# APPENDICES

1) Tables A and B: Application of I-ADApT to six Mass Mortality of Bivalves (MMB) case studies

2) Table C: List of resilience criteria used for the multidimensional resilience framework and indicator.

| Table A | Barra del Chuy<br>Yellow clam (*M. mactroides*) | Puget Sound<br>Oysters (*C. gigas*) | Bay of Bourgneuf<br>Oysters (*C. Gigas*) |
|---|---|---|---|
| STRESSORS | Freshwater discharge (since early 1980s)<br>Increasing SST anomalies since early 1990s<br>Cold winters 2007-08 | Intensifying upwelling events of low-pH and high-CO2 water | Increase of SST (+1.5°C since 1970) and decrease of pH (-0.1 over the past century)<br>High density of cultured stocks<br>OsHV-1-mVar since 1991 |
| NATURAL SYSTEM (change-impact) | Erosion and modification of the coastline (habitat)<br>Reduced survival, growth and fecundity rates<br>Mass mortality since 1993 | Water conditions hostile to calcium carbonate minerals<br>Massive larval mortality between 2005 and 2009. | Spillovers of spat<br>Low yields<br>Invasive species (*crepidula* and wild oysters)<br>Massive larval mortality since 2008 (80-100%) |
| SOCIAL SYSTEM (change-impact) | Reduction of fishers' income and bankruptcies<br>New jobs found in the construction and agriculture industries | Total of 3200 jobs endangered.<br>Lower production (-21%; FAO: 2002-07/2008-11)<br>2 large hatcheries exporting oyster seed are facing high larval mortality rates | Triploid spat from hatcheries.<br>Modified seasonal patterns of cultured stocks.<br>Lower production (-30%)<br>New costs from spillovers |
| GOVERNANCE SYSTEM (change-impact) | Weak governance: open access (1970s-1980s)<br>Co-management system since 1990<br>Fishery closure 1993-2006<br>The fishery re-opened in 2008 with a precautionary approach | Lack of governance to address acute-onset change not driven by harvest levels.<br>Creation of the Blue Ribbon Panel (scientists + growers + managers): action plan against ocean acidification and how to adapt | Lack of management measures to limit spat over-buying and production<br>Restrictions on inter-basin transfers of oysters<br>Technical measures on tables and meshbags |

| Table A | Chesapeake Bay Oysters (*C. virginica*) | Matsushima Bay Oysters (*C. gigas*) | Bay of Quiberon Oysters (*C. Gigas*) |
|---|---|---|---|
| STRESSORS | Presence of diseases (MSX and Dermo) and predation (whelks and rays) since 2002.<br>Harvesting on the public grounds was low to zero by the mid-1990s. | An epidemic of Noro-virus food poisoning after 2011's tsunami because of destroyed sewage facilities. | Occasional hypoxia (more severe in 2006), near the bottom. Role of eutrophication not clear.<br>Occasional toxic phytoplankton (Pseudo Nitzschia) and *OsHV1-µvar* since 2008. |
| NATURAL SYSTEM (change-impact) | Parasites appeared in the early 1960s which are salinity dependent so that the losses in oyster populations were greater toward the mouth of the Chesapeake Bay. Dead zones due to oxygen depletion have also grown since that time. | Lower productivity of oyster due to unsold oyster occupation at the farming system in the bay. In 2011, total seed oyster collection decreased to 40% of 2008.<br>Remain production less than 20% level of the past average after 2011. | Changes in water quality (temperature, Oxygen, Phytoplankton), in growth rates and mortality risks.<br>The invasive *Crepidula fornicate* is present at moderate densities. |
| SOCIAL SYSTEM (change-impact) | Population of 30,942 in the three counties, with a 36% increase from 1960 to 2010.<br>32 small-scale fishers. | Pop. 131,000 inhabitants. 112 oyster farmers in 2012 (-10% since 2003 and -7% since 2011). 15,082 inhabitants affected indirectly.<br>Reduced revenue affects sustainability of oyster farming | 60 small-scale oyster farms (of less than 10 jobs each).<br>Decrease in the number of farms, economic vulnerability. |
| GOVERNANCE SYSTEM (change-impact) | Virginia Oyster Heritage Program initiated in 1999. Restoration of the public grounds at the mouth of the Rappahannock River by the Commonwealth of Virginia in 2000 (shell replenishment in public grounds). Partial funding has come from federal agencies. | Governor of Miyagi prefecture ask Miyagi Fisheries Cooperative best proper management of coastal water. Miyagi Fisheries Cooperative is responsible to manage coastal water production. In 2007, 31 independent Cooperatives have consolidated for cost-cutting purposes. | State intervention, industry representatives at the national (CNC) and local (CRC) levels.<br>Scientific support by Ifremer.<br>No particular change, except the access to public grounds. |

