Value of Exclusion Zones as a Fisheries Management Tool in Europe

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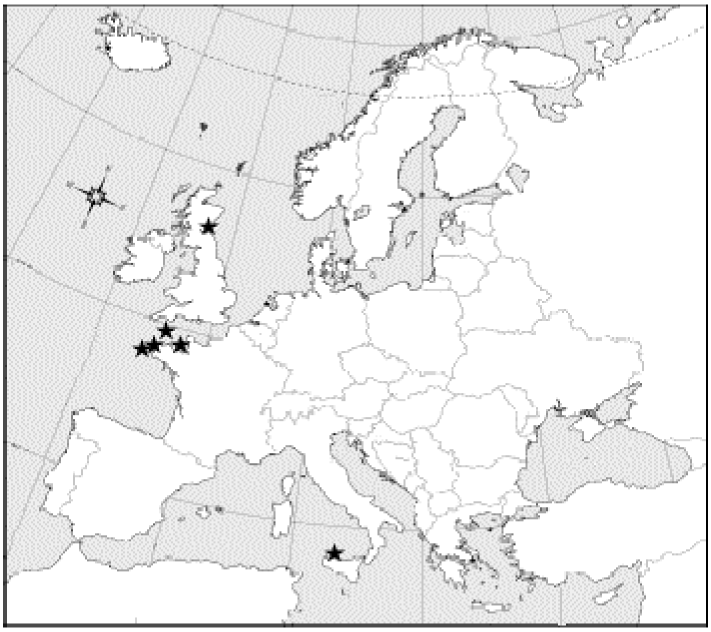
D9/D11 Value and its Sensitivity to Data Uncertainty



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Fisheries Exclusion Zones: Value and its sensitivity to data uncertainty

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This paper focuses on the findings of the project that pertain particularly to the determination of the value of fisheries exclusion zones and the sensitivity of value estimation to data uncertainty. It necessarily draws on both the literature review and the case studies and in terms of its content extracts, presents and summarises the pertinent material therein covered. By collating this material a more directed consideration of the topic of value is facilitated and the findings of the study as a whole more clearly highlighted, and through consideration of uncertainty, also qualified.

1. Evidence of value from the literature

Ideally, value is determined against criteria prescribed by the objectives for which an exclusion zone was implemented, with the determining and auditing of value against these criteria a requirement of the ongoing adoption of any management measure. However, it is evident that, in comparison to the Caribbean and the South Pacific, very few articles have been written cataloguing, describing and analysing the effects of exclusion zones in Europe. With the exception of a few fishing boxes, such as the plaice box, the details of the effects of European exclusion zones are seldom seen in the scientific literature. In addition many exclusion zones are characterised by multiple and changing objectives over time and the absence of any performance criteria or monitoring.

Exclusion zones in the context of the project may be regarded as synonymous with marine protected areas (from here on referred to as MPA), which refer to “any area of the marine environment managed for the primary purpose of preserving biodiversity, aiding in the recovery of overfished stocks, and to ensure the persistence of healthy fish stocks, fisheries and habitats either as multi-use, zoned or no-take areas” (Himes, 2002). In this project, however, the foci is not the value of exclusion zones in general, but rather the value of a subset thereof - fisheries exclusion zones. Fisheries exclusion zones pertain to those exclusion zones that either directly or indirectly exclude fisheries in some form (either intentionally or otherwise). Value in the context of this project is also defined in terms of the value to fisheries (in its broadest sense).

1.1 Potential within the Literature/theory

Exclusion zones are purportedly one of the most effective tools in marine conservation and a valuable component of a successful fisheries management plan, if designed and implemented effectively. They are attributed as holding the potential to build up fish biomass and facilitate growth and reproduction of a number of over-fished or otherwise endangered species, thus creating positive economic as well as environmental benefits (Pipitone *et al*, 2000; Nowlis, 2000). They are correspondingly perceived as a key mechanism for integrating the precautionary principle into fisheries management and protecting fish from excess fishing mortality (Roberts, 1997).

From reference to the various objectives laid out for the different categories of exclusion zones it is possible to elicit the value anticipated from their creation. However, whether this is achieved or not is not prescribed. Drawing on the literature addressing scenarios in which fisheries are in some way included within the objectives for which an exclusion zone is created, in addition to the expectations raised in the previous paragraph the anticipated value lies in the contribution they make to:

- decreasing by-catch and the landings of over-exploited and depleted fish stocks
- reducing fishing mortality on fishes that have not yet reached the age of sexual maturity (growth overfishing)
- increasing the life-span and size reached by individuals within the stock
- increasing the reproductive potential of stocks
- reducing the potential for stock collapse
- protecting natural habitats from fishing gear impacts or assisting in their recovery
- maintaining the integrity and biodiversity of the ecosystems supporting fisheries (e.g. posidonia beds)
- mitigating user conflicts
- increasing the economic benefits available to local fishers
- increasing awareness of fisheries and their associated issues through education
- supporting existing legal provisions (e.g. illegal trawling areas, not complied with)
- supporting categories of fisheries (e.g. artisanal fleets)
- knowledge and research

In terms of whether this potential is manifest in reality, the existing literature provides some useful evidence. The following discussion draws such evidence. While the detailed consequences of exclusion zones depend on their design and situational attributes, the focus here is on drawing generic conclusions.

1.2 Biological/ecological aspects of value

1.2.1 Recruitment

The theoretical literature pertaining to exclusion zones conveys an expectation that the fish living within a no-take zone will produce larger quantities of eggs (Jennings *et al*, 2001; Johnson *et al* 1999) and that there will be enhanced survival of individuals. Direct, observable evidence of the former is not evident within the literature for European exclusion zones. However, gains in recruitment have been observed in a number of cases and can be implied through evidence of increased abundance and biomass. In terms of recruitment, an early assessment of the effects of the plaice box saw the anticipated rise, albeit that the increased fishing effort by exempted vessels throughout the year and heavy fishing in the fourth quarter reduced the gain in recruitment to 8% from 25% (Anon, 1994). In contrast, for a more sedentary species, lobster, the protection afforded by a crustacean reserve was found not to have generated evidence of enhanced larval settlement resulting from spawning stock reserves (Childress, 1997), although there is evidence of enhancement by market-sized lobsters emigrating from protected areas.

1.2.2 Abundance

In terms of abundance, there is a greater body of evidence supporting this aspect of the value of exclusion zones, although it is apparent that changes in abundance are not necessarily positive, if change is experienced at all.

In at least two examples, the protection afforded by an exclusion zone has failed to produce a change in abundance. There was no clear evidence of changes in plaice abundance attributable to the restrictions on fishing within the plaice box, although there were increases in the relative abundance of larger size classes of a variety of exploited species (Piet & Rijnsdorp, 1998). Similarly there were no significant differences in the abundance of fish or mobile invertebrates between an area closed to towed gears in Limfjord (a shallow, brackish inlet in Denmark) and open areas 9 years after closure (Hoffmann & Dolmer, 2000). In both these cases, however, there may be semi-related/external factors masking the effects of protection from fishing: notably fishing pressure on the margins of the box in the case of the former and eutrophication and environmental hypoxia in the latter (Hoffmann & Dolmer 2000). There may also be a temporal dimension at work, as illustrated by a number of exclusion zones reported in the literature.

In the month following the end of a trawling ban near Chioggia the total CPUE of experimental fishing was enhanced 2.8 times in an area within 1 mile of the coast and by 1.6 times in the area between 2 and 3 miles of the coast, as compared to CPUE before the ban (Pranovi *et al.*, 1996). However, any increase disappeared over time, such that eight months after the end of the ban there was no evidence of any increase, and the total CPUE showed no significant difference with that of the pre-ban period. Certainly there is evidence in a number of cases of trends stabilising over time, or benefits disappearing after the removal of protection as one would expect.

The Cyprus trawling ban demonstrates well the stabilisation of change. The ban was shown to enhance the total catches of the trawling fleet (at constant effort) by 12% during the year of implementation of the ban (Garcia & Demetropoulos, 1986). In the second year, total catches increased by 70% when compared to the previous year (i.e., an increase of 80% of the total catches between 1981 and 1983). However, the total catch in the third year stabilised at the same level as the previous year. The small-scale fishery in the areas also experienced a 6% increase in total catch in the first year, a 42% increase in the second year, stabilising in the third year. The Gulf of Castellammare trawling ban, likewise, exhibited a stabilisation of change in abundance over time. In this example, there were dramatic increases in abundance during the early years, but the degree of change reduced over time.

The Gulf of Castellammare trawling ban also demonstrates some of the largest increases in abundance arising from a European exclusion zone cited in the literature. Four years after the implementation of the trawling ban, the total CPUEs obtained in experimental trawl surveys underwent a 8-fold increase as compared to CPUEs obtained two years prior to the ban (Pipitone *et al.*, 2000; Whitmarsh *et al*, 2002). Similarly, increases in overall CPUEs and biomass were also seen eight years after the institution of the ban. The Tabarca marine reserve is another example demonstrating increasing overall CPUEs, along with higher overall catch rates for the local small-scale fishery (although the number of fishers had also increased in the reserve and the *Posidonia* meadows were regularly trampled due to tourism pressure) (Ramos *et al*, 1992). Also in the Mediterranean, the Medes Islands Marine Park similarly experienced significantly higher overall abundance; higher abundance of vulnerable and large species targeted by spearfishing; and higher density inside the protected area as compared to outside it (Garcia Rubies and Zabala, 1990a).

It needs to be noted, however, that such shifts in abundance do not occur uniformly across species. There are several studies and exclusion zones that have demonstrated a shift in the relative abundance of species. In the Gulf of Castellammare trawling ban case the red mullet, *Mullus barbatus* showed the highest recovery across all the time-scales studied (possibly related to the young age at first maturity of this species, which would allow a rapid recovery of the population when subjected to a much lower fishing pressure (Garcia & Demetropoulos, 1986; Relini *et al.*, 1996; Pipitone *et al.*, 2000)). However, the variation is made most evident by contrasting the range of responses, the closure producing an increase ranging from 1.2 (musky octopus) to 497-fold (gurnard), with CPUEs of horned octopus, *Eledone cirrhosa* actually decreasing after the ban. A similar effect was also noted by Relini *et al* (1996) after the enforcement of a 45 days trawling ban in the Ligurian Sea. A higher value of CPUE of fishes was recorded overall, however, *Pagellus erythrinus* and *Spicara flexuosa* showed no significant variation in abundance, while octopus (this time *Octopus vulgaris*) again experienced a decline relative to before the ban (as in the Castellammare experience). Both Relini *et al* (1996) and Pipitone *et al* (2000) emphasized the negative response of the abundance of some species of cephalopods (namely *O. vulgaris* and *E. cirrhosa*) to the implementation of trawling bans. A similar story is also told for the Scandola marine reserve. Francour (1994) found a higher abundance of rare and vulnerable species inside the reserve, as compared to outside areas. Intermediate and large length classes were also more abundant inside relative to outside the reserve (Bell, 1983b; Francour, 1994; Dufour *et al.*, 1995; Francour, 1996). However, Dufour *et al* (1995) observed that the abundance of nine fish species, four of which are highly sought after by fishermen (*Diplodus sargus, Oblada melanura, Symphodus tinca* and *Mullus surmuletus*), were actually greater outside the reserve than inside. Prey-predator relationships, the expansion of opportunistic species and the cascade effect may be responsible for this result.

1.2.3 Size of individuals/growth

Allied closely with abundance, exclusion zones through the protection they offer are expected to also result in a greater proportion of larger individuals within the stock, as a result of reduced fishing mortality and higher survival rates (Jennings *et al*, 2001; Johnson *et al* 1999).

There are a few examples within the literature pertaining to European exclusion zones where this has held to be true, interesting with a focus on crustaceans. Research in an area of 1.05 km^2 on the west coast of Sweden closed to fishing for lobsters (*Homarus gammarus*) in 1989, specifically to investigate the potential fishery benefits of protecting a portion of the spawning stock (Ulmestrand, 1996), found that the total mortality rate of lobsters in the closed area had decreased as expected and a greater proportion of lobsters survived to larger sizes. Latrouite (1998), reporting on the results of experimental fishing in the northeast Atlantic crustacean reserves, also highlights the positive relationship between protection and the larger size of lobsters within reserves. Similar results have also been obtained for spiny lobster (Palinuridae) in reserves elsewhere in the world (Chubb, 1994). However, even for *homarus gammarus* the effects are not clear-cut. In the Swedish reserve there was an indication of reduced female growth rate, perhaps as a result of increased population density. Unfortunately, since no contemporaneous samples were taken in fished areas, it is not possible to know whether growth rate was reduced only in the reserve (Ulmestrand, 1996). Positive benefits are not exclusively the preserve of crustaceans however. Francour (1994) in studying the Scandola marine reserve found that intermediate and large length classes for a range of species were generally more abundant inside than outside the reserve (Bell, 1983b; Francour, 1994; Dufour *et al.*, 1995; Francour, 1996).

Not all previous studies have found the relationship to be positive however. Pastoors *et al.*, (2000) found that the growth rate of juvenile plaice was reduced in the early years of the plaice box by an amount that would be expected to nullify the benefits of reduced fishing intensity. With slower growth the pre-recruit period is extended and the potential for discard mortality increased. The reasons for reduced growth are not clear. However, part of the reduction has been potentially attributed to an increased population density of fish, resulting from high levels of settlement in the late 1980s. Vassilopoulou & Papaconstantinou (1999) in studying Greek trawl bans also found there to be no difference in the mean length of the species they targeted (*Merluccius merluccius*, *Mullus barbatus* and *Pagellus erythrinus*) between the banned and open areas.

