

# How long does it take for tropical marine fish stocks to recover after declines? Case studies from the Southwest coast of India

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**The depletion/collapse and recovery of tropical marine fish stocks have been studied by deriving the time-series of stock status of commercially fished marine species in Karnataka. Majority of stocks (22 out of 47) showed wide fluctuations in catch whereas 15 stocks were dwindling. This analysis of catch trends (as a simple proxy for biomass estimates) shows that, in spite of consistently increasing efforts and absence of many regulatory measures, most species (66%) had fast recovery capacity within 1–5 years whereas 9% were slow to recover. The depleted and declining stocks need to be carefully monitored and conservation and rebuilding plans need to be made.**

**Keywords:** Arabian Sea, fluctuating and dwindling stocks, Karnataka, recovery after decline, tropical marine fish stocks.

SEVERE habitat loss and population declines of species have occurred in the oceans, leading to concerns that populations or species may be at risk of extinction over large spatial scales<sup>1–3</sup>. Fishermen are switching to new fish species as traditional ones are diminishing, sometimes to vanishing point<sup>4</sup>. Small-scale fisheries that employ 98% of the world's fishers<sup>5</sup> and land more than half the world's annual marine catch<sup>6</sup> are poorly understood because there are little formal surveys or monitoring of exploitation. There is practical difficulty in measuring the point at which a taxon becomes extinct, particularly in the sea<sup>2,3,7</sup>. Generally in an ecosystem, diversity is dominated by a few common species followed by multiple rare species. As environments become disturbed, the dominance of the core community usually becomes more pronounced, and rarer species are no longer able to survive<sup>8,9</sup>.

A growing online database of worldwide fisheries research is helping scientists better understand the relationship between managing fishing pressures and restoring depleted fish stocks<sup>10</sup>. Jensen<sup>11</sup> noted that three-quarters of 62 depleted stocks worldwide continue to be fished at intensities too great to allow populations to

recover. There is very little evidence for rapid recovery from prolonged (15 year) declines<sup>12</sup>, and fish stocks which are resilient may recover from overfishing, but only if the harvesting stops at the first sign of depletion. If the overfishing goes on for too long, the stocks may never recover<sup>13</sup>. Over the past decades, an increasing number of studies have reported recoveries of depleted marine populations and degraded ecosystems and there have been significant advances in understanding recoveries in the ocean<sup>14</sup>. Stricter management and improved governance have enabled the rebuilding of some fish populations, whereas others remain in low numbers<sup>15,16</sup>. Exploitation rate which is the ultimate driver of depletion and collapse, if decreased, helps in management of the fisheries, setting the stage for ecological and economic recovery<sup>17</sup>. Recovery occurs in more than 10% but less than 50% of species or ecosystems, suggesting a need for improved management and conservation<sup>14</sup>.

Marine fisheries and seafood industry are recognized as key industries in India showing an average growth rate of 6.4% over a period of 5 decades<sup>18</sup>. Mechanization increased by 57% between 1960 and 1990 contributing to a situation of overcapacity and resultant overfishing<sup>19</sup>. The recent trend in unregulated increase in net sizes and declining of mesh size is not healthy considering the increasing capture of juveniles<sup>20,21</sup>. Recently, the status of marine fish stocks of Kerala and Karnataka (Southwest coast of India) has been studied and categorized into abundant, less abundant, developing, declining and collapsed<sup>22</sup>, with the assumption that catch is proportional to abundance and historical maximum catch being the baseline data. The same methodology has been applied to make assessments of 26 resource groups (pelagics, demersals, crustaceans, molluscs) on a national basis and it indicated that nearly 90% of the resource groups fall under the 'abundant' and 'less abundant' class whereas the remaining under the 'declining', 'depleted' and 'collapsed' classes<sup>23</sup>. For resources that are depleted, recovery is expected to be long and not guaranteed<sup>24</sup>. However, there are few studies<sup>25</sup> documenting such recoveries from the tropical world.

Karnataka is one of the frontline states of India in marine fisheries development<sup>26</sup>, contributing 6–14%

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annually to the total marine fish production of India. It has a short coast line of 300 km, continental shelf area of 27,000 sq. km and 87,000 sq. km of exclusive economic zone (EEZ), within 12°45'N and 14°95'N and 73°45'E and 74°95'E. The state has three coastal districts, Dakshina Kannada, Udupi and Uttara Kannada, and more than 90% of the state's marine fish production comes from the major fishing ports of Mangalore in Dakshina Kannada district, Malpe in Udupi district and Kasargode/Honnar, Tadri and Karwar in the Uttara Kannada district. These centres cater almost exclusively to the mechanized fishing sector and the non-mechanized artisanal gears are mainly concentrated in the northern regions (Uttara Kannada district), whereas mechanized (outboard engines) artisanal gears are in vogue in the southern regions (Dakshina Kannada and Udupi districts)<sup>27</sup>. This state has been a pioneer in the introduction of new mechanized fishing technologies, development of fishing harbours and improvement in the living standards of fishermen<sup>26</sup>. The mechanization caused steep increase in total yields in all fleets in the fishery in the seventies and eighties<sup>28</sup> followed by downtrend due to overfishing. The production peaked again in 2002 and had stabilized to 192,816 tonnes in 2004 (ref. 29) after which it has increased to more than 437,000 tonnes in recent years 2013–14 (ref. 30).

