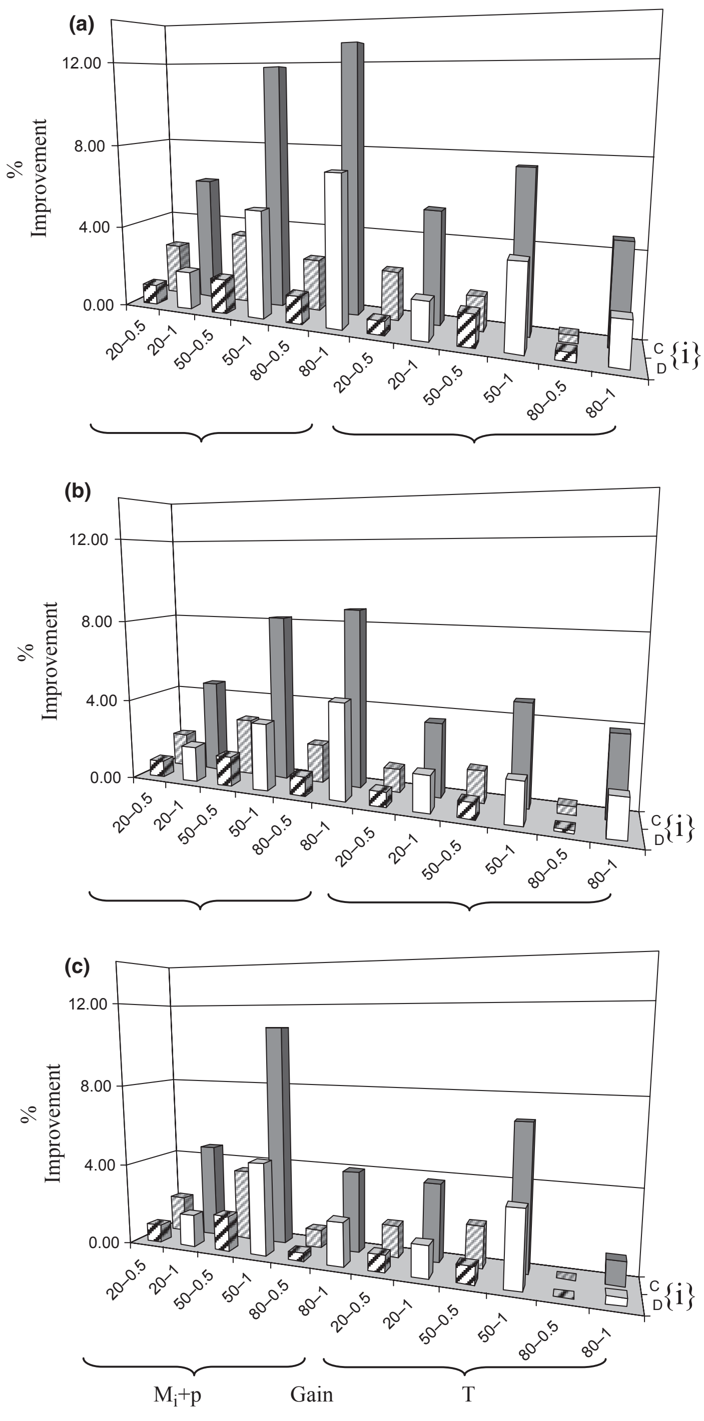

Figure 2 The % improvement in the impact curve of a compliance metric ranging from 0 to a top score of 100. Graphs represent three pre-certification distributions, each with a mean of 50, and with a normal (top two graphs a,b) or a skewed distribution (bottom graph, c), and high (σ = 18, top) or medium (σ = 12, bottom two) variation. The *x*-axis represents cases in which the increase as a result of certification is to the threshold (*T*) or the mean plus the pull value ($m_i + p$) for cases of three thresholds (20, 50, 80) and either a full (1, hatched bars) or half (0.5, solid bars) a standard deviation pull. These scenarios are modelled for cases in where the probability of improvement {*i*} is continuous (C, darker bars), or decreases (D, lighter bars) as the metric approaches the top score.

