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THE FORGOTTEN SHELLFISH REEFS OF COASTAL VICTORIA: DOCUMENTING THE LOSS OF A MARINE ECOSYSTEM OVER 200 YEARS SINCE EUROPEAN SETTLEMENT

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ABSTRACT: Victoria has lost vast areas (>95%) of native flat oyster (*Ostrea angasi,* Sowerby 1871) and blue mussel (*Mytilus edulis galloprovinicialis,* Lamarck 1819) reefs from estuarine and coastal waters since European settlement. We document the decline of these reefs by examining indigenous use of shellfish, the decimation of oyster reefs by dredge fishing in early colonial days (1840s–1860s) and later removal of mussel reefs by the mussel and scallop dredging industry (1960s–1990s). Review of current scientific information reveals no notable areas of continuous oyster reef in Victoria and we consider this habitat to be functionally extinct. While the large-scale removal and destructive fishing practices that drove the rapid declines have not occurred since the mid-1990s, a natural recovery has not occurred. Recovery has likely been hampered historically by a host of factors, including water quality and sedimentation, lack of shell substrate for settlement, chemical pollution impacts, disease of native flat oysters (Bonamia), and more recently introduced species that compete with or prey on shellfish. However, research in the United States has demonstrated that, by strategic selection of appropriate sites and provision of suitable settlement substrates, outplanting of aquaculture-reared oysters and mussels can re-establish shellfish reefs. While a long-term sustained and structured approach is required, there is potential to re-establish shellfish reefs as a functioning ecological community in Victoria's coastal environment.

Keywords: mussels, oysters, Corner Inlet, Western Port, Port Phillip Bay, overfishing, water quality, shifting baseline, shellfish restoration

VICTORIA'S SHELLFISH REEFS — LOST FROM MEMORY

Shellfish reefs are one of the most threatened of marine habitats, with an estimated 85% lost from coastal areas globally (Beck et al. 2011). The situation in Australia is no less serious, with more than 90% of the shellfish reefs that once existed considered to be functionally extinct. However, this extreme modification of the nearshore coastal environment has largely been lost in human memory, reflecting a 'collective intergenerational amnesia' (Alleway & Connell 2015). As such, there is little to no contemporary appreciation or understanding of the historical, ecological and economic role that shellfish reefs have played in Australia. Lack of contemporary appreciation of the value of these marine communities to coastal systems and human wellbeing presents a major barrier for progress towards their recovery and repair.

There are two main species of reef-forming shellfish in Victorian estuaries: the blue mussel (*Mytilus edulis galloprovincialis,* Lamarck 1819; also referred to as *M. edulis planulatus*) and native flat oyster or 'mud' oyster (*Ostrea angasi*, Sowerby 1871). Bivalves first appear in the geological history of Port Phillip Bay at about 8000–9000 years BP, with *Ostrea angasi* shells from sediment cores having been dated at approximately 9500 BP (Holdgate et al. 2011). This indicates their presence shortly after the bay formed, and that they must have previously existed in the nearshore coastal waters. In various middens along the coast, and some now well inland from the coast, oyster shells have been dated at up to 5500 years BP (Gill & Lane 1985; Godfrey 1989). While mussel shells are not well preserved in the sedimentary deposits due to their fragile nature, it is clear from their known importance as food for indigenous communities (Sullivan 1981) that they were once abundant in accessible depths for collection. While it is clear that both native flat oyster and blue mussel have been a feature of Victoria's major bays and estuaries for thousands of years, there has been no attempt to develop a picture of how extensive these habitat formers may once have been.

Understanding what has been lost is the first step for understanding what can be gained from recovery. Here we reconstruct the recent history (200 years) of reef-forming shellfish in Victoria by documenting indigenous, colonial and contemporary use, estimate their past and present extent, and identify factors responsible for their decline.

METHODS

We used an applied historical ecology approach to understand the decline of shellfish reefs in Victoria (Swetnam et al. 1999). This method has been used to reconstruct oyster populations in numerous locations (Kirby 2004; White et al. 2009; Zu Ermgassen et al. 2012; Alleway & Connell 2015) and attempts to recover the 'shifted baseline' of our understanding of what ecological systems looked like before strong human impact (Pinnegar & Engelhard 2008). We used a variety of sources from historical and contemporary literature, interviews with Victorian coastal fishermen, fisheries catch data, and the authors' first-hand knowledge and observations, to establish a baseline of the likely major areas of mussel and flat oyster reef systems in Victoria at the time of European arrival. We document the indigenous and colonial use of shellfish and reconstruct a timeline of decline and possible factors responsible.

Newspaper articles and illustrations can be an important and accurate source for reconstructing environmental histories (e.g. Rosenberg et al. 2005). We used newspaper articles extensively, and a full list of articles used is provided in Table 1. Using the Australian national archive online service, we searched for the words 'shellfish', 'oyster' and 'mussel' in all Victorian newspapers articles between 1830 and 1930. Similarly, illustrations and photos in newspapers and other publications provide strong visual evidence of the cultural and day-to-day relevance of oysters, and we conducted similar searches through the National Library of Australia (Trove).

From these historical documents, we listed all locations where oysters were fished and over what period, and where possible documented commercial catch, relative abundance, the extent of beds or the size of the fishery. Where possible, we converted references to catches in historical units (such as 'dozen oysters' or 'bags of oysters') into estimation of weights. To do this we used conservative estimations of weight of oysters at 65 g and their number per bag between 250 and 750. Further research is required on these figures to accurately estimate historical catches, and hence our catch estimates should be considered speculative.

Fisheries management changes can be used as proxies to understand fishing pressure and stock abundance (Kirby 2004; White et al. 2009). Hence we searched for Victorian legislation relevant to shellfish fisheries and documented key changes in fisheries regulations. In particular, fisheries closures or designated fisheries areas can provide useful information. It is reasonable to assume that the areas demarcated as being closed to oyster dredge fishing would indicate the general areas where the main early productive oyster reefs were distributed.

Fisheries records with spatial references are available for the later part of the twentieth century (i.e. since 1960s) and provide an indication of likely historic hotspots, albeit modified by earlier fishing and environmental impacts.

To better understand the recent (past 50 years) location and abundance of shellfish reefs in areas where scientific or fisheries data are limited, we undertook a number of semi-structured interviews with eight current and retired commercial fishermen. These interviews led discussion around past recreational and commercial harvest of oysters and mussels, and the current fishing activity. We identified areas of current distribution and those that supported some form of fishing 40–50 years ago. Interviews were carried out under Melbourne University Human Ethics permit 1341015.

The authors also used field observations from over one thousand SCUBA dives in Victorian bays and inlets to support the past and current extent of shellfish reefs. Anecdotal and historical records were matched with authors' knowledge of shell deposition and reef ecology.

Extensive scientific and archaeological literature was also used to support the newspaper, legislative, observational and anecdotal reports. Enough information was available when combining these areas to produce maps of the likely extent of shellfish reefs in four Victorian bays and inlets: Port Phillip Bay, Western Port, Corner Inlet–Nooramunga and the Gippsland Lakes.

INDIGENOUS USE OF SHELLFISH IN VICTORIA

Aboriginal kitchen middens are common around Victoria's bays, estuaries and coastal areas. Carbon-dating of shells from middens indicates that the practice of shellfish harvesting by indigenous peoples goes back at least 10,000 years in coastal areas of Victoria (Godfrey 1989; Meehan 1982). Over 350 coastal shell middens have been recorded for the Bellarine and Mornington Peninsula (Port Phillip Bay) and Phillip Island (Western Port) areas alone (Sullivan 1981; Presland 2010). There are middens still observable within the Melbourne metropolitan area of Sandringham and Brighton, but unfortunately many middens sites have been lost to urban and coastal development (Presland 2010).

The composition of middens varies with location but those adjacent to bays and estuaries such as Port Phillip Bay, Western Port and Corner Inlet show a conspicuous presence of mussels and flat oysters, along with a variety of other shellfish, including turbo (*Turbo undulatus*, Lightfoot 1786), limpets (*Cellana tramoserica,* Holten 1802), abalone (*Haliotis rubra,* Leach 1814) and cockle (*Anadara trapezia*, Deshayes 1840). A survey of middens on the Mornington peninsular (between Port Phillip and

Western Port) found *M. edulis planulatus* as the dominant shellfish at all middens on the shore of Port Phillip Bay, with *O. angasi* present at 21% of sites but rarely dominant (Sullivan 1981). These observations add support to the presumption that Port Phillip Bay shellfish beds were dominated by mussels, at least in the north and east. Bass Strait middens were dominated by rocky shore species, with *M. edulis planulatus* and *O. angasi* present at 41% and 2% of sites respectively. Oysters and mussels are also the dominant shellfish located in estuarine middens in East Gippsland at Lake Mallacoota (Simmons 1983).

