NEW ECONOMICS FOUNDATION

NORTH DEVON MARINE PIONEER PROJECT – OUTPUT 1B

ECOSYSTEM SERVICES BENEFITS OF IMPROVED WATER QUALITY FOR SHELLFISH AQUACULTURE

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1. Context: Natural capital and the ecosystem services benefits of improved water quality for shellfish aquaculture.

- A number of EU and UK regulatory drivers are important for improving the condition of the marine environment, including the EU Marine Strategy Framework Directive (MSFD), the EU Water Framework Directive (WFD)[1], the EU Habitats and Birds Directives. The vision of the UK Marine Policy Statement to have 'clean, healthy, safe, productive and biologically diverse oceans and seas'[2] further supports these. English legislation including the Inshore Fisheries and Conservation Authority (IFCA) byelaws and the Marine Plans as well as the Marine Pioneer Projects, share this ambition.
- Ecosystem services have been described as 'the direct and indirect contributions of ecosystems to human wellbeing' and need to be incorporated into management frameworks and strategies as otherwise their degradation is not taken into account.[3]
- Due to the growing recognition of the ecosystem services provided by suspension-feeding bivalves (such as mussels and oysters), estuarine restoration projects supporting natural remediation (water clarity improvements, reduction of nutrient loading / eutrophication, filtration, buffering against algal blooms) can notably improve water quality and enhance resilience of estuarine ecosystems.
- Under the WFD, water bodies are required to have 'good' /'high' ecological, chemical and hydromorphological classification. The ecological status as a whole must reflect the lowest classification across all these three categories. The Taw/Torridge – wild mussel harvest and subject to limits based on annual D&SIFCA stock assessments, the Bristol Channel Inner South and also Bridgwater Bay have failed to meet the required WFD standards (classed as 'Moderate' in 2015). The Taw estuary is designated as a "Polluted Water" under the Nitrates Directive. The Taw Estuary is hyper-nutrified and classified as "moderate" in respect to dissolved available inorganic nitrogen according to the Environment Agency (2016), which has WFD and shellfish implications.[4]

2. Bivalve shellfish – ecosystem engineers

- **Native oyster** (*Ostea edulis*) The European flat oyster (*Ostrea edulis*) is classified as highly endangered throughout Europe. Furthermore, *Ostrea edulis* and *O. edulis* beds are in the OSPAR list of threatened and/or declining species and habitats in the North-East Atlantic[5]. In addition, *O. edulis* appear in the UK Biodiversity Action Plan (BAP) species and habitat lists with 'Marked decline in the UK' being identified and carry a priority habitat expansion and condition based action status[6].

- The native oyster has been harvested for food for around 6000 years, once a food of the poor their scarcity means they now command a high price[7]. The reproductive biology of the *Ostrea edulis* also means that reproductive success is closely related to density.
- In the NDMP area, there were historically native oysters in Porlock Bay, but they are not currently harvested or farmed. At UK level, the cause of decline includes over-exploitation, habitat loss and wider environmental and anthropogenic pressure stemming from pollution, predation[8] and disease.[9]
- **Oyster reefs** are one of the most degraded estuarine habitats globally (over 85% of natural oyster reef habitat have been lost globally in the past 130 years)[10]. *Ostrea edulis* 'beds' are defined by OSPAR as comprising *five or more individuals per m^2.*[11]

Figure 1: the native flat oyster (Source: Sussex IFCA) and Blue Mussel[12]

- **Pacific oyster** (*Crassostrea* /now *Magallana gigas*) was introduced into British waters in 1890 to support an aquaculture industry suffering from the decline of the native oyster. Pacific oyster aquaculture in the UK is economic significant, with a Gross Output and Gross Value Added (GVA) through all stages of the value chain estimated at £13 million (annual Gross Output, 5 times the first sale value), and over £10 million GVA[13]. Seafish (2016) estimated 37 full time jobs in Southwest England associated with pacific oyster production, producing 850 tonnes in England (2012) worth £3.4 million[14].
- **Blue Mussels** (*Mytilus edulis),* are cold-water mussels that play a key role in healthy marine ecosystems in terms of affecting coastal sediment dynamics (trapping and removing sediment), acting as a food source (for some fish and shellfish species as well as wading birds), as well as biodiversity enhancement in an otherwise sediment-dominated environment and as a result they are classified as a UK Biodiversity Action Plan (BAP) species.[15]
- Blue mussels, like other bivalves, are filter feeders, filtering micro-algae, zooplankton and other suspended debris from the water column. They also play a vital role, in particular in estuaries, by removing bacteria and toxins.[16]