1.2.4 Succession

One potentially significant by-product of the reduced fishing mortality and higher survival rates induced by exclusion zones is a shift in the relative abundance of different species. Certain species thrive under protection, while other species suffer through, for example, increased predation and changes in their habitat. Depending on the objectives of the exclusion zone, these effects may be desirable or not.

With respect to the plaice box, it has been suggested that trawling maintains a benthic community comprised of small, productive invertebrates, and that reducing trawling disturbance actually limits the food supply for juvenile flatfish (Rijnsdorp *et al.*, 1998). As noted previously, o*ctopus vulgaris* is another species that does not necessarily benefit from protection, with both Relini *et al* (1996) and Pipitone *et al* (2000) emphasizing the negative response of the abundance of some species of cephalopods (namely *O. vulgaris* and *E. cirrhosa*) to the implementation of trawling bans. Such shifts in the relative abundance of predator and prey species and the loss of opportunities for species that thrive on disturbed seabed can result in a change in the overall species composition of the area, the implications of which should be thought through prior to the installation of an exclusion zone.

Such change need not be a universal occurrence, however. Hoffmann & Dolmer (2000), when sampling fish as well as epibenthos within and outside an area of 40 km^2 closed to towed gears in Limfjord (as noted, a shallow, brackish inlet in Denmark) they found that there were no significant differences in the species composition of fish or mobile invertebrates between the closed and open areas 9 years after closure. While, eutrophication and environmental hypoxia in Limfjord probably masked any effects of protection from fishing (Hoffmann & Dolmer, 2000), this is a potential outcome worthy of note.

In general, however, where specific species are not the foci of protection but rather species richness or diversity, previous studies have found the outcomes to be more favourable. For example, Vassilopoulou & Papaconstantinou (1999) identified a greater number of species and higher species diversity within Greek year round trawling ban areas. Similarly Garcia Rubies and Zabala, (1990a) found species richness to be significantly higher inside the protected area of the Medes Islands Marine Park than outside it. A further example is the Archipelago de Cabrera National Park, the primary purpose of which is to protect biodiversity and promote educational and cultural activities. The reserve has proven biologically successful in terms of sustaining high diversity, attributed to the park's offshore location and level of protection (Francour *et al*, 2001).

1.2.5 Biomass

As one would expect, these changes in species composition and those previously noted for abundance and size also have a manifestation in terms of biomass. Vassilopoulou & Papaconstantinou (1999) reported higher levels of total biomass in areas totally closed to trawling within Greece relative to areas where trawling was allowed for six months every year (from 1 October to 31 March). Similarly, Francour (1994) reported that density and biomass data for rocky substrata in the Scandola Nature Reserve showed higher values for areas protected by the integral reserve than for those within the partially and non-protected zone.

However, Francour (1993) and Bell (1983a) also noted that there is a habitat effect, by highlighting that the results reported above for rocky sub-strata contrasted with those for seagrass beds in the Scandola Nature Reserve, where no differences in density or biomass data were evident between the protected and unprotected areas. As one might expect given indications that trawling bans may limit food supplies for juvenile flat fish, changes in species specific biomass need similarly not be positive: the yields from the plaice fishery and the estimated spawning stock biomass have decreased substantially since the establishment of the plaice box, albeit not necessarily attributed to the action of the trawling ban itself (Pastoors *et al*., 2000).

1.3 Economic aspects of value

Moving on from biological and ecological aspects of value to socio-economic ones within the literature, it is evident that although there is a growing body of literature pertaining to the biological value of fisheries exclusion zones in Europe, there is surprisingly little dedicated to the consideration of the impacts on the fishermen dependent on the resources being protected. The assumption is often one of long-run benefits, through either the recovery of stocks within a zone that is to eventually be reopened to managed fishing or via spillover effects, whereby the emigration of target species for local fisheries from unfished areas to fished areas results in increased economic benefits for local fisheries (Johnson *et al*, 1999).

By design, exclusion zones aim to exclude fishing effort, but the scale and the socio-economic implications of that exclusion have seen little quantification. The plaice box illustrates the potential scale of the effect, however. The closure of the box to heavy trawling throughout the year from 1995 resulted in total effort falling to around 6% of pre-box levels (Pastoors *et al*., 2000; FSBI, 2001).

In contrast, for the Tabarca marine reserve, a positive effect is recorded. The only activities that are prohibited from the Tabarca reserve are diving (only 30 divers a year are allowed to enter the reserve due to opposition from local fishers) and angling (Badalamenti *et al* 2000).

However, fishing is also strictly reserved for local small-scale fishers. Ramos Espla *et al* (1991) reported that five years after the establishment of the reserve in Tabarca, the proportion of catches of high priced species (*E. guaza, Dentex dentex, Sparus auratus, Seriola dumerili*) increased around the reserve, which along with increases in overall catches has contributed to improvements in the economic performance of fishermen in the area. An indicator of this is the index of renovation of boats: the Tabarca fleet had the largest proportion of renewed boats (75%) in the district of Valencia since the establishment of the reserve. Positive economic benefits have also been recorded in respect of the Gulf of Castellammare trawl ban, which has been the subject of prior socio-economic studies. Again the benefits lie with the artisanal fleet permitted to operate within the ban area. Refer to the subsequent discussion of this case study for further elaboration.

1.3.1 The undermining of value

As suggested above, the positive value of fisheries exclusion zones in not necessarily a given. In addition to the above mentioned biological and ecological reasons for why the value of fisheries exclusion zones may not match that anticipated, there are a number of design and socio-economic factors. In terms of the design of marine exclusion zones generally there is a large body of theoretical literature that discusses the potential layout and sub-zoning arrangements, the size of 'effective' zones and their temporal continuity. However, in terms of empirical evidence for European reserves, there has been little dedicated coverage. One example of where the design of a fisheries exclusion zone has been shown to be a constraint on its value is the Mackerel box. In this instance the creation of an exclusion zone of fixed coordinates was shown to not necessarily cater for the inter-annual shifts in the distribution of stocks, including the vulnerable life stages, such that the level of protection offered varies from one year to the next (Lockwood, 1988; Clark, 1998). Similarly, while there is much literature pertaining to the necessity to control fishing effort outside an exclusion zone and/or within a partial exclusion zone to avoid the dissipation of the benefits arising from exclusion (Shepherd, 1993; Horwood *et al*., 1998), there is little empirical evidence within Europe. One exception is work undertaken in respect of the plaice box.

Within the European empirical literature, the predominant socio-economic factor undermining the value of fisheries exclusion zones is not the failure to control fishing effort, but rather the failure to control tourism and recreational impacts. There are multiple examples of this within the literature. A pertinent one to start with is the Ustica Island Marine Reserve (UIMR). While a visitor centre, aquarium, reserve guides, and research have increased overall awareness of the reserve among the general public and scientific research community, negative effects have been recorded as well. Although fishing has historically been an important aspect of the local economy, recent years have shown a rapid decrease in the number of registered fishermen; potentially indicating that fishermen are seeing a decrease in the marine resources available to them and are, therefore, leaving the industry (pers. comm. with the port authority). However, since the institution of the reserve, an increase of approximately 35,000 visitors has been seen (in just four years) (Badalamenti *et al*, 2000), causing significant potential damage to the resources of the reserve (Himes, 2002). The Portofino Marine Reserve in Italy, one of eight Italian reserves currently awaiting a management plan, is experiencing similar pressure. Here, current development and tourism activities are significantly degrading the local coastal ecosystems, and the scale of current tourism and its impacts is leading to protects by local authorities and stakeholders against the establishment of a marine reserve because of the potential impacts on tourism and recreational activities in the area (Salmona and Verardi, 2001). Again in Italy, the Tabarca marine reserve has experienced a regular increase in visitors, which while generating a boost in the tourism infrastructure of the island is leading to the serious trampling of the *Posidonia* meadows, with potential implications for fisheries supported by the important spawning and nursery ecosystems (Badalamenti *et al* 2000). However, the local small-scale fishery seems at present to be increasing its overall catch rates (Ramos-Espla *et al*, 1992), with both a growing number of fishers and an increasing CPUE.

There are also other examples. Ecologically, the Medes Islands Marine Park's downfall is that there were no limits on diving in the park until 1990, when a cap was placed on the number of divers allowed per day. While contributing to the economic prosperity of the local area, the shear numbers of divers has led to a severe decrease in biodiversity (Francour *et al*, 2001). Diving has damaged the *Posidonia* beds and many other important benthic organisms (Sala *et al*, 1996; Zabala, 1996). However, Garcia Rubies and Zabala, (1990a) noticed that some highly spearfished species such as *Epinephelus guaza* and *Sciaena umbra* were observed exclusively in the reserve, and that, in strictly biological terms: species richness; overall abundance; abundance of vulnerable and large species targeted by spearfishing; and density were all significantly higher inside the protected area as compared to outside it. Pozo (1998), likewise, has drawn attention to the substantial human impact of tourism, on this occasion within the Archipelago de Cabrera National Park where dramatic increases in tourism and the lack of regulatory constraint on growth has contributed to a 10 fold increase in the number of licenses for sail boats, a doubling of the number of moorings and a three fold increase in the number of dive trips.

One might hypothesize that the socio-economic contribution of such tourism to the local and national economy may in some way compensate for the reduction in value caused in other respects. However, the contribution of tourism and leisure use does not necessarily compensate for its impacts, as demonstrated by Francour *et al* (2001) for the Port-Cros National Park. Established in 1963, the park is subject to intense seasonal tourism, however, tourism and diving have had a very small impact on the environment and economy of the island (Badalamenti *et al*, 2000).

1.4 Conclusions from the literature

In a general sense, it can be said that while many fisheries exclusion zones probably have problems with enforcement, community support and achieving the overall objectives of the management regime, evidence has been presented showing that when MPAs are managed well they can provide substantial benefits to stakeholders that utilize the area and its resources.

A prime example of this has been seen in trawling bans. The major effect of a short trawling ban (1 or 2 months) implemented in the correct period and area seems to save useless waste of undersized fishes by delaying catches for a period equal to the duration of the ban, thus contributing to the avoidance of growth overfishing. In turn it does not have any significant long-term influence on fish populations and on catches. Short trawling bans seem to be effective immediately after their implementation (Pranovi *et al.*, 1996). On the contrary, longer duration fishing bans (5 to 12 months) have long-term effects by enhancing catches for the whole period following the prohibition. As this management tool affects more deeply the population dynamics of fish populations, the new equilibrium of the fishery is reached after a longer time period (3 years in the case of Cyprus). A similar example can be seen in the Gulf of Castellammare (Italy) where a 8-fold increase in biomass was found (Pipitone *et al*, 2000).

Other major benefits have been seen in the mackerel box off the Cornish coast where juvenile mortality was significantly reduced and the Tabarca Marine Reserve where local fishers have realized increased economic returns as they catch more fish in areas adjacent to the reserve. In many reserves, it has been reported that overall abundance, species diversity and the abundance of large and rare species are all significantly higher inside the protected areas compared with unprotected areas (Francour *et al*, 2001; Garcia Rubies and Zabala, 1990a). However, there have been some unplanned consequences as a result of the implementation of fisheries exclusion zones. This can be seen in the Ustica Island Marine Reserve where CPUE has decreased because of the overall isolation of the reserve from other spawning areas and in the Bouches de Bonifacio Nature Reserve where boating and diving have increased substantially since the installation of the reserve, causing intense pressure on the environment that is unregulated.

2. Case study evidence of value

The paper now moves to explore the particular findings of the case study component of the project for the value of fisheries exclusion zones. As evident from the preceding discussion, the value of exclusion zones is diverse in form and circumstance specific. This is an observation upheld by the findings of this study. Consequently, the discussion of value here is presented by individual case study.

The findings as to value presented derive from a range of analytical techniques and methods, employed by the project specific to answer the key questions relating to the effectiveness and value of fisheries exclusion zones. In four of the six case studies, fisheries exclusion zones and their effects were evaluated *ex ante* (i.e. prospectively) in order to see how the fisheries or other activities might be impacted by their introduction. The other two cases involved an *ex post* (i.e. retrospective) assessment of exclusion zones that are already established. Necessarily bioeconomic models and/or biological models featured prominently in these assessments, both in response to the objectives set and the pre-defined scope of the project. Other approaches, however, were also used to investigate the wider context and provide supplementary information to facilitate interpretation where desirable and feasible within the scope of the resourcing of the project.

Case study	**Exclusion zone**	**Key features of the analysis**
Gulf of Castellammare, NW Sicily	Existing	Biological assessment, bioeconomic modelling, and sustainability analysis of the artisanal fleet
Sea bass in the western English Channel	Proposed	Bioeconomic model based on Channel metiers defining specific gear types and locations
Nephrops in the Firth-of-Forth, Scotland	Proposed	Biological model (age structured) but including price and revenue impacts
Iroise Sea, NW France	Proposed	Bioeconomic model based on a predator-prey relationship and using indicative parameter values

Bay of Brest, NW France	Existing	Financial impact model but not accounting for full bioeconomic interactions
Normand-Breton Gulf, NW France	Proposed	Bioeconomic model incorporating the resource interactions linked with discarding

Given that the evident differences in the scenarios faced in each of the case studies and differing data availabilities, no one methodological approach was appropriate to their analysis. Consequently, no one modelling approach was used, with the choice of models reflecting the requirements of the specific case study and the data challenges faced. Utilising a range of case studies and models has permitted different aspects of the performance and value of fisheries exclusion zones to be explored, yet at the same time requires the following caveat to be made to the interpretation of value: notably that given the unique scenario faced, and the different data sources and modelling frameworks used in each case study, the findings of each cannot be considered directly comparable. However, the form taken, the order of magnitude and the limits or constraints acting on the effectiveness and value of fisheries exclusion zones as fisheries management tools are well illustrated, serving to inform their subsequent evaluation and use as a management option.