The collapse and recovery of tropical marine fish stocks has not been well studied before mainly because of lack of complete time-series on actual biomasses which are expensive to collect. Because catch assessments are an indirect estimate of biomass in the sea, Mohamed *et al.*<sup>22</sup> developed the rapid fish stock classification method. In this analysis, we transform the fish stock classification from a single snap-shot assessment to a continuous yearly assessment and see how tropical fish stocks change from one category to another. If the stock is depleted or collapsed, we assess the number of years it takes for the stock to regain an abundant status.

## Materials and methods

The records containing species-wise and gear-wise catch and effort of marine fish landings of Karnataka (period 1971–2008) maintained by the Central Marine Fisheries Research Institute (CMFRI), Kochi, India in National Marine Fisheries Data Centre were used for the present study. The CMFRI estimates marine fish catch and effort from all along the Indian coast based on a stratified multi-stage random sampling design with the stratification over space and time<sup>31</sup>. These data (37 years) were collected by trained enumerators, who could identify fished organisms to the species level in most cases. The non-standardized effort data in fishing hours from 14 different gears were aggregated and plotted on a yearly basis to delineate the trend in fishing effort.

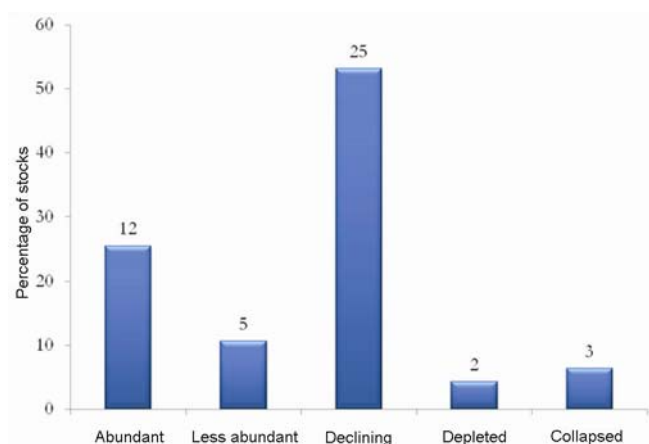
From the list of 47 common species, the stock status (abundant, less abundant, declining, depleted and collapsed) was determined by comparing the historical maximum catch with its recent average catch during 2006–2008 (3 years) using the criteria developed by Mohamed *et al.*<sup>22</sup>. A caveat of this method is that the stock status is not based on actual biomasses.

Yearly stock status was derived by using the same method, but instead of a recent 3-year average catch, a 3-year moving average for 37 years was considered. In this manner, the stock status of all species considered could be derived for every year of the period according to the above criteria. Based on the behaviour of the resulting plots, the species were grouped as developing, fluctuating and dwindling. The year during which the species was depleted/collapsed and the duration taken for their recovery to abundance were then tabulated. The species/stocks which were in the dwindling group were placed in respective taxonomic families and the average years taken by each family were derived.

## Results

From the list of 47 common species, the stock status of the species was generated and it showed that 12 (25.5%) species were abundant, 5 (10.6%) were less abundant, 25 (53.2%) were declining, 2 were depleted and 3 were collapsed (Figure 1 and Table 1). The two depleted stocks were the white sardine *Escualosa thoracata* and giant tiger shrimp *Penaeus monodon* and the three collapsed stocks were the flathead *Sunagocia indicus*, the catfish *Arius* sp. and blacktip shark *Carcharhinus* sp. When the yearly stock status plots were generated, it showed that 22 species were fluctuating, 10 were developing and 15 species were dwindling.

All the species in the fluctuating group (Table 2 and Figure 2) have reached abundant status once or many



**Figure 1.** Percentage of marine fish stocks in Karnataka as per stock-status classification. Actual numbers are shown above bars.

## RESEARCH ACCOUNT

**Table 1.** Most common marine species classified as abundant, less abundant, declining, depleted and collapsed based on comparison between average catch during 2006–08 (last 3 years) to that of the baseline catch in percentage of the historical maximum catch (1971–2005)

