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Insurance mechanisms to mediate economic risks in marine fisheries

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Uncertainty affects the behaviour of fishers and fisheries regulators in a way that can adversely affect the sustainability of fish stocks, fisheries income, and productivity. In agriculture, there has been a long history of using levy funds and public and private insurance schemes to mediate economic risks to growers resulting from environmental variability and quarantine risks. In the United States, the federal government continues to underwrite funds (collected by contracted private agents) that are used to protect contributors from the effects of extreme weather and pest and disease losses. In Europe, there are examples of industry-based mutual funds to mediate risks from exotic agricultural diseases. In agriculture, insurance mechanisms have been successful in reducing risk-inducing behaviour by contractual compliance to risk-reducing codes of practice. For fisheries, insurance may provide a tool to address some elements of uncertainty in a way that would help both the fishing industry and the regulators achieve objectives of sustainability, income security, and productivity. This paper presents a brief review of insurance in agriculture and capture fisheries and uses a stochastic model to illustrate how insurance funds could protect revenue and encourage increased sustainability of fisheries and improve compliance with and enforcement of fisheries regulation. Although insurance may be a partial solution to unsatisfactory fisheries management and fishing performance, some potential challenges to this novel approach are also discussed.

Keywords: capture fishery, feedback dynamics, fisher behaviour, harvest, indemnity, insurance, price, regulation, revenue, risk, sustainability, uncertainty.

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Introduction

Individual fishers can react to inherent risks in ways that increase their own future risks and jeopardize the sustainability of fish stocks. Faced with declining catches, fishers may react in several ways that affect the uncertainties in fish stocks and revenues. They may continue to fish at the regulated effort level, leave the industry, or they might increase catchability and/or effort, thereby overexploiting resources in the short term. Risk can be reduced through structural design measures that move fishery management to become more robust to the uncertainty that pervades fishery systems through, for example, adaptive management that reduces uncertainty by learning about the fishery system over time (Charles, 2007). Here, we ask if insurance can provide such a tool by providing more resilience to uncertainty in a way that would help fishers and regulators achieve shared objectives of sustainability, income, and productivity. However, the nature of fisheries risk, ranging from incipient to acute unsustainability (Cunningham and Maguire, 2002), may determine the forms of insurance that are appropriate and the constraints on any potential benefits from insurance.

Insurance mechanisms have been used to mitigate financial risks presented by environmental and biosecurity uncertainties in agriculture [USDA Risk Management Agency (RMA; www.rma.usda.gov), *Kartoffelafgiftsfonden* in Denmark (www.kartoffelafgiftsfonden.dk), *Potatopol* in Holland (www.potatopol.nl)]. However, the sources of uncertainty that can adversely affect fisheries are diverse and often more difficult to define and predict than in agriculture (Hermann *et al.*, 2004) and, because fisheries are often a shared resource, individuals lacking property rights have an incentive to exploit the resource unsustainably. It is more difficult to define and enforce property rights for fisheries than it is for agriculture; for example, fish stocks are often exploited by several nations and fleets, whereas agricultural property generally comes under a single national jurisdiction. In cases where property rights for fisheries have been established through individual transferable quotas (ITQs; Iceland, New Zealand, Australia, USA), the risk of stock collapse has been reduced (Costello *et al.*, 2008); insurance could complement such a property right system and help reduce various risks further.

The factors that affect agricultural outputs are often evident (weather, pest and disease outbreaks, etc.), whereas the question of what caused a decline in fisheries is usually impossible to answer with the same degree of confidence. Risks in agriculture are often heterogeneous over large areas, whereas fisheries risks may apply to the whole stock. Insurance that covers many farmers planting a particular crop can expect to pay out to only a few farmers in any year, because most events covered by agricultural insurance are location-specific and can be expected to affect only a small proportion of the crop at the same time. The difference from insuring a single fish stock is that it is much more likely that many fishers would need to be compensated by the insurance simultaneously, because the success of each depends on the state of the entire stock and is not as area-specific as for individual farms. Many fish stocks are cyclical owing to broad climatic and ecological factors, whereas others exhibit variability attributable to fluctuations in recruitment success, mortality, and migration. Continued overexploitation of fish stocks can itself lead to greater variability in stock dynamics (Beddington and May, 1977). Risk is also introduced from socio-economic and political spheres via interactions in prices, costs, labour availability, and regulation (Hermann *et al*., 2004).

The fishing industry has repeatedly pointed to difficulties in adjusting to large fluctuations in total allowable catch (TAC) between years, whereas a lack of flexibility in TACs could threaten the sustainability of fishery resources unless TACs were set conservatively (Kell *et al*., 2005). Currently under the European Common Fisheries Policy (CFP), management plans for many stocks specify interannual bounds on TACs. An alternative, or complementary, approach might be to reduce the variation in revenues by insurance, rather than managing TACs directly. For instance, an insurance contract can specify effort and catch restrictions for each fisher, so the variability in catch will be reduced compared with a management system that relies on TAC alone.

Governments worldwide are heavily involved in regulating fisheries, yet few of these fisheries can be described as being both ecologically and economically sustainable. The CFP of the European Union has a reputation for management that has been criticized for lack of sustainability (House of Lords, 2008). Insurance has proved a useful tool in mitigating risks and promoting sustainability in agriculture. Here, we provide a brief overview of agricultural insurance mechanisms, review the literature on fisheries insurance, and illustrate, with a simple herring-like stock example, the potential of simulation models to aid discussion of applicability of insurance in capture fisheries.

Review of specific agricultural insurance mechanisms

In agriculture, there are a number of examples of insurance being used to mitigate financial risks for farmers and to promote sustainability. The insurance mechanisms described are not intended as instantly transferrable options in capture fisheries, but are used to illustrate how insurance in certain situations altered the governance and restructured responsibilities with respect to agricultural risk.

The RMA (www.rma.usda.gov) of the US Department of Agriculture (USDA) provides insurance cover for more than $67 billion of agricultural risk annually in the United States (up 60% since 2003), with more than a million voluntary subscribers growing >100 insured commodities. The programme offers a range of policy options to subscribers, who can insure against variation in price, yield or revenue, at a range of thresholds, about either their own or local county average values over recent years. The indemnity (compensatory payment) is underwritten by the USDA and administered through a network of private insurance agents contracted to the RMA. The programme has operated in a steadily evolving form since 1938. It constitutes a significant subsidy to American agriculture, but requires as a condition of insurance that good agricultural practice be followed by farmers and requires that the regulator obtains statistical information on risks and effectively manages behaviour to achieve environmental quality and social goals. These are important issues for fisheries, for which it would be inadvisable to have a subsidy that simply supported overcapacity that resulted in overexploitation of fish stocks. Two particular difficulties arise: (i) what is a capture fishery's equivalent to "good agricultural practice", and (ii) are actuarial data obtainable?

