APPENDIX 1

Collapse of the Newfoundland Cod fishery

In the early 1990s the Newfoundland cod fishery collapsed despite management measures that were targeted at controlling the access to the resource (Hutchings and Myers 1994, Milich 1999, Mason 2002, Mather 2013). Fishing of cod by foreign fleets was portrayed as the most important source of overfishing by Canadian media (Mason, 2002). However even after the declaration of a 200-mile Exclusive Economic Zone by Canada and bringing of cod management under Canadian control, the social and social ecological processes in the cod fishery developed in a way which led to overharvesting of the resource. We apply SE-AS to develop a hypothesis about a set of interlinked AS that have partially been set off by the ban of foreign fishing in Newfoundland and may have led to unsustainable harvesting and collapse of the resource.

The two key social-ecological ASs before the collapse were the interaction of the foreign and domestic fishers with the Atlantic cod population (Harvesting AS) which created competition between the two types of fishers. The two action situations were, however, affected differently by governance actions (Rule-making AS) that determined who gets to harvest the resource and receives subsidies. The cod population, apart from the fishing pressure, was also affected by environmental factors such as water temperature and to some extent – salinity and seal predation (Hutchings and Myers 1994). Nevertheless, the social factors are emphasized as the major cause in later research (Mather, 2013).

The left figure shows the state of the system before the foreign fishing ban was introduced. Cod was fished both by Canadian fleets and foreign trawlers. The two different types of fishermen competed for cod, and harvesting of the resource by one type of fisherman could lead to reduced availability of the resource for the other. The importance of the local fishing industry to the economy and employment in the region meant a strong domestic fishermen lobby, which increased the pressure on the government to adopt the Exclusive Economic Zone and ban foreign fishing of Newfoundland cod. The figure to the right shows the system after the ban was officially introduced in 1977. The cod was then harvested exclusively by domestic fishermen. The ban of the foreign fleets was interpreted as a sign of state support, as well as the continued subsidies. This has attracted more fishermen and encourage existing ones to invest in their activity – through financial as well as social (knowledge, social relations, building up trust, etc.) capital. After the fishing pressure on the stocks increased further, the catches declined, however it was difficult for the fishermen to stop the activity due to the investments mentioned above, which lead to overharvesting and collapse of the Newfoundland cod population.

This analysis reveals that explanations for the collapse of the Newfoundland cod stock have so far only been sought for in the social systems. It is unclear whether and to what extent changes in ecological interactions between cod and other species or cod and the biophysical environment may have contributed to the cod collapse.