Species/stock	Common name	Historical maximum catch (t)	Year of historical maximum catch	Recent 3-year average catch (t)	Percentage of historical maximum catch	Stock status
<i>Saurida</i> sp.	Lizard fish	3907	2001	10,027	256.7	Abundant
<i>Sphyrna</i> sp.	Barracuda	1612	1995	2427	150.6	Abundant
<i>Mugil cephalus</i>	Flathead grey mullet	128	1998	188	146.7	Abundant
<i>Sepia</i> sp.	Cuttlefish	6328	2005	8501	134.3	Abundant
<i>Trichiurus lepturus</i>	Ribbonfish	15,318	2005	20,444	133.5	Abundant
<i>Nemipterus</i> sp.	Threadfin bream	21,630	2001	25,153	116.3	Abundant
<i>Uroteuthis duvauceli</i>	Indian squid	8220	1989	7712	93.8	Abundant
<i>Sardinella longiceps</i>	Oil sardine	85,915	1981	79,324	92.3	Abundant
<i>Portunus pelagicus</i>	Blue crab	1057	1987	960	90.8	Abundant
<i>Johnius</i> sp.	Croaker	3809	2005	3367	88.4	Abundant
<i>Epinephelus</i> sp.	Grouper	6699	2002	4889	73.0	Abundant
<i>Chirocentrus dorab</i>	Wolf-herring	548	1996	383	69.9	Abundant
<i>Scomberomorus commerson</i>	King seerfish	5829	2004	3573	61.3	Less abundant
<i>Metapenaeus affinis</i>	Jinga shrimp	1051	1987	636	60.6	Less abundant
<i>Himantura</i> sp.	Stingray	237	1989	130	54.8	Less abundant
<i>Parastromateus niger</i>	Black pomfret	3228	1995	1667	51.7	Less abundant
<i>Sardinella fimbriata</i>	Fringescale sardinella	4072	1988	2091	51.3	Less abundant
<i>Leiognathus</i> sp.	Ponyfish	7638	1986	3722	48.7	Declining
<i>Cynoglossus macrostomus</i>	Malabar tonguesole	13,154	2000	6376	48.5	Declining
<i>Lactarius lactarius</i>	Whitefish	4645	2001	2163	46.6	Declining
<i>Portunus sanguinolentus</i>	Three-spot swimming crab	1365	2002	597	43.7	Declining
<i>Pampus argenteus</i>	Silver pomfret	878	1974	372	42.4	Declining
<i>Megalaspis cordyla</i>	Horse mackerel	8056	1986	3194	39.6	Declining
<i>Euthynnus affinis</i>	Kawakawa	4177	1989	1620	38.8	Declining
<i>Parapenaeopsis stylifera</i>	Kiddi shrimp	7332	1987	2727	37.2	Declining
<i>Opisthopterus tardoore</i>	Long-finned herring	2231	2001	787	35.3	Declining
<i>Anodontostoma chacunda</i>	Chacunda gizzard shad	567	1993	198	35.0	Declining
<i>Sillago sihama</i>	Lady fish	244	1993	85	34.6	Declining
<i>Hemiramphus</i> sp.	Halfbeak	700	1985	236	33.8	Declining
<i>Miyakea nepa</i>	Mantis shrimp	46,510	1987	15,477	33.3	Declining
<i>Rastrelliger kanagurta</i>	Indian mackerel	98,817	1986	31,634	32.0	Declining
<i>Metapenaeus dobsoni</i>	Kadal shrimp	8669	1987	2757	31.8	Declining
<i>Fenneropenaeus merguensis</i>	Banana prawn	253	1987	72	28.5	Declining
<i>Otolithes</i> sp.	Croaker	1739	1994	487	28.0	Declining
<i>Caranx</i> sp.	Scads	10,036	1988	2523	25.1	Declining
<i>Thryssa</i> sp.	Anchovy	17,987	2005	4170	23.2	Declining
<i>Stolephorus</i> sp.	Anchovy	11,959	1995	2646	22.1	Declining
<i>Scomberomorus guttatus</i>	Spotted seerfish	3257	1981	574	17.6	Declining
<i>Metapenaeus monoceros</i>	Speckled shrimp	15,890	1987	2343	14.7	Declining
<i>Fenneropenaeus indicus</i>	Indian white prawn	12,853	2005	1866	14.5	Declining
<i>Scoliodon laticaudus</i>	Spadenose shark	1975	1981	278	14.1	Declining
<i>Scomberoides</i> sp.	Queenfish	896	1985	114	12.7	Declining
<i>Escualosa thoracata</i>	White sardine	1533	1989	161	10.5	Depleted
<i>Penaeus monodon</i>	Giant tiger prawn	447	1987	32	7.2	Depleted
<i>Sunagocia indicus</i>	Flathead	2661	1987	131	4.9	Collapsed
<i>Arius</i> sp.	Catfish	10,807	1976	516	4.8	Collapsed
<i>Carcharhinus</i> sp.	Blacktip shark	4354	1972	111	2.6	Collapsed