| Table B | Uruguayan Yellow clam (*Mesodesma mactroides*) | US North Pacific Oysters (*C gigas*) | Bay of Bourgneuf oysters (*C. Gigas*) |
|---|---|---|---|
| ADAPTIVE CAPACITY | Job opportunities in other sectors<br>No financial aid to fishers.<br>Important research activity on YC fishery for a long time.<br>Co-management in force since 1990 | Strong relationships between the industry, researchers, NGOs for solutions.<br>Funds available to do the basic science.<br>High levels of human resources in communities to address problem. | National funds to support affected farms (20 M€.$yr^{-1}$ at the national level)<br>Public research (causes and new virus-resistant species)<br>No private insurance against disease<br>No alternative virus-resistant oyster species |
| RESPONSES | Fishery closure 1993-2007 ;<br>The fishery was re-opened under a co-management system in 2008/2009.<br>a) monthly TAC;<br>b) restricted nb of licenses (40);<br>c) individual quotas;<br>d) minimum clam size;<br>e) only hand-gathering allowed<br>f) spatial management<br>g) harvesting season (summer) | Creation of plan for hatcheries to draw water in at specific times indicated by a warning system.<br>Transfer of hatchery production to unaffected waters in Hawaii.<br>Long-term research, monitoring plan through Blue Ribbon Panel. Genetic studies under way to identify resilient broodstock strain(s). | Restrictions on inter-basin transfers at the national level<br>No new management measure implemented at the bay-level<br>Individual responses: increasing number of spat collectors and hatchery seeds<br>Offshore tech. experiments |
| APPRAISAL | The ecosystem is gradually recovering from overfishing and MMB, but not in line with pre-mass mortality levels, maintaining part-time jobs for fishers and less attractiveness for young people. | Short-term success: hatcheries still open, harvests & jobs preserved.<br>Long-term outcomes still pending. | 5 years after, high survival rate of farms despite the high larval mortality rates<br>The causes of OsHV-1-mVar emergence since 2008 onwards still unknown |

| Table B | Chesapeake Bay Oysters (*C. virginica*) | Matsushima Bay Oysters (*C. gigas*) | Bay of Quiberon Oysters (*C. Gigas*) |
|---|---|---|---|
| ADAPTIVE CAPACITY | Very vulnerable to changes in fresh water flow from storms, pollution levels, sedimentation which reduces population by about 50% per year.<br>Since the decline in the 1960s, alternative sources of income (other species) for fishers. | Changes of the bay environment caused by sudden Tsunami.<br>Sanitary inspection system in every prefecture under government subsidies. Complete sterilization of the virus at the infestation site by public sanitary expert. | Scientific support (Ifremer) with a good monitoring system of water and oyster quality.<br>Government support with intervention schemes (Agriculture Calamity scheme) |
| RESPONSES | A large scale restoration program was initiated in 2000: artificial reefs built in 2001 + intensive shelling (total cost of $2.4 M).<br>The state established oyster harvest rotational grounds opening (season time and length, daily limit, cull size set annually). Gear limitation (only hand scrapes).<br>Creation of brood stock sanctuaries (no-take zones) | Financial support from local government to compensate insurances of Cooperatives.<br>New laws on food safety.<br>Shucked oysters by heat treatment over 85 °C (Noro-virus is inactivated) but prices and incomes halved.<br>Test application of various natural chemicals to inactivate Norovirus.<br>Construction of sewage treatment facilities. | Government subsidies + tax alleviation<br><br>Reduction in the number of farms (from 80 in the early 2000s to 10 in 2010). |
| APPRAISAL | Increased oyster population on shelled grounds. For entire state largest oyster harvest in 26 years in 2012-13.<br>Increase number of violations of regulations including oystering at night, harvesting without a license, gathering undersized oysters. | Effective means for virus inactivation or useful technology to culture the virus have not been established yet. | Production of 15,000 t before 2006, half that level after. |