In a more specific case in the Netherlands, an industry-based agricultural insurance scheme has been used to mitigate financial risk caused by occasional outbreaks of two exotic potato diseases, potato brown rot and potato ring rot. For 2 years in the mid-1990s, the Dutch government provided compensation for outbreaks of these diseases, but would not continue to provide support after the second year of high outbreaks. Potato growers initiated an insurance scheme called *Potatopol* in 1997 (http://www.potatopol.nl/; described in Waage *et al*., 2007). *Potatopol* is an incorporated non-profit entity operated by potato growers with a small professional management staff. Government assisted the scheme with an initial grant of €250 000 to help establish the programme. Growers pay an annual premium based on individual criteria. Part of the contractual agreement is that if, in a bad year, there is particularly heavy demand on the fund, then subscribers may be obliged to make an additional payment into it, with a fixed maximum. If there is a particularly bad year and the fund, despite emergency premiums from subscribers, is still unable to cover the necessary outlay, then *Potatopol* makes use of commercial reinsurance to ensure that all insured risks are covered. Commercial reinsurance premiums are paid out of the annual subscriptions. The fund is capped at a predetermined level, commensurate with likely risk, and any excess funds remaining at the end of the year are returned *pro rata* to the subscribers. Certain risk-reducing activities are stipulated in the contract, and the insurance scheme has mainly benefited the industry by providing a significant incentive to risk-reducing behaviour by growers, a benefit we address in relation to fisheries risk management later. It has also encouraged the Dutch government to continue to support research and regulation, all of which has contributed to a dramatic fall in potato disease outbreaks and helped make the capped insurance scheme viable.

By way of explanation, the concept of reinsurance is an extension of the concept of insurance, in that it passes on part of the risk for which the original insurer is liable. Reinsurance contracts are more specialist than general insurance contracts, but for the most part they work in exactly the same way, except that the insured is another insurer, known as the reinsured (www.lloyds.com). Lloyd's cite four reasons for the importance of reinsurance:

(i) *To protect against large claims*. For example, for a fire in a large oil refinery, a large city hit by an earthquake or the catastrophic collapse of an important fish stock, insurers would spread the risk by reinsuring part of what they have agreed to insure with other reinsurers, so that the loss is not so severe for any one insurer.

(ii) *To avoid undue fluctuations in underwriting results*. Insurers want to ensure a balanced set of results each year without peaks and troughs. They can therefore obtain reinsurance that will cover them against any unusually large losses. This maintains a cap on the claims to which the insurer is exposed.

(iii) *To obtain an international spread of risk*. This is important when a country is vulnerable to natural disasters and an insurer is heavily committed in that country. Insurance may be reinsured to spread the risk outside the country.

(iv) *To increase the capacity of the direct insurer*. Sometimes insurers want to insure a risk but are not able to do so alone because they do not have enough capital to cover the whole risk. By using reinsurance, the insurer is able to accept the risk by insuring the whole risk and then reinsuring the part it cannot keep for itself with reinsurers.

In Denmark, potato growers are supported through a fund (*Kartoffelafgiftsfonden*, www.kartoffelafgiftsfonden.dk; described in Waage *et al*., 2007) set up by the Danish Potato Council (*Specialudvalget for Kartofler*). The fund is administered jointly by farmers, the Potato Council and Government. Growers pay a compulsory levy based on their individual outputs. The fund raises some €540 000 a year on approximately a million tonnes of production. Compensation from the fund is set at 60% of costs faced by a grower through an outbreak, but only covers costs, revenues, and destruction costs, but not replacement seed, borne in the initial year (as in the Netherlands *Potatopol* programme). By 2004, a group of private insurance companies offered additional insurance to potato growers to cover the proportion of the loss from 60% up to 90% of the first-year costs, and including the costs for buying new seed in the following year. The insurance costs €20 per hectare of potatoes, and 10% of potato farmers have taken out the insurance. The potato compensation fund does not carry over unspent funds, but, unlike *Potatopol*, surpluses are invested in potato research carried out by public and private institutions competing for the funds. So far, the fund has not been depleted by claims in any year.

Given the similarity of privately owned aquaculture to agriculture, we should expect that insurance schemes would be applied to aquaculture before they are extended to wild capture fisheries and, indeed, insurance in aquaculture is already widespread (Hotta, 1999).

Review of the literature on applying insurance to wild fisheries

Many capture-fishing risks have been, and continue to be, covered by insurance, including vessel, gear, and crew safety policies. However, the application of insurance to catch, price, or revenue variation is more problematic, because there has been less actuarial information on which to base risk assessments related to production variables in wild fisheries, which explains the scarcity of examples in the literature. Such problems arise from the cryptic nature of fish stocks and the difficulty in attributing causes to losses on an actuarial basis. The harvests of several specific marine fisheries are already covered in Japan by a government-backed Mutual Insurance Scheme, in which the aim is to maintain a viable industry to secure production capacity (Fisheries Agency, 2005). The scheme enables fishers to share risks, shielding individual fishers from ruin caused by natural disasters and other uncertainties. However, the distinguishing feature of these fisheries is that the species are, as in aquaculture, geographically well-defined and contained, such as kelp, sedentary shellfish, and algae. The following section summarizes two important published studies concerning the application of insurance to genuinely wild capture, common resource, mobile fisheries; the first is a theoretical application of insurance theory by Ludwig (2002), and the second is a more applied approach in which the USDA considered extending RMA crop-insurance principles to wild sockeye salmon in Bristol Bay, Alaska (Greenberg *et al*., 2001; Hermann *et al*., 2004).

Ludwig (2002) begins with the premise that fisheries management needs to be precautionary and builds on the idea that taxes and charges can be better instruments in achieving risk-averse management of fisheries than direct regulations (such as TAC or effort control), then demonstrates the utility of insurance with some simple models. The insurance regime is mandatory because one of the objectives of an insurance regime, as conceived by Ludwig (2002), is to place an extra burden (rather than bestow a subsidy) on fishers. In this context, the fishers are creating the risks of stock collapse which are borne by the general public, and the compulsory purchase of insurance by fishers would partly shift the burden back onto the generators of risk. Ludwig does not consider designing an insurance scheme according to the needs of fishers, but rather as a tool to internalize the hazard that excessive fishing effort can have on an ecosystem. He claims that a bond or insurance regime can achieve several objectives that are summarized in Table 1.

Ludwig (2002) uses a stochastic surplus production model with three different harvest control rules: constant harvest rate, constant catch, and adjustable harvest rates, based on abundance level to obtain a target catch. He claims that the main difficulties in setting up an insurance regime are political, institutional, and philosophical, and that sound actuarial calculations can be made for fisheries. He does not substantiate this last claim. However, the management strategy evaluation (MSE) approach would allow the equivalent of an actuarial basis, because management is based on modelled populations rather than real population attributes (Kell *et al*., 2007). Therefore, if the response behaviour of fish stocks and fishing effort can be modelled plausibly in the MSE approach, it would form a suitable foundation on which to add insurance as a management component, because the necessary actuarial data could be generated as a component of model output.