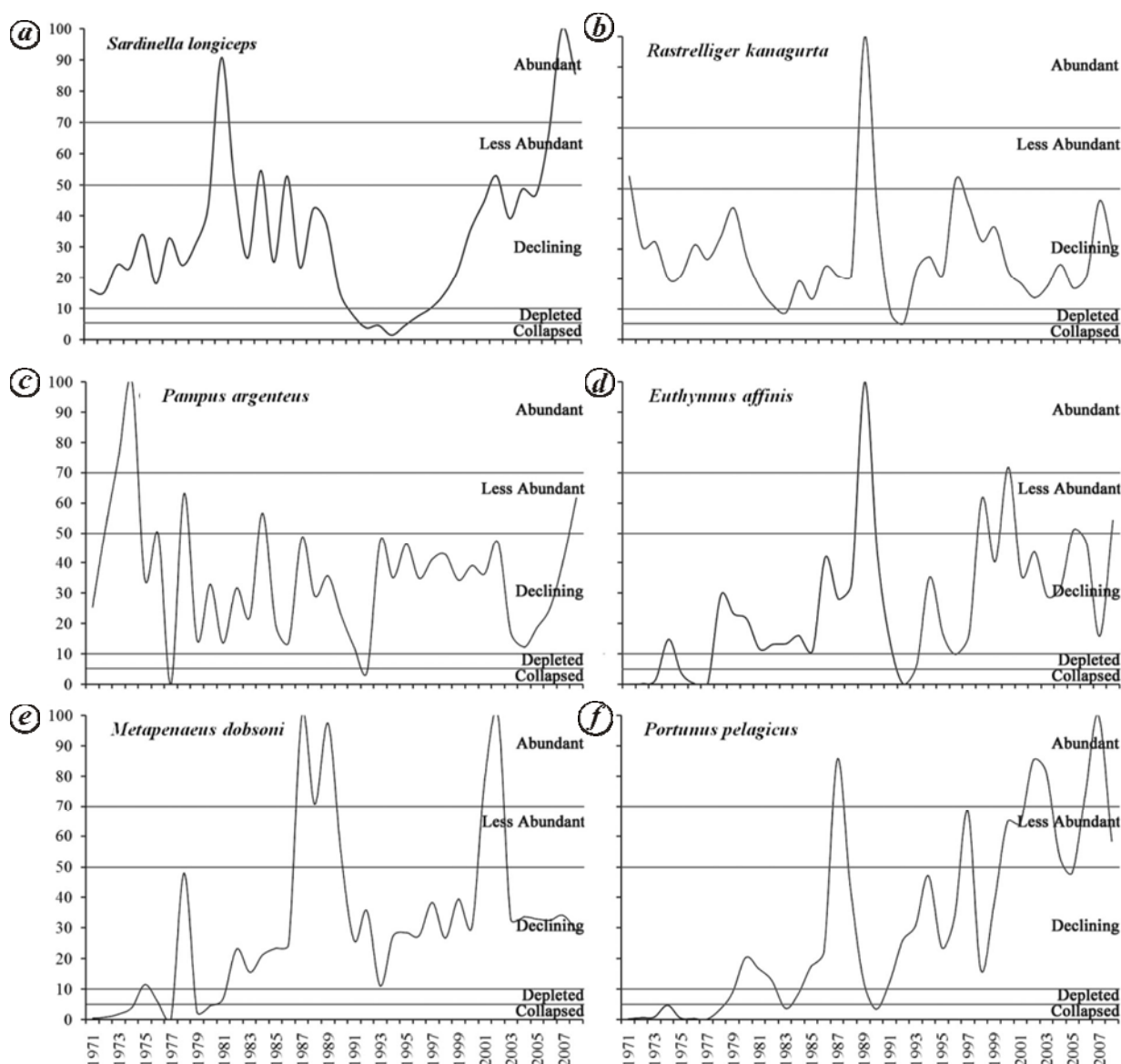
times. Some of the species have reached the collapsed status in the fishery and have again regained the abundant or less abundant status. Oil sardine (*Sardinella longiceps*) and Indian mackerel (*Rastrelliger kanagurta*) are the main-stay in Karnataka's marine fisheries and these species show high fluctuation in catch status cycling between abundant and depleted every 10–20 years (Figure 2 a, b). Black pomfret (*Parastromateus niger*) and silver pomfret (*Pampus argenteus*) have been highly fluctuating and are

currently in the less abundant and abundant status respectively (Figure 2 c). The tuna Kawakawa developed as a fishery after 1973 and it is in the less abundant status currently (Figure 2 d). Fishing for shrimp resources (Figure 2 e) was developed after 1972 and the kadal shrimp (*Metapenaeus dobsoni*) collapsed once and regained abundant status 3 times over the years. The crab fishery developed after 1985 showed fluctuation in catch status and *Portunus pelagicus*, the blue crab (Figure 2 f) is in the less

**Table 2.** Commercial marine species grouped according to their changing stock status (fluctuating, developing and dwindling) and their biological characteristics and habitat

Fluctuating	Growth rate and reproductive strategy		Developing	Growth rate and reproductive strategy		Dwindling	Growth rate and reproductive strategy	
	Habitat	Fast & r-selected		Habitat	Fast & r-selected		Habitat	Fast & r-selected
<i>Sardinella longiceps</i>	P	Fast & r-selected	<i>Scomberomorus commerson</i>	P	Fast & r-selected	<i>Arius</i> sp.	BP	Slow & k-selected
<i>Rastrelliger kanagurta</i>	P	Fast & r-selected	<i>Trichiurus lepturus</i>	P	Fast & r-selected	<i>Scomberoides</i> sp.	P	Fast & r-selected
<i>Cynoglossus macrostomus</i>	D	Fast & r-selected	<i>Nemipterus</i> sp.	D	Fast & r-selected	<i>Scoliodon laticaudus</i>	D	Slow & k-selected
<i>Lactarius lactarius</i>	BP	Fast & r-selected	<i>Epinephelus</i> sp.	D	Slow & r-selected	<i>Carcharias</i> sp.	BP	Slow & k-selected
<i>Pampus argenteus</i>	BP	Fast & r-selected	<i>Saurida tumbil</i>	D	Fast & r-selected	<i>Stolephorus</i> sp.	P	Fast & r-selected
<i>Parastromateus niger</i>	BP	Fast & r-selected	<i>Sphyraena</i> sp.	P	Fast & r-selected	<i>Thryssa dussumieri</i>	P	Fast & r-selected
<i>Leiognathus</i> sp.	D	Fast & r-selected	<i>Johnius</i> sp.	D	Fast & r-selected	<i>Escaulosa thoracata</i>	P	Fast & r-selected
<i>Euthynnus affinis</i>	P	Fast & r-selected	<i>Mugil cephalus</i>	D	Fast & r-selected	<i>Caranx</i> sp.	P	Fast & r-selected
<i>Chirocentrus dorab</i>	P	Fast & r-selected	<i>Uroenthis divauceli</i>	BP	Fast & k-selected	<i>Penaeus monodon</i>	D	Fast & r-selected
<i>Anodontostoma chacunda</i>	P	Fast & r-selected	<i>Septia</i> sp.	BP	Fast & k-selected	<i>Metapenaeus monoceros</i>	D	Fast & r-selected
<i>Megalaspis cordyla</i>	P	Fast & r-selected				<i>Parapenaeopsis stylifera</i>	D	Fast & r-selected
<i>Himantura</i> sp.	D	Slow & k-selected				<i>Sunagocia indicus</i>	D	Fast & r-selected
<i>Sardinella fimbriata</i>	P	Fast & r-selected				<i>Fenneropenaeus indicus</i>	D	Fast & r-selected
<i>Hemirhamphus marginatus</i>	P	Fast & r-selected				<i>Scomberomorus guttatus</i>	P	Fast & r-selected
<i>Opisthopterus tardoore</i>	P	Fast & r-selected				<i>Miyakea nepa</i>	D	Fast & r-selected
<i>Otolithes</i> sp.	D	Fast & r-selected						
<i>Sillago sihama</i>	D	Fast & r-selected						
<i>Metapenaeus dobsoni</i>	D	Fast & r-selected						
<i>Fenneropenaeus merguensis</i>	D	Fast & r-selected						
<i>Metapenaeus affinis</i>	D	Fast & r-selected						
<i>Portunus pelagicus</i>	D	Fast & r-selected						
<i>Portunus sanguinolentus</i>	D	Fast & r-selected						