Test, q = 6.4, 4.6 and 5.6 respectively, P < 0.05), all others being equivalent. For the case of normally distributed data with $\bar{X}$ = 50, only 3 of the 24 model combinations resulted in an improvement >3% when σ = 6. As σ increased to 12 and 18, the number of model combinations resulting in an increase >3% also increased to 8 and 10 respectively. While the significant difference in improvement as a result of initial distribution appears to be a phenomenon of numbers (a larger divisor yields a smaller percentage change), this does not appear to be the case for this model. Comparing the numerical value of the change as a result of certification, there was still a statistically significant difference between the different distribution – mean – variation combinations ($F_{5,138}$ = 4.04, P < 0.001). However, in this case, N50[18] was significantly different from only the low variation runs (N70[6] and N50[6], Tukey's Multiple Comparison Test, q = 5.3 and 5.4 respectively, P < 0.05). Therefore, it appears that the variation of the distribution as opposed to the average initial value of the distribution has a greater role determining the overall increase as a result of certification.

The greatest amount of improvement as a result of the model occurred with a target threshold of 80. This threshold (along with a and b = 1) resulted in the maximal improvement for all of the runs utilizing normal distributions. Reducing T to 50 while keeping all other parameters the same resulted in the second largest improvement, but again for only the runs utilizing normally distributed data. For the skewed distribution, a T = 50 resulted in the largest overall improvement (Fig. 2).

The implementation of multiple thresholds will amplify the improvements discussed above. Whereas the maximum improvement under a single threshold was 12.9% when N50[18], with T = 80, and a and b = 1, this improvement increased to 22.5% when T = 50 was added along with the T = 80. The second greatest improvement occurred with T = 80/20 (18.9%), while T = 50/20 had an overall improvement of 16.8%. A triple threshold of 80/50/20 (for the case N50 [18], and a and b = 1) resulted in an improvement of 27.1%.

Continuous data

In general, the improvement on the water (measured as a decrease) in the number of salmon escaping Norwegian farms each of 3 years as a result of applying the pull = threshold model was greater when the threshold was lower, or when the average number of escapes per farm per year was greater. Within years, T = 20 resulted in the greatest benefits on the water compared to T = 50 or 80 (Fig. 3, bottom), while greater improvements were observed when the average yearly escape was greater (e.g. 30 533 compared to 3996, Fig. 3, bottom). This would culminate in nearly 15 000 fewer fish escaping in a high escape year (30 533) when a low threshold was set (T = 20, Fig. 3, bottom). However, there is a slight disconnect between the results for the decrease in per cent and the number of escapes. The greatest improvement in per cent escapes was −80% and occurred when T = 50 and the average of the pre-model distribution was an intermediate number of escapes (11 856, Fig. 3 top). Thus, for continuous data, the per cent improvement can be disconnected from the measurable change in environmental impact, but the greatest overall impact will by made by targeting those producers with the greatest impacts. In comparison with the compliance data, all of the models for T = 50 or 20 yielded % improvement >5% and could be extensive reaching 80%.

While Volpe (2001) hypothesized that improvements, particularly in escapes, are likely to demonstrate a decreasing return on investment, including a linear decrease in probability of improvement within the pull-threshold model did not significantly alter the results. This decreasing probability had a greatest impact at lower thresholds, because at these values, the probability of not improving was greater. For example, within the 2006 escape data the environmental improvement of the pull-threshold model is reduced by 808, 1837 and 190 fish respectively for T = 20, 50 and 80. While the decrease for T = 80 was a change of nearly 50%, the change on the water was limited to only 190 fish because these farms were close to the final limit of 0.

Similar to the compliance data, increasing the number of thresholds decreased the overall environmental impacts in an additive fashion. There were 64, 88 and 27% fewer escapes after implementation of three thresholds for data from the years 2006 to 2008 respectively.

