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Fisheries restoration: Lessons learnt from four benefit-cost models

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Globally, fisheries are in decline and in many parts of the world illegal fishing is a major cause of these declines. Ecological restoration of fisheries needs to be promoted, *inter alia* through improved enforcement, but, which method is the most successful at improving fish stocks, as well as having the highest economic returns? We compare one open-loop (without feedback) and three closed-loop (with feedback) benefit–cost models representing different restoration interventions aimed at promoting compliance. The hybrid systems methodology has been utilized, combining system dynamics, systems archetypes, mathematical differential equations and economic benefit–cost methodologies. The model is tested with reference to a case study of abalone (Haliotis midae) biomass restoration in the Table Mountain National Park marine area (Zone E), Cape Town. Stocks in Zone E have dropped to below the government's management threshold for sustainable fisheries of 20 percent of the pre-fished levels, and urgent action is required to restore the stocks. According to the model, all proposed restoration interventions produce stock recovery to 100 percent of carrying capacity, well in excess of government targets of 40 percent. Also, all four models had a net present value of greater than zero, indicating substantial positive net benefits to restoration. Each model had specific management recommendations associated with it- greater involvement by the state, capital investment in restoration, changing poacher behavior and entrepreneurship. Although the Post Keynesian and Institutional model produced the highest net returns to restoration over 80years (Net present value=US$12.66 million at a 6 % discount rate, 2021 prices), all the models are essentially co-evolutionary models, and have merit over different time periods, compliance rates and assumptions around discount rates. While the case study is developed for abalone the findings of the model are likely to be applicable in a wide range of fishery restoration contexts.

KEYWORDS

economics, system dynamic model, schools of thought, abalone (Haliotis midae), hybrid system, restoration, wildlife crime/poaching

1. Introduction

Globally, many fisheries are in decline (Pauly et al., 2005; Pauly, 2019; Palomares et al., 2020). Developing countries are particularly vulnerable to biodiversity losses. In a recent assessment, South Africa ranked sixth worst out of 195 countries, with 40 percent of its biodiversity and ecosystem services identified as "fragile" (Retsa et al., 2020). One of the most problematic fisheries is the abalone (*Haliotis midae*) fishery, which has been heavily depleted, due to high levels of poaching and an over allocation of total allowable catch [DEFF (Department of

Environment, Forestry and Fisheries), 2020]. Heavily depleted fish stocks can take much longer to recover, even when fish stocks are protected (Hilborn et al., 2014). Abalone may experience low fertility (Coates et al., 2013) and low dispersal (Tarr et al., 1995), which may further limit their recovery. This slow recovery is not only true for abalone, but for other demersal fish such as hake as well (Vergnon et al., 2008). Demersal finfish and shellfish are also among the taxa with the highest incidence of illegal and unreported catch (Agnew et al., 2009). Therefore, Marine Protected Areas (MPAs) alone are not enough to ensure stock recovery (Higgins et al., 2008).

Restoration is increasingly seen as a means for reversing environmental damage (Taljaard et al., 2021). In recent meta-analyses of the benefits and costs of restoration (De Groot et al., 2013; Elmqvist et al., 2015; Crookes and Blignaut, 2019), it has been demonstrated that the benefits of restoration exceed the cost, and by some considerable margin in most cases. Coastal and marine resources are, however, not well-covered in these reviews despite their very high economic and cultural values (Blignaut et al., 2016, 2017; Zhang et al., 2018). Some of the notable exceptions are reported in TEEB (2011) citing Fox et al. (2005) that estimated the benefits from coral reef restoration following blast fishing and Leschen (2007) that estimated the cost of seagrass restoration.

The Economics of Ecosystems and Biodiversity (TEEB) report also highlights a few studies with respect to the costs of mangrove restoration in estuaries in the United States (US) (Lewis Environmental Services, 2007; Francher, 2008). Barbier (2013) also discusses studies from the US documenting the valuation of ecosystem benefits from coastal system and the challenges associated with the restoration thereof. Van Dover et al. (2014) report estimates for the costs of restoration in the deep sea and indicates that these may be two to three times greater than the costs of restoration of marine systems in shallow water. These costs are for coastal systems restoration, but do not include restoration through marine enforcement activities. To contribute to the literature in this field, this study focuses on a benefit cost analysis (BCA) as applied to the improvement in abalone biomass. This is particularly important, given that in 2021, both the United Nations (UN) Decade on Ecosystem Restoration[1] and the Decade of Ocean Science[2] commenced. In the strategic plans for both these UN initiatives, it was indicated that investments in oceans restoration could yield benefits that are substantially greater than the costs.

The notion of restoration is mostly used within the context of an entire ecosystem. For example, Kennedy et al. (2011) consider fisheries (oyster) restoration through substrate (shell), transplanting hatchery or wild seed (juvenile oysters), bar cleaning, and bagless dredging, and Stewart-Sinclair et al. (2021) define marine restoration in terms of coral reef, mangrove, saltmarsh, and seagrass restoration. This is important, since marine ecosystems are often degraded (Nyström et al., 2012). At the same time, increasingly in the literature, the concept of the "restoration of natural capital" is being promoted. The restoration of natural capital is defined as "any activity that integrates investment in and replenishment of natural capital stocks to improve the flow of ecosystem goods and services, while enhancing all aspects of human well-being" (Aronson et al., 2007, p. 5). This definition includes all forms of natural capital restoration, including living species, ecosystems, replenishable and cultivated natural capital.