P, Pelagic; D, Demersal; BP, Benthic-pelagic.



**Figure 2.** Time series of stock status of selected six species classified in the fluctuating status.

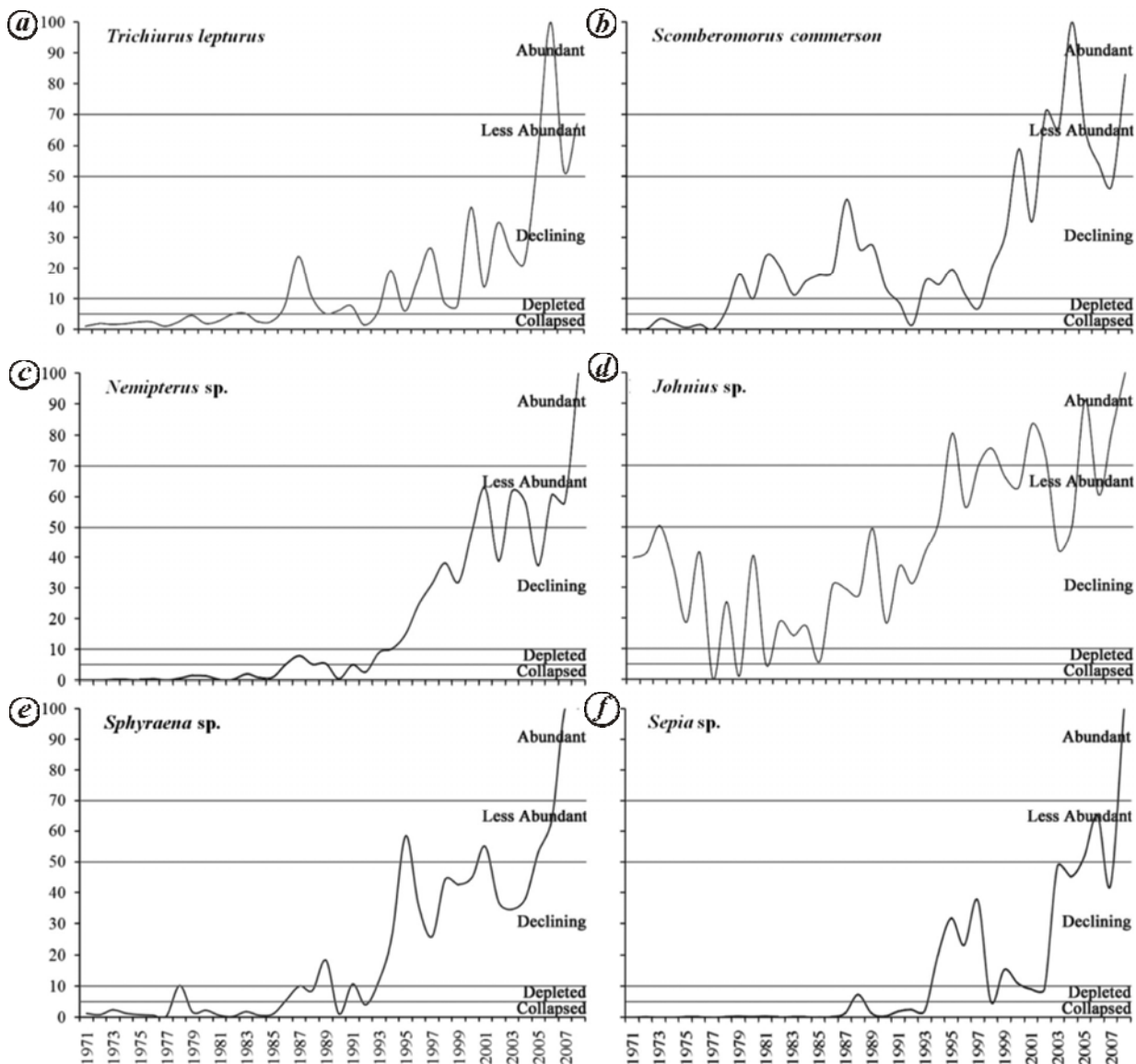
abundant status currently. Almost all the species in this category have fast growth rates and r-selected reproductive strategy (Table 2), except for the stingray *Himantura* sp.