2.1 Gulf of Castellammare Trawl Ban

The Gulf of Castellammare trawl ban is probably one of the best fisheries exclusion zone studied in the Mediterranean Sea, making it a particularly valuable case study for the project. The objectives for this case study were to consider the effects of the trawl ban on fish stocks, the artisanal fleet permitted within the ban area and on the trawlers excluded from the ban area. In particular, the consequences of lifting the trawl ban (partially and wholly) were modelled to establish how this would jeopardise the sustainability of the artisanal fishery, under a number of alternative management scenarios. A bioeconomic model was developed for the Gulf, along with an economic and social appraisal of the artisanal fleet and its economic sustainability.

2.1.1 Catch per unit of effort (CPUE)

Trawl surveys were undertaken as part of this case study to provide the up to-date biological and catch data required for useful modelling outputs and to provide for the comparison and contrast of the ban area and the area outside of the ban. These surveys were undertaken at three depth-stratum in the Gulf, in different seasons (from summer 2000 to spring 2001) and using the same vessels and gears as used in previous surveys in the area. The surveys revealed 121 species plus 6 unidentified higher taxa, including crustaceans, cephalopods and fish species. For the “highly commercial” of these species, the season and stratum combinations revealed the highest CPUE to be found in spring in the 10-50m stratum (str. A) and the lowest CPUE to be found in the 101-200m stratum (str. C) during the same season, indicating differences in abundance between the different strata rather than clear seasonal variations. The most abundant of the target species generally were red mullet (density: 311.2 kg/km^2, biomass: 49.8 t) and hake (density: 96.8 kg/km^2, biomass: 15.5 t).

When these 2000/01 results are compared against those of earlier trawl surveys (1993-94 and 1998-99) some interesting observations are made. Notably, that while CPUE increased in the initial years after the imposition of a ban or exclusion, this increase levelled off. If the yearly average is taken, the catch in 1998-99 exceeded that in both the other two time periods, both for the total area and for each stratum. When the single seasons are considered, 1998-99 figures for CPUE are also higher generally, with the exception of those relative to the winter and spring of 2000-01 for stratum A. Due to the high variability between catches in each of the survey sample area within the Gulf, these differences generally proved not to be significant, but they do demonstrate a levelling off of the gains to CPUE from protection, over time.

2.1.2 Fishing yields and catch composition

In terms of the differential in fishing yields between the protected zone and the area outside it, the experimental trawl catches were found to be generally higher within the zone than outside it. For the Gulf of Castellammare this differential was greatest in 2000-01 than in the previous years assessed. This would imply that the trawl ban led to strong increases in the protected portion of the stocks, while the non-protected portion probably suffered a higher exploitation by trawlers than prior to the ban. Biomass within the trawl ban areas has increased significantly. In saying this, however, there is also evidence from interviews and other sources (albeit sparse) that trawlers are increasingly encroaching on the zone as time goes on (Pipitone et al., 2001), corresponding to a reduction in coastguard patrols. Illegal trawling in the eastern most parts of the Gulf is already impacting negatively upon the artisanal vessels operating from those ports and the trawler owners are generally pressing to be permitted renewed access to the Gulf to take advantage of the enhanced stocks therein (a measure of the ban's success itself).

As with other examples of exclusion zones, the Castellammare trawl ban case study, however, also demonstrated that any gains in stocks and fishing yields arising from protection are not universal across species or time periods. Pipitone et al. (2000b), using experimental trawl survey data, demonstrated that some species declined between 1993-94 and 1998-99. In addition, the increases experienced by other species and for the total catch were also much lower than those increases recorded between 1987-89 and 1993-94. CPUEs of the total catch in 2000-01 were generally lower than in 1998-99. In terms of the species composition, it is particularly the abundance of medium and high value species that has fallen since the ban was imposed. Catches are now dominated by medium and low value species. From the bioeconomic model, concentrating on 5 of the main species for which data was more readily available it is evident that despite the above observation, catches of these species are stable, and in two of the artisanal ports are contributing significantly to total catches (Balestrata and Castellammare). In Trapetto and Terrasini a greater proportion of the total catch comes from other species, although these 5 species also feature.

2.1.3 Revenue and profits

The bioeconomic model also found the revenues for the 5 target species to be stable (highlighted by both the simulation and optimisation of boats in the fishery resulting in the same solution). The revenues to the fishery were also shown to be relatively stable by the modelling of the consequences for revenues of changes in the numbers of artisanal craft in the fishery.

The benefits of protection measured in terms of revenue, however, have not been felt uniformly across the artisanal fleet. The levels of revenue, for example, achieved in

Balastrate are higher than for the other ports, attributed in part to the more formal market structure in the vicinity. In contrast, the situation in Trapetto is considered to be unprofitable in the long-term despite current stock levels and the existence of the trawl ban. If the trawl ban was to be removed, the situation in Trapetto would be made even worse and all artisanal fishers within the Gulf would see their revenues deteriorate. The illegal trawling encroaching on the eastern side of the trawl ban area already provides an indication of the potential adverse effects of the removal of the trawl ban for the profits of the artisanal fleet. However, if a seasonal lifting of the ban was done in part of the Gulf, then the effects may not be as great as expected.

2.1.4 Simulated changes to the existing trawl ban

Against the baseline of the existing situation, certain scenarios were modelled to establish the effect of changing and removing the current trawl ban: permutations of seasonal, permanent, complete and partial relaxation in combination with trawlers of different fishing powers. The bioeconomic model was a long-term equilibrium based model where any solution suggests the sustainability of the modelled stocks at the levels indicated. It was developed fundamentally as a simulation tool, to evaluate effects on the artisanal fleet given the current structure of the fleet with “current” activity levels. Using this approach a range of consequences were highlighted.

(i) Year-round changes

Simulations of the effect of removing the trawl ban showed the consequences for the artisanal fleet to be dramatic, especially under the worst case scenario modelled: the total, year round removal of the trawl ban and the influx of trawlers with ten times the fishing power of the artisanal fleet. Under this scenario, economic profit would be halved over the long-term, with revenue experiencing a reduction of around 25%. As one would expect, the scale of the effect of this complete removal of the trawl ban exceeds that arising from the other management options modelled.

The effect of the scenario involving the reduction in size of the trawl ban area, through permitting trawling within area C, was shown to be much smaller, both in terms of profit and revenue. As with the total removal of the ban, the relative differential in fishing power between the incoming trawlers and the artisanal fleet factored in the scale of the effect. The difference in average boat revenue relative to the current scenario was shown to be 3-5% when the incoming trawlers had four times the fishing power of the artisanal fleet, and 9-11% where the incoming trawlers had ten times the fishing power. In terms of profit, the effect was higher, with the artisanal boats experiencing an average drop of around 12% and 20%, respectively. Contributing to these simulated outcomes is an evident differential in the effect of opening up part of the trawl ban area on different species, with some species being more affected than others, given their habitat preferences and vulnerability to trawling. If area C were opened up to trawling for the whole year, the impact on artisanal catches of red mullet and Pandora (both valued as highly commercial) would be of greatest concern. As the fishing power of the trawling fleet was increased however, it was evident that the reduced availability of all the 5 target species to the artisanal fleet could be substantial: falling to 72% for picarel if Area C was opened up to trawlers of 10x fishing power, and to 50% for Pandora if areas B and C were opened for vessels of similar power.

(ii) Seasonal changes

The alternative scenario to a permanent removal or reduction in the size of the trawl ban, a seasonal trawl ban was also modelled for the Gulf, with the trawl ban being lifted for one season in the year to allow in the trawlers (in the model, areas B and C). The effect on the profitability of the artisanal vessels of this alternative was demonstrated to be far less than the year round removal of the ban, with the season chosen making little difference (although its removal in the summer and autumn would have a slightly larger effect than for the other seasons). The change in the revenue of the artisanal vessels caused by seasonal opening came out to be far less prominent, suggesting a more distinct change in species mix, which was a clear outcome of the simulations.

From the simulations, it is evident that the more powerful the trawlers permitted access, the more dramatic the change in the species mix caused. When the trawlers had ten times the fishing power of the artisanal fleet, there was a change in the variability of the 5 target species of between 77% and 99%. With trawlers of four times the power, the change was between 90 and 99%. Over the long term, this scenario would have least effect on annular seabream and axillary seabream and most effect on pandora and picarel, with red mullet in the middle. Note that the seasonal component to this pattern demonstrated more effect for pandora in the autumn and more effect for annular seabream in the summer. Given that the species mix in the catch differs between the ports, these changes would generate different consequences for the different ports.

2.1.5 Optimisation of the fishery

In addition to being utilised as a simulation tool, the bioeconomic model was also implemented in an optimisation framework where the levels of boats in each of the regions were optimised under the various year round and seasonal management options permitting trawling activity. In these runs of the model, the numbers of vessels in each region were allowed to vary between current numbers and half that level, using the assumption that artisanal vessels would not increase under the scenarios (having not done previously). This further demonstrated the implications for the artisanal fleet, tending towards a reduction in fleet size.

In the case where trawling was assumed to be 4 times more powerful than the artisanal fleet, the average boat revenue actually increased slightly over current levels for "area B, C". An almost identical response was also found when the whole Gulf was opened up to trawling. However, in both of these cases, while the regions of Balestrate and Terrasini did not experience any change from current levels, the number of active artisanal vessels fell by half in both Castellammare and Trappeto. This would suggest that the vessels in the two latter regions are less efficient per day fished than the former, if only by a small amount. However, it is indicative, along with the results from the simulations, that in order to maintain revenues to the artisanal fleet if trawling were to be allowed in the Gulf some rationalisation to the artisanal fleets would have to be made. In the case where trawling is assumed to be 10 times more powerful, the consequences are more dramatic, although it is interesting to note that Terrasini is less affected than the other regions. It could be surmised that this region is already affected implicitly to some degree by the illegal trawling currently underway within the Gulf, and therefore the opening up of the fishery to trawling would not have so marked an effect as for the other ports.

The average optimal economic profit per artisanal vessel followed a similar pattern to that of average revenue, with the 4 times fishing power case accompanied by a significant increase over the current situation. In the "area B, C" scenario, even the profit in Trappeto is indicated to increase to positive long-term levels. The 10 times fishing power case, however, is far less positive, with average boat profits seeming to halve over the long-term. This is a similar result to the simulation adopting current levels of artisanal vessels.

From the optimisation outcomes, it is evident that the artisanal fishery is being supported, both in terms of its size and economic performance by the trawl ban, and that even a partial relaxation of the trawl ban would have a negative impact on the fishery. In economic terms, however, the support being offered to the artisanal fleet does not necessarily equate with the optimal situation, with average profits and revenues likely to increase with a reduction in the size of the fleet and the limited resumption of trawling in the Gulf. However, in the current situation there are clearly vessels operating with negative long-term profits. With or without the trawl ban this cannot be sustained and some rationalisation will take place. Hence, the opening of the Gulf to trawlers for part of the year under strict conditions, with reduced conflict and less illegal trawling, may have a positive effect ultimately. These findings re-emphasize the significance of defining the objectives of creating an exclusion zone and the assessment of the value of the exclusion zone against performance criteria related thereto.

2.1.6 Economic and social appraisal of the artisanal fleet

As aforementioned, there was a third major component to the analysis of the Gulf of Castellammare trawl ban: an economic and social appraisal of the artisanal fleet and its economic sustainability. Utilising a stylised picture of a fishery, mimicking the Gulf scenario, it was possible through theory and the experience gained from other exclusion zones and fisheries globally to identify the bioeconomic tendencies that could be expected under alternative management regimes. The core component of this theory was that anything that makes a fishery more profitable will encourage more effort and result in a reduction in the exploitable biomass, until that point at which entry ceases due to vessels finding that there is no more profit to be obtained, biomass having adjusted to a new (lower) equilibrium level.

In a fishery that is spatially partitioned and comprised of vessels of differing technical efficiencies within the different partitions (as under an exclusion zone scenario) there is a tendency for stock density to be higher in the zone reserved for vessels with lower catchability. The commercial viability of fishing in the partitions reflects this catchability coefficient, and also such factors as biomass dispersal and intrinsic growth rate, which determine whether the stock within the partition can support this catchability. It is evident from theory and from the wider global experience cited that the policy of merely creating fisheries exclusion zones and restricting access to certain types of vessel (e.g. artisanal) will not guarantee that an economically sustainable fishery based on those vessels will necessarily occur as a result.