- Oysters and mussels also have the potential to improve water clarity, remove algae through suspension-feeding and thereby improving water quality. At current depleted abundance their positive effects are minimal, which alongside the socio-economic impacts on employment in the fishery and the overall health of the marine ecosystems makes this a major issue to resolve.[17]

3. Bivalves in the NDMP area

Oyster Aquaculture

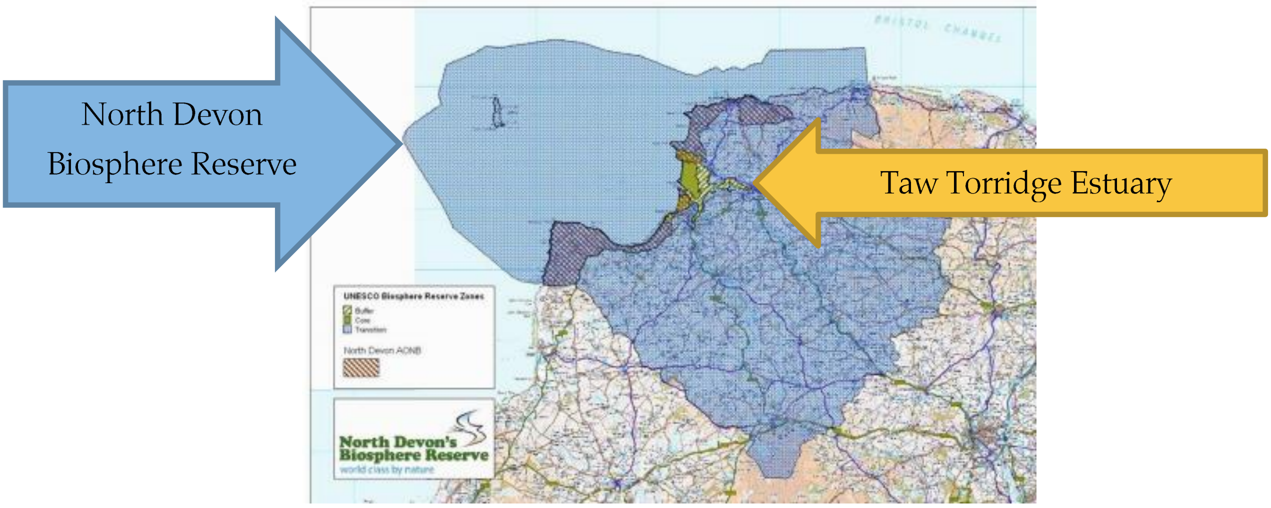
- On the coast of the Exmoor National Park, in Somerset, Porlock Bay Shellfish is the first community-based Pacific oyster farming project in the UK, which began in April 2014. The project aims to bring back the village's traditional trade of shellfish farming (the 19th century oyster industry) and to create at least three full-time jobs in the area as a social enterprise (residents have set up a Community Interest Company called Porlock Futures C.I.C.) The Fishmongers Hall, Exmoor National Parks Authority, and Porlock Parish Council co-funded the project.
- Porlock Bay Shellfish was awarded (2015) Grade A hygiene rating by the Food Standards Agency, which means that the oysters do not need to be cleaned before eating and can therefore be sent directly to local restaurants.
- Annual oyster festivals to attract tourists to the area hold much promise to increase the benefits and local economic activity as a result of small-scale aquaculture.
- Currently 75,000 oysters are growing in Porlock Bay and around 500,000 seed and part grown oysters are at Bantham. A further 550,000 seed oysters have been laid at Bantham.[18]
- In an area with fewer than 850 households, over 140 have given the company loans (>£65,000). A grant from Power to Change of £75,000 has enabled Porlock Bay Oysters to supply local restaurants and food outlets while employing 7 part time staff. [19]