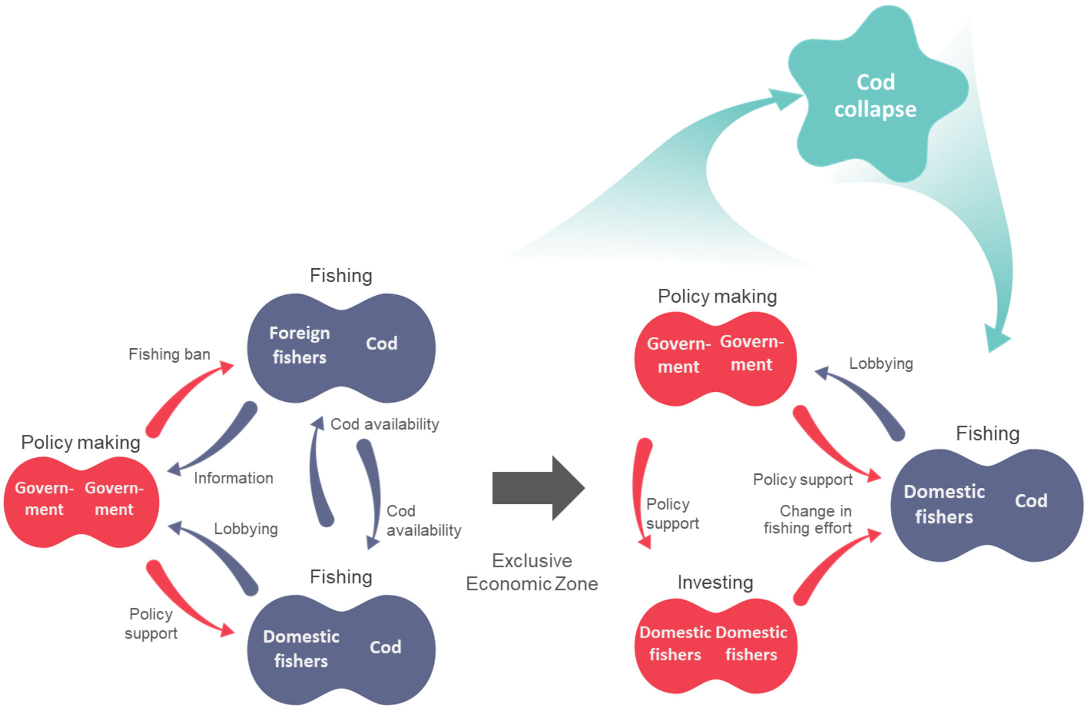

Figure A1: SE-AS representation of the configuration of social-ecological (dark blue) and social (red) action situations hypothesized to explain the collapse of the Newfoundland cod fishery

Regime shifts in lake Ringsjön

Shallow lakes that shift rapidly from a clear to a turbid state are a classic example for regime shifts. They are often caused by a slow accumulation of nutrients in the lake sediments from fertilizers used in nearby agriculture but also from insufficient sewage treatment in private houses along the lakeshore (Pers 2005, Jöborn et al. 2005). Turbid, highly eutrophied lakes pose a challenge for communities and lake managers who aim to restore the clear state of the lake to support lake-related ecosystem services such as recreational activities and drinking water supply. We apply the SE-AS framework to develop a hypothesis about key social-ecological interactions required to enable a successful lake restoration. The analysis is based on lake Ringsjön, a turbid lake in Southern Sweden where lake restauration activities have been under way for many years, including regulation of sewage treatment and bio-manipulation, however with varying success.

In this case there is no single key social-ecological AS, rather interactions between different actors and different aspects of the lake jointly influence the success of restoration. First, there is the social-ecological AS of nutrient pollution by private lakeshore house owners (Pollution AS) that causes harmful algae blooms and changes the food web towards a dominance of commercially low valued fish species such as bream and roach. Once an awareness of the problem reached policy making, algae abundance was monitored (Monitoring AS) and the municipality and the water council (an expert and stakeholder committee for lake use) agreed on policies for nutrient regulation (Policy making AS). The successful implementation of the regulation, i.e. the installment of new sewage treatment technology which is a high cost investment, however, depends on enforcement measures and how individual house owners were involved in the regulation process (Enforcement AS). In this case enforcement was carried out through visits of representatives of the municipality to house owners (Wallin et al. 2013). As the lake was already in a turbid state, the municipality engaged in bio-manipulation, i.e. a direct manipulation of the food web through the removal of white fish which is expected to decrease algae blooms and favor commercially higher valued fish (Restoration AS). Both enforcement and bio-manipulation are costly thus requiring repeated interactions within the policy making AS to allocated the required budgets. One future vision and motivation for the restoration of shallow lakes is that investments to restore a clear state facilitates more touristic lake use which will eventually provide revenues for municipalities (Recreation AS).

The AS configuration exemplifies that the overall success of lake restoration depends on three major outcomes to happen simultaneously. First, governing institutions need to deal with the legacy of past activities that affect the state of the lake today, for example through high nutrient levels in sediments, as well as ongoing pollution. They require measures to actively shift the lake back (bio-manipulation) as well as regulation and enforcement measures to reduce new inflow. Second, municipalities need to employ experts to conduct the practical restoration after evaluating carefully which methods are suitable in the local case. And third, the lake use through tourism (recreation) is both dependent on success of the first two activities while at the same time reinforcing their implementation. It may possibly accelerate the whole restoration process to include potential beneficiaries of the improved lake ecosystem from the beginning.

In summary, applying the SE-AS framework highlights that lake management needs to deal with three challenges at once: past practices of pollution in the catchment, present ecosystem manipulation and pollution and potential future income through touristic activities. These threefold challenge requires a sufficient investment in collaboration between different actors while it is uncertain when and how much of this investment will pay out. As a first step, we are investigating interacting time lags resulting from a subset of these linked action situations using a hybrid system-dynamics and agent-based model (Martin and Schlüter 2015).