In the Gulf of Castallammare case, the higher catch per unit of effort within the protected area relative to the unprotected area indicates that the higher stock density predicted has been fulfilled. The higher level of trawling outside the ban area since the trawl ban was introduced has also had the expected affect, by reducing catch per unit of effort in this area. The CPUE figures for 2000-2001 outside the ban area were down to approximately 30% of those inside. In terms of whether the partitions can support the fisheries dependent thereon, the assessment of the financial viability of the artisanal fleet under the current scenario (in which the trawl ban is maintained, with vessel catch rates maintained at 1998-99 levels) demonstrated that for over ¾ of the artisanal fishermen their activity would be considered as financially viable (generating a positive net present value NPV). An interesting observation from the current situation in the Gulf of Castellammare that does run counter with the theoretical underpinnings and expectations of this component of the analysis is that there is no evidence of any expansion within the artisanal fleet, or expansion of fishing effort, to take advantage of the expansion of stocks.

Upon removing the partitioning arrangement (as in the opening up of a trawl ban area), the vessels of higher technical efficiency would be expected to spread out into the area previously occupied by less technically efficient boats, given the potential for increased profits from the higher stock levels in that area. This in turn would be expected to result in a fishing down of stock levels in that area to a new lower equilibrium level, which may in turn result in insufficient returns being accrued by certain vessels in the fishery. The implication of removing zonal protection is therefore stark: the more efficient vessels are likely to expropriate the less efficient in the competition to exploit the resource. Though the speed of this expropriation will depend on the dynamics of the fishery system, the end result would appear clear.

In the Castellammare case, where the assumption is made that artisanal catch rates directly reflect the changes in stock abundance (with their catchability coefficient staying the same), the removal of the trawl ban when modelled inevitably has implications for both stock levels and the artisanal fishers' financial viability. Taking a scenario where artisanal catch rates are down 60% of their 1998-99 levels as a result of the relaxation of the trawl ban the number of vessels that could be regarded as financially viable (with a positive NPV) falls to just under 50%. The rest would accrue insufficient returns on their investment. Hence, even with the influx of trawlers, some artisanal fishers' would remain financially viable at this level of effect. This prediction is validated by the observation that in 1998-99 a number of trammel net boats did, in fact, operate outside the trawl ban area (from the port of Terrasini) despite the overt competition from trawlers and despite experiencing on average lower physical productivity than their counterparts located at ports inside the protected zone (Whitmarsh et al. 2002).

If the effect on catch rates was larger however, the opening up of the trawl ban could have far more dramatic impacts on the artisanal fleet. If catch rates are assumed to be down to 30% of their 1998-99 levels, none of the artisanal craft would reap positive NPVs, meaning that even the more efficient operators would become financially unviable and in the long run be expected to exit from the fishery. Given that this scale of effect is not unreasonable to assume, being based on the most recent set of observations, the prospects for the artisanal fishery of any lifting of the trawl ban would seem less than auspicious.

The decline in the artisanal fleet as a result of the lifting of the trawl ban is a scenario that the artisanal fishers themselves foresee. The motivational survey undertaken in 1998-99 (Pipitone et al. 2000b) revealed that many artisanal fishermen would give up fishing if the trawl ban were removed, the major reasons given being intensified competition, worsening gear conflict and the increased costs of gear replacement. Those that signalled their intention to carry on typically stated that it was because there were no alternative sources of employment, implying that the opportunity cost of their labour was low or close to zero. Just over 44% of the sample surveyed declared explicitly that they would carry on if the trawl ban were lifted, while 50% confirmed that they would exit from the fishery. Interestingly, the fishermen committed to carrying on in the face of a relaxation of the trawl ban generally out-performed those intending to give up when their financial performance was independently assessed, the former having a mean profit ratio of 0.547 as against 0.072 for the latter.

2.2 English Channel Bass Fishery Case Study

This case study targeted the potential value of introducing a mid-water trawl ban to restrict access to Bass (*Dicentrarchus labrax*) in the western half of the English Channel (i.e. ICES sub-division VIIe), the fishery for which has become an issue of increasing concern in recent years. English Channel Bass is a high-value species that is not subject to the EC system of Total Allowable Catches (TACs), only to a minimum landing size. In the spring and early summer months, the Bass mass at the western edge of the Channel and have come to be targeted at this time primarily by pair-trawlers from the UK and France. Due to this congregation, the catchability of vessels is high, affecting the sustainability of the Bass stock and restricting the "downstream" benefits for inshore and recreational fishers and impinging on cetaceans also targeting the Bass.

The analysis of the value of introducing a mid-water trawl ban for this fishery used a long-term optimisation-based model previously developed for the English Channel fisheries. The model (the details of which are provided in the detailed case study description) was used to investigate some of the effects of restricting access to this fishery in the form of a fishery exclusion zone, by removing the effort of mid-water trawls targeting bass and altering the rules within the model as to the behaviour of the displaced fleet. The economic components within the model included, inter alia, costs and prices derived from economic surveys of the fishery (Boncoeur and Le Gallic, 1998; Coglan and Pascoe, 2000).

Given the geographical location of the fishery, three scenarios were investigated relating to the Western Channel involving (1) a ban on midwater trawl effort, (2) the displacement of midwater trawl effort, and (3) an increase in the external fishing power applied to the midwater trawl metiers directly. Each scenario considered the potential effects of implementing an exclusion zone for Sea Bass in this area. Two scenarios (4 and 5) designed to evaluate the effects of the standard regulation in relation to an exclusion zone were also explored: a TAC of zero and 250 tonnes per country, implemented for the whole Channel. A sixth scenario modelled, which was shown to have no effect economically over the "current" situation in the long-term, was an increase in the permitted age-of-first-capture of Bass.

The results of the model under scenario 3 above indicate that as has already been experienced in the fishery, an increase in the fishing power of the external fleet targeting Bass has a significant negative impact on both the profitability of the Channel fleet and the potential levels of catch in the long-term. The results of the model suggest that the effect of this on the profitability of the Channel-based fleets in the long-run could be considerable. There is anecdotal evidence of this already from the recreational fishermen and other Channel-based commercial fishing vessels, who note that the availability of Bass has been less in recent years. It is against this baseline that the value of an exclusion zone becomes particularly apparent.

If midwater trawling is banned in the Western Channel under scenario 1, the model indicates that despite the removal of this activity, there is little change in total revenue in France or the UK. However, there are likely to be increases in long-run profits for both countries and distinct positive "downstream" benefits for the smaller vessels targeting Bass as well as potentially the recreational fishing sector. Those groups shown to experience the greatest gains are the UK Western under-10m vessels and French liners. The model used suggests that an exclusion zone would not only assist in the protection of the stock, but also benefit the long-term profits achievable by these Channel-based fishers. Note that albeit desirable, a factor not considered in the analysis due to lack of data and knowledge is that of cetacean bycatch, which is through anecdotal evidence conjectured to reduce under an exclusion zone.

The losers in this scenario would be the external midwater trawlers who have come to target the spawning Bass in the Western Channel during the spring and early summer months. If this midwater trawl fleet effort was displaced in the Channel then there would also be a negative effect on the Channel fishers, and particularly the UK fleet (the French fleet seemingly more flexible in their options), although as much of this effort is from external vessels, it could be surmised that this effort would not be displaced in other Channel metiers. However, it is not possible to analyse the "true" effect on the external midwater trawl fleet, as the Channel model statically represents the structure of the external fleet. With improved data and knowledge, the two-phase model could be developed to a higher level of detail hopefully to address this. The drive to do this is currently being undertaken by the ICES Study Group on Sea Bass. This is just one of the areas where data availability makes the determination of value more difficult.

The TACs investigated in the model (scenarios 4 and 5), as alternatives to a fishery exclusion zone indicate that although the availability of Bass may be greater in the long-term as a result of imposing TACs, the benefits to the Channel fishers would not be significant. In fact, the model indicates negative long-run profits in the simulations for both the UK and France. Even in the optimisation of the fleet, negative effects are indicated for France and only slight long-term increases in profits for the UK. This is an interesting contrast, emphasising the scale of benefits derived from the creation of an exclusion zone.

Supplementing these results, it would appear that downstream benefits are also to be reaped in terms of the prices for Bass, given the greater stability of catches and larger individuals reaped by downstream groups.

2.3 Nephrops Case Study

In the nephrops case study a hypothetical dynamic, age-structured model was formulated to investigate the potential effects of fishery exclusion zones and changes in fishing effort in Norway lobster (*Nephrops norvegicus*) fisheries. The species was targeted by the study to illustrate the value of the fisheries exclusion zone concept for crustacean and relatively sedentary species. The aim was to elicit the form of response to two potential variants of the concept (static and alternating) in a generic Norway lobster fishery, although the model used biological parameters determined for the Firth of Forth fishery in eastern Scotland given the data advantages and the suitability of the characteristics of this fishery. Notably, it has the advantages of: being a well-studied fishery, the appearance of comparative stability over several years, being dominated by a single type of fishing gear (single otter trawl), and the area being thought to be comparatively spatially homogenous in sediment type and *N. norvegicus* population characteristics (Anon., 2001).

The model was run with different combinations of exclusion zone size and fishing effort:

(1) no fishery exclusion zone but with changes in fishing effort, to compare the stabilised dynamic results on a per-recruit basis with the steady-state analyses performed previously (Anon., 2000) and to assess potential changes in yield and revenue through effort control alone.
(2) single, static fishery exclusion zones of different sizes and changes in fishing effort.
(3) alternating exclusion zones of two equal-sized areas (25% of the original fishing area) alternately opened and closed to fishing at a defined periodicity, with a third area (50% of original area) permanently open to fishing. The modelled zone alternation periods ranged from 2 y to 10 y in 2 y increments. Effort levels were the same as for the static exclusion zone simulations.

As with the other case studies, the results of the analysis reveal that the value within the concept is far from clear-cut, and is somewhat dependent on the characteristics of the stock and fishery. The more detailed findings in terms of value for each of the combinations /scenarios are presented below:

2.3.1 Scenario – no fisheries exclusion zone, but changes in fishing effort

From the results of modelling purely effort control (without the use of an fisheries exclusion zone) it is evident that male nephrops are currently subject to slight growth overfishing, although when taking recruitment into account, this picture changes to one of full exploitation (assuming average fishing effort over the long-run). Females on the other hand benefit from being burrow bound for a significant portion of the year, and are under-exploited. For both sexes, however, a reduction in fishing effort would contribute to an increase in first-sale value (especially for males).

2.3.2 Scenario – single, static fisheries exclusion zone and changes in fishing effort

(i) biomass and recruitment

Against this baseline, the model results for the introduction of a static fishery exclusion zone revealed some interesting effects and implications for value. As one might expect, there were positive gains within the fisheries exclusion zone in terms of biomass. The introduction of the zone led to an initial rapid increase in stock biomass within the fisheries exclusion zone due to the reduction in total mortality rate (fishing mortality having been removed), giving rise to an increase in the average age and size of lobsters within the exclusion zone. While this peaked and subsequently oscillated over a period of years, when it stabilised, it did so at a higher level than the pre-exclusion zone value. In the open zone, the counter scenario played out, with biomass initially falling due to displaced fishing effort increasing total fishing effort in the open zone. However, while this again oscillated, it stabilised at a level little different from the pre-exclusion zone values. Consequently, the introduction of the fisheries exclusion zone led to a long-term increase in total stock biomass, although with larger fisheries exclusion zones, oscillations in biomass within the model failed to stabilise even after a 100 yr time period.

Female spawning stock biomass (SSB) showed a similar response, although the increases were reversed. After zone introduction, due to the higher SSB density and the overcompensatory stock-recruitment relationship, recruitment within the fisheries exclusion zone fell, ultimately to stabilise at a lower level than preceded the exclusion zone. Recruitment to the open zone in contrast increased, owing to the combination of greater total female SSB and reduced female SSB density within the open zone itself. However, with larger exclusion zones, recruitment in the open zone oscillated widely and failed to stabilise even after 100 yrs.

In terms of the effects of different sizes of fisheries exclusion zone, with lower fishing effort the simulations revealed that the size of zone made little difference to the long-term change in female SSB, but under high prior fishing efforts, larger zones resulted in higher female SSB. Larger zones were associated with greater recruitment in the open area, which was more marked under higher prior fishing effort.

These findings would suggest that fisheries exclusion zones may have value for sustaining recruitment and restoring spawning stock biomass in fisheries where effort is not well controlled by other means, given the enhanced recruitment to the fished zone (once the oscillations in biomass and recruitment had stabilised) and particularly when fishing effort is high. The smallest size of fisheries exclusion zone modelled (20% of the fishery, which would no doubt be considered a significant closure by fishers) resulted in a 27% increase in recruitment to the fished area when fishing effort was double the current level, but only a 12% increase at current fishing effort. If reduced levels of fishing effort are possible via other means, however, an fisheries exclusion zone would have little impact on recruitment to the fished zone.

(ii) fishery yield

In terms of yield, the results were not so favourable. Due to the assumption that there was negligible movement of lobsters between zones, the introduction of a static, permanent fisheries exclusion zone led to a reduction in overall fishery yield, despite increased fishing intensity within the open area due to the displacement of fishing effort. The reduction was found to be greater, the larger the exclusion zone. Depending on the prior level of fishing effort, there were also large oscillations in yield for larger fisheries exclusion zones. In combination with this, the introduction of a fisheries exclusion zone also led to a reduction in the average size of lobsters through increased fishing intensity in the open area. The simulations indicated that the proportions of recently-recruited lobsters within the catch would be likely to increase the higher the fishing effort and the larger the fisheries exclusion zone: the observation holding for all modelled combinations of zone size and fishing effort. Minimum yields across most zone sizes were shown to occur at levels of fishing effort approximating to the status quo.