Wild mussel harvest

- The Taw Torridge estuary (Figure 2) is located within the NDMP area and links to marine and terrestrial areas (the AONB and Biosphere reserve).[20] The Taw Torridge Estuary is a SSSI and the mussel beds provide an important food source for the overwintering birds, which are notable features of the SSSI.[21] Recreational hand gathering of cockles in the Taw Torridge also takes place.
- Devon and Severn IFCA undertakes annual surveys of the mussel beds to assess the stock levels and the amount of food available to the overwintering birds. This also helps determine an allowable catch for the commercial removal of mussels to prevent too much mussel being removed without allowing a provision for the

birds and the beds. After a notable loss of mussel, stock in 2013 and 2014 the stocks are now improving and this highlights the importance of annual surveys to determine the condition and allowable take from this important UK Biodiversity Action Plan (BAP) Priority Habitat.[22]

Figure 2: the Taw-Torridge estuary in relation to the NDMP.



4. Ecosystem Services (ES) - The Millennium Ecosystem Assessment (MEA, 2001-2005)[23]

The MEA (2001-2005) examined the consequences of changing ecosystems for human well-being involving 1,300 global experts to provide the scientific basis for action to improve the conservation and the sustainable use of ecosystems - including the provision of clean water, food, timber, fuel, forest products, flood control, and other natural resources.[24]

The main findings of the MEA were:

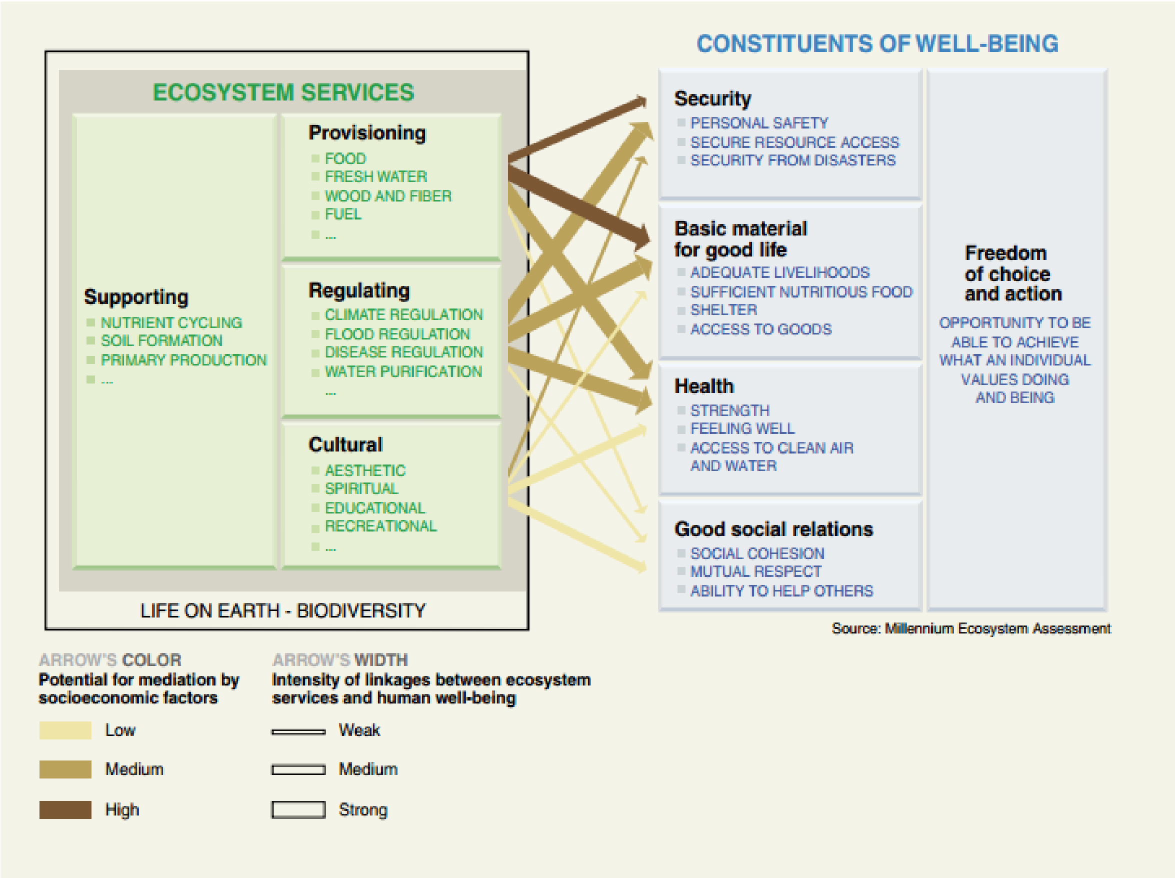
- Between 1950 and 2000 ecosystems were impacted and changed faster than ever before in human history, largely as a result of human activity.
- 60% of the 24 ecosystem services examined were being degraded. Irreversible biodiversity loss has been one major consequence.
- Any benefits derived from exploiting nature came at the cost of significant degradation of ecosystem services, resulting in higher risks of irreversible change and increasing poverty.
- The long term impacts for future generations were shown to be a severely depleted resource / natural capital base.
- 'Non-linear' changes such as new diseases, water quality decline, fish stock collapse and coastal 'dead zones' were identified, together with regional climate shifts.