Sockeye salmon case study

In 2001, the RMA of the USDA contracted the University of Alaska Fairbanks Agricultural and Forestry Experiment Station to scope a pilot crop-insurance programme for the Bristol Bay commercial salmon fishery (Greenberg *et al*., 2001; Hermann *et al*., 2004). It was the first attempt to extend USDA crop insurance to wild fisheries. The report concluded that until the fishery reached stability, it would be difficult to design and administer an insurance policy that would benefit the industry. As a result, an insurance programme was not set up. However, the initial design phase identified many practical issues regarding guarantees, insurance triggers, and indemnity payouts relevant to the design of potential insurance schemes in other wild fisheries.

The salmon study drew some important differences between risk factors and insurance schemes in agriculture and wild fisheries. The RMA identifies three important components for crop insurance, peril, moral hazard, and adverse selection. In agriculture, peril is defined as unanticipated/unavoidable events that affect some outcome, such as low yields caused by bad weather, fire, and uncontrollable pest-induced losses. In fisheries, the definition of peril needs to be modified because it is difficult, perhaps impossible, to develop a sound actuarial basis to determine the contributory effect of natural events to catches in a given year. For this reason, the authors suggested that peril in wild fisheries should be redefined as an outcome: low catches or low fishery

Table 1. Summary and comments on the insurance paper of Ludwig (2002).

Ludwig's points	Observations
Prevent risky exploitation by increasing the costs through premiums which are proportional to risks, so rendering the most risky activities unprofitable	Insurance may keep fishers in business that otherwise would have been forced to leave
Shift the risk burden from the public to the fishers—the "polluter pays" principle	Punitive insurance premiums, as envisioned by Ludwig (2202), will not necessarily lead to greater social fairness. It is not always possible to determine who within an industry is causing the loss, or how much, so everyone in the industry pays, even if they do not cause loss
A clear link between a harvesting strategy and a premium would alter the behaviour of fishers and make them less likely to cause harm to the stocks and the ecosystem	In theory, modelling approaches such as risk assessments or MSE can be useful in linking the size of premiums to harvesting strategies, but the potential effectiveness of insurance to influence the behaviour of fishers is unknown. The difficulties of monitoring activities at sea could make fisheries insurance less effective than agricultural insurance at lowering risks, through its influence on individual behaviour
The assessment of risk depends on the state of knowledge, so charging for risk would provide financial incentives for industry-sponsored research	Knowledge, particularly the ability to predict future harvest, creates a problem for insurance by enabling fishers to "fish" the insurance by purchasing the cover in anticipation of payouts. On the other hand, there is no guarantee that the knowledge obtained would be useful enough to reduce insurance premiums. A final case, in theory, could be that information would obviate the need for insurance by effectively eliminating risk

ex-vessel revenues rather than identifiable causes. Moral hazard is defined by the RMA as producers taking an action to maximize their return from the insurance product by wilfully undermining their production of the insured crop. Controlling moral hazard requires good risk insurance design to avoid incentives for harvesters to "fish" the insurance. Good design would likewise ensure that insurers were able to differentiate between legitimate and illegitimate claims and, conversely, prevent insurers from rejecting legitimate claims. A marine fishery equivalent to "best agricultural practice" was not easy to define, which would have made it difficult for loss adjusters to identify causes and weights of contributing factors. For these reasons, individual performance-based guarantees were rejected, and various group-based catch-per-unit-effort triggers were simulated in the salmon-study calculations of modelled insurance payouts. The third RMA component, adverse selection against the insurance provider, occurs when the insured person has better knowledge of the relative risk of a particular situation than does the insurance provider. In fisheries, harvests are dependent on biological phenomena. In the salmon case study, run strength over time may be correlated with previous events and therefore, to some extent, could be predictable. Fishers may be able to predict insurable events in years when poor runs were expected, which would severely compromise an insurance programme. A multiyear obligation to subscribe to insurance was suggested as a solution to prevent fishers taking out insurance only in those years when they were anticipating payouts.

Unlike in crop insurance, the insurable units in fisheries are rarely homogeneous: fishing opportunities do not determine individual performance. For this reason, the report suggested that indemnity payouts should be paid based on average performance histories (APH) of individual fishers within the fleet so that, in poor years, they would be compensated commensurate with their fishing performance in previous years, assuming demonstrably similar effort.

The sockeye salmon fishery in Alaska was suffering from poor prices at the time of the study as a result of other salmon species gaining favour in the Japanese market. As a result, Bristol Bay fishers desired revenue-based triggers so they would be covered for poor catches and/or lower prices. Finally, the report raised a concern that insurance could interfere with the economically and ecologically based need to reduce capacity in the fishery by essentially subsidizing fishers that would otherwise leave either permanently or temporarily.

An illustrative model of fisheries insurance

The success of insurance in agriculture, aquaculture, and certain wild fisheries in Japan makes the issue of wider use of insurance in fisheries worthy of further investigation. Setting up experiments to discover features of a viable insurance scheme, as was attempted in the salmon study, is costly. For a particular fishery, it is cost-efficient to use a simulation approach to analyse the implications of different sources of uncertainty for insurance costs and the effectiveness of a particular insurance scheme to mitigate risks. Here, we construct a simple model to illustrate the potential for model-based investigations of fisheries insurance issues and to provide some graphical representations of how an insurance regime can function in fisheries. Simulation models have been widely used to evaluate alternative management decisions (Kell *et al.*, 2007). Adding an insurance component to such models can provide a measure of risk via the calculation of insurance premiums. The cost of insurance is generally familiar to stakeholders and can be used as a way of measuring the costs of risk mitigation. Therefore, expanding MSE models with insurance features would be an easy-to-communicate method for quantifying the benefits of reducing uncertainty (through either different management actions or improvements to stock assessments).

General insurance modelling methods

A stochastic population dynamics model of a herring-like stock was developed to illustrate how the economic and biological stability of a fishery can be affected by an insurance regime. The model is purely illustrative and makes use of various components from agricultural insurance examples mentioned above to build a notional hybrid insurance mechanism for a capture fishery. It also includes features identified by Greenberg *et al.* (2001) as being necessary for a capture fishery scheme: "peril" is defined as an outcome (low revenue because of low catch and/or price) rather than a specific unavoidable event, the insurance guarantee is based on overall fleet catch or gross revenue rather than individual catch, and indemnity payments are based on individual APH. The model allows us to examine the effects that insurance has on collective fisher revenue risks as well as possible benefits through a reduced stock-collapse risk that would result from insurance-modified fisher behaviour. It also provides a transparent mechanism for calculating premiums to cover risks (to the levels that could be chosen by subscribers) under different scenarios.