McNiven (2000) found that mainland middens of the Brataualung of Corner Inlet – Nooramunga comprised native flat oyster (*O. angasi*), spindle shell (*Pleuroploca australisia*, Perry 1811), cockle (*A. trapezia*), mud cockle (*Katelysia* sp.), blue mussel (*M. edulis planulatus*), top shell (*Austrocochlea* sp.), triton (*Cabestana spengleri*, Perry 1811) and pipi (*Donax deltoids,* Lamarck 1818). Shell assemblages at the nearby island middens surveyed were dominated by native flat oyster, with spindle shell and mud cockles.

An interesting example of a Wathawurrung midden dominated by *O. angasi,* with some cockle (*A. trapezia*) is at Lake Connewarre near Geelong (Gill & Lane 1985). Carbon dating indicated this midden was formed from harvesting of flat oysters from the area between 3000 and 6000 years ago, when the sea level was higher and the Lake Connewarre area was a large coastal lagoon connected to the ocean. There are reports of other *O. angasi* dominated middens in the Geelong region (i.e. North Shore, Batesford) and further west at Warrnambool (near the Hopkins River estuary), indicative of the occurrence of flat oysters and their harvesting by indigenous people from the Geelong area and along the west Victorian coast during the period of higher sea-level 4000–6000 years ago (Gill & Lane 1985).

The coastal-dwelling clans of the Wathawurrung (western Port Phillip Bay), and Bunwurrung (eastern and northern Port Phillip Bay and Western Port) appear to have been particularly fond of mussels, with flat oysters, limpets, turbo, scallops and cockles being of secondary importance (Sullivan 1981; Gaughwin & Sullivan 1984; Presland 2010). Early European accounts of indigenous clans around Port Phillip reported that their 'food is almost entirely shellfish' (Peron 1803, quoted in Sullivan 1981) and cockles and mussels were found in huts on the Nepean Peninsular (Knopwood 1803, in Sullivan 1981). Indigenous collection of mussels around Melbourne was reported by W. Thomas in 1840: 'While encamped in Melbourne in general a number of lubras would go three times a week to gather mussels' (quoted in Sullivan 1981).

PAST AND PRESENT EXTENT OF SHELLFISH REEFS IN VICTORIA

Port Phillip Bay

Port Phillip Bay is Victoria's largest estuary, covering approximately 1930 km² with a shoreline of 264 km. The earliest European reference to shellfish in Port Phillip Bay is in the journal of Matthew Flinders, who remarked in 1802, upon exploring the coast of eastern Port Phillip Bay near Mornington: 'Quantities of fine oysters were lying upon the beaches between high and low water marks'. Evidence of the large historic mussel reefs in north Port Phillip Bay is indicated in this extract from a letter by W.P. Buckhurst to the *The Argus*, Melbourne, 28 November 1891: 'Sir – After every south-westerly "buster" or gale during the last four or five years tons of fine mussels are washed up on the beach between St Kilda and Sandridge at South Melbourne, and there, after a hot day or two, become an abominable nuisance. What does this indicate? To my mind it shows clearly that during the last few years extensive mussel banks have grown up on the comparatively shallow mud or sand banks extending out two or three miles from St Kilda towards Williamstown'. More recent recollections of local fishers (Mr Bob Pearce, Albert Park Yachting and Angling Club) confirm that this phenomenon continued to occur up until the 1970s.

Historical references, fisheries records of catches since 1950 and contemporary observations indicate that the predominant reef- or bed-forming shellfish species in Port Phillip Bay have been the blue mussel and native flat oyster (Figure 1). Winstanley et al. (1982) carried out a bay-wide survey of benthic communities in the early 1980s and identified mussel aggregations throughout the bay. The northern and eastern section of the bay supported large areas of mixed mussel and oyster reef between 6 m and 10 m depth, with mussel the dominant species. The large reefs were scattered with a range of other suspension-feeding and habitat-forming macroinvertebrate species, such as *Pyura stolonifera,* Heller 1878 (referred to as 'spuds' by local fishers), sponges (Porifera) and macroalgae. While large mussel and oyster reefs did not appear to occur in the central muddy basin of the bay, recent surveys suggest that they would have been present in these areas, perhaps as dispersed small clumps (Cohen et al. 2000). Data on mussel densities presented by Winstanley (1982) and Cohen et al. (2000) suggest a decline of over 80% in abundance of mussels in north-east Port Phillip Bay since 1980.

Contemporary observations of large oyster-shell aggregations in the Geelong Arm (Figure 2), along with numerous lime kilns and related place-names (e.g. 'Limeburners Bay' and 'Limeburners Lagoon' on the

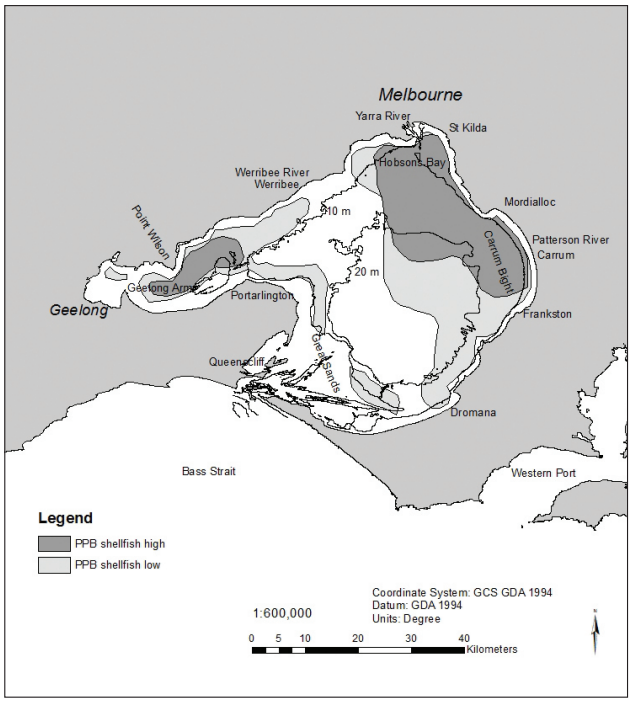

Figure 1: Approximation of historic major areas of blue mussel (*Mytilus edulis galloprovincialis,* Lamarck 1819) and native flat oyster (*Ostrea angasi,* Sowerby 1871) reefs in Port Phillip Bay.

south and north sides of Geelong) indicate likely historical oyster reefs in these regions. Burning oyster shells for lime provided a supply of mortar for the colonial building industry (1830–1860) prior to limestone mining, and would have required a large and consistent supply of oyster shells (Harrison 1996). The importance of the Geelong Arm as an area for oyster reefs is further confirmed by earlier fisheries reports. Lynch (1966) indicated that oyster dredge fishing occurred at least up until the late 1950s or early 1960s in the Geelong Outer Harbour (also discussed further below).

While flat oysters and blue mussel can still be found throughout Port Phillip Bay (Cohen et al. 2000), there are currently no known areas of extensive mussel or flat oyster reefs occurring on the bay sediments. Flat oysters now only occur in occasional small isolated groups attached to hard structures (Figure 3a, b) or as solitary or a few individuals attached to old scallop, mussel or oyster shells (Figure 3d), and are much more abundant in the outer reaches of the Geelong/Corio Arm than any other location.

Mussels are mostly found on raised hard surfaces, particularly on fringing rocky reefs, on top of boulders on subtidal reefs (Figure 3c, e) and on most manmade structures (pier and jetties, navigation marks etc).