- Significant policy changes were urgently needed.

The MEA raised the question of how changes in ecosystems impact human well-being and how to communicate to decision-makers, as the economic value of non-marketed services was almost non-existent and costs of the depletion was not tracked in national economic accounts.[25] These still do not feature in the UK's Gross Domestic Product (GDP), although the Natural Capital Committee advice to Government on the 25 Year Environment Plan[26] makes recommendations of using a natural capital accounting approach to the environment).

Figure 3 below illustrates the linkages between ES provision and human wellbeing, according to the MEA.

Figure 3: From Ecosystem Services to human wellbeing (MEA, 2005)[27]



The economic valuation of ecosystem services involves expressing a value for these services in monetary terms, to bring hidden costs and benefits to view – and to the attention of decision makers (via Cost Benefit Analysis – CBA in the form of Impact Assessments)[28]. All investment decisions and interventions involve trade-offs and valuation of ecosystem services is a step towards more inclusive decision making, by making these trade-offs explicit and comparable in monetary terms. A full valuation of the wide array of services provided by shellfish would enable decision makers to better understand and compare trade-offs.[29]

5. Ecosystem services provision by shellfish

- Scientific publications recognise the crucial role of shellfish (oysters in particular) in the maintenance as well as the stability of coastal ecosystems.[30] High density oyster bed ecosystem services in the USA (excluding harvest, i.e. the non-market ecosystem services) were valued between $5,500 and $99,000 per Hectare per annum and shown to cover their median restoration costs in 2-14 years[31].
- The ecological functions and processes, which shellfish provide, contribute to human well-being, and these ecosystem services are recognised by the MEA.[32] Despite this, the management of shellfish and shellfish habitats for objectives beyond commercial and recreational fisheries is not yet widespread.[33] A major concern is the common / public good nature of fisheries / shellfish resources, which risk a *tragedy of the unmanaged commons* as many of the non-market benefits (un-priced) accrue to society as a positive externality and society-at-large remains unaware of their contribution to wellbeing and healthy ecosystems and therefore cannot value them.[34]
- The only directly priced ecosystem service provision by shellfish is post-harvest at market prices. This does not however comprise a full quantification of their total value to society and the ecosystem as a whole. Furthermore, for that value as a food source to be captured, the shellfish must be harvested, which in turn reduces the ongoing ecosystem services beyond food provision (they no longer form a habitat, filter water, store carbon or reduce shoreline erosion once removed).[35]
- Further impacts of depletion on their ecological functions include negative impacts on their nutrient cycling ability, linked to fish and shellfish production and nursery habitat creation as well as bentho-pelagic coupling.[36]

6. Bivalve shellfish ecosystem services and natural resource management

- Oysters fulfil many roles and functions[37] within estuarine and coastal ecosystems. Quantifying ecosystem services has important applications for natural resource management, as failing to consider the true costs resulting from the degradation of these ecosystems can result in a reduction of those beneficial flows which humans derive from nature. Non-native oyster reefs can also fulfil these functions, despite being listed as invasive, non-native species (INNS).[38]
- Using an ecosystem services framework (see table 1 below) can enable regulation and investment to protect and conserve those flows of benefits, while also allowing interventions to be targeted, e.g. a focus on those species, which have experienced a stark decline as a result of human activity, that could be restored through particular strategies and interventions.
- Oysters and other suspension feeing bivalves (such as clams, mussels, scallops, cockles etc) provide benefits through their filter feeding behaviour, which removes particles such as phytoplankton, organic / inorganic matter from the water column,

which has a clarifying effect, reducing turbidity and the settlement of some other marine invertebrates as well as transfers of matter to the seabed / estuary. The beneficial impacts of these activities are most pronounced in dense aggregations, i.e. 'high density beds' as described by OSPAR, due to their cumulative impact. In providing these reefs, shellfish also provide a diverse structural habitat for other species and in muddy estuarine environments, they provide a hard substrate for settlement.