Discussion

To date, there has been virtually no assessment of how seafood production has improved as a consequence of certification implementation, in large

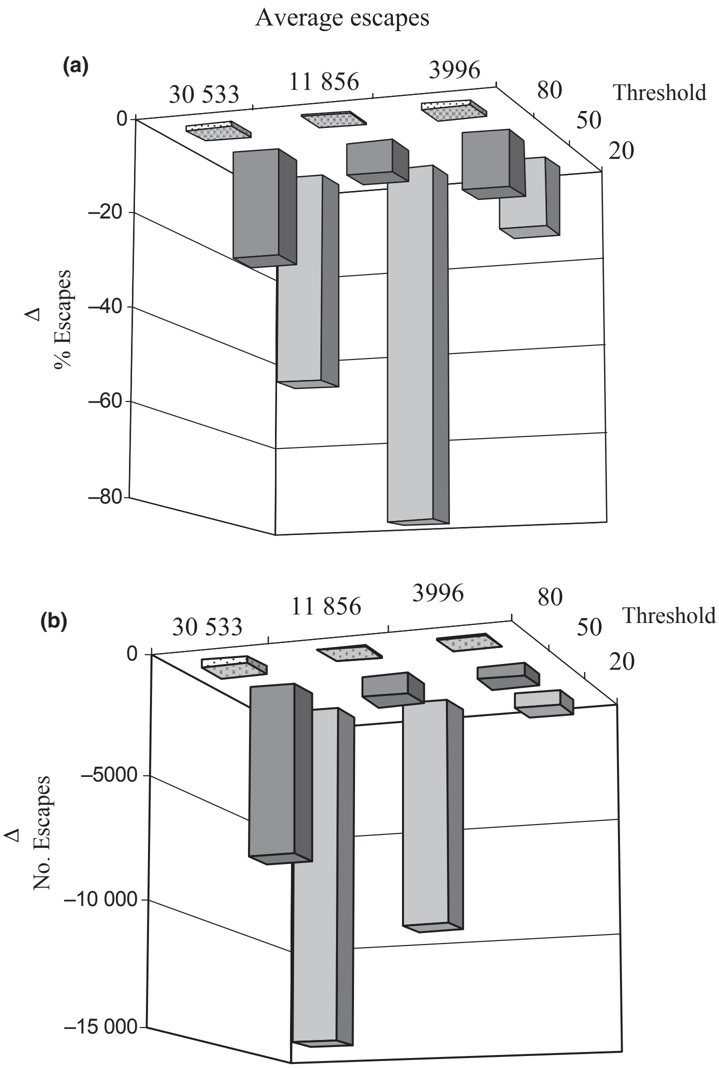

Figure 3 The change in the per cent (top, a) and number (bottom, b) of salmon escapes from Norwegian farms between 2006 and 2008 (indicated by average number of escapes greatest to least) when the pull threshold model is applied at three different thresholds (20, 50, and 80).

part because limited comprehensive data exist (Boyd *et al.* 2007; Ward and Phillips 2008). Because data were lacking, a model was created to explore the factors that will be important in decreasing the environmental impacts of seafood production as a result of certification. The pull-threshold model developed within this paper assumed that improvement will only occur for fisheries or farms which are below the threshold, but within a sufficient range of the threshold through which improvement can be made. This sufficient range is termed the 'pull' of the certification and depended on a variety of factors including the pre-certification distribution of scores, the variation in this distribution, and probability that a score can be improved. Thus, maximizing the threshold pull and enticing producers to improve beyond the threshold are critical parameters to maximize the effectiveness of a certification programme. While the pull here was modelled as the σ of the distribution, there are numerous factors that could influence the true value of the pull. Market-based initiatives including getting retailers to require certification is on means to increase the pull. Other more direct means include developing educational programmes that will aid lower performing farmers to develop the ability to improve their production methods, thus decreasing environmental impacts, and ultimately to be certified. Programmes such as Aquaculture without Frontiers (www.aquaculturewithoutfrontiers.org) that work in developing countries to provide technical and managerial aquaculture experience is a method by which education can be used to increase the pull of a certification programme. Within the GAA's 'Best Aquaculture Practices' standards programme, the Aquaculture Certification Council utilizes education to assist the 'aquaculture public regarding the benefits of applying Best Aquaculture Practices and the advancing scientific technology that directs them' (http://www.aquaculturecertification.org). An integrated education programme will enable a certification programme to increase the range of its certification pull and to have a greater impact.