The model is not intended to be a meticulous econometric or MSE tool and is deliberately simple in many respects, because its purpose here is to serve as an illustration for the discussion and as a proof of concept. This is why it contains assumptions, such as having perfect knowledge of stock sizes to define maximum sustainable yield (MSY), and lacks harvest control rules that react to the perceived developments in stock dynamics, although such features can be added easily if necessitated by a new set of questions. We assume that regulators aim to manage the fishery according to a MSY objective by controlling effort rather than catch. However, the model allows for implementation uncertainty and for the strategic behaviour of fishers, who may respond to recent declines in revenue with a short-term increase in effort. Harvest rate is a random variable with the mean based on MSY equilibrium. Short-term response is modelled by allowing this random value to increase within set limits for 1 year following a decline in revenue; this seasonal increase is permitted until the decline in revenue is halted. With insurance, the fisher receives a payment when revenue falls below a pre-set trigger. The model assumes that the fisher complies with the contractual obligation not to increase fishing effort unless warranted by a decline in revenue. This is an example of a contractual agreement under an insurance regime, and not an instance of a particular interpretation of socio-economic theory of effort–revenue interaction.

The insurance policies modelled here are based on systems employed in agricultural risk management, such as the USDA RMA. Revenue shortfalls are covered at preselected levels. Indemnity payments are triggered when the revenue falls below the covered proportion of a historical average (e.g. the previous 5 years). The size of an insurance payment depends on an agreed coverage level (CL), and a premium calculated for that level of coverage.

Several fund-creation and management options are available for industry, including: fixed premium, variable fund; variable premium, fixed fund; invest or return surplus in fund, at various intervals; frequency of premium or fund review; liabilities of the fund can be limited to a fixed level or left uncapped; reinsure upper tail of liability or leave unmet. Our example model has been developed for a fixed on/off premium variable fund with capped liabilities (using reinsurance), but any system could be simulated and their impacts evaluated.

The insurance liability is split between an industry-generated mutual fund and private reinsurance. The industry fund covers the higher frequency, lower cost end of the annual payout distribution, whereas commercial reinsurance is used to protect the industry fund from high cost, lower probability events at the upper end. We calculate the size of a premium needed to guarantee that the insurance fund is sufficient to cover losses after the first 10 years of operations in 75% of the simulations. In the illustration, payouts from the mutual fund are capped at the 75th percentile. The excess above the maximum mutual fund payment cap is covered by commercial reinsurance; the premium charged to the fund for reinsurance is calculated separately. During the first 10 years of operation, the mutual fund is allowed to borrow money at 8% interest to cover any payouts beyond the value of the fund. The insurance fund is assumed to earn 5% annual interest when not used to make payments. The model-fund building and liability-capping method is similar to that used in *Potatopol*.

The herring-like population model is stochastic and age-structured, with lognormal process errors in a Beverton–Holt type stock–recruitment relationship. Prices are considered to be elastic with respect to the supply of fish. The MSY equilibrium harvest rate is computed from mean values of parameters (stock–recruitment, maturity, mortality, and weights-at-age) based on the ICES assessment of herring stocks, and this rate is the base harvest level applied throughout the runs of the model. For a full description of the model, see the Appendix.

To illustrate the role of insurance, five scenarios were modelled:

(1) No insurance, no effort increase on falling revenue. Expected fishery performance: noisy but stable mean net revenue;

(2) No insurance, effort increase on falling revenue. Expected fishery performance: noisy and declining mean net revenue;

(3) Insurance, no effort increase on falling revenue. Expected fishery performance: smoothed revenue, lower mean net revenue than Scenario 2 at the beginning, but higher than Scenario 2 at the end of 30 years;

(4) Insurance, effort would increase on falling revenue, but is less likely to occur because revenue is maintained by insurance payouts. Expected fishery performance: smoothed revenue, lower mean net revenue than Scenario 2 at the beginning, but higher than Scenario 2 at the end of 30 years;

(5) Insurance, 1% annual increase in fishing mortality attributable to an increase in catchability, no increase in effort on falling revenue. Expected fishery performance: long-term downturn in stock stability and revenue.

Outputs of the model are used to illustrate various points in the Discussion below.

Discussion

Cunningham and Maguire (2002) observed that: " . . .uncertainty is a major factor of unsustainability, and that its effects increase as the fishery management system becomes more elaborate. In the absence of management, fishers are confronted with uncertainties related to the natural variability of the environment and of that of the markets. Under active management, uncertainties about management decisions, their effects and their implementation are added. Current fishery management approaches have evolved from control theory which may not be appropriate to control unpredictable and complex systems such as fisheries". Charles (2007) argued that structural uncertainty (model, implementation, and institutional) is best dealt with by robust management, e.g. by creating an adaptive portfolio of mutually reinforcing management tools. Insurance could be one tool in that portfolio.

The purpose of a potential capture-fishery insurance scheme varies between industry and regulators. For industry, we have assumed that the focus is principally on revenue (a product of catch and price) set against individual or fleet average records and effort deployed. The primary role of insurance from this perspective would be to use the fund to reduce short-term revenue risks, i.e. to bolster income in years of low catches and/or price (Greenberg *et al.*, 2001, Herman *et al.*, 2004). The variability in costs, which together with revenues determine the profitability of a fishery, would need to be covered by other mechanisms, such as forward contracts on fuel and long-term labour price agreements. Figure 1a illustrates the smoothing of revenue (after allowing for the cost of insurance premiums) that occurs at 80 and 100% CLs; the 100% CL offers greater smoothing of net revenue for a commensurately higher premium.