- A case study from the USA showed the avoided-cost concerning Nitrogen removal to meet the Clean Water Act (1972) from 1 hectare of oyster-bed habitat of $1385–$6716 per year and substantial replacement costs (for providing the rocky sea defences provided by oyster reefs), as were the benefits in terms of habitat enhancement and the resulting fish and crustacean productivity enhancement.

Table 1: Ecosystem services provided by shellfish[39]

Type of Ecosystem service	Types of benefit flows
Provisioning services: products / goods people obtain from a restored or maintained shellfish population	Commercial, recreational and subsistence fisheries
	Aquaculture / food production / food for intertidal birds
	Habitat provision for fish and shellfish; Fertilizer and building materials (lime)
	Materials (shells) for building aggregate of jewellery
Regulating services: benefits people obtain from the regulation of ecosystem processes.	Water quality maintenance / filtration
	Protection of coastlines from storm surges and waves
	Reduction of shoreline erosion
	Carbon sequestration
	Stabilization of submerged land by trapping sediments
Supporting services: while not providing direct services themselves, supporting services are necessary for the	Cycling of nutrients
	Alteration of energy flows

production of all other ecosystem services.	Nursery habitats for commercial fish species
Cultural services: nonmaterial benefits people obtain from ecosystems	Tourism and recreation (improving recreational fisheries and water quality for tourism.)
	Symbolic of coastal heritage

7. Description of key bivalve shellfish ecosystem services

Provisioning services:

- *Food, jobs and revenues*
  Shellfish landed provide food and employment as well and downstream economic benefits to local communities. The full economic value of shellfish fisheries is beyond landed value, through value-adding along the supply chain. Financial benefit accrue to the producers, buyers / wholesalers, restaurants, exporters and the national/international food industry and also carries a tourism value. Shellfish shells also have a market value (e.g. jewellery, building aggregate, agricultural lime).

Regulating services

- *Water quality maintenance*
  Bivalve shellfish contribute to buffering in shallow estuarine and coastal waters against excessive phytoplankton blooms, which are created by excess Nitrogen. By removing inorganic sediments they counteract the impact of sediment loading. Shellfish maintain water quality via direct removal of suspended material, and also by controlling the rate of nutrient exchange.
  When bivalves move nutrients, organic carbon and nitrogen to the bottom, this provides nutrients for micro- and macroalgae, other plants and invertebrates that serve as prey species in the food web. Oysters have a very high filtration rate (a single oyster filters 15-50 gallons a day) and also have the capacity to discharge pseudofeces (which means they can continue filtration under conditions of high turbidity). The biodeposits created by mussels and oysters induce denitrification, which helps counter-act eutrophication by releasing nitrogen into the atmosphere as inert nitrogen gas. [40]

- *Carbon sequestration*
  The external shells of bivalves are made of calcium carbonate, absorbed naturally from the ocean water, which becomes a physical store of carbon until harvest (or the point they are dissolved through ocean processes or sponges – which also acts as an

alkaline buffer against ocean acidification). If they are buried in the substrate they can prevent the carbon from entering the atmosphere.[41]

- ***Protection of Shorelines and Sediment Stabilization***
  Reducing nearshore erosion, through reducing wave action is particularly important in protecting salt marsh as well as in decreasing the rate of loss of aquatic vegetation (e.g. seagrasses), is a key benefit of intact shellfish beds. Stabilising aquatic vegetation also increases nutrients available to seagrasses through deposition.