The pull-threshold model was tested for both compliance and continuous data. Compliance data is common among certifications, as they often establish if farms and fisheries conform to specific requirements. The distributions examined within this paper are on par for known distributions of metrics within the seafood production industry. For example, Thailand shrimp farms comply with approximately 50% of the GlobalGap certification criteria in the Aquaculture Base Module (Leepaisomboon *et al.* 2007). In a slightly different analysis, WWF Switzerland and Norway (2007) scored GlobalGap at 54.75 compliant. For the first 20 MSC-certified fisheries, the average score for principle 2 was 85 with $\sigma = 9$ as scored by two main certifiers (Ward 2008b). This average is expected to be greater than scores of all programmes because the MSC data (Ward 2008b) are of certified fisheries and thus represent programmes that have superseded a threshold. However, both the average and variation in the distributions assessed for the model appear to be within range of distributions of metrics within the seafood production sector.

Overall, a single threshold model of compliance data resulted in a maximum improvement of 12.9% (for $T = 80$). The location of a threshold for a single certification programme depends in part on the pre-certification distribution of values. For a normally distributed compliance metric, $T = 80$ results in larger gains through certification than lower thresholds. When there is a negative-skewed distribution, $T = 50$ will result in the greatest gain. For metric-based data, an intermediate threshold results in the greatest per cent improvement, while a low threshold results in the greatest improvement on the water as measured as a direct impact and not the per cent impact.

However, the difference between the gains of changing threshold levels pale in comparison with the gains made through increases in the number of thresholds.

Multiple thresholds are the means to enact the largest amount of change through certification, because they broaden the extent of the pull (the pull increases as the number of thresholds increases). For compliance data, the 12.9% improvement of a single threshold increased to 22.5 and 27.1% for double and triple threshold models. However, this is not to say that a plethora of thresholds is the best means to enact maximal improvement through certification. The first consideration is that there are a specific number of thresholds for each distribution that will prevent an overlap of standards. To determine the maximal number of non-overlapping thresholds, the number of thresholds can be calculated as the range of the metric values divided by the pull. Thus, if the range of a metric can be between 0 and 100, and the pull is 50, there could be two thresholds (100, 50). Decreasing the pull to 25 could increase the number of thresholds to four (100, 75, 50, 25). There needs to be a balance between the number of thresholds and market saturation. While additional thresholds will result in increased improvement, the additional thresholds will return a smaller benefit in terms of environmental improvement because their effective pull will be smaller. While there is a mathematical determination of the potential number of thresholds, there are a variety of market-based forces at work that will likely limit the number of thresholds prior to any numerical limitation. The critical factor at play to determine the number of thresholds is the consumer's ability to discern between the thresholds (Roheim 2008). It will be irresponsible to set up a graded system with five thresholds if the consumer can only discern two. This differs between commodities, as examples from other food products shows variety in the number of levels of certification or grading that appear in the marketplace. National Organic Standards (NOS) provide three levels of demarcation (www.ams.usda.gov/AMSv1.0/nop, accessed 24 April 2009), while United States Department of Agriculture (USDA) quality grading for terrestrial animal proteins provide six grades for beef, three for chicken, while pork is not quality graded (ag.ansc.purdue.edu/meat_quality/ext_ed_meat_grading.html, accessed 24 April 2009). It is unknown as to how many levels of quality or certification would be ideal to implement for seafood.