Few studies (if any) focus specifically on fisheries restoration. For the case study we consider the improvement of abalone biomass through improved enforcement effort. Other interventions that could be undertaken (but are not costed here) include reducing the Total Allowable Catch (TAC), and trans-locating west coast rock lobster away from vulnerable abalone nursery grounds [see DEFF (Department of Environment, Forestry and Fisheries), 2020]. The reason enforcement effort was focused on was because: (i) the legal landings of abalone are a small fraction of the illegally caught abalone; (ii) the Department of Environment, Forestry and Fisheries (DEFF) have identified the reduction in illegal harvests as a major management objective [DEFF (Department of Environment, Forestry and Fisheries), 2020]. But which method of ensuring compliance is best? We apply four different restoration methods based on models from four different economic schools of thought, in order to investigate which behavioral response is likely to generate the highest returns and the greatest recruitment success.

The aim of this study is to develop a framework for fisheries restoration, based on a hybrid systems approach that incorporates systems theory (archetypes), mathematics (first order differential equations), economics (benefit–cost analysis) and system dynamics modelling.

2. Materials and methods

2.1. Background

Four approaches are employed in order to analyze the benefits from fisheries restoration (Figure 1): Firstly, a theoretical approach is considered, based on a hybrid systems methodology, whereby different economic schools of thought are linked with systems archetypes. Secondly, an empirical model is developed, by converting the theoretical framework into four benefit cost models. Thirdly, a case study is proposed, where the framework is applied to a specific fishery. Finally, results of the case study are used to make inferences about fisheries restoration in general.

2.2. Classification of the economic schools of thought

We utilize a hybrid systems methodology (HSM) approach (Powell and Mustafee, 2014) to classify different economic schools of thought. The HSM approach combines methods and techniques from the systems discipline and methods from other disciplines such as economics and applied computing (Eldabi et al., 2016).

The systems discipline identifies *inter alia* four different types of models (or archetypes, see, e.g., Senge, 1990, Sterman, 2000). An archetype is simply a representative model, but these predefined modelling frameworks have become very influential in the systems modelling community:

1) Limits to success (growth) archetype. These are models where one entity preys on or otherwise inhibits another one.

1 https://www.decadeonrestoration.org/
2 https://oceandecade.org/

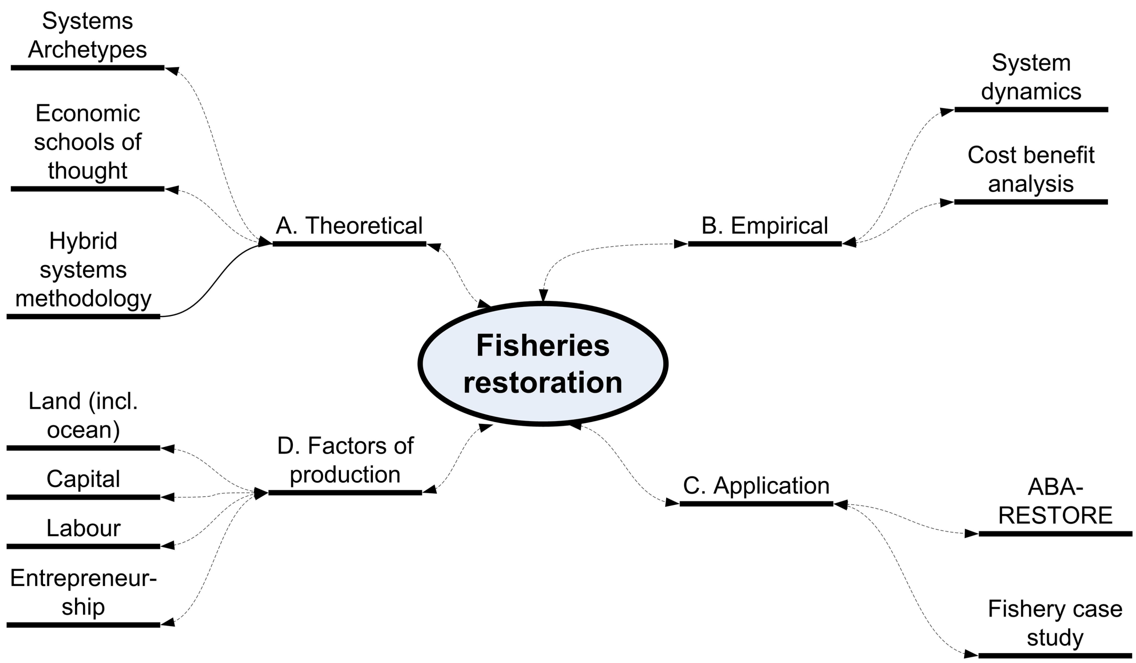

FIGURE 1
Mind map showing topics and sub-topics related to the fisheries restoration problem.