In a market with alternative sources of supply, the smaller individuals would attract a reduced price, which in combination with the reduced yield would generate a lower first-sale value of landings. Minimum value was found to occur at effort levels 80% higher than the status quo. In terms of value, therefore, it would seem that under the motility assumptions adopted, the gains arising from the introduction of an fisheries exclusion zone lie more with biomass than any potential return to the fishery.

It is evident that the improved level of recruitment to the fished zone with a static fisheries exclusion zone may not be sufficient to offset the expected reduction in yield-per-recruit (Polacheck, 1990) to prevent a reduction in yield. With the concentration of fishing effort in the fished zone after the establishment of the exclusion zone, combined with the higher level of recruitment resulting in the simulated fishery mainly exploiting recently-recruited lobsters, the value of the catch in a Norway lobster fishery would in all probability be reduced by a exclusion zone. From the viewpoint of the fishermen, there would be little value in adopting a static zone, especially given that the simulations under scenario one revealed the populations to be relatively robust.

Given the current selectivity of the fishing gear, the modelling work undertaken also indicated that the increase in the exploitation of small lobsters arising out of the introduction of a fisheries exclusion zone would lead to a greater destruction of lobster biomass through discarding, which is undesirable ecologically, economically and ethically. The concentration of fishing effort in the fished zone would also intensify the damaging impacts of trawling on the seabed there, although the seabed in the exclusion zone would, in time, be expected to return to an undisturbed state (Jennings & Kaiser, 1998). By-catch of juveniles of commercially important gadoids in Norway lobster fisheries could also be of major concern. Together such concerns would undermine the societal value of the fisheries exclusion zone.

It should also be noted that the model did not include any component of fishers' behaviour. It is likely (albeit not inevitable) that faced with a reduction in yield, fishers would initially increase their fishing effort, if technically possible and legally permissible. This would have a tendency to exacerbate growth overfishing, discarding and ecological impacts within the fished zone. Fishers may also be tempted to fish illegally within the fisheries exclusion zone, which would undermine protection of the spawning stock and diminish the reproductive value to the designated fishing zone.

2.3.3 Scenario - alternating fisheries exclusion zones and changes in fishing effort

(i) biomass and recruitment

Running simulations on alternating fisheries exclusion zones revealed that the value of this varient of the exclusion zone concept was similarly constrained in a number of ways, principally due to the temporary and alternating characteristics of the two zones. The implementation of alternating exclusion zones was found to lead to reciprocal oscillations in total biomass, female SSB and recruitment in the alternately opened and closed zones. With short alternation periods, the oscillations in these values in the two fisheries exclusion zones were constrained by exposure to or protection from fishing. In this situation, the oscillations nearly cancelled each other out, such that total values across the whole area were little different from pre-exclusion zone levels.

With longer alternation periods, biomass and recruitment within the alternating fisheries exclusion zones were constrained by density-dependence in the stock-recruitment relationship. While biomass initially increased within the designated exclusion zone, it subsequently began to decrease before the exclusion zone was re-opened. Some alternation periods (e.g. 6 and 8 yrs), appeared to be near a resonant frequency for the system, leading to large increases in total biomass, total female SSB and recruitment, with the rotation of the zone coming before decline set in. However, there were also large fluctuations in these variables within the two fisheries exclusion zones and, to a lesser extent, across the area as a whole. With longer alternation periods (10 yrs), biomass within the closed zones peaked, but the temporal continuity of the zones permitted the decline to set in before the zone was re-opened. This prevented sustained accumulation of total biomass, total female SSB, or recruitment. In contrast, for some combinations of exclusion zone alternation period and fishing effort, biomass increased to probably unrealistic levels and the pattern of fluctuations failed to stabilise even after 100 yrs (e.g. status quo fishing effort and 8 yr alternation period).

When changes in fishing effort were facted in, the simulations revealed that the magnitude of effects varied for the different alternation periods, revealing that the choice and value of each would be in part be reflective of fishing effort within the particular fishery. For reductions and moderate increases (≤+40%) in fishing effort, an alternation period of 8 yrs generated the greatest change in female SSB from pre-exclusion zone levels (e.g. 162% increase with status quo fishing effort). With higher levels of fishing effort, the maximum increase in female SSB occurred with an alternation period of 6 yrs (approximately double the minimum generation time). In terms of the change within the recruitment to the open zones, adjustments to fishing effort also had an influence on the outcome. Higher levels of fishing effort served to increase the level of change in recruitment to the open zones, which was maximised for an alternation period of 8 yrs (80% increase in recruitment with status quo fishing effort). In contrast, under low fishing effort, open-zone recruitment was reduced slightly from pre-exclusion zone levels with alternation periods of 4 yrs to 8 yrs.

On the basis of these simulations, the ecological/resource value of alternating reserves is evidently dependent on the characteristics of the species and fishery.

(ii) fishery yield

Associated with the changes in exploitable biomass, the fishery yield also fluctuated widely in the simulations, particularly for alternation periods of 6 or 8 yrs, peaking in the year in which an fisheries exclusion zone was re-opened and declining thereafter as the newly exposed stock was depleted. When changes in effort were incorporated within the simulations, the increase in yield experienced appeared greatest with alternation periods of 6 yrs (48% increase in yield with status quo fishing effort). With more frequent alternations or low fishing efforts, however, the alternating exclusion zones appeared to actually reduce yields.

In terms of first-sale value, since the average size of lobsters caught from newly re-opened zones was greater than otherwise, this was also typified by fluctuations, which in some cases were even greater than those in yield. These fluctuations would represent somewhat of a problem for the stability of the fishery. In contrast to yield, however, when fishing effort was included within the simulations, it was alternation periods of 6 yrs under higher levels of fishing effort that generated the largest increases in first-sale value. Lower levels of fishing effort saw the first-sale value peak with an 8 yr exclusion zone alternation period (111% increase with status quo fishing effort). However, the maximum increases in value were of a magnitude that is probably unrealistic (several hundred percent at higher fishing efforts).

In this simplified scenario, while the implications for value are far from clear cut, there is evidence to suggest that biomass, yield and revenue could be increased by allowing biomass and the average size (price) of lobster within one fisheries exclusion zone to increase to the peak of the first oscillation before reopening that zone and closing the other. The optimum alternation period (6 yrs) appeared to be approximately twice the minimum generation time (the size of maturity in female *N. norvegicus* in the Firth of Forth is equivalent to an age of just over 3 yrs). However, the increase in average yield and value were achieved at the expense of stability in the fishery, with the large fluctuations in production associated with the opening of the fisheries exclusion zones.

With some combinations of alternation period and fishing effort, biomass, yield and value increased to levels that are probably unrealistic. Caution, therefore, needs to be paid to the vulnerability of the models to information about likely carrying capacities of Norway lobster habitat.

2.4 Iroise Sea Case Study

In this case study, the intent was to simulate the possible impact of creating a fishing exclusion zone on both fishing and ecotourism within an area destined for national marine park status in the Iroise Sea to the west of Brittany (the first park of this type in France). While the prospect of fisheries exclusion zones has not, as yet, been formally discussed as a management measure, it is a potential option available for both ecosystem conservation and fisheries management reasons. The selection of this case study permitted the implications of a broader initiative to be considered. The main stakes in the Iroise Sea are ecosystem conservation, fishing (both commercial and recreational) and tourism. The fishery is a multi-species multi-gear fishery, and up to now the regional organisation of fishermen (*Comité régional des Pêches Maritimes et des Elevages Marins*) has been backing the project, because representatives of local fishermen regard it as an opportunity to improve the management of the fishery.

Though based on real world considerations (both as regards biology and institutions), the modelling undertaken for the case study does not pretend to entirely capture the complexity of ecosystem interactions at stake[1]. Moreover, due to the arbitrary parameter values used in the simulations, the significance of the findings that may be drawn from the simulations are principally qualitative.

The modelling work undertaken has revealed that the value of the reserve is highly dependent on the level of fishing effort. When the fishery is lightly fished the natural increase of the stock in the fished zone is the main source of catch, with the contribution of fish out-flowing from the reserve unimportant (due to the densities of fish biomasses being similar in both the fished zone and reserve, due to the low fishing mortality). In contrast, under high levels of fishing effort the outflow from the reserve becomes more important, as the densities increasingly differ between the two zones; most of the catches come from transfers from the reserve. When the size of the reserve relative to the fishing zone is varied, the model revealed that the relative size of the reserve that maximises catches also varied according to the level of fishing effort. When fishing effort was low, the relative size that maximised catches approached zero. However, as fishing effort increased the desirable size of reserve also increased. Therefore, if fishing effort and its impact on fish biomass are under perfect control the implementation of a marine reserve may constitute a second best solution as regards fisheries management. However, in situations where the entry into the fishery is limited but

[1] For instance, the global treatment of fish does not allow the model to deal with the fact that, in most marine systems, the largest predator of fish are other fish, not marine mammals. However, the reasons why we give a special treatment to the seal-fish relation in the model are not biological, but institutional and economic : we suppose that, as opposite to various fish stocks, marine mammals are protected by law and may derive an economic value from non-extractive uses. These seem to be realistic assumptions in a number of temperate inshore waters cases.

the regulator's ability to lower fishing effort is bounded by social / political constraints the reserve holds greater value. If uncontrolled though, high fishing effort, and any expansion therein after the introduction of the reserve, can have the opposite effect - undermining the value of the reserve, as discussed by Hannesson (1998) and Anderson (2000). The value may also be undermined in situations where a non-harvested stock of predators inhabits the area, competing for fish with fishers and taking advantage of the creation of the reserve (see below).

Focusing on the size of the reserve and its consequences for the fishery, the modelling revealed that the steady-state rent derived from the fishery increases with the relative size of the reserve, for an unchanged level of effort, up to a certain reserve size (under the scenarios explored here, of between 30% and 40% of the total area). This is the direct consequence of the increase in catches derived from the growth in fish biomass protected by the reserve. However, beyond a certain reserve size the catches decrease because the net transfer of fish from the reserve is not important enough to compensate for the negative impact of the decrease in the size of the fishing zone. Assuming that the level of effort and unit prices do not change, the fishery rent follows the same pattern.

Predator-prey interactions (aforementioned and in the form of seal predation) within the Gulf model were shown to have a marked effect in lowering the benefits of the reserve for fishers. They affected the steady-state fishery rent for any given level of fishing effort, but also the expected results of the reserve in terms of conservation effects, as the safe minimum fish biomass level provided by the implementation of the reserve was reduced by the fish mortality due to the unharvested stock of predators. The importance/scale of this effect will necessarily depend in reality on the actual scale of the impact of predation by seals on fish biomass. However, in the case where the stock of predators may be economically valued by means of a non-extractive use (ecotourism), there is an evident potential gain through the implementation of the reserve, generating additional incomes through this channel. The growth in the seal stock generated by a higher relative size of the reserve increases the opportunity of making money through ecotourism.

Unlike the relationship between fishery rent and the size of the reserve, the relationship between the latter and ecotourism rent is monotone. According to local circumstances, these extra incomes will partly or totally offset the negative impact of the predator-prey interaction on the fishery rent. In this case, the model suggested that the optimal relative size of the reserve, from a global cost-benefit analysis point of view, is larger than that when only fishery rent is considered. This is endorsed if the benefits of "bet-hedging" advocated by Lauck et al (1998) are also factored in and the possibility for fishers to participate in the benefits generated by ecotourism explored.

2.5 Bay of Brest Case Study

The Bay of Brest case study focused on establishing the value of a fishery reserve in the context of a restocking program, by comparing the benefits of intensively sowing scallop beds in a reserve area against those achieved from extensively sown, unprotected natural beds.

2.5.1 Rates of return

From the results of the case study, initially it seemed that the reserve contributed little additional benefit, the rates of return to the money invested by fishermen being similar for the protected and unprotected areas when compared on the basis of profitability. According to the simulation, each money unit spent by the fishermen in the financing of the program yielded 2.4 money units of additional skipper-owner's net income[2], whether scallop juveniles were sown extensively on natural beds or intensively in the rotating reserve.

However, the balanced result in the relative profitability of the two alternatives is due to the fact that only marginal revenues and costs are being compared. In both the reserve and natural bed cases, the additional variable costs of catching aquaculture-originated scallops were found to be negligible[3], either because CPUE was high (reserve), or because it was taken as increasing in accordance with stock abundance (natural beds). If it turns out that the bulk of catches on natural beds persistently come from aquaculture-originated scallops, it would be necessary to assess the relative profitability of the two management alternatives taking into account the full costs of fishing on the natural beds. In this instance, the reserve system would seem to be favoured, since CPUE is approximately 10 times higher in the reserve than on natural beds.

2.5.2 Fishing effort and landings

Under the assumptions adopted in the analysis of the case study, the contribution of the restocking programme to fishing effort was limited to some 7% of the total fishing time devoted to scallop dredging, wholly corresponding to the estimated time necessary to harvest the rotating reserve. This contribution was even less when compared to total dredging in the bay (including all species (4%)) or to the total time at sea spent annually by the boats involved in the fishery (0.3%). However, in contrast, the contribution of the program to catches equated to two thirds of the total landings of scallops, of which some 40% were provided by the rotating reserve (reference year: 2000-2001). [Note: if total shellfish landings[4] are used as a calculation basis the percentage falls to 50% and 30%, respectively]

2.5.3 Turnover and fishing related costs

In terms of fleet turnover, according to the simulation, the restocking program was shown to contribute 18% of the total yearly turnover of the fleet involved in the Bay of Brest fishery, 11% being attributed to the harvesting of stocks in the rotating reserve. In contrast, the contribution of the program to boat variable costs was shown to be very limited (1%). This is due to the fact that, according to the scenario under investigation, the influence of the restocking program on fishing effort was limited to the harvesting of the reserve, an operation that does not consume much fishing time due to high CPUE.