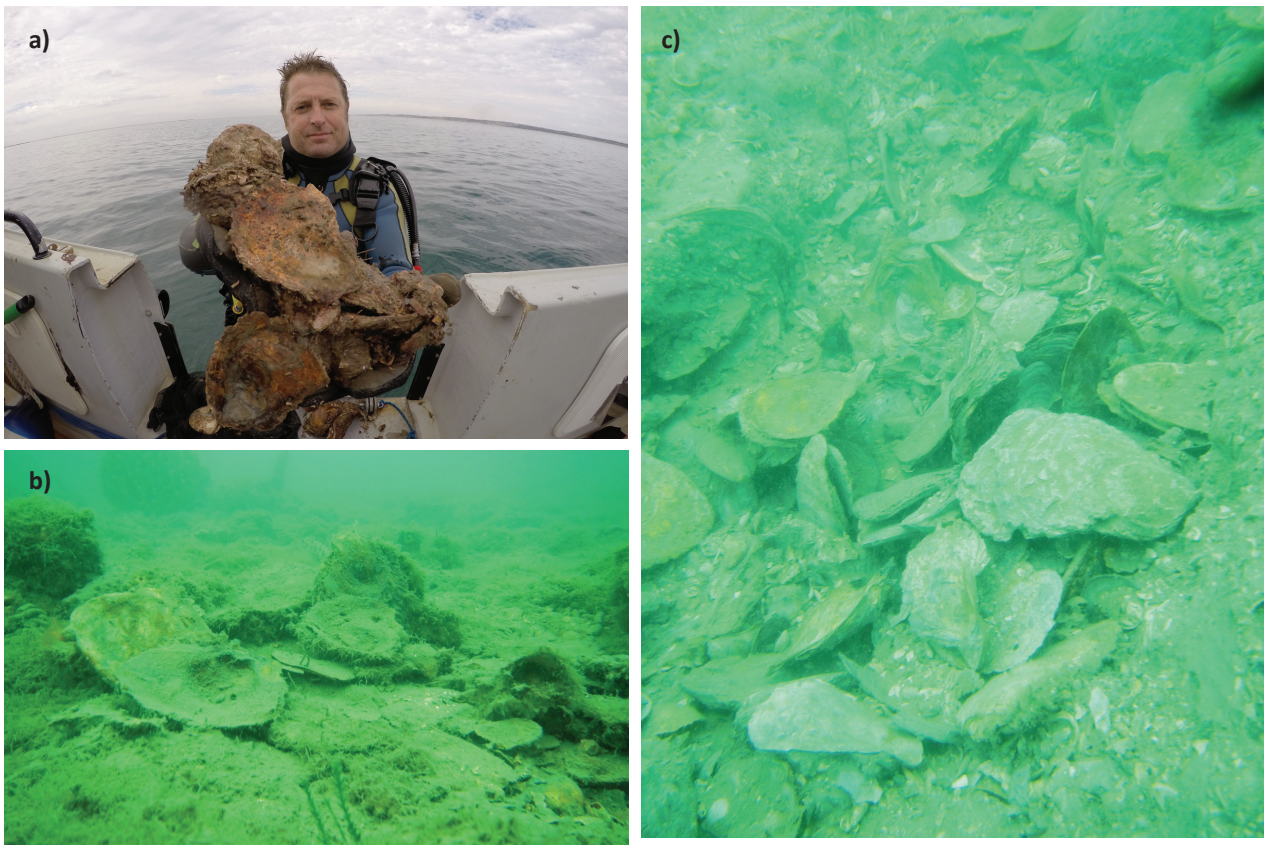

Figure 2, a–c: *Ostrea angasi* (Sowerby 1871) shell deposits at an old reef — Wilson Spit, Geelong Arm of Port Phillip Bay, 2014. Photo credits: B. Wommersley (a) and P. Hamer (b-c).

Figure 3: a) *Ostrea angasi* (Sowerby 1871) growing on isolated rock in northern Port Phillip Bay; b) juvenile *Ostrea angasi* recruited to artificial reef structure in eastern Port Phillip Bay; c) *Mytilus edulis galloprovinicialus* (Lamarck 1819) recruited to artificial reef structure in eastern Port Phillip Bay; d) *Ostrea angasi* clump attached to old scallop shell in southern Port Phillip Bay (Pinnace channel – Great Sands); e) *Mytilus edulis galloprovinicialis* growing on the top of boulders at Anonyma shoal, Sandringham, approximately 2–3 m depth. Photo credits: P. Hamer (a, c and d), B. Cleveland (b) and J. Ford (e).

Western Port

Western Port was a major river drainage system before it was inundated by the rising sea at the around the same time as Port Phillip Bay was flooded (about 10,000 years ago). The Western Port 'sunkland' now forms an extensive tidal bay covering an area of 680 km², of which 270 km² are exposed as mud flats at low tide, and the rest are tidal channels with moderate to strong currents (Marsden et al. 1979).

Assessing historical distribution and abundance of native flat oyster and mussel in Western Port relies mostly on accounts from the early colonial fishery days — well summarised in Hannan & Bennett (2010). The blue mussel is not referred to as a fishery species in colonial times and does not appear to have been historically a major reef building shellfish in Western Port, but is common attached to rocky substrates and manmade structures. The native flat oyster, however, appears to have been very abundant in Western Port when Europeans arrived, forming large reef areas (see early fishery description below). While there have been no recent surveys of subtidal benthic invertebrates in Western Port and the current status of native flat oyster reefs in Western Port is unclear, sporadic oyster harvesting is reported to have occurred at least until the mid-twentieth century (Hannan & Bennett 2010).

A survey of benthic invertebrates using grab sampling in the 1970s (Coleman et al. 1978) did not record native flat oyster and blue mussel, although more recent surveys for exotic pest species did record *O. angasi* to be present in the

port area at Hastings (Currie & Crookes 1997). Anecdotes from retired commercial fishers indicate that occasional harvests of flat oysters along the banks of channels around French Island, mostly for personal use, occurred until recent times (at least 1980s), and that the Western Port oysters were much better to eat than those dredged from Port Phillip Bay (Henry Kernot, retired commercial fisher, Western Port). Hannan and Bennett (2010) also indicated from interviews with fisherman that smaller commercial harvests of oyster were still obtained until the early 1970s but that the few patches of oyster remaining at that time died out about the same time as a major seagrass die-off in the 1970s (described in Jenkins et al. 1993). The most recent review of the Western Port environment (Melbourne Water 2011) does not mention flat oysters and makes only minor reference to mussels related to intertidal surveys and aquaculture.

The best indications of the general areas of Western Port's historic flat oyster reefs (Figure 4) are derived from the historical newspaper archives and government gazettes related to the oyster dredge fishery closures in 1886. While the areas demarcated in Figure 4 provide a broad representation of the distribution of oyster reefs, the main oyster reefs were along the channel banks and subtidal shoal areas, where shingle and shell was abundant, rather than the intertidal zones/mud flats (Hannan & Bennett 2010). The locations of individual reefs were not widely communicated as fishers tried to protect their finds for their own personal gain, and newly discovered reefs were a closely guarded secret (Hannan & Bennett 2010). As such, our literature search did not identify any historical maps of the major reefs, although historical accounts would suggest the banks and channels along the southern fringe of French Island were particularly productive.

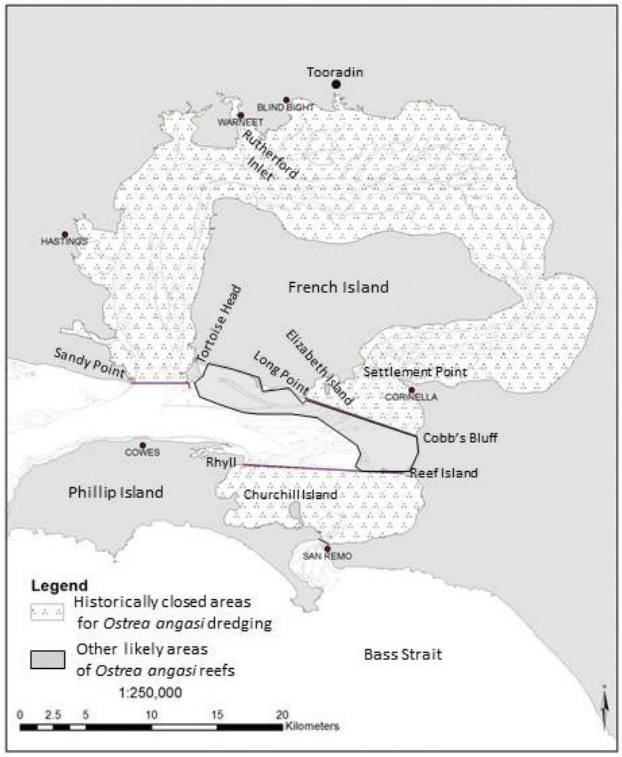

Figure 4: Approximation of broad regions of Western Port that encompassed the distribution of the bays major native flat oyster reefs at European settlement. The closed fishing area was legislated in 1886 in response to population crashes. The additional likely area of distribution was identified using a combination of historical accounts and habitat similarities to known areas of distribution.

Corner Inlet – Nooramunga

Corner Inlet – Nooramunga is a submerged coastal plain of approximately 600 km^2 sheltered from the ocean by over 40 sand islands in the east and by Wilsons Promontory in the south. It comprises predominantly shallow sand and mud banks < 2m deep, separated by a complex series of deeper channels 3–20 m deep.

Our review did not identify any historical maps or detailed accounts of the locations of shellfish beds in Corner Inlet – Nooramunga. However, the area supported a dredge fishery that ran intensively from around 1840–1860, with numerous short revivals in the 50 years thereafter (Bowen 2012). The short period over which beds were depleted, the absence of fisheries inspectors and a lack of government interest in commercial fisheries at the time (Harrison 1996) can explain this absence of official information. Details instead come predominantly from historical newspaper articles, all referring to the fishery as targeting oysters, with no evidence that mussels were caught and sold from the region. Recent scientific surveys have identified remnant *O. angasi* beds (i.e. dead shell) in channels at 10–15 m (O'Hara et al. 2002).

Through the evaluation of historical fishery information (indicating a large dredge fishery), the observations of local fishermen (oysters were still common in some locations in past 50 years) and contemporary observations of the marine environment, we conclude that Corner Inlet – Nooramunga supported large beds of *O. angasi* both in the many tidal channels, and also likely on the shallow banks co-existing with seagrass (Figure 5). Known recent populations documented from fishermen's knowledge occur in a variety of habitats, including shallow mud flats, channel edges and deeper muddy basins. In all cases, however, the oysters were predominantly subtidal. Historical accounts of extensive oyster beds co-existing with scallops in 15–24 m of water off the coast of Corner Inlet also provide the only evidence of commercially fished oyster beds in the coastal waters of Victoria (*Illustrated Australian News*, 7 November 1891). The presumed past distribution of *O. angasi* in Corner Inlet – Nooramunga is hence almost the entire enclosed waterway and some sandy stretches on the open coast.