**TABLE C - List of criteria used in the multidimensional resilience analysis.**

| **R-dimensions / definitions / references** | **Criteria (I-ADApT questionnaire, literature)** |
|---|---|
| **H-Resilience** (Holling 1973 – static resilience of the natural system). The H-Resilience determines the persistence of relationships within a system and measures the ability of this system to absorb changes of state variables, driving variables, and parameters and still persists. | Q6. Prior to the main issue, what is the ecological status and habitat of the ecosystem at the ecosystem level (**L** if severely degraded; **M** moderately; **H** if not degraded)?<br><br>Q7. What was the productivity of the system prior to the main issue (**L**ow, **M**edium or **H**igh)? →**H** if high productivity; **M** if moderate; **L** if low) (Palumbi *et al.* 2008).<br><br>*Stability of the natural system (≠resilience) = variability around a state equilibrium. A system can be unstable but resilient (e.g. highly fluctuating climate conditions) and the other way around (in temperate systems not prepared to cope with climate shocks).* →***H*** *if high fluctuations;* ***M*** *if moderate;* ***L*** *if stable) (Holling 1973).*<br><br>*Probability of sustainable biomass (****H*** *if the biomass level is close to MSY;* ***M*** *if slightly beyond MSY;* ***L*** *if far beyond MSY).*<br><br>*Same abundance and number of species, number of trophic levels and interspecific interactions (****H*** *if true,* ***M*** *if partially true,* ***L*** *if false).* |
| **P-Resilience** (Pimm 1984 – "how fast the variables return towards their equilibrium following a perturbation" | Q24ab. What were the results of the short term and the long term responses of the natural system? (**L** if negative or positive but take years, **M** if months, **H** if weeks or days).<br><br>*Prior to the issue, did the natural system recover rapidly or not after an external shock? (****H*** *if rapid –few weeks to a couple of months-;* ***M*** *if moderate –few months to a couple of years-;* ***L*** *if slow recovery –years to decades).*<br><br>*"Greater connectance drives community and ecosystem stability" (McArthur 1955).* ***H*** *if high connectance with weak interactions on average;* ***M*** *if medium;* ***L*** *if few, but strong connections*<br><br>*Diversity-stability debate (McCann 2000). Multiplicity on the number of prey and predator reduces the dramatic changes of a population when one of the prey or predator declines in density (McArthur 1955). Most experiments show that "diversity is positively related to ecosystem stability" (McCann 2000, p. 230). "Ecosystem changes occur more quickly when ecological redundancy is low" (Palumbi et al. 2008, p. 36).*<br>***L*** *with only a few TL (1-2) and few species;* ***H*** *if great number of TL and species (e.g. 5 or more);* ***M*** *between these values.*<br><br>*Persistence of the natural system = "the time a variable lasts before it is changed to a new value" (Pimm 1984).* →***H*** *if the persistence of abundance and variety is high for years;* ***M*** *if it remains for a few weeks or months;* ***L*** *for a few days only.* |
| **S-Resilience** (Social and economic static resilience): ability of an economy to minimize welfare losses after | BI. Number of people affected by the Main Issue expressed as a ratio to the total number of people (**H** < 10%; 10 ≤ **M** < 20%; **L** ≥ 20).<br><br>Q8. How many activities were impacted by the main issue? (**L** if more than |