Multiple thresholds can be implemented in two ways; through the creation of multiple tiers within a single programme (e.g. USDA, NOS, or Leadership in Energy & Environmental Design certification), or through a differentiation of multiple independent standards. Within the basis of the model presented here, three different programmes could cooperatively coexist if they had distinct thresholds (20/50/80) and were clear to distinguish these targets as being instrumental to the definition of programme success. Within the global seafood industry, there are a multitude of certification schemes. Lee (2008) cites 21 programmes, while the WWF benchmarking study (WWF Switzerland and Norway, 2007) evaluated 17. These programmes are widely divergent and may have a focus on organic production, environmental attributes, social aspects, animal welfare, and standard development and verification (WWF Switzerland and Norway, 2007). Furthermore, they have different geographical scopes, where some programmes are global, while others are national. Thus, even though there are a substantial number of certification programmes, only a handful may be competing directly in the same market. Overall, it is fair to assume that a route to multiple thresholds given the current state of seafood certification programmes, and the fact that no programme has yet to incorporate a tiered approach, would be to engage different programmes to work synergistically as opposed to having a single programme develop multiple levels. But for this course to be effectively navigated, it is important to avoid the principle of minimum differentiation in which two products become similar and centre on a common value (Hotelling 1929) even if they are of heterogeneous quality (de Palma *et al.* 1985). Therefore, it is critical for certification programmes to *a priori* state their thresholds to prevent undue similarity and overlap between the synergistic programmes. Moving ahead, certification programmes should (i) identify pre-certification effects and set a threshold appropriately; (ii) identify programmes with similar scope in geography and species, and work in consort, maintaining threshold separation; (iii) work to increase the pull of the certification so that all regions of the impact curve are equally covered; and (iv) evaluate progress to assure the certification makes a difference.

A need of any certification programme is to be able to identify those farms or fisheries that meet the criteria. If a threshold is set at 80 or even 90%, what will encourage those passing the grade to continue to improve? Any certification programme setting a bar at 100% would not be able to certify product and could not function. Thus, to encourage continual improvement, one option is that a seafood advisory programme assesses sustainability as a trajectory (Costa-Pierce 2010) with the end point being a threshold of 100% compliance or zero environmental impact (Tausig *et al.* 2008). Rather than certification, this would be guidance for driving the industry towards an ideal end goal, and not to demarcate a stage along the journey of continual improvement. The other means to continue moving the industry towards minimal impacts is through innovation. One of the challenges of a global industry is that while effective competition depends on low-cost inputs, environmental progress demands innovation to raise resource productivity (Warhurst 2005), and in the case of certification, to continue improvement beyond any threshold (Fig. 4).

For seafood production, innovation, particularly around feed issues, is tied to questions of economic efficiency (Duarte *et al.*, 2009). The question which then needs to be addressed is how certification will interact with innovation. If certification programmes are overly prescriptive in the practices that need to be implemented, innovation to solve environmental problems may be constrained. Innovation may also be constrained when the environmental benefit carries an economic cost. Yet innovation is critical, as it has been identified as a force for shifting the entire curve of environmental impacts to a lower state (Fig. 4). Practically, inno-

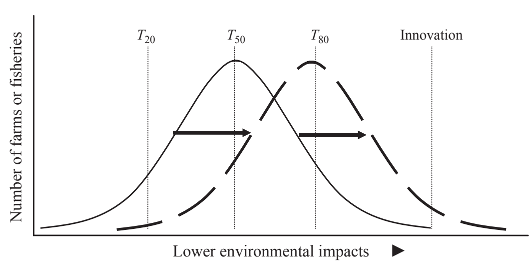

Figure 4 A proposed system to completely translocate a fishery or aquaculture compliance impact curve towards lower environmental impacts. Multiple thresholds pull a majority of the curve, while innovation improves those production units that are beyond the greatest threshold.