Wage costs were more significantly affected, due to the share system that relates this type of costs to the difference between net sales (turnover minus landing taxes) and common costs, a subset of variable costs. The gap between the relative impact of the program on skipper's net

[2] calculated before deducing the cost of the contribution to the program.
[3] This does not include the cost of monitoring and surveillance of the reserve, which is covered by landing taxes. These taxes are used to pay for the general monitoring and surveillance costs of the fishery, among which it is difficult to isolate the specific costs induced by the reserve.
[4] i.e. mainly adding warty venus to common scallops landings (other scallops play only a marginal role in the fishery in 2000-2001).

income (21%) and wage cash costs (12%) is due to the fact that the latter include national insurance contributions, which are not affected by the program.

2.5.4 Profitability

The contribution of fishermen to the program, which in the recent past has been high enough to balance its operating cost, is split into two parts, one related to the intensive sowing of juveniles in the reserve, the other to extensive sowing on natural beds. These parts were calculated proportionally for each type of sowing (on average 60% in the reserve and 40% on natural beds during the 1990s).

Notwithstanding the unusually high cost of access to fish resources due to these contributions, the simulation indicated that the restocking program contributed to 26% of the total full equity profit of the boats involved in the fishery (the average rate of which was 13.8% of the insured boat value). The reserve system alone contributed 16% of total full equity profit. The contribution of the program to skipper's income was similar: 28% of total net activity income (skipper's wage, plus full equity profit, minus opportunity cost of capital), of which 17% could be attributed to the results of intensive sowing in the rotating reserve system.

2.5.5 Short-term v. long-term

However, the reserve effect is not without issue. The reserve system cannot be regarded as stable. The control over the rate of mortality of aquaculture bred post-larvae and juveniles is considered questionable, and concern about waste during the harvest and predation in the reserve has recently developed. Moreover, the profitability of the whole program depends on the landing price of scallops, a variable governed by factors external to the fishery and rather unstable (as historical records attest). There is also the institutional commitment of the fishermen to a program they finance on a yearly basis, with no formal right to its long-term benefits. These are issues that will affect the value of the reserve in the longer term, if not in the short-term.

Relaxing some of the oversimplifying assumptions that had to be made in the above described scenario is the purpose of the bioeconomic model currently being developed for the fishery, the building of which is in progress at the time of writing the present paper.

2.6 Normand-Breton Gulf Case Study

The Normand-Breton Gulf case study focused on establishing the value of a seasonal trawl ban within the gulf, aimed at preventing discards by trawlers of bycatches of juveniles belonging to various species, mainly black sea- bream and spider-crab, which if protected offer a valuable fishery during their later life stages. These discards constitute a source of economic loss for the fishery as a whole, but particularly hits (but not exclusively) fishermen using more selective gears (Morizur et al., 1996). The problem gets especially acute when low selectivity gears are used in nursery areas, a phenomenon which is not uncommon in the Normand-Breton Gulf (Berthou et al., 1996).

The results of the analysis reveal that there is significant value within the concept of a seasonal trawl ban in the area, with the avoidance of the losses to producer and consumer surplus arising from the discards being a major component.

2.6.1 Impact of discards (producer and consumer surplus)

At the level of activity prevailing in the 1990s, end-of-summer discards of spider-crabs amounted to 1200 tons per year on average. For potters and netters targeting this species, the resulting mortality generated a deficit of catches and landings close to 40% of total actual landings. At the end of this period, the price-effect resulting from this deficit of landings represented 13% of the actual landing price, resulting in an economic loss for potters and netters of 22% of their actual revenue - i.e. approximately 8.6 million francs (1.3 million euros) for an average recruitment year.

If the loss of consumer surplus, representing approximately 6 million francs (0.93 million euros) for an average recruitment year, is added to this loss of producer surplus, the social cost of end-of-summer discards of spider-crabs represents 14.7 million francs (2.2 million euros). In a high recruitment year, this cost could be even higher, exceeding 23 million francs (3.6 million euros), while in a low recruitment year it is unlikely to fall below 9 million francs (1.4 million euros).

2.6.2 Gross margins of trawlers

The gross margin generated by bottom-trawling in the Gulf during the months of August and September at the end of the 1990s was estimated to be 9 million francs (1.4 million euros) for trawler-dredgers and 3 million francs (0.5 million euros) for straight trawlers. However, these figures may overestimate the true picture to an extent given the coefficients that were used in the model for the space-time distribution of the yearly activity of trawlers. The consequences of these estimates is that under normal circumstances this activity may only be profitable because it does not bear the social cost of the discards it generates. With average recruitment, the overall balance between the gross margin generated by trawling and the social cost of discards gives a positive value to the seasonal trawl-ban, amounting to approximately 2.5 million francs (0.4 million euros) per year, and this may be an underestimate.

There are a number of reasons why this value ascribed to the seasonal trawl ban may be an underestimate:

1. Spider-crab mortality is not the only negative effect of bottom-trawling in the Gulf (and particularly its coastal areas) during the months of August and September. This activity also generates large quantities of discards of juvenile sea-breams, with a mortality rate approximating to 100%. According to Fifas (1998), a seasonal trawl-ban associated with the enforcement of a legal mesh size could improve (without effort changing during the rest of the year) the annual harvest of adult sea-bream in the Gulf by 190 tons on the average. Assuming a landing price of 12 F/kg (1.83 euro / kg)[5], this would generate an additional income of approximately 2.3 million francs (0.35 million euros) for fishers.

[5] Average price in 2000 and 2001 at the auction market of Granville, which is the main landing harbour in the gulf for this species.

2. With regard to other species, the annual loss of income borne by the trawlers as a consequence of the seasonal trawl-ban would not equate to the level of the gross margin formerly realised during this period. Part of the corresponding catches would simply be caught outside the ban closure, during the following months. The use of the gross margin figure would, therefore, greatly over-state the losses to the trawlers arising from the seasonal trawl ban.
3. The cost of the measure for trawlers would also vary for different fleets. For trawler-dredgers, which are almost entirely dependent on the Gulf fishery, the seasonal trawl-ban could imply a temporary stop in their activity (assuming the cost of the measure for trawlers to their seasonal gross margin is then accurate). But for pure trawlers, which are larger offshore units operating only occasionally inside the gulf (with a few exceptions)[6], the seasonal bottom-trawl ban would simply mean a limited change in the geographical distribution of their fishing effort during two months of the year[7]. It is likely that the cost of this reallocation would be significantly smaller than the gross margin realised in the Gulf.
4. The positive effect of the seasonal trawl ban on the landings in the Channel Islands and on the activity of French recreational fishers is not taken into account in the above scenario.

These elements strengthen the case for a seasonal bottom trawl-ban in the Normand-Breton Gulf (or at least part of it). However, the overall benefits that may be expected from a trawl-ban are challenged by its distributional effects, which, if not properly addressed, may undermine the adoption of a globally efficient management measure. Moreover, whatever its specific value, this measure will fail to realise its value if it is taken as a substitute for the treatment of overcapacity in the fishery.

3. Value sensitivity

There is evidently a diversity of form to the value of fisheries exclusion zones, which corresponds to the specific circumstances and objectives of specific exclusion zones. The above discussion well illustrates this. The discussion also alludes to the fact that such value is not clear-cut, being influenced by a range of factors. The significance of these factors to the outcomes of the models developed highlights not only the need to incorporate the consideration of such factors within any evaluation of the effectiveness of a fisheries exclusion zone, but also the importance of accuracy in delimiting the form, scale and influence of such factors. The question of accuracy and the basis to its antonym ‘inaccuracy’, notably uncertainty, is an issue common to marine fisheries management, and particularly worthy of coverage here.

As Gordon and Munro (1996) highlight, uncertainty is a fundamental characteristic of fisheries and their management, and one of far greater significance than has been researched by biologists and economists until recently. The development of the precautionary principle is a classical reflection of this uncertainty: the complexity and stochasticity within the natural system – the shocks and variability experienced by the fish resource, ecosystem and broader environment – the human interaction with that system, and the uncertainty arising from

[6] These exceptions apply to midwater trawlers, rather than to bottom-trawlers.
[7] For the trawlers combining midwater and bottom-trawling, the ban would concern only their bottom-trawling activity.

incomplete knowledge and information. Walters and Hilborn (1978) classified these into three categories for fisheries and their modelling:

1. random effects whose future frequency of occurrence can be determined from past experience;
2. parameter uncertainty that can be reduced by research and acquisition of information through future experience; and
3. ignorance about the appropriate variables to consider and the appropriate form of the model.

It is a classification that holds across the board; for socio-economic, biological, and environmental uncertainty.

Uncertainty is particularly a feature of fisheries exclusion zones in Europe, with the absence of prior studies as to their effects (previous studies having been largely confined to fishing boxes such as the Plaice Box) and key parameters for which ready secondary data is absent and primary data costly to collect and difficult to isolate. Uncertainty is also a feature of modelling within the natural marine sciences and socio-economic dimensions of marine fisheries. Given this, any presentation of, or proposition as to the value of fisheries exclusion zones needs to be qualified in terms of the uncertainty, and the sensitivity of that value to uncertainty. This is the focus of the next section of this paper, drawing both from the case studies and underlying data collection and parameter estimation.

There are three key categories of uncertainty relevant:

- science: notably data collection, observation, replication and control that is often problematic in fisheries, such that it is difficult to acquire knowledge and attribute changes in fisheries and the marine environment to specific forces and events;
- social dynamics and instititutional behaviour: the response of fishers, other marine users and regulators to changes in the resource and socio-economic environment;
- parameter estimation and model specification: the extent to which models can capture reality and provide a valid basis for informed management

(after Hilborn and Walters, 1992)

3.1 Scientific uncertainty

Some of the key issues with respect to scientific uncertainty within the context of the modelling of fisheries exclusion zones lie with: the lack of consistent, comprehensive and comparable data sets; the absence of baseline studies; technical data collection issues; and resourcing issues.

In the process of scientific development over time, there are advances made in the techniques and accuracy of data collection. Added to which the often funding-dependent and policy-led nature of data collection and the shifting objectives of research and data collection over time means that data collection is rarely consistent in what is collected, how it is collected and how often it is collected over time and space, leading to comparability and interpretation problems. It is not uncommon for analysis to necessarily be based on data that is not particularly recent, collected for unrelated purposes, having a level of detail inappropriate to the application and suffering from omissions and inconsistencies, such that extrapolations have to be made and any questions as to the accuracy of the data unavoidably aggravated.

The paucity of data is a noted problem for all the case studies in one form of another. In the Normand-Breton Gulf case study, as an illustration, data issues included, inter alia, the absence of reliable data to test the extent of excess fishing capacity in the Gulf, limited knowledge on the landings of certain species (mainly crustaceans), limited detail as to the geographical origin of catches, and a lack of homogeneity and consistency with the fleet in time series data for registered vessels in the Gulf. These data issues necessitated reliance on partial, approximate and indirect data within the model developed for the Gulf. As Walters & Ludwig (1981) note, such imperfections of data collection ideally requiring and data sets presented or used to be accompanied by estimates of error variance, without which the data tends towards being meaningless and misleading. Unfortunately, the data available is not always accompanied by such supplementary information or details of the modes of collection, requiring assumptions to be made.

Taking another example, one of the key forms of uncertainty raised in the Firth of Forth nephrops fishery case study was in relation to the exact form of the stock-recruitment relationship (SRR), albeit far from the only additional biological information noted as useful to further analysis. Although the SRR used in the model was based on one of the best-studied Norway lobster fisheries (in the Firth of Forth), the historical spawning stock biomass (SSB) and recruitment data did not give a clear indication of the level of SSB below which recruitment begins to decline, nor of the slope of the ascending limb of the SRR at low stock levels. The influence of the size distribution and sex ratio of spawners on recruitment at given total SSB that could result from size-specific fecundity was also uncertain, yet considered important to investigating changing patterns of exploitation arising from the introduction of closed areas. Other biological data for which additional knowledge was regarded as valuable to modelling the consequences of simulated closed areas for the enhancement of the nephrops fishery included, inter alia: their reproductive dynamics, post-settlement processes, mortality, growth rates and migration. From an environmental standpoint, additional information on the carrying capacity of the environment may have also assisted in grounding some of the extreme outcomes generated by the models given that the carrying capacity was not known.

One of the biggest omissions in data collection of relevance to an evaluation of the effectiveness and value of fisheries exclusion zones is the absence of baseline data. Exclusion zones have often been implemented without forethought as to the assessment and monitoring of their performance. A common offshoot of which is the absence of any baseline data as to the pre-exclusion zone state of the resources and the fisheries dependent thereon. Measures of performance are, therefore, based on estimates or ad hoc indications of the state of resources and fishery, which do not constitute a reliable basis for comparison. Despite, the existence of baseline data for the Gulf of Castellammare trawl ban (a rare example of where such exists, hence its value to this project (Pipitone et al, 2000a), neither of the other two trawl bans in Sicily implemented at the same time were as fortunate. Within the Mediterranean, the only similar experience to that in the Gulf of Castellammare lies in Greece (Vassilopoulou & Papaconstantinou, 1999).