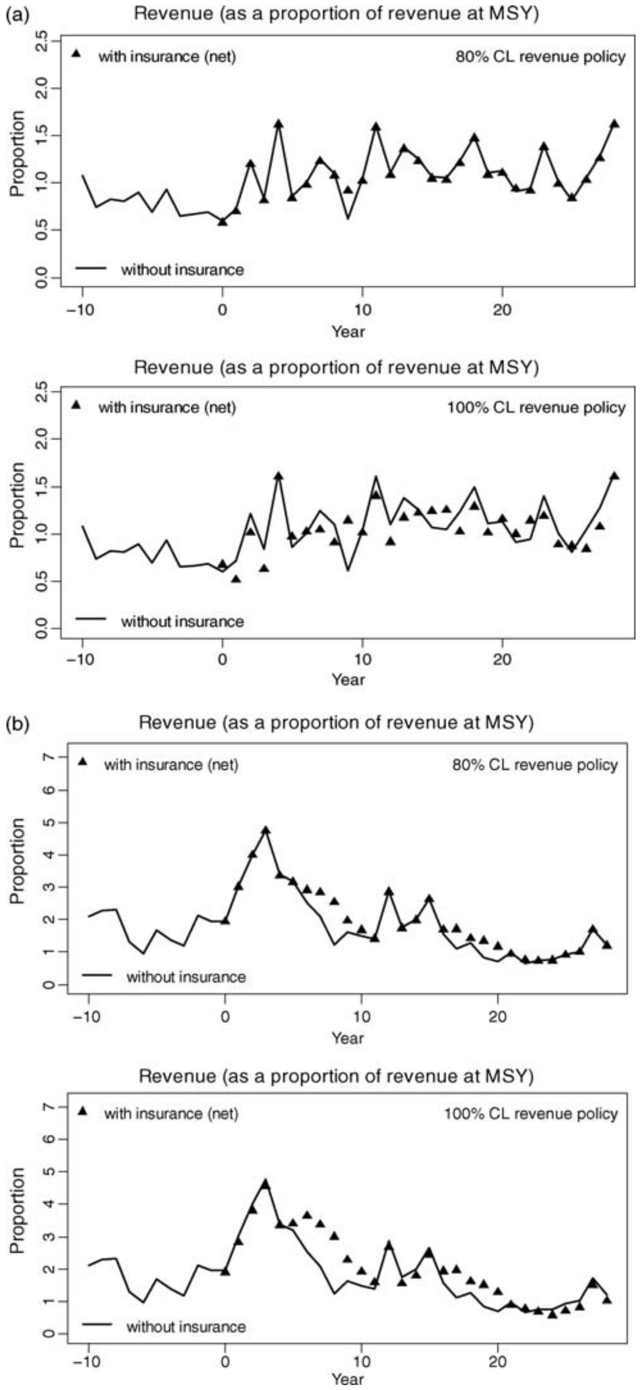

Figure 1. An example of how insurance works in Scenario 3 (insurance, no effort increase on falling revenue) at two revenue CLs, 80 and 100% CL for two trajectories, (a) where insurance mitigates losses during unexpectedly bad year(s) (see year 9), and (b) where insurance provides a soft landing after a period of extraordinary luck (see years 6–11).

A necessary condition for the start of the insurance scheme would be to reduce overcapacity in the fishery at the start of the scheme, or else there would be no incentive for fishers to harvest at a sustainable rate or to pay the start-up costs. Additionally, in the first years of an insurance scheme, start-up costs, required to build an industry-based mutual fund, could be prohibitive. For *Potatopol* in the Netherland, the government assisted by providing a one-off grant towards the fund. To illustrate the effect of initial fund-building requirements, Figure 2 shows median revenue trajectories from 1000 iterations of the model for each of the five scenarios over 30 years. Scenarios 1 (without insurance) and 3 (with insurance) show revenues from fishing to "perfect knowledge", strictly enforced MSY. Note how the insurance start-up costs (to create the mutual fund) in Scenario 3 generate lower net revenues for fishers in the first 10 years than with Scenario 1. This effect is also seen in the with/without insurance comparison of Scenarios 2 and 4.

The industry might be reluctant to bear the full cost of mitigating the risk of revenue fluctuation especially because the costs vary also, so smoothing the variability in revenue does not necessarily translate into smoothing the variability in profits. However, the same problems have been addressed in agricultural insurance, where it is common to insure revenue (outputs) rather than costs (inputs in agriculture include fertilizer, seed, water, and labour). The solution partly lies in the level of government support of insurance. The government interest in supporting insurance schemes is to ensure greater stability of food supply, protecting the producers, and securing a more sustainable use of natural resources by forcing the industry to accept "good practice" contracts in return for lower risks. Enforcing best-practice standards also prevents issues of moral hazard in which growers

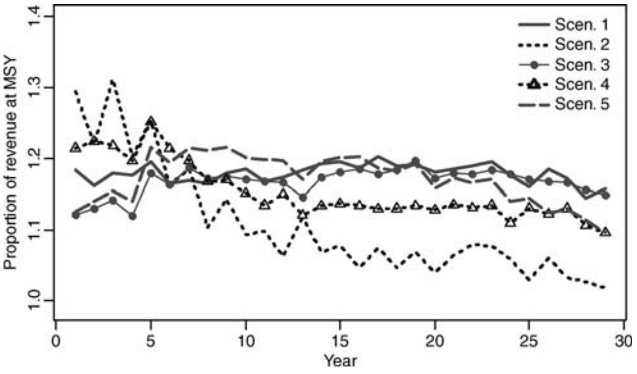

Figure 2. Median revenues for five modelled scenarios: (1) no insurance, no effort increase on falling revenue; (2) no insurance, effort increase on falling revenue; (3) insurance, no effort increase on falling revenue; (4) insurance, effort increase on falling revenue; and (5) insurance, 1% annual increase in fishing mortality (100% CL for Scenarios 3–5; maximum effort increase= 1.7 for Scenarios 2 and 4). The process errors are lognormally distributed so that the median MSY values are slightly higher than the MSY calculated under-deterministic conditions.

could reduce inputs (and hence costs) and demand compensatory payments for lowered yield falsely attributed to insured losses.

The advantages of insurance are inversely proportional to controllability of various uncertainties: the less controllable the system, the greater the need for insurance. To illustrate this, we modelled two scenarios (Scenario 1, without insurance, and Scenario 3, with insurance) where we assume perfect knowledge of expected MSY values and total compliance with management. Differences between Scenarios 1 and 3 are small: insurance in Scenario 3 bolsters revenues in poorer years and smoothes the lows in poor ones, while softening fall in revenue for medium-term downturns (Figure 1). In the two scenarios, there is no linkage between revenue and effort, so the simulated fishers harvest to the regulated MSY level, giving them relatively constant revenues over the 30-year simulation.

In fisheries where TACs are less strictly enforced and there is a tendency for fishers to increase effort in the event of downturns in revenue, the long-term benefit of insurance might be to reduce stock risk by removing the incentive to increase effort after a year in which revenue decreased (illustrated in Figure 2, Scenarios 2 and 4). This anticipates that insurance imposes a contractual obligation not to increase fishing effort in the pay-out year. Note that the initial years for Scenarios 2 and 4 are even more divergent than Scenarios 1 and 3, increasing effort in Scenario 2 resulting in short-term benefits (and serious long-term stock risks), whereas the fund start-up costs of Scenario 4 cause net revenue to drop before stabilizing at a higher level than the non-insurance equivalent (from year 13 on).

Insurance payouts may provide a "soft landing" when there are short, sharp declines in harvest (such as in Figure 1b, years 6–11), giving a few years reprieve from lost revenue and allowing for longer term structural or regulatory adjustment. Where there is a long-term decline in catch, insurance is not likely to be able to help.

As shown by the salmon insurance study (Greenberg *et al.*, 2001; Hermann *et al.*, 2004), the level of insurance is important in determining the extent of the smoothing/cushioning effect on subscriber revenues. However, the salmon insurance studies did not include premium estimates and payments. Consequently, smoothing of revenue (net of premiums) may not be as straightforward as expected; Figures 1a and 1b illustrate the fact that short-term revenue downturns may be cushioned by higher CLs, but at times, choosing higher rate coverage could lead to more variable revenues attributable to irregular premium payments and/or mutual fund dividend returns.