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| a disaster; "Reducing the consequences of failure and assuring business/service continuity under adverse conditions" (Rose 2004, 2007; Rose and Krausman 2013; Hallegate 2014). | two activities severely impacted ; **M** if two; **H** if one only)<br><br>Q9. Number of other livelihood opportunities? (**H** if more than two; **M** if one or two only; **L** if none)<br><br>Q10. What % of the total catch/production is used for household consumption (not sold)? (**H** if less than 20%; 20% ≤ **M** < 60%; **L** ≥ 60%)<br><br>Q11. What proportion of HH income comes from local sales of fish catches, processing, and wholesaling? (**H** if less than 20%; 20% ≤ **M** < 60%; **L** ≥ 60%)<br><br>Q22. What were the short term responses of the social system to the main issue? (**L** if no response; **M** if one or two only; **H** if there are more than two responses). |
| Economic resilience indices developed by Cutter et al. 2010; Bruneau et al. 2003; Jordan et al. 2011; Mayunga et al. 2007; Fisher et al. 2010 ; Norris 2011 ; Burton 2012; Rose 2009 (Rose and Krausman 2013, p. 79). | *State aid, insurance or any supporting emergency scheme at the local, regional, national or international levels (private insurance, mutual funds against natural disasters, tax policy, risk management plan, etc.)* → ***H*** *if the direct market and non-market costs –output losses, business interruptions, capital damages, casualties, lower demand…- are fully covered;* ***M*** *if they are partially covered;* ***L*** *if they are not covered at all).*<br><br>*Profits, savings, access to loans of fishers-farmers-households to cope with a business interruption for a few weeks or months* →***H*** *if amount equivalent to a 3 to 6-month activity;* ***M*** *if less than 3 months;* ***L*** *if none).*<br><br>*Inventories, excess capacity, relocation, opportunities of input substitution, import substitution, (Rose and Krausman 2013)* → ***H*** *if large capacity;* ***M*** *if moderate;* ***L*** *if low.* |
| **D-resilience** ("ability to reconstruct and recover quickly", capacity to innovate, to diversify…); "capacity of innovation and use of disturbances as opportunity" (Berkes et al. 2003; Hughes et al. 2005; Hertzler and Harris 2010) | (Q11). Change of HH % income coming from local sales of fish catches, processing, and wholesaling? (**H** if the rate is lower or equal to -5%; **M** if the rate is negative and greater than -5%; **L** if no change)<br><br>Q22. What were the long term responses of the social system to the main issue? (**L** if no response; **M** if one or two); **H** if three or more responses).<br><br>*Degree of diversification. Capacity of fishers/farmers to turn to other marine productions or to alternative jobs. (****H*** *if more than two alternatives;* ***M*** *if one or two alternatives and* ***L*** *if none).*<br><br>*Ability of fishers/farmers to innovate (proved in the past);* → ***H*** *= strong innovating capacity;* ***M*** *= moderate;* ***L*** *=poor*<br><br>*Turnover of marine products over time –seasonally, from year to year…- (vs stability)* →***H*** *if frequent turnover;* ***M*** *if moderate;* ***L*** *if stable and limited scope of goods.* |
| **STG-Resilience** (Short-term governance: Collective capacity to cope with disturbances with existing institutions) (Hughes et al. 2005; Charles 2007; Kajitani and Tatano 2009*).* | Q15. What are the key rules, regulations, instruments and measures employed to achieve the management objectives? (**L** if none, **M** if input or output measures alone, **H** if both input and output measures or formal co-management)<br><br>Q16. Are there any informal rules, regulations, instruments and measures that play an important role in the governance of fisheries and aquaculture? (**L** if none, **M** if one or two, **H** if more than two).<br><br>Q19. How concentrated is social power in the area? (on a 5-point scale: **L** if |