vation in the aquaculture industry in the absence of certification was amply demonstrated by the salmon-farming industry during the last two decades. During this time, salmon became a commodity, export prices declined, and to keep profitable, farms had to decrease their operational costs (Guttormsen 2002). The most important method to control on farm costs was to control feed costs specifically eliminating feed wastage (Talbot *et al.* 1999). A variety of innovations were made with respect to feeding with examples including the implementation of feed tables or charts, and underwater cameras (Lien 2007). The goal of these and other innovation was to control feed costs, and the result was that the feed conversion ratios (FCRs, dry feed to wet fish weight) decreased from above 3 to 1.3 (Naylor *et al.* 2009) or 1.1 (Guttormsen 2002) during this period. The outcome of this decreased FCR was that less feed reached and impacted the sea-bed. The long-term forecast for salmon FCRs is 1.3 (Tacon and Metian 2008), indicating that for salmon, FCR may be approaching the minimum limit, and thus returns have diminished (Volpe 2001) to the point where little additional advancement can be made. Feed use efficiency was not the only improvement to occur in the aquaculture industry prior to certification (Tidwell and Allan 2001), and thus innovation has the potential to generate environmental improvements for many aspects of both aquaculture and fisheries. Within the data examined here, escapes from Norwegian salmon farms have decreased by nearly an order of magnitude within 3 years.

In the context of the model presented here, innovation is likely to drive shifts to producers having the lowest impact, while the pull of certification will work to continually improve the industry between the periods of innovation. Certification will be important for moving the lower tiers of the impact curve. However, following a period of significant innovation, those certification programmes reliant on high thresholds will need to be reviewed in relation to that innovation, and thus the notion of best will quickly change, requiring an update of the certification programme (Lien 2007). There will likely be a limit to improvement and innovation within a species, and thus as modelled within, $\{i\}$ will decrease as the metric reaches the limit (Volpe 2001). The concern is that if innovation is closely tied to economic inefficiencies, then progress will decrease as innovation becomes less profitable. Certification may be necessary to drive environmental gains in the absence of economic benefits associated with production efficiency particularly if producers were paid a premium for being certified (and thus environmental and economic gains still remained coupled).

Summary

Aquaculture is currently growing in importance and will continue to do so as global protein needs increase (Naylor *et al.* 2009), yet it is still in its infancy (Tidwell and Allan 2001). Because it has much growing left to do, there are still a number of environmental improvements that can be made. On the other hand, commercial fishing has a long history, and even now is being called upon to improve. Improvement is possible, as has been demonstrated by the South African hake fishery which through the use of tori lines has reduced seabird mortality from 18 000 to 200 per year (Agnew *et al.* 2006). These improvements will continue to be made because of the inherent link between environmental benefits and economic gains (Tidwell and Allan 2001) and will occur through both innovation and the increased role of certification programmes that drive market and consumer interest in more environmentally sustainable seafood (Roheim 2008). However, to assure that certification programmes are indeed making a difference, more care needs to be exercised to collect information and data in a manner that allow for improvements to be tracked. The most critical information required includes the knowledge of the pre-certification distribution of the metrics being assessed. This will allow for an estimation of σ and will allow for more and more accurate determination of T. Enlarging the pull (p) and encouraging producers to exceed T are means to derive the most improvement. Finally, it needs to be understood how the probability of improvement changes as metrics reach their final goal. The larger the decrease in the probability of improvement when close to the metric limit, the more difficult it will be to increase the environmental performance of fisheries and aquaculture.

Overall, certification programmes that operate individually are not a panacea to decrease the environmental impact of seafood. They will have a limited scope and will target only a small proportion of the producers. In the case of compliance data, single programmes will result in little overall improvement. Certification programmes focused on continuous, metric-based data have the potential for greater improvements, provided the threshold is appropriately placed. In the end, single certification programmes will be a marginal solution, and the most promise for improvement will come through a combination of certification programme(s) with multiple thresholds and innovation. Relying on improvement through a single threshold programme will limit improvement to a fraction of what could be achieved.

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