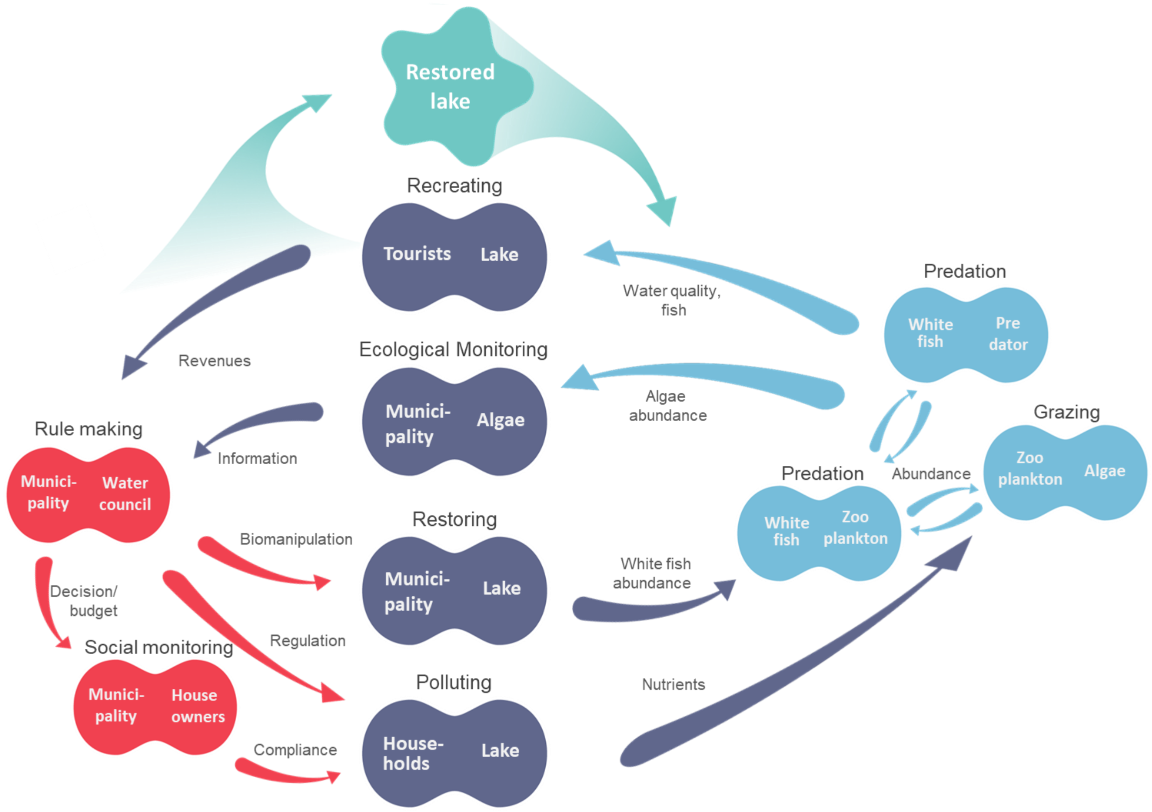

Figure A2: SE-AS representation of the configuration of social-ecological (dark blue), social (red), and ecological action situations (light blue) hypothesized to influence the success of restoration of the turbid lake Ringsjön.

The dominance of patron-client relationships in small-scale fisheries in Mexico

Small-scale fisheries in Mexico are to a large extent self-governed through fishing cooperatives (co-ops) that were promoted by the government since the 1930s (Young 2001). In recent years, however, patron-client relationships (PC) between fishers and fishbuyers seem to be rapidly on the rise (Leslie et al. 2015). The ecological and social consequences of an increase of patron-client relationships are unclear and will, most likely, depend on the specific social-ecological contexts in which they operate. Rather than examining the effect of the different organizational forms (co-ops and PCs), we were interested in understanding under which conditions one form or the other is more likely to establish and persist in the first place. Theoretical and empirical research has highlighted the importance of trust for the persistence of both self-governance forms. We apply the SE-AS framework to develop a hypothesis about the role of different dimensions of trust, such as reliability and loyalty for the persistence of each organizational form within a dynamic social-ecological environment.

The key social-ecological AS in this case is fishing (Fishing AS). Fishing pressure affects the competition for food and habitat between fish in the population affecting the growth of the fish population (Competition AS). The catch provided by fishing is then traded with the co-op or PC that provided the fisher with the fishing means or with another coop or PC that offers a better price (Selling catch AS). The outcomes of the Fishing and Selling catch AS influence the revenues of each organization. The outcome, however, also influence the building of trust within each organization as the trust between a fisher and his coop or PC will decrease after cheating or increase if the catch was landed in the organization providing the fishing means. The loyalty in an organization together with the revenues determine its functioning (PC or Coop Functioning). While coops cannot select their members, PCs engage in an interaction with free fishers to select those with highest reliability. Fishers' reliability and their loyalty to the coop or PC they are working with determines their level of cheating.