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|---|---|
| | dispersion; **M** if moderately concentrated; **H** if concentrated)<br><br>Q22. What were the short term responses of the governing system to the main issue? (**L** if no response; **M** if limited; **H** if variety of responses). |
| **LTG-Resilience** (Long-term governance: ability to reform existing institutions and strengthen the adaptive capacity of the system in the LR); "supporting flexible institutions and social networks in multi-level governance systems" (Hughes et al. 2005). | Q17. Nature of the relationship between occupations (conflict / cooperation on a 5-point scale)? (**L** if conflict; **H** if cooperation; **M** in-between)<br><br>Q18. Who dominates or wields the most social power in the area? (**L** if very centralized –government-; **M** if devolved power to regional officers; **H** if very decentralized –fishers associations).<br><br>Q20. Were there any structural changes in the governing system or individuals prior to the main issue? (**H** if large, **M** if some, **L** if no change).<br><br>Q21. Were there any changes to the key rules, regulations, instruments and measures, or have any new ones been introduced prior to the main issue? (**L** if no change; **M** for several new rules; **H** of many new rules).<br><br>Q22. What were the long term responses of the governing system to the main issue? (**L** if no response, **M** if limited, **H** of variety of responses).<br><br>*Research-development capacity (number of researchers, facilities, national or regional funding schemes, quality of research measured by the number of publications on the issue, creation of panels, clusters,…) to cope with the issue (**H** for high capacity, **M** for medium and **L** for low capacity).*<br><br>*Degree of compliance and acceptation of new rules and institutions (**H** for strong degree of compliance, **M** for moderately organized or **L** for individualism and non-organized behaviors).* |

Legend:

BI = Background information in the I-ADApT questionnaire. All criteria with a Q(question) number are taken from the I-ADApT questionnaire (http://www.imber.info/Science/Working-Groups/Human-Dimensions/I-MBER-ADApT).

The variety and nature of answers given by experts in the I-ADApT framework and sometimes found in the literature are far richer (included in *italic* in the table). These answers can therefore be used to extend the list of criteria (e.g. research-development capacity related to the main issue, government financial support for the fishing/aquaculture industry, etc.).

**TABLE D – Monte Carlo analysis of Multidimensional Resilience Index**

**(500 random trials - uniform distribution law)**

| | MB | PS | BB | CB | BdC | BQ |
|---|---|---|---|---|---|---|
| **Mean** | 0.40 | 0.33 | 0.31 | 0.29 | 0.18 | 0.05 |
| **St. Dev.** | 0.07 | 0.08 | 0.06 | 0.06 | 0.04 | 0.02 |
| **Mean St. Error** | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| **Minimum** | 0.23 | 0.14 | 0.17 | 0.13 | 0.08 | 0.00 |
| **First Quartile** | 0.35 | 0.27 | 0.26 | 0.25 | 0.15 | 0.04 |
| **Median** | **0.40** | **0.32** | **0.30** | **0.29** | **0.18** | **0.05** |
| **Third Quartile** | 0.45 | 0.38 | 0.34 | 0.33 | 0.21 | 0.07 |
| **Maximum** | 0.57 | 0.56 | 0.46 | 0.44 | 0.31 | 0.10 |
| **Skewness** | 0.08 | 0.17 | 0.24 | 0.08 | 0.19 | -0.06 |
| **Kurtosis** | -0.65 | -0.22 | -0.33 | -0.16 | -0.41 | -0.63 |

Legend: MB = Matsushima Bay, PS = Puget Sound, BB = Bay of Bourgneuf), CB = Chesapeake Bay, BdC = Barra del Chuy, BQ = Bay of Quiberon.

Interpretation: Skewness identifies how symmetrical the distribution is; a long tail to the right (left) has a positive (negative) skew. Kurtosis identifies how Gaussian the distribution is: a flatter (more peaked) distribution has a negative (positive) value.