2) The tragedy of the commons systems archetype. These models are where resource limitations prevent the expansion of an entity.
3) Drifting goals archetype. This archetype states that if there is a gap between the current state and the goal, corrective action needs to be taken to bring the current state in line with the goal.
4) Open loop models. These are models with no defined archetype, no feedback, and are usually characterized by linear systems (see Supplementary material, Annexure 1, for a further elaboration).

These four models were chosen from the list of 10 archetypes that are available in the literature due to their relevance to the abalone fishery management problem in South Africa. We utilize these didactic models in order to match the archetype to different economic schools of thought.

The economic schools of thought are summarized as follows:

1) Evolutionary economics (EV)- Law (1985) states: "evolution of the biotic environment of a population is a well-known phenomenon when the environment is composed of species for which the population has antagonistic interactions, such as predator–prey, host-pathogens and competitors"; see also Magain et al. (2017) for a more recent affirmation of this point. Although the evolutionary economics literature is vast and diverse, e.g., Van Den Bergh (2007) has linked these models to evolutionary economics. Gould and Cleveland (2018) have also coupled the "limits to success" archetype with the evolutionary system.
2) Neoclassical economics (NC)-Although there are some similarities between the EV and NC schools, one of the fundamental differences between neoclassical and evolutionary economics is its focus of the NC school on scarcity (Panayotakis, 2013). For example, Samuelson and Nordhaus (1989), a highly influential neoclassical textbook, defines economics as the study of "how people choose to use scarce or limited productive resources (land, labor, equipment, technical knowledge) to produce various commodities (such as wheat, beef)" (p.4–5). As a result, authors such as Garrity (2012) have linked the neoclassical school with the "tragedy of the commons" archetype.
3) Post Keynesians and Institutional economics (PKI)- fundamental to the understanding of Post-Keynesian economics is the concept of historical and dynamic time. Lavoie (2006) explains that: "We must always consider the transition from one dynamic time position to another and recognize that the conditions under which this transition occurs may affect the final position of equilibrium."

A second element of Post-Keynesian economics is that it is demand driven. As Lavoie (2006) explains: "supply adapts to demand." According to Lavoie (2006), Post-Keynesians emphasize the role of the state in stimulating effective demand, thereby seeking full employment [see also Whalen (2013) and Keller (1983) who make a similar point also with reference to the institutional school]. Although we found no other authors who have definitively linked the PKI school with the drifting goals archetype, in the context of the abalone problem discussed here it does seem particularly relevant, given that the focus in on government undertaking corrective action to solve an environmental problem.

Though we acknowledge that the PKI school could be linked to a number of different archetypes, we believe that the "drifting goals" archetype is particularly relevant to this school, since Saeed and Radzicki (1993) argue that the PKI school is a disequilibrium approach, and the drifting goals archetype is suitable for correcting imbalances between supply and demand.

4) Open loop economics (OL)- these focus on tools for appraisal that are independent of an economic ideology. These can include open loop game theory (Lofgren, 1999), life cycle assessment (Klöpffer, 1996; Ekvall, 2000; Williams et al., 2010), and linear dynamic economics (Narraway and Perkins, 1993; Kookos, 2001). The OL school would not be linked to any specific archetype, since all archetypes contain feedback whereas the OL school is a linear system. It is nonetheless important to consider the implications of fisheries restoration in this case as well.

2.3. Benefit–cost analysis

The decision-maker must take decisions as to the most beneficial use of limited resources today by examining the impact thereof in the future. They will seek the option where the benefits most exceed the costs, or the least cost option (loss minimization). For such an analysis and project appraisal, a Benefit–Cost Analysis (BCA) is most useful (Argyrous, 2017). The formula for conducting a BCA is as follows:

$$PV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t}$$

Where:
PV = present value.
R_t = cash inflow (benefits) or outflows (costs) during a single period t.
i = social discount rate.
n = number of time periods.

The Benefit–Cost Ratio (BCR) is calculated as the present value of the benefit stream divided by the present value of the cost stream. A BCR greater than 1 indicates that the present value of benefits exceeds the costs. From an economic efficiency perspective, any project with a BCR greater than 1 represents an efficient allocation of resources (Kee, 2004). The BCR can be useful for calculating the annual returns of a project if the timeframe of the project is known.

Static BCA (sBCA) is usually conducted using a spreadsheet and generates a single point estimate, notably Net Present Value (NPV) or related measure (Argyrous, 2017). Dynamic BCA (dBCA) is mostly conducted using a system dynamics modelling framework and a "cumulative NPV" is generated (Schade and Rothengatter, 2003). In both instances, however, time matters. Here, we combine these two concepts and use the dynamic Benefit–Cost Ratio (dBCR) as the project evaluation criteria. This metric was proposed by De Groot et al. (2013) in relation to the evaluation of ecological restoration projects.