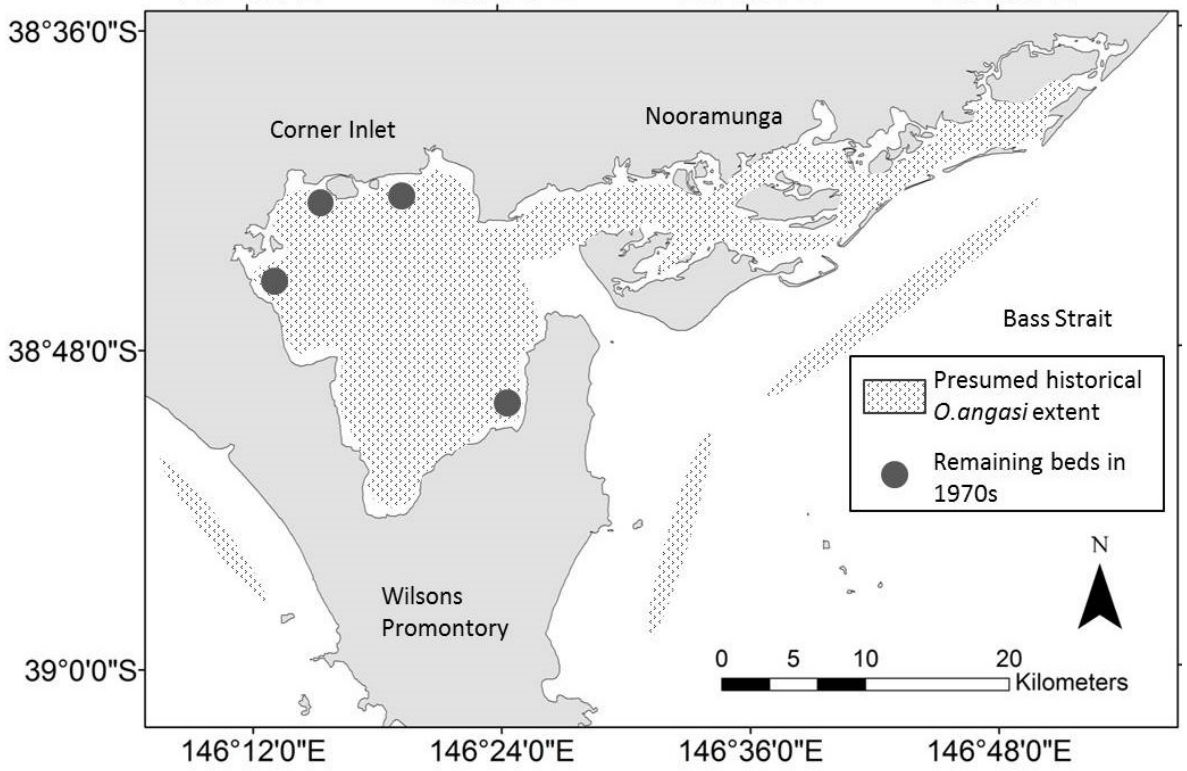

Figure 5: Approximate distribution of flat oyster in Corner Inlet – Nooramunga at European arrival derived from historical records and location of remaining beds in 1970s derived from fishermen's local knowledge.

O. angasi is still present in many locations in Corner Inlet – Nooramunga, but consists mainly of isolated clumps or individuals and no longer form a continuous reef matrix (J. Ford, P. Hamer, pers. obs). Interviews with commercial fishermen have revealed the location of a number of oyster beds in shallow water that were still recreationally fished during the 1960s and 1970s (Figure 5). While oysters are likely still present in these areas, they are not considered to be in abundances worthwhile for collection. A comprehensive study of the macrobenthos of Corner Inlet did not record *O. angasi* in either seagrass beds or mud flats (Morgan 1986), and they were similarly absent in a more recent survey of seagrass associated fauna (O'Hara et al. 2002).

Gippsland Lakes

The Gippsland Lakes are a network of estuarine lakes, marshes and lagoons that cover an area of about 354 km^2 in eastern Victoria. They were once periodically cut off from the sea by sand bars; however, in 1889 a permanent entrance was constructed at the town of Lakes Entrance to facilitate the development of a port. Although there is no indication that a significant flat oyster fishery occurred in Gippsland Lakes during colonial times, they were likely to have been present as they were in other nearby inlets such as Corner Inlet. Blue mussel may have been common in large beds throughout the lakes system for many years, although their abundance at the time of European arrival, and prior to the creation of the artificial entrance is unclear. These beds were most significant in the region from Metung to Lakes Entrances (Figure 6), and were exploited by a dive fishery during the latter half of the twentieth century.

Current state of shellfish reefs in Victoria

Given the lack of evidence for contemporary flat oyster and mussel reefs in Victorian bays and estuaries, we conclude that they are ecologically or functionally extinct. There are currently no known areas of healthy expansive flat oyster reef in Victoria, although degraded reefs with sparse live oysters have been located around the Geelong Arm of Port Phillip Bay near Point Wilson and along a shallow bank between the Corio Bay and outer Geelong Arm (Figure 7). Mud oysters are still present across Corner Inlet but in very low abundances and do not provide reef structure. Healthy blue mussel beds have been observed in the Gippsland Lakes (i.e. Bell Point, near Metung); however, no soft-sediment mussel reefs remain in Port Phillip Bay. Based on observations by the authors, the once vast mussel reefs of north and eastern Port Phillip Bay are all but gone, with remnant populations occurring on artificial structures and shallow rocky reefs. Hence, we conclude that > 90% of oyster and mussel reef has been lost from Victorian coastal bays and inlets, which supports the finding of Beck et al. (2011) that 99% of shellfish reefs within the region are functionally extinct.

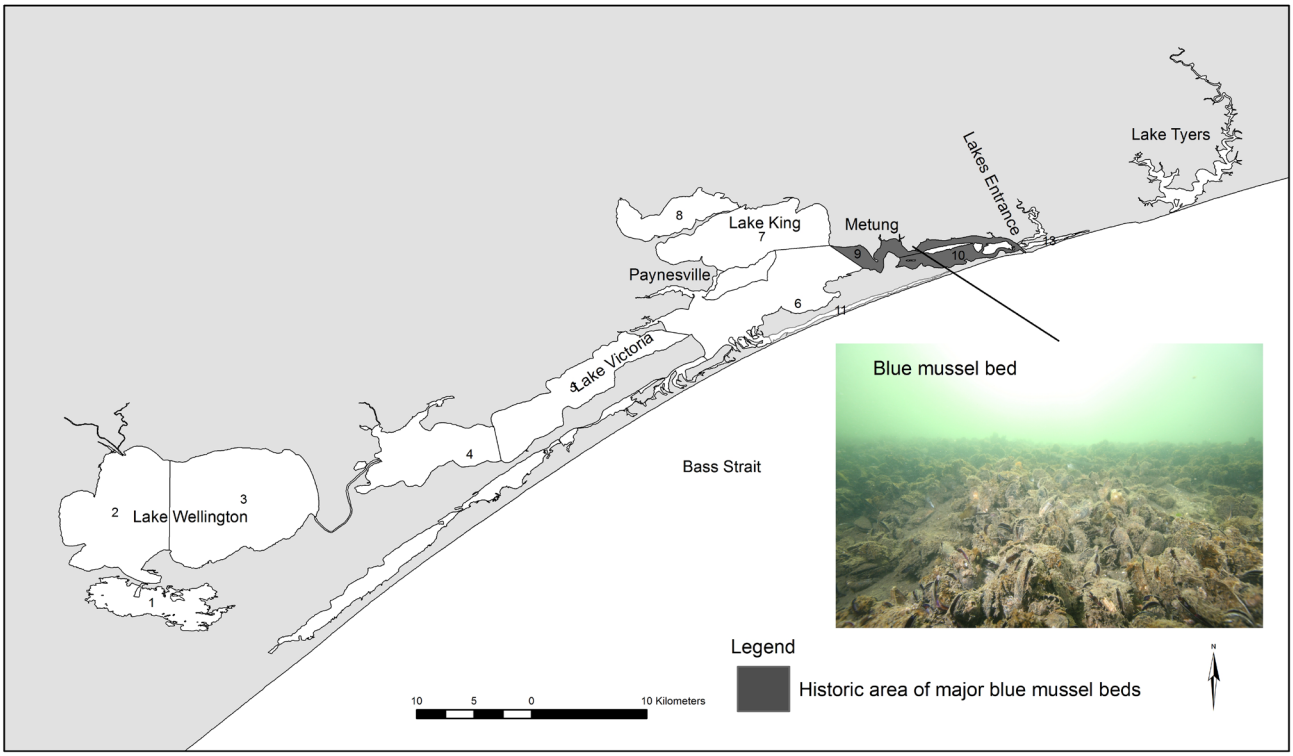

Figure 6: Map of Gippsland Lakes showing area of recent important blue mussel beds, with inset of recently photographed blue mussel bed at Bell Point near Metung.