From the technical data collection viewpoint, the challenges of operating in the marine environment and collecting the key biological parameters for inclusion in fisheries models have led to a variety of survey and data collection methodologies being developed and employed, each with their own distinct advantages and disadvantages. For example, many models rely on accurate age, length, and age-length calculations of a stock. The collection of this data, however, rarely provides the level of accuracy often inferred in its presentation. For example, while survey vessels may offer the most reliable source of such information, the scale and cost of the operations relative to the fishery tends to be small and large, respectively, such that there are possible trade-offs between this and other modes of data collection. Even within one mode of collection there are also choices and trade-offs to be made between different techniques. For example, in the determination of the age of fish, the typical alternative to surveys at sea is to take samples from the catch when landed; via either scale and otolith readings. Otolith ageing is less adaptable to a fishery-wide sampling program than scale readings, due to the difficult and time-consuming nature of collection. However, otolith morphology is an effective tool for stock discrimination in certain species (Freidland and Reddin 1994). Trade-offs are necessarily made in terms of suitable accuracy, coverage and cost. As further illustration of the uncertainty introduced into modelling through the data collection process, three relevant data collection methods are explored below:

3.1.1 Survey data problems

Independent data collection via fishing surveys helps address limitations apparent from actual fishery dependent data. However, as with commercial fishery operations, variable catches and weather conditions affect operations and as aforementioned, the scale of such operations are necessarily limited due to cost and resourcing issues. Nevertheless, in the determination of age structures, growth, mortality rates and historical trends, survey techniques may provide the only basis of data collection (Clark 1979). For use in the context of simulating fleet activities however, the specifications of the fleet and the survey vessels can differ. Technical influences such as mesh size and vessel efficiency may not coincide with actual fleet averages and changes in vessel efficiency, or shifts in effort may not assist in accurately determining trends in abundance or fishing mortality. It is not uncommon for simplistic and unrealistic assumptions to be taken as given, as with the assumption that survey trawls are giving unbiased samples both as to species and size of the local demersal fish abundance. Such assumptions have the potential to prove inaccurate and damaging in the long-term.

3.1.2 Tagging data problems

A further illustration of data collection method associated causes of uncertainty is tagging, which is often used to identify migration patterns (a key dynamic in exclusion zone modelling), but which can also be used to, inter alia, gain imprecise levels of natural mortality (Shepherd 1988). The main weaknesses with this method lies with the sometimes over-expectant assumptions that need to be made. While tag recovery and monitoring permits an indication of migration patterns, the loss of tags (at sea and through non-return by fishermen), the size of the sample feasible and the influence of the tag itself on fish behaviour can undermine the value of the technique, or at least require explicit recognition of its limitations. In terms of its use as an indicator of natural mortality, a fixed population with an equal capture rate and no change in catchability level, coinciding with no loss of marks or tags, all seems a little un-realistic. Despite the potential for sizable error in the data generated by such methods however, the technique can offer up data not readily acquired by other means, such that the technique is used globally.

Migration is one of the biggest single problems faced when examining the potential effects of fishing exclusion zones; the determination of the mobility and migration patterns of fish into or out of the exclusion area. Where the analysis focuses on a single stock, as with the plaice box, and the stock and life stages are well known and defined, tagging combined with the survey vessel sampling of the stock can provide an indication of migration if it is not well known. In other circumstances, as with the Gulf of Castellammare, the species mix and geographical and environmental characteristics of the area may permit reasonable assumptions to be made. However, in other cases the migratory routes and extent of migration may be largely unknown, with the ability to reduce the level of uncertainty compromised by the number of species potential involved, the technical ability to tag or sample at different life stages, and the resourcing implications. There may also be environmentally and seasonally driven patterns to migration that would not readily be delimited within a short sampling frame.

The difficulties in quantifying mobility coefficients was cited in the Iroise Sea case study as one of a number of reasons for the model outcomes being indicative rather than predictive, the latter being potentially an over-simplication as a result of this, among other factors. In the Gulf of Castellammare it was considered reasonable to assume that migration out of the reserve would probably be minimal as the Gulf is bounded on both sides by very deep water. Migration within the Gulf does, however, have huge implications for the four fishing ports. Ultimately, the seasonal density of fish in any particular area of the Gulf was used as a proxy for fish migration throughout the year.

3.1.3 Reporting schemes

When the data compilation is through industry generated reporting, rather than independent data collection, further data collection issues arise. Given the essential role played by catch data in biological stock production and bioeconomic models, upon which management decision-making is based, inaccurate or biased collection can have damaging long term effects. Problems arise such as discards. Log book data in the EC does not generally take account of this issue and accordingly, the failure to record such discards means that part of the stock goes unaccounted for. Errors in the data such as this may then lead to incorrect advice being given. Although managers are aware of the existence of such error, the lack of records means that estimates of the scale of the activity and the species and cohorts affected are subject to a high degree of uncertainty. This incorrect estimation of stocks can result in either continued over-exploitation or economic hardship in response to the imposition of mitigation measures. Some stock production and bioeconomic models include discard data, but there could still be reliability issues. Further, there is an associated uncertainty as to the level of survival amongst discarded individuals. As Mesnil (1996) points out, the general assumption is that discard mortality is 100%, although there is proof in some fisheries (usually shellfish) that a significant fraction of those discarded are able to survive. Either way the incorrect analysis of discarded fish will affect estimates of the fishery. Where the excessive and detrimental level of discards are a rationale for the creation of an exclusion zone, the possibility of which is explored within the Normand-Breton Gulf case study in terms of sole, black sea bream and spider crab, then the lack of discard data and uncertainties therein is even more critical.

When such catch records are combined with effort data, as in catch per unit effort (CPUE), then further questions of uncertainty and accuracy are raised. While CPUE can be a very important factor in a broad range of fisheries models, both bioeconomic and essentially biological stock production models (the latter particularly if based on age and composition) (Kimura et al. 1984), its use needs qualification. Roff (1983), for example, suggests that catch/effort data in biological models is only reliable to detect major fluctuations in population size and "attempts to determine equilibrium yields from catch/effort data are as likely to be successful as finding the pot of gold at the end of the rainbow". Collie & Sissenwine (1983) further express difficulties in the standardisation of CPUE data from commercial and recreational fisheries, highlighting the 'constant catchability coefficients' and continued 'technical improvements' as areas vulnerable to biased data. The role of recreational fishers in the status of some of the case study fisheries potentially raises the profile of this latter proposition.

3.2 Social dynamics

Some of the key issues with respect to uncertainty surrounding social dynamics within the context of the modelling of fisheries exclusion zones lie with: the consistency of behaviour with fundamental theories (e.g. that fishers are profit maximisers), the variability in the performance, behaviour and ability of fishers, the unpredictable response of other coastal users to the change in regulatory regime, and compliance issues.

Interestingly, this research project has found that there are fundamental assumptions upon which fisheries economic models are traditionally based that have not panned out as predicted. Key among them is the behaviour of the fishermen, which an economist would assume to be profit maximising, but in the case of the artisanal fishermen in the Gulf of Castellammare trawl ban case study appeared to tend towards profit satisficing. The behaviour and effort demonstrated by fishermen is often also assumed to be founded on perfect information and the maximisation of profit. However, fishermen while benefiting from experience, do not have access to perfect information. Further, in making generic assumptions as to behaviour and operational efficiency, models tend not to account for the differences therein between ports, individual vessels and fishers. The modelling work undertaken on the Gulf of Castellammare case study identified distinct differences between categories of fishers, such that while the direction of impact was consistent across the artisanal fishers, the degree and consequences for the financial viability of fishing operations varied between the ports and individual vessels. The use of the findings of such models can result in management decisions that are skewed and misinformed. Assumptions generally are one of the main avenues through which uncertainty is potentially introduced into models, albeit necessary for their simplification and operationalization.

The lack of supplementary information on the fishery also undermines the ability to explain those differences, which can therefore be wrongly attributed. Such characteristics of the fishery, however, fall with the second category of Walter and Hilborn's (1978) classification, with the potential for uncertainty to be reduced by research and the acquisition of information. The significance of this supplementary information is emphasised by the Gulf of Castellammare case study, in which anecdotal information suggests that recreational fishing has expanded over time to partially fill the gap left by the trawlers. Given the absence of data on catches from recreational fishing within the Gulf, the impact of this activity unfortunately cannot be incorporated into the models developed for the fishery, introducing a potentially significance source of uncertainty in the accuracy of the outcomes of these models. Recreation and tourism also introduced challenges for the Iroise Sea case study (albeit in this instance in a predictive scenario) given the challenges of measurement and the fact that no well-defined industry corresponds to "tourism". Except from a few specific islands in the Iroise Sea, there was a general absence of quantitative knowledge on tourism visits to the area, such that only indirect, incomplete and rough estimates formed the only available sources of information. Similarly, inter alia, there was a lack of knowledge as to the extent of recreational sea fishing in the area and the associated catches. In the Bay of Brest case study reference is made to the potential, yet indeterminate, impact of another coastal activity; waste products from the adjacent urban areas on the decline of shellfish stocks within the Bay. In each of the aforementioned case studies, it is almost impossible to isolate the relative impacts of these activities on the fisheries concerned and thereby identify with precision the role and contribution of the exclusion zone.

One key aspect often ignored in the modelling of exclusion zone possibilities is the legal, political and institutional dimension: the outcomes, consequences and effectiveness of decision-making in a variety of contexts and the response of fishers and other marine users thereto. Although, zoning and access rights can be incorporated within certain modelling frameworks, along with the responses of fishers thereto, rarely has this analysis gone beyond the purely theoretical or taken into account behaviour such as trawler non-compliance to a trawling ban or the legal feasibility of possibilities within predictive modelling. In the Normand-Breton Gulf case study, the significance of compliance issues was raised not only in terms of the complexity of the legal rules faced by the fishermen in the Gulf, but also in terms of the beneficial effect on discards of enforcing the existing legal mesh size, which would result in a 50% reduction in discards of undersized sole without resorting to the use of an exclusion zone.

In terms of the feasibility of possibilities, depending on the status of an exclusion zone programme in a particular country and the extent that it represents an innovation as a management tool, legal and institutional considerations can also prescribe the design, management and effectiveness of a fisheries exclusion zone. The associated uncertainty either falls within the second or third categories of Walter and Hilborn's (1978) classification; the former potentially determined through research and the acquisition of information (where a legal regime providing for such an exclusion zone already exists), while the latter (where a legal regime has not been finalised) represents true uncertainty, being the subject of future interpretation and political debate. Interestingly, rather than face the uncertainty generated by the latter in the creation of a dedicated legal framework, one often finds that exclusion zones are created under legal frameworks dedicated to other purposes, not wholly suited for the specific purpose of the exclusion zone in hand. This introduces compromise, which can undermine the performance of the exclusion zone through limiting possibilities, failing to provide adequate controls, resourcing and enforcement, and the largely unpredictable nature of the associated outcomes.

3.3 Parameter estimation and model specification

Within the context of modelling the key aim is, as far as possible, to capture at least the important aspects of the aggregate behaviour of the majority of fish and fishers to facilitate statistical predictability or the validity of simulations. Although the real world scenario facing any fisheries or exclusion zone modeller will always mean that a model can never be completely or correctly specified (misspecification is unavoidable), the aim is to inform management with as much reliability as possible (Oreskes et al., 1994). Similarly, the aim of parameter estimation is to provide as robust estimates as possible and to accompany those estimates with confidence indicators, taking into account: how biased the estimate is likely to be, the variance of the estimate, and how confounded the different parameter estimates are when more than one parameter is estimated (Hilborn and Walters, 1992).

In terms of validity, while testing formally for validity in a natural science context involving such complexity and uncertainty is almost impossible, there are several important aspects of validity to be taken onboard in model development, notably content validity, theoretical validity and convergent validity. Content Validity addresses the framing of the study, whether it is appropriate to that being valued. Theoretical validity stipulates that the behaviour of model parameters and the model outcomes should be in accordance with theory (either those of the natural sciences or socio-economics), and if not, be explainable by reference to contextual information on the fishery or resource. Convergent validity stipulates that the outcomes of the modelling process should be similar to those predicted by other methodologies or the differences explainable away. The extent to which several methodologies can be utilised is largely determined by the resourcing and data available. However, as demonstrated by the Gulf of Castellammare case study, which used several complementary analyses to address differing, yet in part over-lapping, aspects of the question of value, there is potential to address this aspect of validity. However, other exclusion zones do not necessarily have the luxury of the breadth and duration of the data available here, nor the resourcing to compile it.

During the process of attempting to ensure such validity in the models developed during this study, a number of key issues have come to light: notably, the choice of assessment type and the trade off between simplicity and complexity in terms of model specification, and the choice of sample frame, core data and estimation method in terms of parameter estimation.