The focus of regulators tends to be towards increasing the sustainability of exploitation and hence production. It is likely that the primary requirement of an insurance instrument would focus on increasing sustainability of production rather than solely protecting revenues. This could be built into a MSE modelling approach to test fisheries management actions. Where fishers were simulated to increase short-term fishing effort to chase falling revenues compared with previous years (Scenarios 2 and 4), the risk of stock collapse increases (Figure 3), and the expected revenues over time decrease (Figure 2). However, insurance triggers compensatory payments in years with falling revenue (set against the insurance cover level), and this reduces the pressure to increase fishing effort, so lessening the ecological risk from overfishing (compare Scenarios 4 and 2 in Figure 3). Scenario 5 simulates "technological creep", a steady improvement in catching efficiency through investment in better technology. In that scenario, the actions of fishers not only maintain income but also increase income through increased short-term catch, and it could be that insurance stimulates investment in fishing technology by reducing risk. If so, then insurance only smoothes revenue in the short term, whereas steady increases in fishing effort cause long-term declines in the stock and hence long-term reductions in revenue. This possibility was also cited as a concern by Greenberg *et al.* (2001) and Hermann *et al.* (2004).

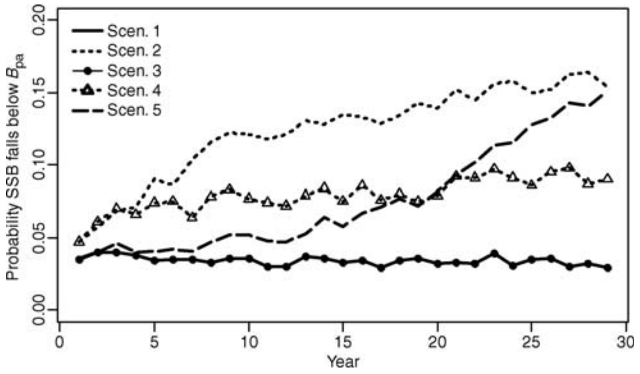

Figure 3. Probability of stock-collapse risk that SSB falls below B_{pa} (precautionary level to maintain a stock) in a particular year under the five scenarios: (1) no insurance, no effort increase on falling revenue; (2) no insurance, effort increase on falling revenue; (3) insurance, no effort increase on falling revenue; (4) insurance, effort increase on falling revenue; and (5) insurance, 1% annual increase in fishing mortality (100% CL in Scenarios 3–5; maximum effort increase=1.7 for Scenarios 2 and 4).

Previous work (Mumford *et al.*, 2008) used a purely reactive approach to insurance payment that acted like the salmon insurance example (Greenberg *et al.*, 2001), in which the sole purpose was to limit the low points of revenue for the fishers. Scenarios 2 and 4, with the implicit concept of contractual compliance not to increase fishing pressure, introduce dynamic feedback between the behaviour of fishers and the stock. There is a potential role for insurance to reduce the insured's risk behaviour, as was seen in the reduction of potato disease outbreaks in the Netherlands after the implementation of *Potatopol*. For example, in Scenario 4, insurance payments reduced the destabilizing effect on stocks caused by short-term increases in effort after revenue declines. This system resembles Ludwig's (2002) proposal and is more prospective than that described in Mumford *et al.* (2008), because it reduces financial risk to fishers each year while satisfying regulators by dampening ecological risks from overfishing in the future.

The size of the payouts, and therefore the premiums, is influenced by all the factors that contribute to the variability in predictions. We can use insurance models to explore how changing the assumptions regarding the variability of model parameters could affect insurance. This is useful because certain sources of uncertainty are ultimately controllable: knowledge can be improved, reducing uncertainty in the estimates of model parameters, and fishing can be controlled to reduce both the level of exploitation and the variability of harvest rates. In the Danish *Kartoffelafgiftfonden*, for example, any unspent insurance fund at the end of each year is invested in research to reduce potato disease risks in the future. This also conforms to Ludwig's (2002) concept of an insurance fund contributing to research. It would be possible to develop a model, similar in essence to our illustrative model (described in the Appendix), to investigate the benefits of reducing the controllable sources of uncertainty measured by the lowered cost of insurance.

We also suggest that insurance, through the creation of an industry-based fund, may help to transform the governance framework. In the agriculture examples, insurance has led to the establishment of more convergent objectives and behaviour among stakeholders (industry, regulators, and consumers) with particular reference to economic and agricultural sustainability. This occurred through:

(i) changes in responsibility (shifting the burden of risk), and increased trust between regulators, industry, and scientists;

(ii) incentives for industry to increase knowledge to reduce uncertainty and hence premiums (interest from an industry insurance fund could pay for research and such industry-funded research might be more trusted by industry, improving compliance with the resulting scientific advice);

(iii) immediate feedback into the system through fisher anticipation of insurance stabilizing revenue, rather than lagged responses by regulators that may be too late to influence dynamic ecological processes.

Currently under the European CFP, the interannual variability in TACs for many stocks is constrained to allow the industry to plan their activities better. This, as Cunningham and Maguire (2002) point out, requires a level of control that may not be appropriate for unpredictable and complex systems such as fisheries; instead, insurance might provide a robust way of achieving a similar result without the need for such strict control.

The CFP is also a potential setting for a Europe-wide insurance regime. If all stocks were insured in Europe, then at least in the future where structural reforms have taken place and fleet overcapacity is eliminated, a universal insurance scheme could be justified. It might make sense to set up a single-crop insurance scheme in agriculture, with discrete homogenous units, but insuring a single fish species may not work where fishers catch more than one species. Moreover, it could be expensive, because in a single-species fishery, risks cannot be spread except over time. The conditions needed for the introduction of insurance should be determined, such as the impact of an insurance system on levels of stock health, using the MSE framework.

The ability to switch between species (Nagasaki and Chikuni, 1989; Matsuda and Katsukawa, 2002) in multispecies fisheries may itself act as a form of insurance, in the sense of a risk mitigation measure, against uncertainty in stock abundance. However, under the CFP, for example, regulations such as relative stability (where catch quotas are set on historical rights) limit the ability of fishers to switch between stocks and would consequently prevent fishers switching from depleted to abundant stocks.

The use of an insurance model to calculate annual premiums also provides a transparent logical method of converting risk into a convenient (monetized) metric. Using the principles of an insurance approach to uncertainty (and not necessarily an actual insurance scheme), it is possible to place a value on the various components of uncertainty that arise from lack of accuracy or other causes of non-credibility. This could be done for the various sources of uncertainty item by item and in combination, to estimate the added value of reducing each component of uncertainty. The values from various case studies could be tested with stakeholders to see if they accept the relative values of any component (and overall) improvement. It may also be a way of introducing a value for mutual trust among stakeholders (showing them what it costs to disagree). For actual insurance, the agreement to subscribe and adopt accepted practices can add to trust, because subscribers are paying premiums and signing contracts and can suffer a penalty for not behaving as prescribed.

The Economist newspaper recently (20 September 2008) headlined that “Scientists find proof that privatising fishing stocks can avert disaster”, based on the paper of Costello *et al.* (2008) on ITQs. Such “privatized” stocks are more likely to have appropriate levels of control and stakeholder commitment that would favour insurance than other fisheries. Models that incorporate uncertainty explicitly will add further opportunities to explore the potential for insurance.