Figure 7: Remnant *Ostrea angasi* reef at '9ft Bank' in outer Corio Bay, east of Geelong. This is currently the only living oyster reef in Victoria known to the authors.

THE VICTORIAN OYSTER AND MUSSEL FISHERIES 1830S – 1990S

Early settlement

The first European explorations of Victoria's major embayments of Western Port and Port Phillip occurred between 1800–1803. Journals from these early explorations indicate the presence of abundant flat oysters, which were at that time popular European seafood.

When Lieutenant John Murray brought the *Lady Nelson* into Western Port in 1801, he remarked in his journal that '…today gave the shore a strict search at low water and plainly perceived that a company of 6 or 8 men would not run any risk or hazard of being starved here for several months from the vast quantity of shell fish to be found at low water'. The shellfish he referred to were no doubt native flat oysters.

Despite some early failed attempts, it took another 30 years for settlement of the region to progress, with Melbourne and Geelong becoming established towns by the late 1830s to early 1840s. Smaller settlements were established at Port Albert in 1841 (Corner Inlet – Nooramunga) and various locations around Western Port during the 1840s.

Oyster fishing industry in the 1840s–1860s

Initially, oyster fishing was both an important source of carbonate shell for lime production (Pearson 1990) and of food for the colony (Hannan & Bennett 2010). Use of shell material for making lime was replaced by mined limestone by the mid-1800s in Victoria (Pearson 1990), but the colonial taste for oysters saw the oyster dredge fishery develop rapidly to supply the local trade. 'Oyster Saloons' became established in Melbourne and Geelong and vendors selling oysters were common in the streets of Melbourne, as depicted in various illustrations from the time (Figure 8).

Historically the fishery was concentrated around two main centres: Corner Inlet (out of Port Albert) and Western Port (from the ports of Hastings, Corinella, French Island and Phillip Island/Rhyll), as documented in the illustrations in Figure 9. Both fisheries seemed to follow a similar pattern of growth in 1840s, high production in the 1850s and collapse in the 1860s. The accounts from numerous

Figure 8: Historical illustrations showing colonial consumption of flat oysters: a) Royal Oyster Saloon Bourke St, Melbourne, 1860s (illustrator: K.J.Halla); b) Oyster Saloon, The Arcade, Melbourne, 1856 (illustrator: S.T.Gill); c) a cartoon depiction of diners eating flat oysters in a Melbourne oyster saloon, 1855 (appeared in *The Punch*, credit Edgar Ray and Frederick Sinnett); and d, e) street vendors selling flat oysters in Melbourne circa 1870 (illustrator: Samuel Culvert). Images sourced through Trove, National Library of Australia.

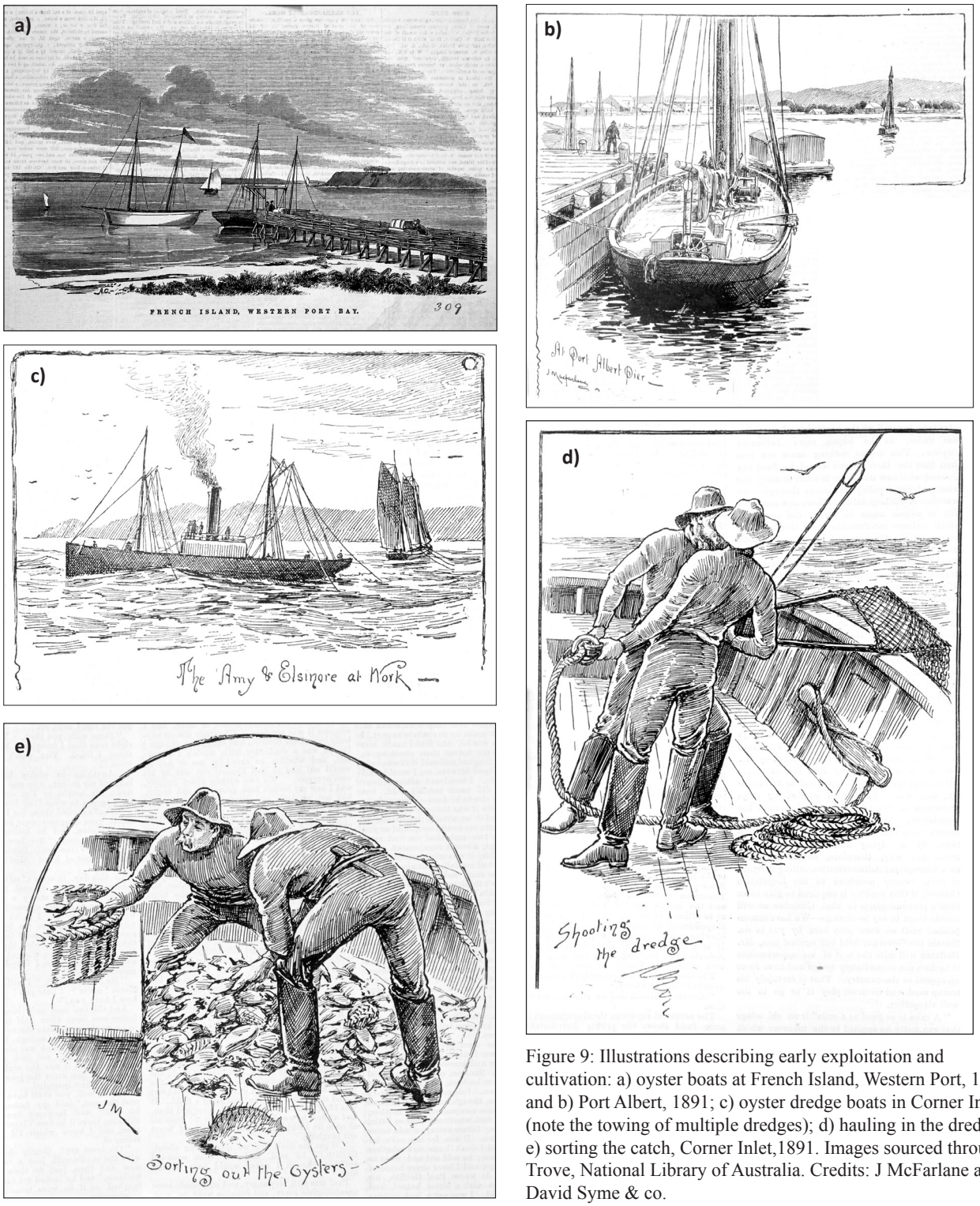

Figure 9: Illustrations describing early exploitation and cultivation: a) oyster boats at French Island, Western Port, 1866, and b) Port Albert, 1891; c) oyster dredge boats in Corner Inlet (note the towing of multiple dredges); d) hauling in the dredge; e) sorting the catch, Corner Inlet,1891. Images sourced through Trove, National Library of Australia. Credits: J McFarlane and David Syme & co.

newspaper archives and government gazettes indicate the abundant flat oyster beds of Western Port had become commercially unviable by the late 1850s, and regulations were first passed in 1869 (the first Fisheries Act in Victoria's history) restricting the season to only four months a year and a size limit of crown piece or 38.5 mm circumference (Victoria Government Gazette 1 March 1869: Act for the regulation of oyster fisheries). The fishery was officially closed in 1885 (Victorian Government Gazette 8 June 1885), although newspapers report the closure occurring in 1894. Similarly, the Corner Inlet fishery was most productive between 1842 and 1854, but was considered depleted by the early 1860s (Bowen 2012).

We identified few records of flat oyster catches from the early colonial fisheries in Corner Inlet and Port Phillip Bay. In 1843 it was reported that 2900 dozen oysters were shipped from Port Albert to Melbourne, and sold for 2 shillings a dozen (Hannan & Bennett 2010), and during

the 1850s '12,000 to 14,000 dozen were taken a week from twenty to twenty five boats' (from Hannan & Bennett 2010). The latter equates to on average 156,000 oysters per week during the 1850s, when at a conservative estimate of 65 g per oyster would equate to about 10 t per week. These types of weekly catch rates suggest the fishery would have been at least several hundred tonnes per year at its peak. It is thought that during this period at least 30 vessels may have been involved in oyster fishing in Western Port employing 100 or more people (Hannan & Bennett 2010).

The only details of boat numbers and value of catch from Corner Inlet – Nooramunga come from around the time of the fishery's final productive year in 1860, when Port Phillip and Western Port boats relocated to Port Albert. The *Gippsland Times* 7 February 1862 reported: '…some years must elapse before the oyster beds in this neighbourhood will recover from the excessive working it underwent in 1860, in which year, it is a noticeable fact, that upwards of £3000 worth of oysters were shipped from this place to the Melbourne market'.