The species under the developing group are shown in Table 2 and Figure 3. These are the fish stocks whose status has continuously improved over the years. Here, the depleted/collapsed status in the earlier years does not point to actual depletion and in fact indicates the developing status of the fishery. Of the 10 species in this category, 9 have fast growth and 8 have r-selected reproductive strategies. Two cephalopods have fast growth and are k-selected.

The species under the dwindling group were catfish (*Arius* sp.), queenfish (*Scomberoides* sp.), spadenose shark (*Scoliodon laticaudus*), blacktip shark *Car-*

*charhinus* sp., anchovy (*Stolephorus* sp.), Dussumier's anchovy (*Thryssa dussumieri*), white sardine (*Escaulosa thoracata*), scads (*Caranx* sp.), giant tiger prawn (*Penaeus monodon*), speckled shrimp (*Metapenaeus monoceros*), kiddi shrimp (*Parapenaeopsis stylifera*), flathead (*Sunagocia indicus*), Indian white prawn (*Fenneropenaeus indicus*), spotted seerfish (*Scomberomorus guttatus*) and mantis shrimp (*Miyakea nepa*) (Table 2 and Figure 4). Two of the collapsed species and one declining species in this category have slow growth and are k-selected. The remaining 12 species have fast growth and have r-selected reproductive strategy.

Catfish which is an important mid-water resource is currently in the depleted status after collapse of the fishery in 1992 (Figure 4a). Spotted seerfish which was in abundant status once during 1981 is seen in declining



**Figure 3.** Time series of stock status of six species classified in the developing status.

status (Figure 4b). Among the sharks, Spadenose shark fishery has declined after 1990 and the Blacktip shark—which showed abundant status for 3 years (1971–1973) has collapsed and is yet to recover (Figure 4e). The flathead fishery developed after 1981 and showed fluctuation but declined in fishery after 2002 and is in the collapsed status currently (Figure 4d). The giant tiger prawn (Figure 4f), speckled shrimp, kiddi shrimp are all grouped in the declining status currently.

The species which had depleted/collapsed and recovered to abundant/less abundant status, during the study period along with the number of years it took for their recovery is shown in Table 3. According to this, 32 species were in depleted or collapsed status at least once during the 37 years of study. Most of them (21 species) took short duration of 1–5 years for recovery whereas 7 species (oil sardine, Indian mackerel, kadal shrimp, pony-

fishes, chacunda gizzard shad, flathead and giant tiger prawn) took 6–10 years for recovery. Blacktip shark, speckled shrimp and mantis shrimp took a longer period of more than 10 years for recovery whereas the catfish had recovered once after 9 years and after the collapse in 1992 it is yet to recover (>20 years).

When these stocks were grouped into taxonomic families, it showed that the Stomatidae, Loliginidae and Hemiramphidae families took the shortest time averaging 1 year to recover (Figure 5). Eleven families were observed to recover in 1–5 years whereas 4 families took 6–10 years to recover. The remaining 3 families Squillidae, Carcharinidae and Ariidae took longer time to recover, i.e. 12, 14 and 16 years respectively (Figure 5).

The trend in non-standardized aggregate annual fishing effort is shown in Figure 6. In 1971, the aggregate effort was a little more than a quarter million hours and it grew