Conclusions

There is a role for economic mechanisms that help to address the many issues of uncertainty that affect adverse behavioural responses by fishers and short-term regulatory changes. Agriculture has provided some examples of how crop insurance against certain perils has reduced risk through changing the adverse behaviour and reducing controllable uncertainty through research, development, and dissemination of good practice. Insurance can provide some mitigation against these uncertainties, and along with other measures that give a long-term stake in the fishery, might result in significant improvements in insured fisheries compared with uninsured fisheries.

There are, of course, limits to the role of insurance:

(i) concern that insurance could interfere with efforts to reduce capacity in the fishery by essentially subsidizing fishers who would otherwise leave either permanently or temporarily (Greenberg *et al.*, 2001);

(ii) financial incentives may mean that insurance payouts do not reduce fishing effort (as in our Scenario 5, with increasing technological capacity in harvesting), so enforcement by government and/or industry bodies would still be required.

A major obstacle to any insurance programme is overcapacity in most capture fisheries (FAO, 2005). Once this is resolved and the industry faces more normal risks, then insurance may offer real benefits to transforming the governance framework. Further research and more detailed modelling approaches may offer greater insights into how insurance mechanisms could be implemented, and identify fishing levels in which insurance presents a tool for increasing stability in stocks and sustainability of exploitation.

Acknowledgements

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References

Beddington, J. R., and May, R. M. 1977. Harvesting natural populations in a randomly fluctuating environment. Science, 197: 463–465.

Charles, A. T. 2007. Adaptive co-management for resilient resource systems: some ingredients and the implications of their absence. *In* Adaptive Co-Management, pp. 83–104. Ed. by D. Armitage, F. Berkes, and N. Doubleday. University of British Columbia Press, Vancouver. 344 pp.

Costello, C., Gaines, S. D., and Lynham, J. 2008. Can catch shares prevent fisheries collapse? Science, 321: 1678–1681.

Cunningham, S., and Maguire, J. 2002. Factors of unsustainability in fisheries. *In* Report and Documentation of the International Workshop on Factors of Contributing to Unsustainability and Overexploitation in Fisheries, Bangkok, Thailand, 4–8 February 2002, pp. 53–90. Ed. by D. Gréboval. FAO Fisheries Report, 672. 173 pp.

FAO. 2005. Topics Fact Sheets. Fishing capacity. Text by Rebecca Metzner. *In* FAO Fisheries and Aquaculture Department [online]. FAO, Rome, Updated 27 May 2005 [cited 30 January 2009]. http://www.fao.org/fishery/topic/2898/en.

Fisheries Agency. 2005. Trends in fisheries, fisheries measures for FY 2006. Outline Report by Trend Analysis Section, Policy Planning Division, Fisheries Policy Planning Department, Fisheries Agency, Ministry of Agriculture, Forestry and Fisheries, Japan. 51 pp.

Greenberg, J., Herrmann, M., Geier, H., and Hamel, C. 2001. Wild salmon risk management in Bristol Bay. Draft Final Report to the Risk Management Agency of the US Department of Agriculture. 326 pp.

Hermann, M., Greenberg, J., Hamel, C., and Geier, H. 2004. Extending federal crop insurance programs to commercial fisheries: the case of Bristol Bay, Alaska, sockeye salmon. North American Journal of Fisheries Management, 24: 352–366.

Hotta, M. 1999. Fisheries insurance programmes in Asia: experiences, practices and principles. FAO Fisheries Circular, 948. 54 pp.

House of Lords. 2008. The Progress of the Common Fisheries Policy. 21st Report of Session 2007–08, House of Lords European Union Committee, 1. The Stationery Office Limited, London. 81 pp.

Kell, L. T., Mosqueira, I., Grosjean, P., Fromentin, J-M., Garcia, D., Hillary, R., Jardim, E., *et al.* 2007. FLR: an open-source framework for the evaluation and development of management strategies. ICES Journal of Marine Science, 64: 640–646.

Kell, L. T., Pastoors, M. A., Scott, R. D., Smith, M., Van Beek, F., O'Brien, C. M., and Pilling, G. M. 2005. Evaluation of multiple management objectives for Northeast Atlantic flatfish stocks: sustainability vs. stability of yield. ICES Journal of Marine Science, 62: 1104–1117.

Ludwig, D. 2002. A quantitative precautionary approach. Bulletin of Marine Science, 70: 485–497.

Matsuda, H., and Katsukawa, T. 2002. Fisheries management based on ecosystem dynamics and feedback control. Fisheries Oceanography, 11: 366–370.

Mumford, J. D., Leach, A. W., Levontin, P., and Kell, L. T. 2008. The potential for insurance to mediate economic risks in marine fisheries. *In* Proceedings of the 14th Biennial Conference of the International Institute of Fisheries Economics and Trade, 22–25 July 2008, Nha Trang, Vietnam. Achieving a Sustainable Future: Managing Aquaculture, Fishing, Trade and Development. Ed. by A. L. Shriver. International Institute of Fisheries Economics and Trade, Corvallis, OR, USA. ISBN 0-9763432-5-8

Nagasaki, F., and Chikuni, S. 1989. Management of multispecies resources and multi-gear fisheries. FAO Fisheries Technical Paper, T305. 68 pp.

Waage, J. K., Mumford, J. D., Leach, A. W., Knight, J. D., and Quinlan, M. M. 2007. Responsibility and cost sharing options for quarantine plant health. Report to the Department for Environment, Food and Rural Affairs, London. Centre for Environmental Policy, Imperial College London, Ascot, UK. 126 pp. http://www.defra.gov.uk/planth/costsharing/costsharing.pdf.

Appendix

Population model description

The model is implemented in R, using three-dimensional arrays storing numbers of herring in billions by age (a), year (y), and simulation (s). Before starting the insurance regime, we assume that the stock has been exploited at a sustainable MSY level for 100 years to establish a historical record of population trends. The harvest is assumed to take place at the beginning of the year, and spawning in the middle of the year; age at recruitment is taken to be 1:

$$C_{a,y,s} = N_{a,y,s} H_{a,y,s}, \tag{A1}$$

where C denotes the catch (in billions of fish), N the number of herring (in billions of fish), and H the harvest rate.

Yield (Y) is given in millions of tonnes:

$$Y_{y,s} = \sum_a C_{a,y,s} W_{a,y,s}, \tag{A2}$$

where W is the weight (kg) of individual fish at age.

$$N_{a+\Delta t,y+\Delta t,s} = (N_{a,y,s} - C_{a,y,s}) \exp(-M_{a,y,s}\Delta t), \tag{A3}$$

where Δt is equal to half a year and M the instantaneous rate of natural mortality.