We implemented this set of action situations in an agent-based model to explore the conditions under which one organizational type dominates (Lindkvist et al. 2017). The model shows that PCs dominate when the initial loyalty within coops is low and the community is very heterogeneous, i.e. fishers' reliability varies greatly. Under these conditions only very few coops manage to develop a level of loyalty that lowers cheating to a level that enables them to persist and accumulate enough revenues when resource conditions are bad (because of competition between the different organizations). While coops have fixed members, PCs can select fishers with high reliability (depending on their availability) from the beginning thus reducing cheating. They can also dismiss fishers or engage more when needed. The latter, however, can also be detrimental as it causes PCs to increase their size when fish resources are low with the aim to increase their catch to meet the market demand. Overall, the persistence of an organization depends on the initial level of loyalty in an organization, its composition with respect to the reliability of its members, the competition with other coops are PCs for fishers and fish and the state of the fish population.

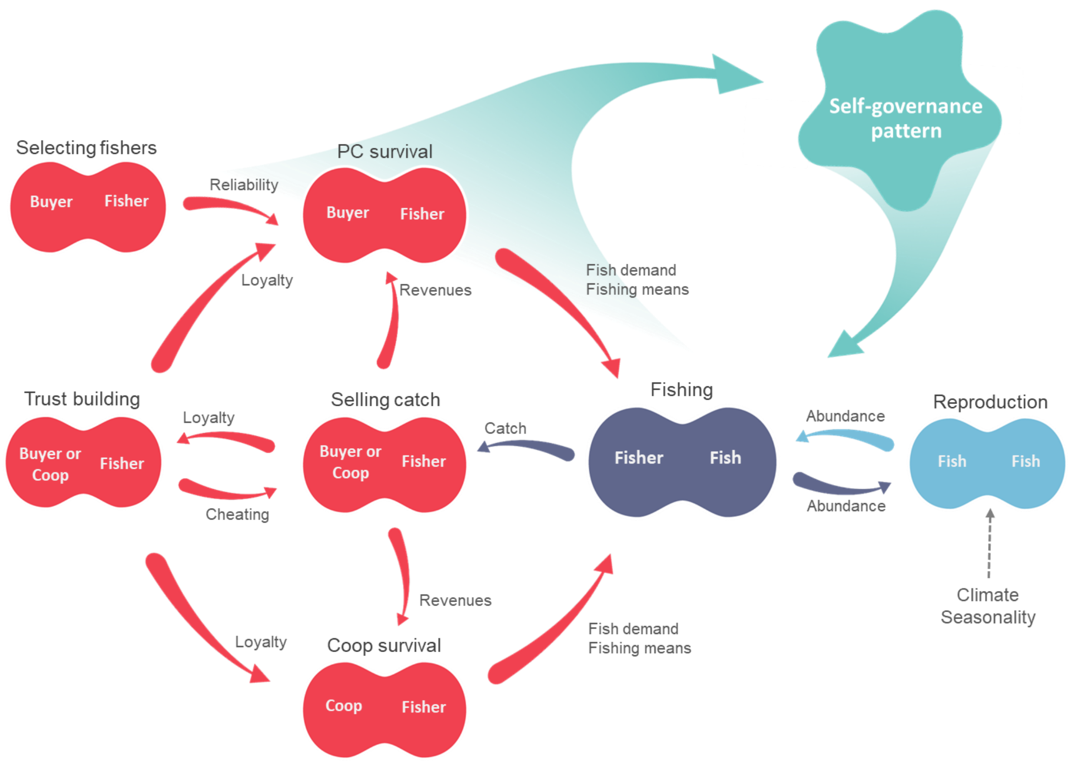

Figure A3: SE-AS representation of the configuration of social- ecological (dark blue) and social action situations (red) hypothesized to explain the dominance of patron-client relationships versus cooperatives in small-scale fisheries in Mexico.

Poverty traps in Tanzania

In contrast to the Pamir case above, in which a trap and attempted escape from it were analyzed, we now apply the framework to the descent into a poverty trap (Figure A4) in the Makanya region of Tanzania (Enfors 2013, Boonstra and de Boer 2014). Prior to the 1960s, families in the Makanya region of Tanzania engaged in low-intensity agriculture, growing maize for subsistence and vegetables for cash crops. Beginning in the 1960s, a number of drivers led to intensification of cultivation, our focal social-ecological interaction. Population growth led to increased pressure to produce food, and farmers responded by cropping twice per year. This intensification degraded soil quality and reduced the productivity of the cropland. In response, through a second social-ecological interaction, families relied more heavily on common resources from the rural landscape such as fodder, wood and vegetables, which also became degraded. Resource degradation was further exacerbated by a social and an ecological driver present at the time: 'villagization' policies that reshaped communities and their leadership led to decreased trust in community leadership and resource use rules and to degradation of the common pool resources; and increasing frequency of dry spells further degraded the productivity of the cropland.