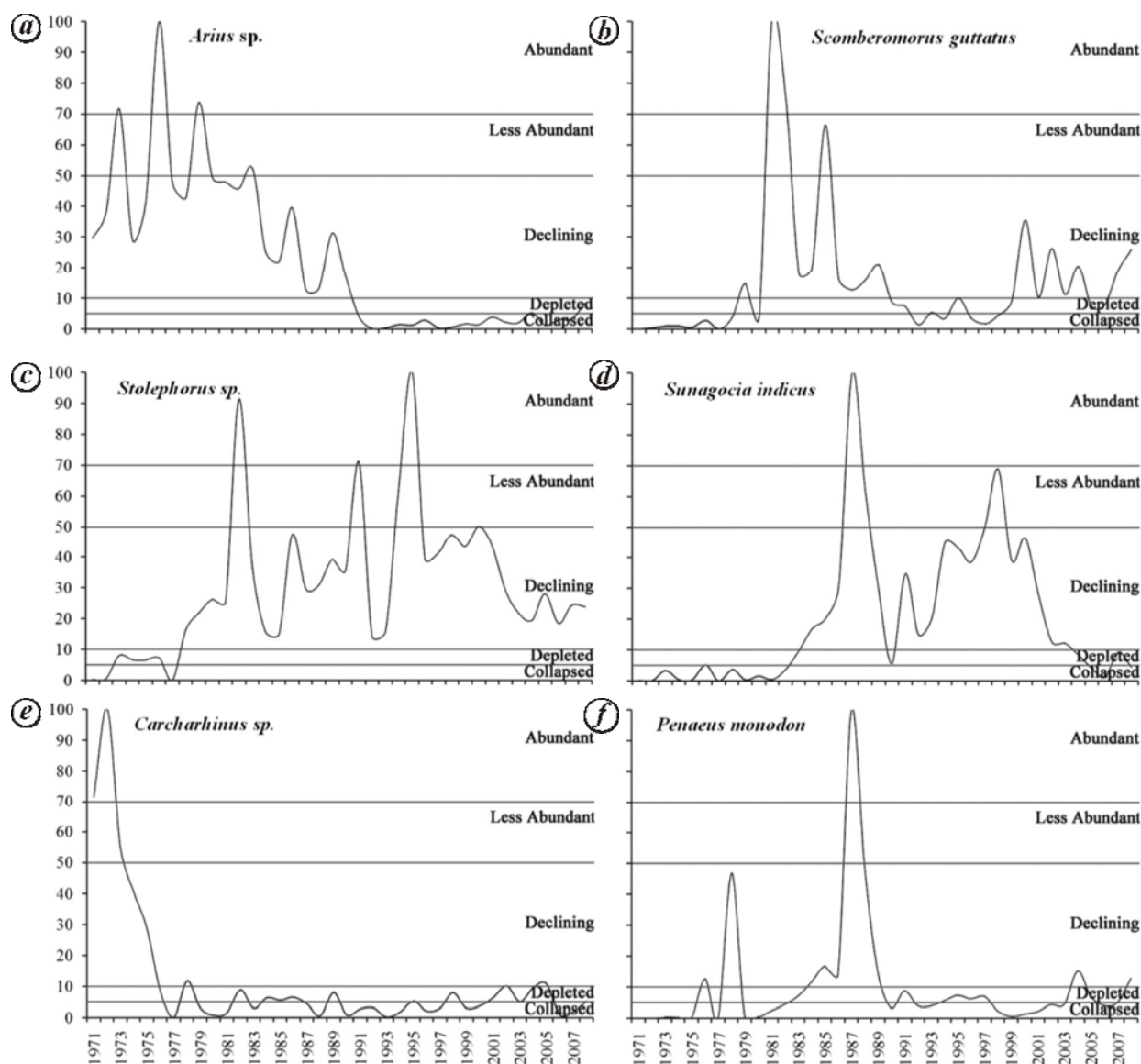


Figure 4. Time series of stock status of selected six species classified in the dwindling status.

more than 20-times to nearly 6 million hours in 2008. There was a significant dip in effort during the early nineties, otherwise, effort showed consistent increase with minor dips.

## Discussion

Analysis of the stock status showed that in 2008 the maximum numbers of species/stocks were in the declining group (53%) and there were only two depleted stocks; white sardine (*Escualosa thoracata*) and giant tiger prawn (*Penaeus monodon*). Three stocks, flathead (*Sunagocia indicus*), catfish (*Arius* sp.) and blacktip shark (*Carcharhinus* sp.) were in collapsed status. These results compare well with those of Mohamed *et al.*<sup>22</sup> who studied 19 species from Kerala and 22 species from Karnataka

and concluded that the maximum of 47% were in declining status. George and Abowei<sup>32</sup> state that a decline status may or may not indicate risk of extinction at the population level. But at the ecosystem level, the decline of an abundant species may represent a massive biomass loss which may be of greater concern<sup>33,34</sup>, than the loss of a small number of individuals of a rare species. Global records over the past millennium revealed a rapid decline of native species diversity since the onset of industrialization due to fishing<sup>35</sup>. Using a different criteria, they<sup>35</sup> noted that 29% of globally fished species were considered collapsed whereas in our study only 6% of the commonly fished taxa were under the collapsed category.

The stock status indicator when expanded to a time series was able to reveal how stocks changed from one status to another over time. The method also helped to

**Table 3.** Marine fish stocks which were depleted/collapsed and the number of years needed for recovery to abundant status

Species	Year depleted/ collapsed	Year recovered	No. of years to recover	Year depleted/ collapsed	Year recovered	No. of years to recover	Year depleted/ collapsed	Year recovered	No. of years to recover	Average years needed for recovery
<i>Sardinella longiceps</i>	1994	2002	8							8
<i>Rastrilliger kanagurta</i>	1961	1971	10	1983	1989	6	1992	1996	4	7
<i>Lactarius lactarius</i>	2003	2007	4							4
<i>Pampus argenteus</i>	1992	1993	1							1
<i>Parastromateus niger</i>	1992	1995	3							3
<i>Metapenaeus dohsoni</i>	1993	2002	9							9
<i>Fenneropenaeus merguensis</i>	1995	1996	1	2008		Yet to recover				1
<i>Euthynnus affinis</i>	1992	1994	2	1996	1998	2				2
<i>Leiognathus</i> sp.	1992	2001	9							9
<i>Chirocentrus dorab</i>	1992	1996	4							4
<i>Anodontostoma chacunda</i>	1987	1990	3	2000	2008	8				6
<i>Megalaspis cordyla</i>	1987	1990	3	1992	1995	3	2007	2008	1	2
<i>Sardinella fimbriata</i>	1996	1998	2	2000	2008	8				5
<i>Hemiramphus marginatus</i>	1988	1989	1	1990	1991	1	1992	1993	1	1
<i>Otolithes</i> sp.	1997	2001	4							4
<i>Sillago sihama</i>	1999	2002	3	2007	2008	1				2
<i>Arius</i> sp.	1961	1970	9	1992	Yet to recover					9+
<i>Portunus pelagicus</i>	1990	1994	4							4
<i>Uroteuthis duvauceli</i>	1992	1993	1							1
<i>Scomberomorus guttatus</i>	1992	2000	8	2006	2008	2				5
<i>Scoliodon laticaudus</i>	2005	2008	3							3
<i>Carcharhinus</i> sp.	1980	2005	25	2006	Yet to recover					25
<i>Thryssa dussumieri</i>	2006	2008	2							2
<i>Scomberoides</i> sp.	1991	1994	3	2004	2005	1	2006	2007	1	2
<i>Escualosa thoracata</i>	1991	1995	4	1997	2001	4	2004	2008	4	4
<i>Caranx</i> sp.	1992	1997	5							5
<i>Sunagocia indicus</i>	1990	1998	8	2006		-				8
<i>Penaeus monodon</i>	1990	2004	14	2006	2008	2				8
<i>Metapenaeus monoceros</i>	1992	2006	14							14
<i>Fenneropenaeus indicus</i>	2006	2007	1							1
<i>Parapenaeopsis stylifera</i>	1979	1984	5							5
<i>Miyakea nepa</i>	1990	2002	12							12