Given that time matters, it is not surprising that arguably the single most dominant variable in the PV equation shown above is that of the social discount rate, the indicator of the time preference of money. A positive rate implies that the time preference of money in the future is less than the present, and the higher the discount rate is the less important the future financial streams become. Blignaut and Aronson (2008), however, argue that in the case of ecological restoration, when such restoration activity enhances the economic value of a resource in future value and reduces resource scarcity, a negative discount rate as an indication of the future value of restoration is appropriate. We thus utilize both positive and negative discount rates.

2.4. System dynamics model

To improve abalone biomass, at least three different interventions could be considered related to enforcement effort: (1) government could stimulate the demand for the improvement in abalone biomass through education, training and investment in enforcement efforts; (2) the focus could be on confiscations, arrests and general deterrence in the restoration sector; or (3) the government could privatize several interventions that would lead to the improvement of abalone biomass, such as by hiring private firms to patrol fishing waters.

These interventions are features of different schools of economic thought. The intervention of government is a feature of the PKI school, enforcement through prosecution of offenders represents the evolutionary school, the role of business represents the neoclassical school, and a linear specification represents the open loop school.

A system dynamics model was constructed for each of the four economic systems (neoclassical, open loop, Post Keynesian and Institutional, and evolutionary) using the Vensim DSS software (version 6.4b). This methodology is well described in Sterman (2000). A series of differential equations are constructed representing each of the schools of thought in the system (Crookes, 2022). Purnomo and Mendoza (2011) provide a recent application of this methodology to renewable resources in a developing country. The stock flow diagrams for the resulting abalone model is included in the Supplementary material, Annexure 2.

The causal loop diagram for the ABA-RESTORE model is given in Figure 2. A description of each of the loops in the system are given here (the reader is referred to the diagram for the names of the loops).

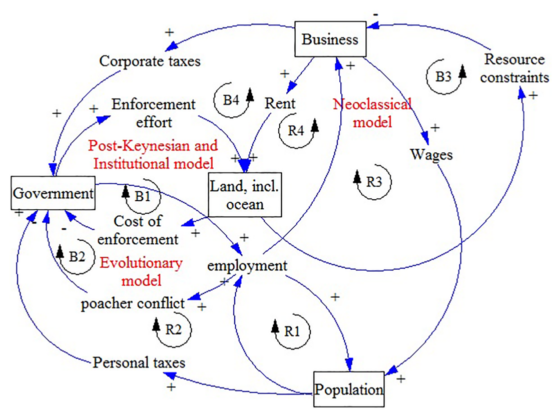

FIGURE 2
The causal loop diagram for the ABA-RESTORE simulation model. The different loop combinations represent the different archetypes in the model. Loops B1 (government) and its archetype (PKI); loops R1 and B2 and R2 and B2 represents the "limits to success" archetype (EV); loops B3, B4, R3, and R4 represent the "tragedy of the commons" archetype (NC).

Firstly, the reinforcing loops are described. Reinforcing loops lead to exponential growth or decline.

- Loop R1: An increase in employment increases population (by increasing migration into an area) which increases employment again. This is the household sub-model.
- Loop R2: An increase in government increases employment which increases population, which increases personal taxes which increases government. This is the government sub-model.
- Loop R3: An increase in business increases wages which increases population which increases employment which in turn increases business. This is the business sub-model.
- Loop R4: An increase in business increases taxes which increases government, which increases employment which increases business. This is the taxation sub-model.

Secondly, the balancing loops are described. Balancing loops lead to goal seeking behavior or convergence on an equilibrium:

- Loop B1: An increase in government increases enforcement effort which in turn increases the marine ecosystem, which in turn increases the cost of enforcement which decreases government. This is the government sub-model
- Loop B2: An increase in government leads to an increase in employment (for example in the ecosystem restoration sector), which leads to an increase in conflict (for example poacher conflict) which leads to a decrease in government resources. This is the poaching sub-model.
- Loop B3: An increase in the business (entrepreneurship) increases rent paid, which increases land (including oceans) utilization, which increases resource constraints which decreases business (entrepreneurship). This is the capital sub-model.
- Loop B4: An increase in business results in an increase in taxes which increases government, which increases enforcement effort, which increases fishery recovery, which increases resource constraints (since demand for poaching increases), which decreases business.

2.5. Case study

We develop a model (the ABA-RESTORE model) that presents various strategies for abalone biomass improvement based on the different schools of economic thought using a simulation model developed for the Table Mountain National Park (Crookes, 2016). The Marine Protected Area (MPA) is situated in Zone E, and includes almost 1,000 km2 of the sea and coastline around the Cape Peninsula from Moullie Point in the North to Muizenberg in the South. Fishing is allowed in the MPA, although there are five "no take" areas where no fishing or extractive use is allowed (see Figure 3).

There are two main sources of input data. The first set of input data pertains to the benefits of improving abalone biomass, or the enhancement of its *in situ* (existence) value, see Supplementary material, Annexure 3. As a conservative, lower-bound, proxy of the existence value the traded value of illegally harvested abalone is used. This is since it is an indicator of the willingness to pay for the resource and thus should reflect its existence value, albeit only in part.