Supporting services

- *Improved habitat for fish nursery areas*
  Particularly when in high densities living and dead shells provide habitats for commercially or recreationally important fish and shellfish species.[42] The provision of habitat and food by intertidal shellfish is also important for overwintering birds, which rely on the shellfish, and this provision needs to be considered for their conservation and management. Shellfish bed or reef structures also provides a habitat and protection for other macro inverts which in turn provide nutritional inputs into the food web. There are shellfish beds, which are designated features of European Marine Sites, Marine Conservation Zones, and SSSIs throughout the UK. In the NDMP area– the Taw Torridge is a SSSI and mussel beds lie within the Braunton Burrows SAC.

  Improving water clarity / quality also improves the submerged vegetation or seagrass growth as sunlight can penetrate deeper, providing 'nursery habitat', where juvenile fish and invertebrates are protected.[43] The knock-on benefit of more seagrasses for example in increased sediment trapping and thus further adding to water quality.

  Biodiversity and available surface area in sediment-dominated habitats are improved by the creation of "biogenic"[44] substrate, which provide high quality nursery habitat for a wide diversity of species and boosting recruitment. Overall the ecology is greatly enhanced in shellfish habitat compared to surrounding areas of the seabed.[45]

  An understanding of the basic 'habitat provisioning' ecosystem service delivered by horse mussel (*Modiolus modiolus* (L.)) reefs (which have suffered similar declines as native oysters due to their vulnerability to physical impact and slow recovery) is also helpful when considering other bivalve shellfish. Mussel reef systems are important feeding and nursery areas for whelks (B. undatum), providing 'essential fish habitat' value of these species-rich ecosystems.[46]

- ***Nutrient cycling***
  Shellfish have a major impact on nutrient cycling in estuarine systems, through their filter feeding, which contributes to maintaining the stability of the ecosystem.

Nutrient cycling includes moving carbon, nitrogen and other essential materials which keeps the system in balance and functioning well.

- *Flow alternation and sediment trapping*
  Hard substrate in soft sediment environments disrupts the hydrodynamic flow and creates channels as well as depositional zones, which influence recruitment, growth, and other processes of shellfish, through both flow rate impacts and habitat creation and stabilisation.[47]

Cultural services

- *Tourism, heritage and community benefits*
  High density oyster beds act as a living breakwater, which is more natural and also aesthetically appealing than man-made structures fulfilling the equivalent role.

  Community-based shellfish restoration efforts[48], such as Oyster farming in Porlock Bay or the Solent Oyster Restoration Project[49] have also been noted in literature to provide benefits around community cohesion and helping connecting people with local foods and traditions.[50] The Solent project and others around the UK, including the Native Oyster network[51] are using oyster restoration as an educational tool and forming partnerships with schools, which also holds potential for wider community benefits.

  Shellfish fisheries and aquaculture can also indirectly bring local environmental problems to the attention of nearby communities and serve as a starting point for wider engagement into environmental issues.

8. Opportunities for the NDMP area

Bivalve shellfish fisheries and aquaculture, as well as some limited opportunities to re-wild and restore oyster reefs (possibilities for mixed native-pacific enhancement need to be evaluated) around Porlock Bay and mussel beds may provide opportunities for pioneering management measures and restorative action for the North Devon coast. While the coastline is very exposed (which brings challenges for aquaculture development) there may be opportunities to scope out more sheltered locations in bays and estuaries which could be candidates for re-wilding, community-based aquaculture and the enhancement of the ecosystem role played by bivalve shellfish in the NDMP area. Restoration is difficult if the right habitat and cultch is not present. Increasing pacific oyster protection might become increasingly difficult in MPAs with the current stance on its INNS status.

The Porlock Bay CIC model demonstrates that communities (when given the support needed) can develop plans and projects to deliver local benefits, covering socio-economic (jobs, income and restoring past industries) to environmental (though restoration of natural habitat, biodiversity and improved water quality).

The mussel fishery in the Taw Torridge demonstrates the need for good science (in the form of annual stock assessments) and regulation in the management of the mussel fishery, to ensure the wide range of benefits continue into the future.

The NDMP could develop a baseline study of where bivalve shellfish reefs could be restored as part of coastal management efforts, while also investigating the opportunities for community supported bivalve aquaculture. Wider opportunities which do not rely on finding suitable coastal areas (e.g. rope-grown systems in sheltered bays or even offshore aquaculture such as is being developed in Lyme Bay) should be discussed and feasibility studies could be used to determine the viability of such schemes.

ENDNOTES

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