3.3.1 Choice of assessment type

The choice of assessment type necessarily depends on the biology of the species, the nature of the fishery, the time scale required, the area and purpose of the assessment and any specific goals of the fisheries manager. As with the aforementioned data collection there are trade-offs to be weighed up prior to the selection and adoption of a particular form of assessment. This choice may be difficult. For example, stock production models used for long-term management are frequently no better in the forecasting of the following years' CPUE than is the previous years' CPUE (Stocker & Hilborn 1981). Long-term assessments may aid strategic decisions by managers, and can contribute information such as maximum sustainable yield (MSY) and formulate relationships between stock and recruits. Short-term assessments can focus on catches and CPUE in the next year or so and explore the consequences of recruitment over the same time period. In terms of bioeconomic models trade-offs are also made. Within the structure of the Castellammare bioeconomic model, for example, effort is applied to an area rather than an individual species for the five specific target species: annular seabream, axillary seabream, red mullet, Pandora and picarel. Catches of each species are correspondingly estimated on the level of fishing activity in a given area in a given season and the relative density of each stock in that area in a specific season, rather than for the individual species as a whole. This necessarily reflects the spatial basis to the purpose of the analysis. The approach to be used in any assessment should reflect its purpose, with any strengths and weaknesses weighed prior to selection and application. It should also reflect the data available as discussed elsewhere in this report and the assumptions prescribed by both theory and operational practicality.

Knowledge as to the uncertainties accompanying the different assessment methods for the purposes in question particularly require to be specified, to facilitate the decision-making process dependent there-on, but also to inform any subsequent analysis undertaken on the data generated (especially if that data is to be used in a context not originally intended, as with the subsequent analysis of other management alternatives – e.g. exclusion zones). As Rosenberg & Restrepo (1994) suggest, risk and uncertainty themselves should also be the focus of assessment in the formulation of management alternatives. They propose a number of methods for analysing and assessing risk in management strategies.

3.3.2 Simple versus complex models

One of the key decisions to be taken in choosing the assessment method and modelling approach is between simplicity and complexity and the trade-off between simulating the complexity of the real world system and modelling the fundamental relationships for which the data available is the most robust. Authors such as Ludwig and Walters (1985, 1989) and Hilborn and Walters (1992) argue that the best model choice is not necessarily the more complex. The best model choice they highlight can be one that is known to be unrealistically simple, given the estimation and data challenges encountered in the more complex models. The quantities and detail required of data by assessment methods that tend to take onboard the complexities of the biological and ecological systems, raises the probability of data inaccuracy and unavailability undermining the advantages of these methods. As in other respects aforementioned, the researcher necessarily has to make a trade-off between the theoretical advantages and practical applicability of the methods used in the light of data availability in the quest for accuracy and validity. Some of the typical problems arising include missing year data, changes/differences in survey techniques and age determination methodologies (Richards et al. 1997). While there are recognised statistical techniques that to some extent identify and remedy the errors encountered (Richards & Schnute 1998) and alternative indicators (as with length for age) may be used, there is potential also for the errors to be compounded through complex analysis or where the alternatives lack precision. Christensen (1996) highlights three particular sources of error that tend to be undetectable: discard levels, the estimation of terminal fishing mortality, and predation mortality, to which others can be readily added.

The balance of argument, however, does not all lie in favour of simplicity. One of the largest sources of imprecision within the more simple models lies with the lack of acknowledgement of the inter-species relationships therein. As Bax (1998) and Pereiro (1995) note, while many single species models assume that fishing mortality alone is responsible for the variation in fish survival, losses to predation can potentially exceed losses to fisheries in certain situations or at least feature significantly, meaning that the assumptions of single species models are potentially misleading. However, predation is a challenge that many multi-species models equally do not attempt to address (as noted for the English Channel bioeconomic model used in the bass case study). The detailed biological data for each species and its predator-prey relationships required is potentially prohibitive, although more hypothetical simulations can be undertaken, as in the Iroise Sea case study with respect to seal predation. The questions of feasibility and reliability raised by such data requirements, underpin that fact that as in this project, multispecies models inclusive of explicit predator prey relationships are rare, although acknowledged as having a role in the outcomes of protection. It is interesting to note that many of the predicted affects of the trawl ban in the Gulf of Castellammare have not been realised, even though the overall biomass in the Gulf has increased. The observed failure of sharks and the biomass of some key species to benefit as predicted is a scenario that reflects the complex trophic and opportunistic relationships operating in the ecological system within the Gulf, which models do not readily pick-up on. With baseline data and subsequent time series analysis, however, catch data may be used as an implicit indicator of predator-prey relationships, albeit tending to focus on a few key species as evident in the shifts in species abundance in the Gulf of Castellammare case study over time.

Despite not attempting to address such challenges directly, multi-species models are particularly important within the analysis of fisheries exclusion zones, given that the foci and purpose is the conservation of an area rather than species and that area is inevitably occupied by multiple species. The Gulf of Castellammare is a classic example of this, with 96 species having some commercial value. Given the data collection task associated with such a diverse and complex fishery and resource, the modelling of the performance of the exclusion zone is hampered by the data demands and the inevitable selectivity necessary to operationalize the model. The bioeconomic analysis undertaken on the Gulf of Castellammare trawl ban ultimately targeted only 5 specific species and 1 "other" category due to data and model complexity issues. The data issues principally lay with limited knowledge of the biology of many species (Pipitone et al 2002). However, many of these species when landed are also combined and sold under the generic term 'soup fish', such that economic data was also limited. Knowledge of the biology of species was also a constraint on modelling in the English Channel Bass fishery case study. The Channel fisheries bioeconomic model utilised in this case study had a number of advantages: namely the complexity and interactions it incorporated between the fisheries through the fleets, species and metiers, which were explicitly modelled using the best biological and economic data available. However, the model was calibrated using biological data from the mid-1990s, which could not readily be updated (unlike the socio-economic data in the model). For many of the species modelled their biology had not changed over the past few years. However, it is clear for Bass that the impact of the external midwater trawlers had had a significant impact on the offshore Bass fisheries.

3.3.3 Parameter estimation

In the socio-economic analysis of fisheries exclusion zones a key consideration is the appropriateness (representativeness and comparability) of the sampling frame. Sampling theory provides the framework on which decisions on sample sizes, distribution and timing can be made. The considerations involve an assessment of the desired limits of error and the intended purpose and form of analysis, matched against the resources available and the challenges of data collection. The advantages and disadvantages of random, systematic and stratified sampling frames are among the options to be considered, while in biological sampling the following considerations potentially also feature (depending on the nature of the resource, fishery, purpose and resourcing): inter alia, depth strata, bed conditions and the determination of appropriate sampling units; the frequency, seasonality and temporal duration of sampling; and the number of hauls, type of gear and duration of submersion. Further to which, the issue of comparability with previous surveys or those undertaken on other exclusion zones may also feature in the selection of the sampling frame adopted. The selection of the sampling frame may well be a compromise between that theoretically desirable to optimise the accuracy of the subsequent analysis and that operationally achievable and desirable. The sampling frame may similarly be out of the control of the persons undertaking analysis on the data, especially where the data has been collected for other purposes, such that the analysis is uninformed as to the sampling frame or the sampling frame proves inappropriate to the analysis the data is ultimately put to. In such circumstances uncertainty is indeterminable.

A second key decision influencing uncertainty in parameter estimation is in the choice of core data and estimation method. One biological example is where age data is sparse or the species cannot easily be aged, such that length based assessments are used as an alternative. Chen's (1997) comparison between age and length structured yield-per-recruit models showed that length structured techniques better incorporated information observed from fisheries, but age structured models gave more precise and conservative estimates of yield-per-recruit (hence its more widespread use in fisheries management contexts). Assumptions of growth patterns have to be made, along with the influence of environmental variables thereon. To complicate matters further, for certain species dimensions other than length may be more appropriate indicators, as with width for certain decapod species. However, in such instances, the general use of length on board fishing vessels to sort fish means that data collection does not readily adapt to such species-specific requirements.

In terms of socio-economic parameter estimates, as with species, there are multiple occasions when gaps in the data necessitate the use of alternative base data, as where data is missing or inconsistent for certain fleet segments (as for the trawlers in the Gulf of Castellammare case study) and prices for certain categories of landings (as in the Iroise Sea case study). In the English Channel Bass fishery case study, effort data for both the English and French fleets was lacking, such that a "pure" Channel offshore bass model could not be produced. As a result, alternative data and an alternative modelling strategy had to be adopted, notably catch data was used to enhance the results from the Channel fisheries model through detailed validation in a second phase of the model. Even with the utilisation of this alternative, however, the lack of detailed and consistent effort data compromised the ability to investigate fully several aspects of the impact of a trawling ban on the Bass fishery, as with the consequences of the rapid growth in mid-water trawlers already seen on bass fishing in the Channel in the absence of such a ban. In the Bay of Brest case study another issue of note was raised with respect to the data used and relevancy of parameter estimation. Due to the particular features of the small-scale fisheries affected by the exclusion zone, the economic significance of classical indicators such as the rate of profit was questioned. An alternative performance indicator with attributes more in line with the nature of the financial operations of the vessels concerned were proposed. The components of the models may well require such modifications from the norm to enhance the validity of the outcomes of the modelling process.

Finally, it is worth drawing to attention the consequences of incomplete parameter estimation and model specification for the potential over- and under-estimation of value and the uncertainty introduced by natural trends and cycles to their interpretation. In relation to the former, while the challenges of data and model complexity may mean that certain facets of an exclusion zone, resource or fishery are inevitably omitted from the modelling process, it is worth noting the potential contribution those omissions make to uncertainty. In the Normand-Breton Gulf case study the social cost of discards were calculated only for spider crabs, a limitation that culminates in a potential underestimation of the value of the exclusion zone given that the social costs of the discards of sea bream and plaice were not calculable and, therefore, not included. However, as only the direct effects of the exclusion zone on the fishery were incorporated within the model, the value estimation also does not account for the costs of the displaced fishing effort, which would be likely to have a negative influence on value. In terms of the uncertainty introduced by natural trends and cycles, a similar interpretative problem is encountered, with it being difficult without reference to a control to apportion gains or losses to management measures or natural cycles. Even with control sites, the specificity of stocks may make this apportionment problematic. This problem was noted within the Bay of Brest case study in terms of the growth in scallop landings in the 1990s, which could have either be attributed to the restocking programme or improved natural recruitment.

4. Conclusions

Despite the various caveats discussed above, in their various forms, which are caveats not uncommon to biological and bioeconomic modeling in fisheries (and natural resources per se), it is evident that there is value embedded within the concept of fisheries exclusion zones. It is also clear that despite data problems and other sources of uncertainty, the modeling frames profiled in this study are useful tools in the evaluation of exclusion zones as a fisheries management tool. It is evident that no one methodological approach can be applied uniformly to their evaluation, necessarily being specific to the situation facing each exclusion zone. However, there is a toolbox of approaches that can be drawn upon to inform management, as illustrated through the case studies.

The case studies employed have explored value mainly from the perspective of dedicated fisheries exclusion zones. However, as noted there are also many marine nature reserves and other types of marine exclusion zones in Europe that have an impact to some extent on the main commercial finfish fisheries, since they are usually close to the shore and comparatively small in relation to the scale of the major fisheries. Restrictions within reserves are significant at a local level for inshore fisheries, although in many cases, only the most destructive fishing techniques, such as trawling and dredging (Jennings & Kaiser, 1998), are prohibited, while harvesting by other means is permitted (Laffoley, 1995). In many cases, naturalness has been a primary criterion for the selection of existing marine nature reserves (Salm & Price, 1995), implying low pre-existing fishing intensity and consequently limited effects of implementation on fisheries and fished species. In future, however, areas damaged by fishing may be increasingly proposed as candidates for protection (Pullen, 1996; Jennings *et al*., 2001).

From the literature it is evident that in the majority of cases in Europe where exclusion zones have been implemented with consequences for fisheries, these consequences have rarely been explicitly considered either in the planning, management, or evaluation of the zones. There is a tendency for fisheries to be considered as an after-thought. As such, baseline data is almost completely absent, added to which the evidence of value typically lies with ad hoc, predominantly natural science studies designed and implemented for purposes unconnected with fisheries. Comprehensive studies of the biological and socio-economic value of exclusion zones for fisheries are few in number. The fishing boxes are the main exceptions, yet even here there is a tendency for the analysis to have a theoretical focus. In noting this however, it is possible to draw from the literature indicators of value and to identify the potential within the concept for the management of fisheries; a potential which this project aimed to explore further.

Within the scope of this project evidence has been provided of the diversity of the potential benefits accruing from the creation of fisheries exclusion zones: biological, ecological and socio-economic. However, this project has also shown that the “value” of fishing exclusions zones, whether positive or negative, is not a general question nor necessarily readily anticipated or explained. It has been shown to be dependent on the scenario under analysis with multiple factors affecting it, including the: structure and socio-economic characteristics of the fishery, nature and state of the stocks, fishing method(s) employed, and management policy applied. Even in situations sharing common characteristics, these factors can result in very different outcomes. The complexity of multi-species interactions and the complex relationship between fishing effort, gear effects and species biology are confounding influences in the drive to an effective fisheries exclusion zone.

It is evident that the promotion of fisheries exclusion zones as the panacea of fisheries management is misplaced. They represent a valuable tool of management in certain circumstances and in accordance with certain objectives or combinations of objectives. Their benefits are rarely felt uniformly across species, segments of the fishery or across geographical sub-areas. There is also the potential for exclusion zones to have a range of undesirable side effects and unanticipated costs and for their benefits to be dissipated by external forces, such as the growth of tourism. Unfortunately, without analysis prior to the deployment of any one exclusion zone it is impossible to definitely say for which circumstances and objectives the concept has value. Each application and set of circumstances is unique. In saying this, however, fisheries exclusion zones have a demonstrated potential, and are worthy of consideration as a management tool alongside other more traditional fisheries management options.

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