Secondly, the costs of enforcement represent the patrolling costs that the marine authorities incur, see Supplementary material, Annexure 3. These costs would include payments to crew, as well as boat costs (Crookes, 2016). Brown et al. (2018) estimate that the cost of restoring a marine protected area from a highly depleted state to near pristine is US$29/km2 (2017 prices). Multiply this by the area of TBNP and making appropriate CPI and PPP adjustments gives a cost of improving the abalone stock in Table Mountain National Park at US$32637 per year (2019 prices).

2.6. Model validation

Model validation is essential if the model is to be used for forecasting. Crookes (2022) reviews the validation techniques proposed by eight prominent system dynamics modelers, and concludes that structure verification, parameter verification, dimensional consistency and boundary adequacy tests are *sine qua non*. Structure verification compares the model with structures found in the real world. Since the modelling structure is based on four systems archetypes, their relevance to the real world has already been established. Parameter verification is undertaken by comparing parameters with the real world. Many parameters used in the model are derived from the literature. Dimensional consistency is assessed by checked whether or not the units in the model are consistent across different equations. The model passed the dimensional consistency test. Boundary adequacy is usually assessed through different tests. Again, since the models are didactic models, the parameters and structure of the model are complete. The behavior of the models are also in accord with *a priori* expectations. Although not an exhaustive list of validation techniques were employed the model is deemed sufficiently robust for forecasting purposes.

A final validation question relates to the general applicability of the ABA-RESTORE model. The model is created for a single taxon (abalone). Is the model relevant to other fisheries restoration problems? Figure 4 indicates the boundary of the study. As one moves towards the center of the diagram, the study becomes more relevant. However, it is evident that the study is also relevant to other developing country contexts, to demersal species, specifically shellfish taxa, and cases of illegal, unregulated and unreported fishing (IUU) in developing countries, and also to demersal taxa consumption (as indicated by the interacting segments in the diagram). The data in the diagram show that these interacting segments represent a sizeable portion of the relevant interaction area. Although these interacting segments comprise the main realm of applicability of the model, the model may also be relevant to other segments, notably restoration focused on aquatic consumptive species, other demersal species, and worldwide IUU (the outer extent of the diagram).

3. Results

3.1. Classification of economic schools of thought

The definitive features of the different economic schools of thought under discussion are given in Table 1. The PKI School argues that government interventions are essential and necessary to stimulate

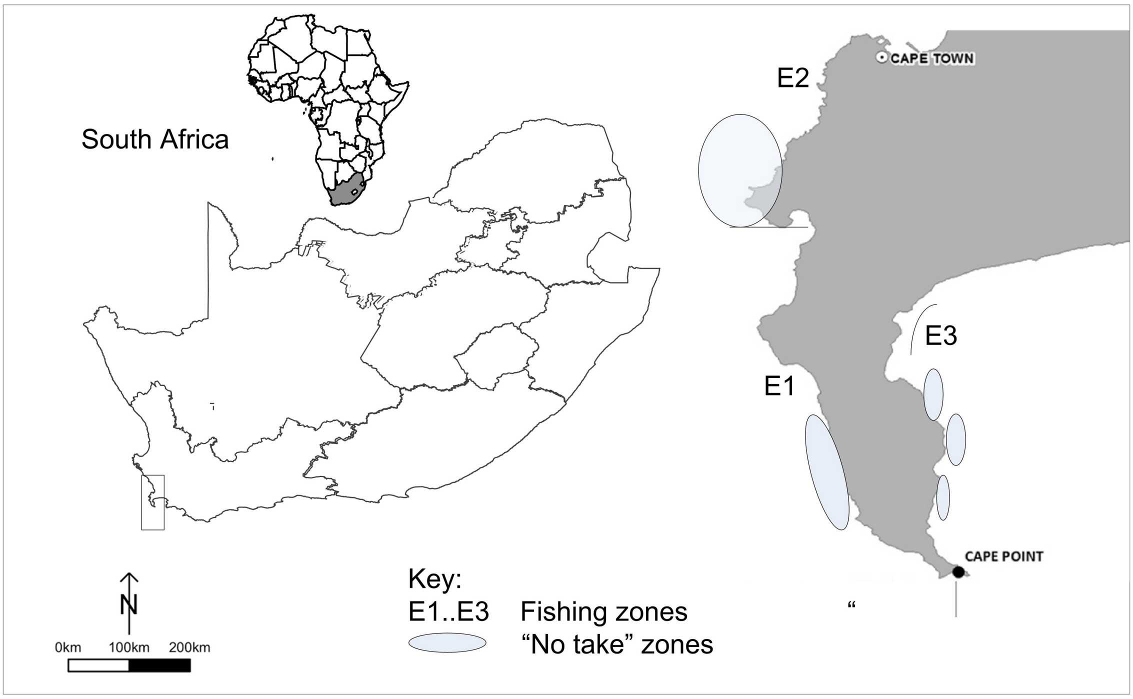

FIGURE 3
Map showing location of Table Mountain National Park.