Enfors (2013) analyzed how the causal interactions between these action situations led to the reinforcing feedbacks that are commonly understood to define a trap (Carter et al. 2007). Boonstra & de Boer (2014) analyzed how the historical sequence of these and other action situations led through a critical juncture to the appearance of the poverty trap.

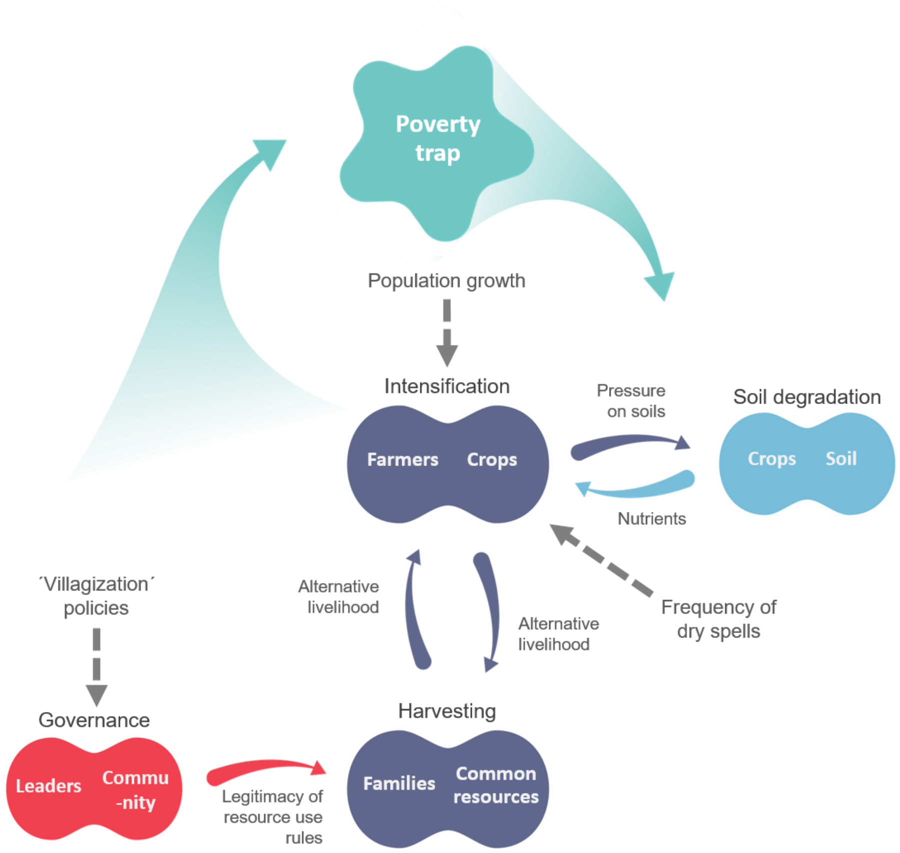

Figure A4: SE-AS representation of the configuration of social-ecological (dark blue), ecological (light blue) and social action situations (red) hypothesized to explain the emergence of a poverty trap in Tanzania.

Spread of Avian influenza

The local outbreaks of H5N1 subtype of avian influenza and its potential to spread from Asia poses a risk of an emergent global epidemic. The disease uses wild water birds as its natural reservoir. However various social-ecological processes have contributed to the spread of avian influenza to domestic birds and further to humans (Figure A5). Particularly, free-grazing domestic water birds (e.g. ducks) can interact with wild birds in their habitat (wetland), allowing for cross-species transmission (Kapan et al. 2006). Use of wetland for rice farming and conversion of wetland in general has decreased the habitat available for wild water birds, leading to increased contact between domestic and wild populations (Gilbert et al. 2008). The cross-species exposure via spill-over and spill-back, increasing human population density and poultry sector intensification have led to an emergence and local transmission of a pathogenic strain of avian influenza that could occur in humans (Kapan et al. 2006). The local spread of avian influenza has occurred mainly through interactions with poultry – particularly in crowded conditions, such as 'wet markets' or factory farms (Kapan et al. 2006). Both the spread of H5N1 and its ability to transcend the species barrier have been exacerbated by changes in precipitation, temperature and its further impact on wetlands (Kapan et al. 2006, Galaz et al. 2011).