Renewed fishing and oyster culture during the 1880s–1910s

By the early 1860s the Westernport fishery was in steep decline (Hannan & Bennett 2010). The consequent relocation of fishing effort to Port Albert triggered stock collapse in Corner Inlet – Nooramunga and the end of the boom period for the Victorian flat oyster fishery. The demise of the Corner Inlet and Western Port oyster fisheries and the recognition of the need to promote creation and cultivation of new (artificial) beds were important drivers for the establishment of the *Victorian Oyster Act* in 1859. This act regulated the allocation/leasing of areas for oyster cultivation and licensing of oyster fishing. Increased regulation over the next 50 years, included daily catch limits and various spatial closures, leading to a complete closure in 1886. Over the period from 1859–1930 there were 120 Victorian Government Fisheries Gazettes issued that related mostly to regulatory controls on oyster fishing and granting of leases for trials of artificial cultivation (sea ranching), but by 1950, there had been only a further 25 gazettes. The reduction of gazettes appears to indicate the decline of activity in the oyster industry during the early/mid part of the twentieth century as the natural beds failed to recover and the numerous trials of artificial cultivation also failed for technical and or economic reasons (Nell 2001).

Early oyster culture was focused on Western Port in the 1860s and involved a number of methods and also included trial introductions of the Sydney rock oyster (Hannan & Bennett 2010). Many operations involved the supplementation of natural beds through oyster, spat or shell addition, although the widespread movement of oysters from natural beds to unsuitable artificial beds was a likely key driver of the broader failure of the farming attempts (Hannan & Bennett 2010).

There was renewed interest in oyster cultivation in Port Albert during the late 1880s and early 1890s, mostly attributed to the work of the fisheries scientist William Saville-Kent (Harrison 1996). Saville-Kent promoted the culture of oysters and significant investment was made in farming leases around Port Albert and in Western Port, many of which were fenced to mark property boundaries (Figure 10). Their subsequent failure was attributed to being '…silted up by reason of the obstruction of the fences' (*Gippsland Times*, 23 August 1889) or because 'Mr Saville-Kent tried to rear oysters on a copper wire bed, but the copper killed both old and new oysters' (*Illustrated Australian News*, November 7 1891). Later unsuccessful ventures included the transplanting of 116,000 (160 bags) of flat oyster from Western Port beds to an area 15–20 feet deep between Brighton and St Kilda ('Oyster Culture Experiment in Port Phillip Bay', *The Telegraph*, 1913).

Despite his failures, Saville-Kent also predicted that oyster beds would be found offshore (Harrison 1996), and in this he was correct. An account of oyster dredging offshore from Corner Inlet describes an oyster bank 'from Shallow Inlet towards Wilson Promontory for a distance of 12 miles' and another '3 miles long beginning at the (Corner) Inlet' (*Illustrated Australian News*, 7 November 1891). Oysters were found 'at 8.5 – 13 fathoms' and hauls were accompanied by diverse bycatch, including many scallops. A £500 reward was offered for the discovery of new beds in 1891 (*Gippsland Times*, 16 December 1891), but by 1893 it appears few new beds were being discovered, the *Bairnsdale Advertiser* reporting on 23 March 1893: 'Oysters…which not long ago could be dredged up by the bagful offshore of Port Albert, have now become almost extinct'.

Interestingly, there were later bursts of oyster-dredging activity in Western Port, as areas were reopened in 1894, and reports indicated that flat oyster were once again abundant, but the rush to harvest soon depleted the reopened areas. In 1895, 4000 bags were sent to the markets in Melbourne and prices dropped rapidly (Hannan & Bennett 2010). Unfortunately we do not have a good understanding of the number of oysters in a bag, but there were likely to be between 250 and 750. At an average of 500 per bag and 65 g per oyster this equates to 130 tonnes of oysters. Later periods of activity also occurred from 1905–1950 in combination with net fishing, but nothing to the scale of the early colonial fishery.

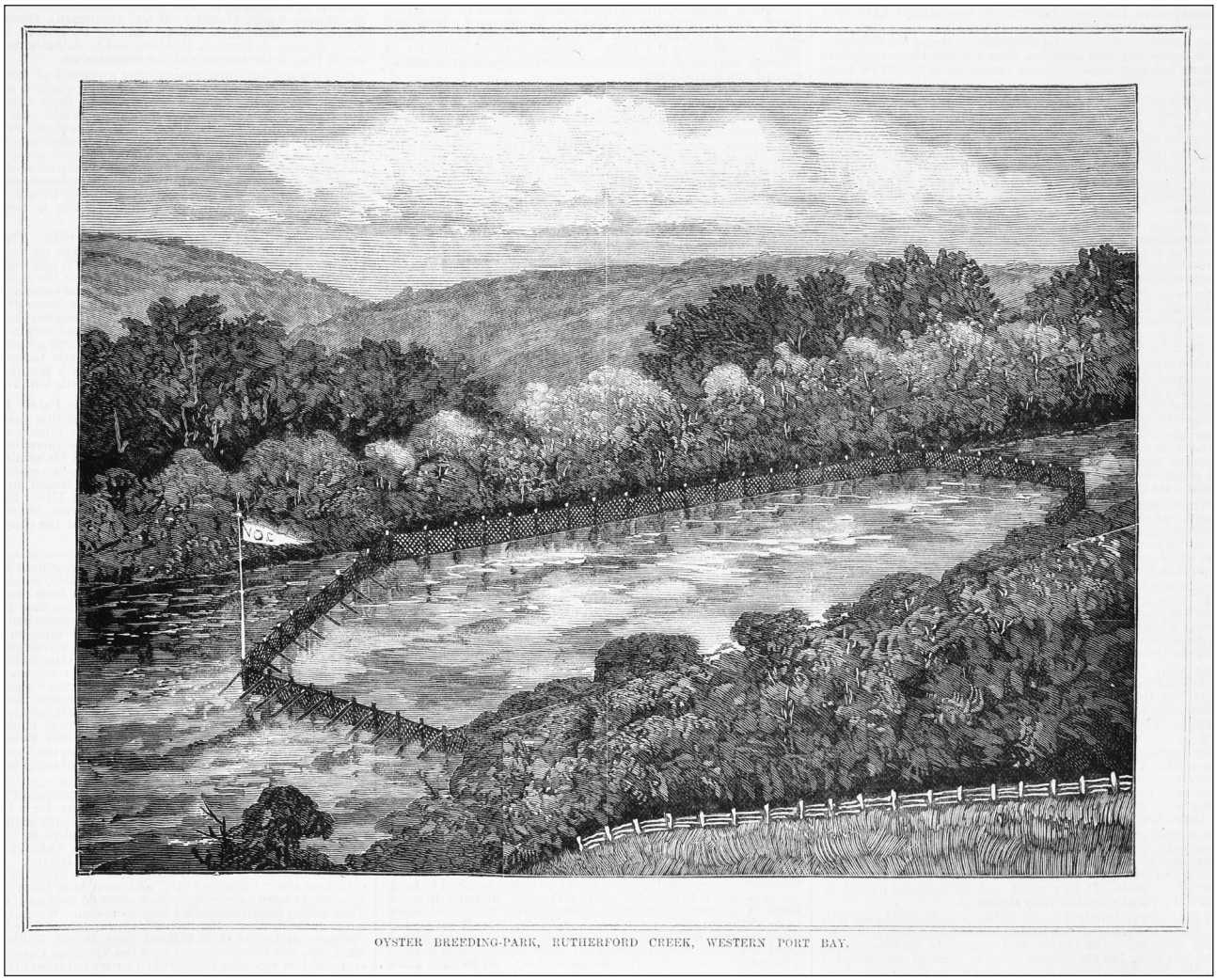

Figure 10: Early attempts at flat oyster artificial cultivation, Rutherford Inlet, Western Port 1884. Illustrator: Alfred Martin Ebsworth. Sourced through Trove, National Library of Australia.

Port Phillip scallop, oyster and mussel fishery (1960s – 1990s)

By the early 1960s the oyster-fishing industry was limited largely to Port Phillip Bay, where around 30 tonnes were taken yearly from the Geelong Arm (Lynch 1966). The catch fell to approximately 3 tonnes in 1964–1965. Controls on flat oyster harvesting at that time included closure during the spring–summer spawning season (November – February, inclusive) and a catch limit of 30 bushels (~800–900 kg) of flat oysters per fisher in any one week. At this time the dredge fishery for scallops and mussels was rapidly gaining momentum, with the number of boats actively dredging scallops increasing from two in September 1962 to 75 boats by July 1964 (Lynch 1966), then to more than 80 boats by the 1980s. The then Assistant Director of Fisheries T.W. Burdon in 1966 stated that: 'The oysters are also caught in large numbers incidental to the taking of scallops in Port Phillip Bay, but are returned to the sea owing to the limited market outlet'. At its peak during the 1980s the Port Phillip Bay scallop-dredge fishery involved up to 250,000 dredge tows per year and dredging activities were widely distributed throughout the bay (Coleman et al. 1997). Although oysters were no longer a target species, we can assume that many of the returned oysters would have been damaged and did not survive (McLoughlin et al. 1991). Post-1978 catch and effort data indicate sporadic minor catches of flat oysters reported from Port Phillip Bay, varying from 1.4 t to 7.9 t per year. Most of the more recent catches of flat oysters were taken off Portarlington and Mordialloc, adjacent to ports for the scallop dredge fleet.