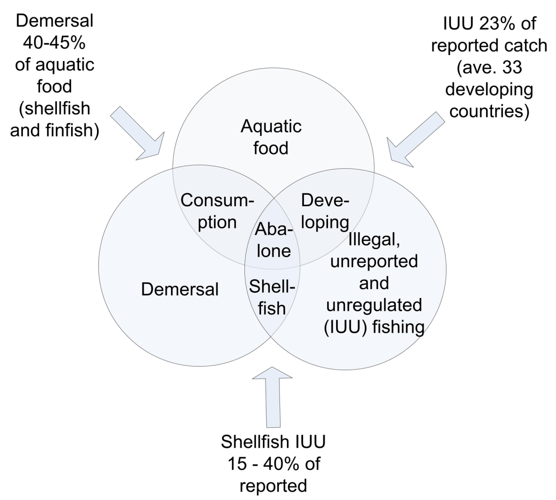

FIGURE 4
Boundary of the ABA-RESTORE model. How applicable is it to other fisheries? References for the data: Agnew et al. (2009), MRAG (2005), and FAO (2022).

the demand for the improvement of abalone biomass. Government interventions are in both the labor (supply) market as well as stimulating effective demand in the business sector. The OL model assumes no behavior and recovery is linear and exogenous. The EV school focuses on the criterion of conflict between government and poachers. The intent is for antagonism with poachers to ultimately lead to behavioral change and an improvement in abalone biomass. Finally, the NC school argues that privatizing natural capital assets, or the management thereof, is the optimal strategy to ensure the recovery of the stocks.

There are also implications of these models for the different system archetypes. As we saw previously, the PKI School is characterized by the drifting goals archetype in systems theory. The drifting goals archetype hypotheses that the gap between the goal and the current activity can be rectified through corrective action (Maani and Cavana, 2007). In this case (the case of the abalone fishery), corrective action is through the labor market reform (focusing on supply) and through stimulating demand.

The evolutionary school is characterized by the 'limits to success" archetype. It is characterized by a reinforcing and balancing loop. The reinforcing loop represents the "success" aspect, whereas the balancing loop represents some force that is working against that success. In the case of the abalone fishery, it is potential conflicts with poachers that works against poaching behavior.

The neoclassical schools comprises the tragedy of the commons archetype. In this archetype, a desirable activity results in increasing demand, which ultimately leads to disastrous consequences (Maani and Cavana, 2007). In the case of the abalone fishery, successful restoration interventions lead to wage increases, population stimulus and ultimately (financial) resource constraints.

The open loop school has no archetype, since it is merely a linear specification. However, its implications on the abalone fishery are that there is uniform impact on stock recovery over space and time.

In the next section, we will consider the results of the ABA-RESTORE model, where the results from the different abalone biomass restoration interventions (characterized by the different schools of economic thought) are compared.

TABLE 1 Classification of different schools of economic thought.

	Post Keynesian	Open loop	Evolutionary	Neoclassical
Systems archetype	Drifting goals	None	Limits to success	Tragedy of the commons
Definition	These models and are often characterized by disequilibrium between supply and demand	These are linear systems where no behavioral assumptions are made	One entity preys on or otherwise inhibits the "success" of another entity	Resource limits affect the extent to which economic rents may be achieved
Differential equation system (name)	Hill-climbing[1]	Linear	Predator-prey[2]	Gause[3]
Time frame over which benefits realized	Short	Medium	Long	Long
Implications for ecological restoration	The solution for biomass restoration is greater involvement by the state to stimulate demand for biomass restoration		For biomass restoration the solution is to act in an antagonistic way towards poachers through confiscations, fines and imprisonment	The solution for ecological restoration is to privatize the ecological assets
Scale	All scales (including ecosystem scale)	Local, provincial	Global, regional and national	Sub-national- districts or provinces

[1]Sterman (2000).
[2]Wilson and Bossert (1971).
[3]Clark (2010).

TABLE 2 Benefits from restoring abalone biomass: In 2021 US$ prices.

	PKI	OL	EV	NC
Abalone biomass pre restoration (% of carrying capacity, at $t=2021$)	17.9	17.9	17.9	17.9
Maximum sustainable Yield (MSY, % of carrying capacity)	48.8	48.8	48.8	48.8
Abalone biomass post restoration [% of carrying capacity, at t = 2100, ($t=2040$ in parenthesis)]	100 (56.1)	100 (39.5)	100 (18.1)	100 (18.1)
Government targets for stock recovery, all zones (% of carrying capacity)	40.0	40.0	40.0	40.0
PV benefits (2021 million US$ @ 6% discount rate)	12.66	7.99	2.90	2.33
BCR @ $t=2100$, 6% discount rate	22.16	13.99	5.07	4.09

PKI, Post-Keynesian and Institutional; OL, Open-loop; EV, Evolutionary; NC, Neoclassical; Timeframe, 80 years; Stock status: $B > B_{MSY}$ = Abundant; $B \approx B_{MSY}$, Optimal; $B < B_{MSY}$, Depleted; $B << B_{MSY}$, Heavily depleted.

3.2. Economic modelling

Our results show that abalone stocks in Table Mountain National park (Zone E) are heavily depleted. Stocks are currently at less than 20 percent of carrying capacity, compared with a Maximum Sustainable Yield (MSY) of around 48% of carrying capacity (Table 2). This is a crucial threshold, since the government has set as management target to prevent abalone in each zone from dropping below 20 percent of its pre-fished levels, and to promote recovery to at least 40 percent of that level [DEFF (Department of Environment, Forestry and Fisheries), 2020].