The spawning-stock biomass (in millions of tonnes) is denoted by SSB:

$$\mathrm{SSB}_{y,s} = \sum_a \left(N_{a+\Delta t,y+\Delta t,s} \mathrm{Mat}_{a,y,s} W_{a,y,s}\right), \tag{A4}$$

where Mat denotes the proportion of sexually mature herring by age, and

$$N_{1,y+1,s} = \frac{\alpha_s \mathrm{SSB}_{y,s}}{\beta_s + \mathrm{SSB}_{y,s}} \varepsilon_{y,s}, \tag{A5}$$

is a stochastic stock–recruitment relationship that gives the number of age-1 herring for the following year, where α and β are Beverton–Holt recruitment-function parameters, and ϵ is a lognormally distributed process error with specified precision (Figure A1). The population dynamics of herring (and fish in general) are driven largely by the variability in recruitment success from year to year. The parameters of the stock–recruitment function are based on the estimates of the recruitment relationship for Norwegian spring-spawning herring (*Clupea harengus*); the recruitment time-series for Norwegian spring-spawning herring for the past 57 years is shown in Figure A1, along with a random modelled trajectory for a herring-like stock over a sample period of the same length.

For the older-than-recruitment-age groups, the transition from year to year is modelled by

$$N_{a+1,y+1,s} = N_{a+\Delta t,y+\Delta t,s} \exp(-M_{a,y,s}\Delta t). \tag{A6}$$

For insurance calculations, we use the average price per kilogramme of catch ($P_{y,s}$), rather than an age-specific price, $P_{a,y,s}$:

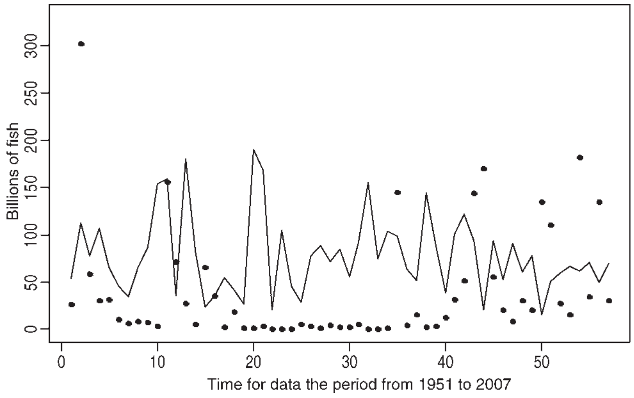

Figure A1. Random recruitment trajectory (line) alongside the estimated recruitment time-series for the Norwegian spring-spawning herring stock for 1951–2007 (points).

$$P_{y,s} = \frac{\sum_{a} P_{a,y,s} C_{a,y,s} W_{a,y,s}}{Y_{y,s}}. \tag{A7}$$

To illustrate the functioning of the insurance regime, we simulate 1000 iterations over 30 years for each scenario. For that period, we calculate the size of the insurance payouts for a policy of 80% revenue CL, i.e. compensation would be triggered if revenue falls below 80% of the average. First, for each year and iteration, we calculate the average revenue ($\overline{\Pi}_{y,s}$) for the preceding 5 years:

$$\overline{\Pi}_{y,s} = \mathrm{mean}(Y_{y-6,s}P_{y-6,s}, \ldots, Y_{y-1,s}P_{y-1,s}). \tag{A8}$$

The trigger, $T_{y,s}$, for insurance payment is based on the average revenue, $\overline{\Pi}_{y,s}$, and on the CL selected, which we assume for now is 80%:

$$T_{y,s} = 80\%\, \overline{\Pi}_{y,s}. \tag{A9}$$

If the simulated revenue (yield × price) $Y_{y,s}\ P_{y,s}$ is $< T_{y,s}$, then an insurance payment $\mathrm{IP}_{y,s}$ is the difference between the current revenue and the trigger:

$$\mathrm{IP}_{y,s} = (T_{y,s} - Y_{y,s}P_{y,s}). \tag{A10}$$

To calculate the premium, we use a search algorithm that finds the minimum premium required such that the insurance fund raised is sufficient to cover up to the 75th percentile value of the annual payouts over all simulated scenarios (we implement a "while" loop that increments the premium until it is sufficient for the 75% of the least costly simulations). The insurance fund has a pre-set limit at which it is capped, so that annual premium payments are suspended while the fund is at or above its pre-set limit, and once the fund is at or above the pre-set limit, the interest earned is returned to policy-holders yearly. This is referred to as the mutual fund. During the first 10 years, the fund is allowed to borrow money if needed at 8% interest; conversely, the money not used for payouts is invested at a 5% annual rate of interest (Figure A2). The operating costs are assumed to add 10% to the total premium collected for the mutual fund. The interest rates and operational cost values are arbitrary estimates based on reasonable rates during 2007.

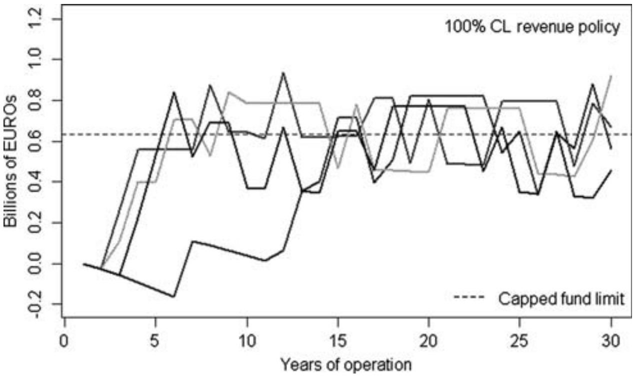

Figure A2. Building an insurance fund over 30 years in four simulated scenarios, assuming 100% revenue CL. Note that the fund value (*y*-axis) sometimes exceeds the pre-set upper limit of the fund because of the fixed premium level, but it drops back to the pre-set limit soon after because payments stop until the fund falls below the limit again as a result of payouts.

The upper 25% of liability is covered by private reinsurance bought in the market. The premium for reinsurance, Ψ, is calculated by adding a 25% profit margin to the expected annual reinsurance payouts (re-IP$_{y,s}$, the total payout less the reinsurance threshold level at the 75th percentile of annual payouts) in the extreme 25% of the simulations:

$$\Psi = \underset{s}{\mathrm{mean}}\left(\underset{y}{\mathrm{mean}}(\mathrm{re} - \mathrm{IP}_{y,s})\right) \times 1.25. \tag{A11}$$

Fisher behaviour is modelled as follows: whenever the revenue falls from one year to the next, fishers increase the following year's effort proportionally to the change in revenue, aiming to compensate for falling revenue. However, it is assumed that this increase relative to the level compliant with the MSY management strategy is never greater than 70% of the effort at MSY. This is because we assume that there is a practical, as well as a contractual, limit to the additional effort fishers could make:

$$E_{y+1} = \min\left(1.7E_{\mathrm{MSY}}, \frac{\Pi_{y-1,s}}{\Pi_{y,s}} E_{\mathrm{MSY}}\right). \tag{A12}$$

Additionally, we assume that unless the revenue is falling, the effort stays at the MSY level, i.e. it does not decline when revenues rise. Revenue, denoted by $\Pi_{y,s}$, that affects fisher behaviour is inclusive of insurance compensation and dividend surplus fund payouts, and less premium payments.