Blue mussel harvesting does not appear to have been important in colonial times, but appears to have increased with the arrival of eastern European immigrants in the 1950s and 1960s, along with the start of the scallop dredge fishery. During the period 1964–2005 (no wild commercial mussel harvests have been recorded from Port Phillip Bay since 2005) over 11,000 tonnes of wild blue mussel were removed from Port Phillip Bay, mostly by dredging of the seabed, with peak annual catches of approximately 1000

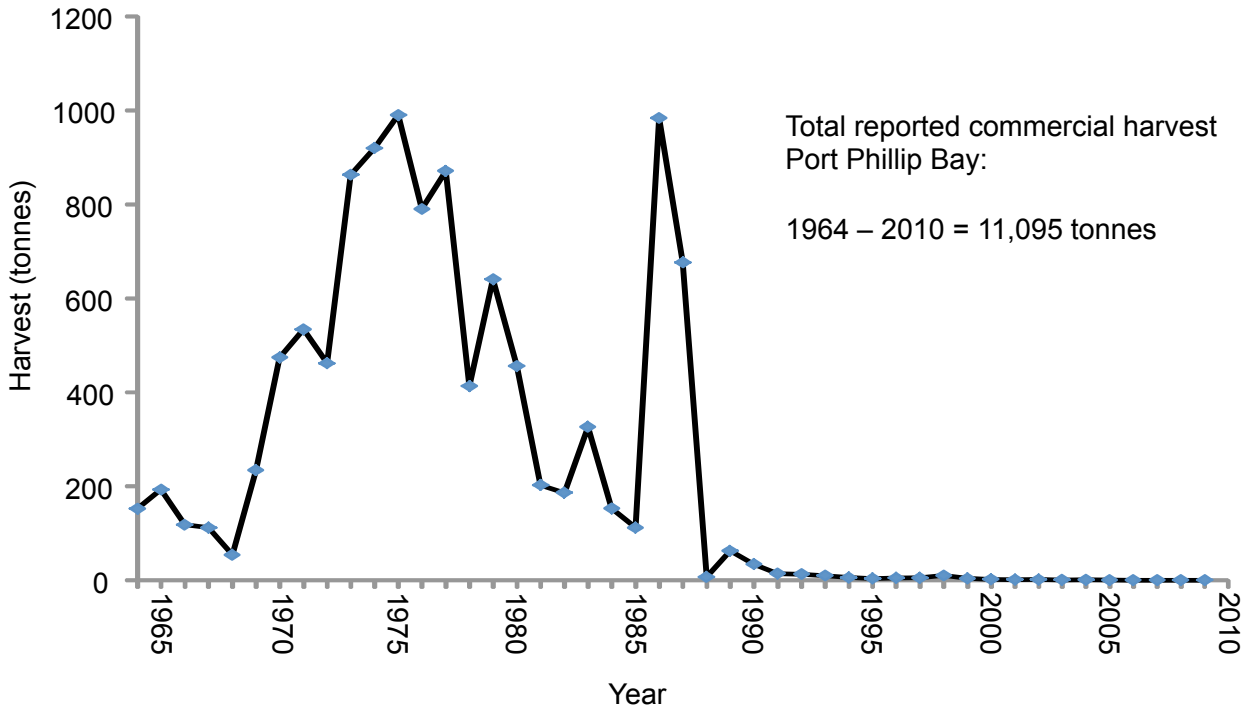

Figure 11: Annual harvest of wild mussels from Port Phillip Bay beds: 1964–2010.

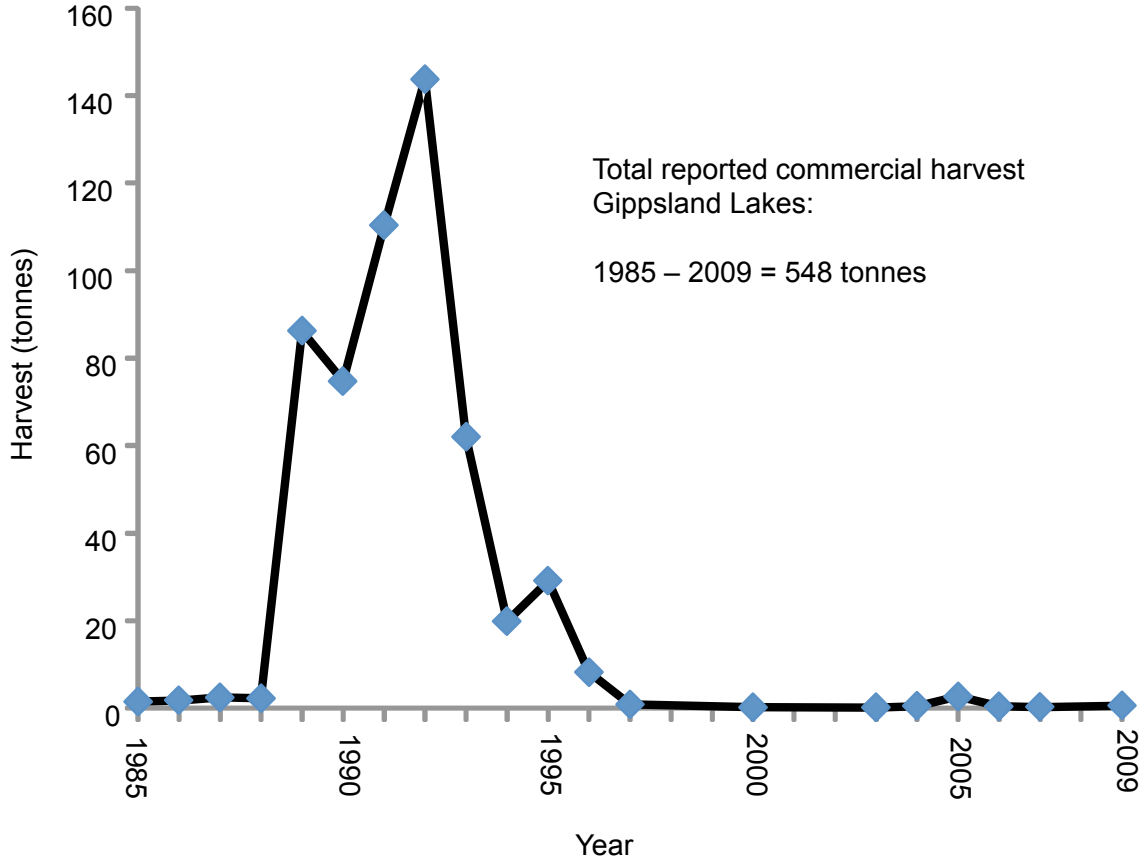

Figure 12: Annual harvest of wild mussels from Gippsland Lakes beds: 1985–2009.

tonnes in the mid-late 1970s and again in the mid 1980s (Figure 11). After 1987, catches dropped to an average of less than 10 tonnes per year, mostly taken by divers, and nowadays the mussel market is entirely supplied by aquaculture.

During this period a small fishery for mussels also occurred in the Gippsland Lakes, primarily conducted by divers from the mid-1980s to late 1990s, with approximately 550 tonnes of blue mussel harvested (Figure 12). Fisheries production statistics indicate mussel catches from other Victorian estuaries have been minor.

DECLINE OF VICTORIAN SHELLFISH REEFS

We conclude that destructive dredge fishing practices and long periods of large-scale removal of biomass (over-harvesting) have played a major role in the decline of flat oyster and blue mussel reefs from Victoria's major bays and estuaries. The massive removals of biomass and associated shell material, and disturbance of the sediments and their macro-faunal assemblages, are likely to have greatly reduced the available settlement substrates for oyster and mussel larvae. Reducing the number and extent of reefs also likely reduced the resilience of the remaining isolated patches against local impacts such as disease and predation, as well as decreasing fertilisation success during breeding. Removal of entire beds and or massive reductions of adult densities would have impacted on reproductive success, further limiting recovery from overfishing or other impacts. It is interesting that the anecdotes from the commercial fishers in Western Port describe how the flat oysters came back in some areas after reducing exploitation, but that the sustained demise occurred at the same time as the major seagrass die off in the 1970s (Hannan & Bennett 2011). Increased sediment loads have been implicated in the loss of seagrass, and may have also impacted on oyster recovery by siltation and burial of both live oysters and the shell material required for larval settlement.

For flat oysters, disease is an important factor to consider as a contribution to their historic decline (Ogburn et al. 2007). Bonamiasis of native flat oysters is a disease caused by infection with the haplosporidian protozoan *Bonamia* — the taxonomy of this parasite is unresolved in Victoria but appears similar to the exotic species *B. exitiosa* that may have been introduced from New Zealand (Adlard 2000; Corbeil et al. 2006 a,b). Given that *Bonamia* has been discovered throughout Australia wherever the flat oyster is found, it is thought that the disease is likely to have been endemic for a long period of time and may have even contributed to declines in flat oyster reefs that were attributed to overfishing in the 19th century (Hickman et al. 2000). While flat oysters can cope well with sub-clinical Bonamia infections, increased stress appears to be an important factor triggering large-scale infections and mass mortalities (Hickman et al. 2000). The history of Bonamia-related mortality events in Victorian populations remained a subject of conjecture prior to the confirmed 1991 outbreak in Port Phillip Bay. Fisheries Victoria researchers working on oyster culture in the late 1980s reported dense oyster reefs at Points Henry and Wilson and Arthur the Great, and scattered within the Geelong Arm/Geelong Outer Harbour (Hickman et al. 2000). These areas were used for brood stock collections in research towards developing an oyster aquaculture industry, but heavy mortalities due to Bonamia infection decimated these reefs in 1991 (Hickman et al. 2000).