All four ABA-RESTORE models resulted in good recovery of the abalone stocks, with stocks rebounding to 100 percent of carrying capacity over the next 80 years, well in excess of government targets for stock recovery (Table 2). However, only the PKI and OL model achieve or exceed government targets of 40% stock recovery by the year 2040. All four scenarios showed positive net present values and BCRs substantially in excess of unity (the lowest was the NC model with a BCR of over four). The PKI model shows the highest net present value benefit–cost ratios (BCRs) of the four scenarios, with potential returns of almost $13 million in the value of ecosystem restored over 80 years, at a 6 % discount rate (Table 2). This was followed by the OL model (almost $8 million), the EV model (almost $3 million) and the NC model (over $2 million).

We test the sensitivity of the BCRs to different assumptions. Firstly, we model the possibility that in an imperfect world, only 75% of total economic value from abalone recovery will be realized (De Groot et al., 2013). Secondly, we investigate the sensitivity of the BCR to changes in the timeframe over which restoration is assumed to occur. Three different timeframes are investigated namely 20, 40 and 60 years. Finally, we model sensitivity to different discount rates (6% and − 2%). The results (Figure 5) show that for positive discount rates (6%), the PKI model is clearly the winner (top graphic). However, for negative discount rates the results are far more ambiguous (bottom graphic). Any one of the models could be selected and generate equivalent results.

3.3. Implications for fisheries restoration

The policy of setting a restoration goal and pursuing it (the PKI model) is economically optimal (Figure 6). However, this is not what the South African government is currently doing. Rather, it seems to be pursuing an EV approach of maximizing revenues through

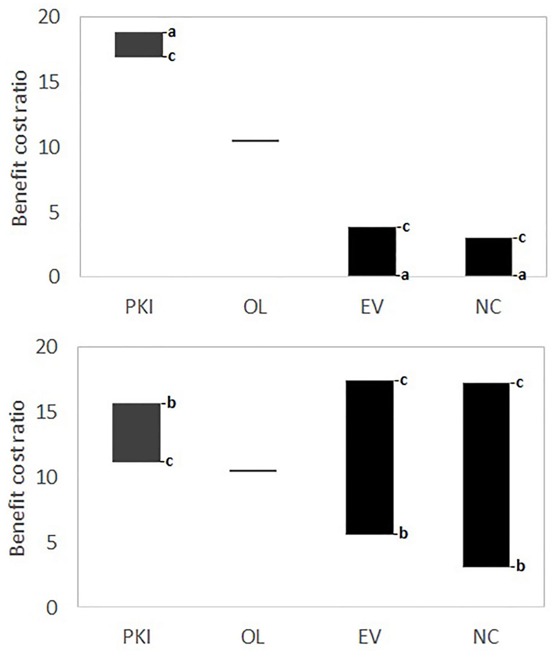

FIGURE 5
Comparing the benefits of abalone biomass restoration with the costs thereof. Variation in BCRs at 75% of TEV realized, for discount rate of 6% (top graph) and–2% (bottom graph): Timeframe for intervention: a=20years; b=40years; c=60years.

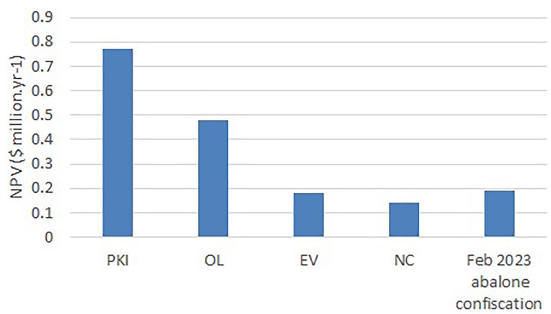

FIGURE 6
Annualized Net Present Values (in 2021 US$ million.yr-1) for the different schools (this study), compared with revenues from confiscations (Nene, 2023).

enforcement confiscations (see, e.g., Nene, 2023). Naturally, these *ex post* seizures do not preserve the resource in the short term, as the abalone are already dead. Ex ante incentives to prevent the crime from occurring (the PKI model) not only restores the abalone population, but also maximizes societal welfare (Figure 6).

In one sense all of these models are co-evolutionary models. They consider how the system evolves over time. But the EV model deals explicitly with predator–prey interactions. It is "man versus man." Evidence from the African bush shows that, when two antelope fight each other, they are more vulnerable to attacks from predators. Currently, the South African government is fighting poachers. This approach still has environmental spinoffs, but the benefits are only realized over the very long term (around 80 years). The PKI model on the other hand seeks to focus on maximizing an environmental goal (restoration of the fishery). It focusses on getting to the new equilibrium as quickly as possible. This results in greater returns as well as restored populations.