However, avian influenza has had the potential to spread from its origin in South-East Asia to other countries due to both human and non-human factors. For example, through wild bird migration the virus can spread not only through regions of SE Asia, but to other continents (Gilbert et al. 2008). The migration behavior and distribution of wild birds are also greatly affected by climate change, potentially affecting the avian influenza epidemiology and global spread. Another link connecting local and global H5N1 spread is poultry trade. Changes in market price, trade conditions, modernized transportation also affect the spread of the virus via poultry products from its local origins to global market (Karesh et al. 2005, Kapan et al. 2006). The human-to-human spread of H5N1 has been suspected but not yet identified as an efficient source of transmission. However its evolution in this direction is possible, exacerbated by the population density and conditions for avian-human exposure on the local level (Kapan et al. 2006). The risks for potential global epidemic of avian influenza are thus maintained by the interconnected social-ecological processes on the global level (trade patterns, wild bird migration and climate change) and local level (land-use and wetland reduction, population increase) (Bahl et al. 2016).

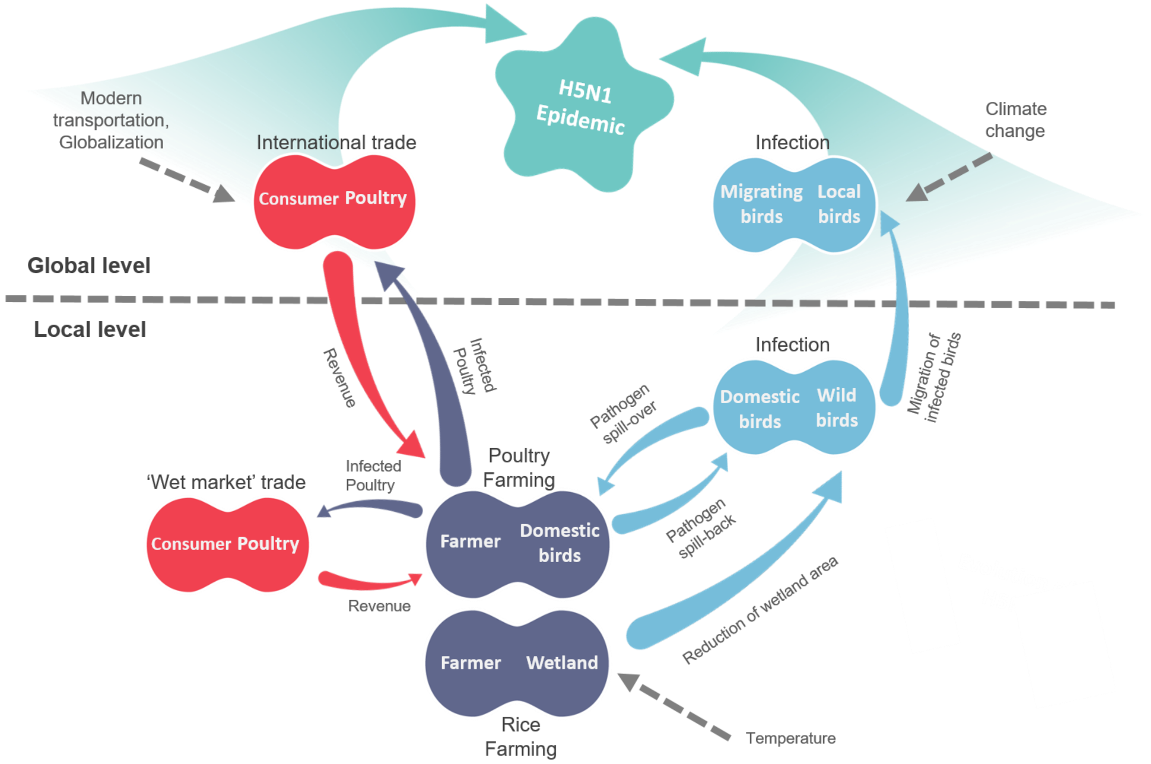

Figure A5: SE-AS representation of the configuration of the social-ecological (dark blue), ecological (light blue) and social action situations (red) hypothesized to influence the potential global outbreak of H5N1 avian influenza.

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