Introductions of exotic predators such as the North Pacific sea star, *Asterias amurensis,* Luetken 1871 (introduced in 1996), and competitors for settlement substrates, such *Sabella spallanzanii,* Gemellin 1781 (introduced in the 1980s) and various ascidian taxa (sea squirts), may have implications for natural recovery of oyster and mussel reefs (Hewitt et al. 2004). These species are unlikely to have driven the historical declines, which occurred before their introduction, but may be limiting the re-establishment of significant mussel beds in many areas of Port Phillip Bay. Many of these exotics have also not become established in Western Port and Corner Inlet.

We suggest that a sequence of linked events/processes has resulted in the large-scale and sustained loss of native flat oyster and blue mussel reefs in Victoria's major bays and estuaries. These factors are overfishing (removal of critical mass) by destructive fishing methods (removal, destruction and burial of remaining settlement substrates); ongoing increased sediment loads from altered catchments (Western Port in particular); historic dredging practices (local impacts – Geelong Arm), increased sediment re-suspension once reefs were lost, and associated increases in stressors leading to episodic disease outbreaks in oysters.

FUTURE MANAGEMENT AND REPAIR

While there are few identifiable oyster reefs in Victoria, and those that have been identified are in poor condition, should more reefs be discovered we strongly recommend initial protection by the relevant agencies from any form of harvest. There is currently allowance for recreational harvest of flat oysters (50 per person per day) and mussels (10 litres whole per person per day) in Victoria. The current level of harvesting of flat oysters by recreational fishers is unknown, but is likely to be negligible. Nevertheless, there is a risk that recreational harvest could increase if repair works are successful and the growth of local aquaculture of flat oyster generates renewed interest by consumers and increased market value. Areas that are demarcated for repair could be offered more formal protections beyond those of harvest to limit physical damage from activities such as dredging.

As is being realised in many parts of the US (Beck et al. 2011), opportunities for repair of oyster reefs exist in Port Phillip Bay, Western Port and Corner Inlet. However, the most attractive and logistically feasible prospects are in Port Phillip Bay for a multi-species approach to reef repair involving both flat oyster and mussel. Port Phillip Bay makes the most logistical and economic sense because of the local availability of advanced mussels from the bay's mussel aquaculture industry and flat oyster spat from the Victorian Shellfish Hatchery on southern Port Phillip Bay. It is also the centre of marine recreational fishing in Victoria and has large community interest from the surrounding population centres of Melbourne and Geelong. This is important for establishing stakeholder support, volunteer involvement, and a funding base for repair activities.

A scoping study into the prospects for repair of shellfish reefs in Port Phillip Bay has recently been conducted (Hamer et al. 2013), and a trial project to develop and test repair methods has begun. While dredge fishing is no longer permitted, and the water quality has improved, other changes have occurred that present risks to successful repair. These including introduced species, particularly the predatory North Pacific seastar, the high mobility of the bay sediments that now lack the stabilising mussel beds, and Bonamia disease.

Based on the assessment of past distributions of oyster and mussel reefs within Port Phillip Bay, three focus areas were identified and approved in 2014 under the state's *Coastal Management Act* for repair activities to progress. Small-scale trial experiments began at two of these sites (Hobsons Bay and Geelong Arm) in 2015 involving both flat oysters and blue mussel. The broader vision is for establishment of many larger scale mixed oyster/mussel reefs in strategic locations that are self-sustaining and act to replenish lost populations.

CONCLUSION

We conclude that Victoria has lost over 95% of native flat oyster (*O. angasi*) and blue mussel (*M. edulis galloprovinicialis*) reefs from estuarine, bay and coastal waters since European settlement. There are no known areas of oyster reef in Victoria and we consider the ecosystem to be ecologically extinct. While removal and destructive fishing practices drove rapid declines, recovery of oyster and mussel reefs over time appears to have been hampered by a host of factors including water quality, sedimentation, lack of shell substrate for settlement, disease and introduced species. Opportunities now exist for testing approaches to aid repair and recovery of shellfish reefs in Victoria's major bays and inlets and we hold a future vision for the re-establishment of shellfish reefs as a functioning ecological community in Victoria's coastal environment.

Acknowledgements

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Table 1: Key historical sources of information used estimate past distribution of oysters and the scale of the fisheries involved.

Source	Date	Title/article	Summary
The Argus	20 Mar 1856	To the editor – Oysters	Claims that the best season to eat oysters is in the winter months, and they are out of season during Dec and Jan
The Argus	29 Mar 1856	Extract from Mr Blandowski's report on Westernport	Describes swamp oyster as abundant in Western Port
The Argus	21 Sept 1857	To the editor – Oysters	Complaint of getting ill from local oysters
Victorian Act of Parliament (England)	24 Feb 1859	An Act for the regulation of the oyster fisheries in Victoria	Places restrictions on the industry including a restricted season and size limits, and regulates oyster farming
Geelong Advertiser	8 Oct 1859	Oysters Off	Several fishers were fined for breaches of the new 1859 oyster regulations (taking out of season)
Gippsland Times	7 Feb 1862	Oysters	Describes the overfishing of Port Albert oyster beds in 1860 and their lack of recovery
The Argus	2 July 1863	Oysters: A gossip about their natural and economic history	Discusses oyster biology and promotes farming
The Age	5 Nov 1863	Artificial breeding of oysters in Western Port Bay	Refers to the deplorable state of oyster beds in Western Port
Geelong Advertiser	6 Nov 1863	Artificial breeding of oysters in Western Port Bay	Describes the importance of oysters as food and promotes oyster farming in Western Port
The Australian News for Home Readers	23 Feb 1866	Hastings and French Island, Westernport Bay	Refers to the destructive overfishing of oysters in Western Port
Bendigo Advertiser	26 Jun 1867	Melbourne News	Describes a large oyster beds within 25 miles of Melbourne that will be dredged by a Mr Dickinson
The Australasian	19 Dec 1868	Hayling oyster culture	Describes oyster culture techniques
Melbourne Punch	7 July 1870	The drudgery of dredging	Refers to dredging at Geelong and accumulation of shell
The Australasian	20 Aug 1870	To the editor – Fish and oysters	Refers to oysters found on the coast between Refuge Cove and Corner Inlet, and Port Albert and Shallow Inlet
The Argus	20 Feb 1875	To the editor – Fish	Refers to overfishing of the Western Port oyster beds
The Argus	15 Jun 1883	To the editor – Oyster culture	Describes methods of oyster culture including placing shell on old beds

Source	Date	Title/article	Summary
The Argus	2 Jan 1885	To the editor – Oysters in Port Phillip Bay	Refers to oysters still in Port Phillip Bay, and disagrees with closure of Westernport. If not dredged 'beds of oysters will form and die from oysters becoming too thick'
Mornington Standard	9 May 1895	The oyster	Discusses overfishing and refers to experience in English channel
The Argus	14 June 1885	Oyster culture in Victoria	Promotes oyster culture and describes methods
Victorian Government Gazette	8 June 1886	The Fisheries Act 1873 – Natural oyster beds in Westernport	Bans the take of oysters or brood from Western Port
Geelong Advertiser	5 Apr 1888	Oyster culture	Describes work of Mr Saville-Kent in promoting oyster culture
Gippsland Times	23 Aug 1889	Oysters	Describes failure of oyster culture in Corner Inlet
The Argus	15 April 1891	The cultivation of oysters	Proposes that disease was the cause of oyster declines, and oyster culture will be difficult because of this
The Illustrated Australian News	7 Nov 1891	A visit to the oyster beds near Port Albert	Describes oyster beds in coastal waters off Corner Inlet
The Argus	28 Nov 1891	A new industry and a nuisance abated	Describes mussels washing up in northern Port Phillip and promotes a new industry for mussel fishing
Gippsland Times	16 Dec 1891	Searching for an oyster bed	Offers a reward of 500 pounds for discovery of new oyster beds
Bairnsdale Advertiser	23 Mar 1893	Oyster fishing off Port Albert	Notes that fishing was once good but no longer, that oysters are almost extinct in Port Albert and that exploratory fishing expeditions off the coast were unsuccessful
The Age	4 Jun 1894	The Western Port oyster fishery	Bay is opened for dredging for boats less than 5 tonnes, only 1 bag per day per person and oysters not less than 2.5 inches to be taken
Victorian Government Gazette	28 May 1895	Oyster Dredging in Westernport Bay	Revokes the fishing closure of Western Port
The Argus	26 Nov 1895	Sly grog selling – raid upon city oyster saloons	Describes oyster saloons in Melbourne
Gippsland Standard	20 Feb 1914	Oysters	Describes oyster trade from Corner Inlet to Melbourne in 1845