Adam Smith, the father of neoclassical economics, developed his theory of the invisible hand, where self-interested agents achieve outcomes that are societally beneficial, even though this was not their intent. Charles Darwin, in his theory of evolution, posited the same thing. That competitive behavior caused taxa to adapt and therefore become more resilient. There is merit in both of these arguments. The NC model shows that privatization of the resource may result in benefits to the resource, as private agents seek to maximize returns. The EV model indicates that antagonism towards poachers may ultimately result in them changing behavior. The present study shows however it takes time for these benefits to be realized. Furthermore, it is shown that setting and pursuing an environmental goal has greater economic welfare implications than these other two approaches. This is largely owing to the fact that the environment has a high intrinsic value compared with its use value (total economic value will always be greater than its consumptive value).

Different schools are relevant at different stages, depending on the level of compliance (Table 3). At low levels of compliance, the EV school is indicated, and at moderate levels of compliance the NC school is indicated. However, the ultimate goal is to shift towards a system of voluntary compliance (see also Hauck and Kroese, 2006; Arias, 2015).

TABLE 3 Typology of different methods to promote fisheries restoration in the context of wildlife crime.

Increasing rates of coerced compliance	Methods	School
Voluntary compliance	Legitimacy, incentives, alternative livelihoods, persuasive communication	PKI
Mostly compliant	Private enterprise, community based natural resource management (CBMNRM)	NC
Non-compliant	Enforcement (fines, prosecution, imprisonment)	EV

Own analysis based on Arias (2015).

4. Discussion and conclusions

Non-equilibrium approaches to ecological restoration have become very important in the literature (Perring et al., 2015). We present here an approach to fisheries restoration based on the natural capital approach (Clewell and Aronson, 2012). This approach has not yet been extensively applied to fisheries restoration. The present approach incorporates a hybrid systems methodology that includes systems archetypes, economic schools of thought, system dynamics modelling, mathematics (differential equations), cost benefit analysis, and a case study, where the framework is tested.

Our findings show that the improvement of biomass can generate positive economic benefits irrespective of the behavioral model assumed. Under all simulations over the lifetime of the project (80 years), a BCR of greater than one is achieved. For both the evolutionary and neoclassical models, however, society must value the future more highly than the present (negative discount rate) for model results to be comparable to the Post Keynesian and Institutional model.

Hauck (2008) argues that: "to better understand the factors influencing (non)-compliant behavior and thus effectively respond to them, it is necessary to gain a broad understanding about the inter-relationships that exist, and the complexities that are evident in a system where people and the environment co-exist." (p.637). One such ecological systems approach is presented here, that considers both socio-economic considerations as well as ecological imperatives.

Complex socio-economic systems require new ways of promoting compliance. Government interventions in natural resource management in developing countries should take into consideration issues such as alleviating poverty as well as intervening in ecosystem restoration (Van Wilgen et al., 1998; McConnachie et al., 2013). Government initiatives such as Working for Water, Working for Wetlands, Working for Woodlands, Working for Wetlands and Working on Fire have proved successful in achieving these goals in the past (Turpie et al., 2008). At present, these programs are confined to terrestrial ecosystems. Expanding this program to the marine environment could result in numerous positive benefits for both job creation as well as marine ecosystem health.

It is important to note that we should not draw universal conclusions from the benefit cost studies on how well the different economic schools performed in the benefit cost studies. The data are case specific and only applicable to the abalone fishery in the Table Mountain National Park. At the same time, abalone is a fairly indicative fish species. The biological attributes of abalone (Edwards and Plagányi, 2008) are similar to around 20 percent of the 170 fish species reported on in Jensen et al. (2012). We can also observe that all four schools resulted in positive net present values and the policies that they propose are applicable to fisheries restoration in general, across a wide range of fisheries and geographical contexts. A number of these policies have not been previously considered in the context of fisheries restoration in South Africa and elsewhere.

There is a growing body of literature dealing with the enforcement as it pertains to fisheries management [e.g., Sutinen and Andersen (1985), Mazany et al. (1989), Charles et al. (1999)]. Most of the economic theory of enforcement derives from the basic deterrence model first postulated by Becker (1968), with further development by Stigler (1970). Here we utilize the hybrid systems methodology (Powell and Mustafee, 2014; Eldabi et al., 2016) to model compliance, in order to promote fisheries ecological restoration. Enforcement in the context of fisheries restoration should focus on ex ante revenue maximization (i.e., through preventing fisheries crime) rather than through ex post revenue maximization (i.e., through confiscations).

In conclusion, the paper presents a toolkit that may be used to operationalize the restoration of natural capital in a marine environment, based on economic principles (including benefit cost analysis and economic schools of thought), but also systems theory (systems archetypes and system dynamics modelling) and mathematics (first order non-linear differential equations). The specific context here was fisheries restoration, but the framework may be generalized to other forms of natural capital restoration when there is a wildlife crime element.

Data availability statement

Publicly available datasets were analyzed in this study. This data can be found here: http://www.scielo.org.za/scielo.php?script=sci_abstract&pid=S0038-23532016000200019&lng=en&nrm=iso.

Ethics statement

Ethical review and approval was not required for the animal study because desktop data only was used. No sampling.

Author contributions

The author confirms being the sole contributor of this work and has approved it for publication.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2023.1067776/full#supplementary-material

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