categorize stocks on the basis of their change in status over time. Majority of stocks (22 out of 47) were those which showed wide fluctuations in catch irrespective of continuously increasing fishing efforts. These stocks, mostly small pelagics and small and medium demersals, moved between declining to abundant status rapidly in spite of increasing effort. In some cases, the change was within 2 years, and in no case it was more than 3–4 years. For example, the Indian mackerel, *R. kanagurta* was in the depleted status in 1983 and moved up to an all-time high abundant status within 6 years and again reached depleted status in 1993 within 4 years. This indicates the inherent resilience of these stocks to fishing pressure and/or the environmental influences on their recruitment to the fishery. A recent global study on resilience and recovery of overexploited marine fish populations mainly of the temperate region shows that majority of the stocks are resilient to moderate overfishing and have a good chance of recovery within 10 years if fishing pressure is reduced substantially<sup>36</sup>. In spite of the limitations of this study, in the tropics, the fluctuation in abundance of these stocks in the absence of reduced efforts appears to be a function of their inherent biological capacities<sup>37</sup> such

as fast growth, high fecundity and speedy regeneration times.

The 15 stocks identified as dwindling included the large, slow-growing predators such as catfish, sharks and queen fish, and highly targeted, but fast growing shrimp stocks such as tiger and speckled shrimp. Habitat assessment showed that most of the species (9 out of 15) in this category were demersals or benthopelagics exploited by trawls, pointing to the non-selective, destructive nature of the trawl gear. Most of these stocks have had exceptionally high abundances during the 37-year-study period and are now in declining, depleted or collapsed status. For instance, the tiger shrimp, *P. monodon* was abundant in 1987 and thereafter, the stock collapsed in 1990 after which recovery has been slow. All of them, with the exception of carcharhinid sharks and shrimps, have recovered during this period. Hutchings<sup>12</sup> stated that there is very little evidence for rapid recovery from prolonged declines, in contrast to the perception that marine fishes are highly resilient to large population declines<sup>38</sup>. Our study points to the high regenerative capacities of tropical fish stocks in general. The numbers of fish stocks categorized as developing were comparatively few (10 out of 47). This is keeping with the global trend where only few fish stocks are in the less-exploited status (~10%)<sup>39</sup>.

Indian maritime states are characterized by the absence of an objective oriented fisheries management regime. The only broad regulation that is followed is the ban on mechanized fishing for a period of 47 days every year. In temperate waters, studies have found that marine resource exploitation can deplete stocks faster than regulatory agencies can respond<sup>40</sup>. A caveat of the present study is that the assessments are made from estimated catch trends and not from biomass assessments. The catch trends showed that most species (66%) had fast recovery capacity within 1–5 years whereas 9% were slow to recover. The exceptions were the blacktip shark which had just started recovering after 25 years of collapse and the catfish which had also started recovering after 20 years. Worm *et al.*<sup>35</sup> in their global assessment noted that rates of recovery were positively correlated with fish diversity as enhanced recovery was noted when fishers switch more readily among target species, potentially providing overfished taxa with a chance to recover. In temperate waters, there is only limited evidence for recovery of depleted fisheries based on the present management strategies employed<sup>12,41</sup>. Most severely overfished stocks hence tend to stay depressed or recover only slowly; exceptions to this rule mostly concern particular fast-growing species such as herring and sardines<sup>42</sup> and certain stocks of cod which are well managed<sup>43</sup>. The most important point to be noted is that currently there is no ability to engineer fast recovery of marine resources under the fisheries management regulations in vogue<sup>42</sup>. Sathianandan *et al.*<sup>23</sup> showed that catfish which is collapsed in Karnataka and Kerala<sup>22</sup> come under abundant status mainly due to the

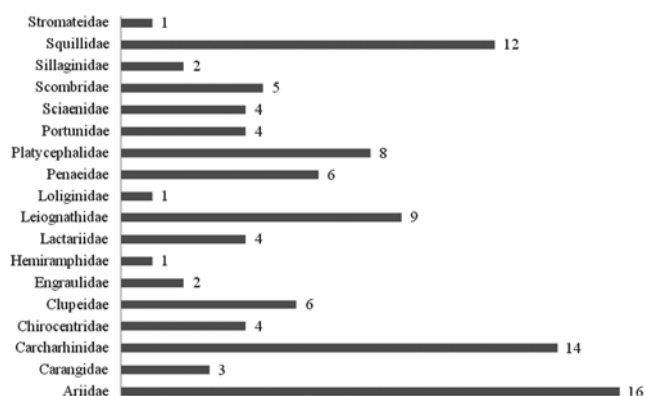


Figure 5. Number of years needed for recovery of different taxonomic families of depleted/collapsed stocks.



Figure 6. Annual trend in non-standardized aggregated annual fishing effort from all gears in Karnataka.

high catches from other states or in other words, a wider spatial footprint. In Karnataka, during 2008, it was seen that the fishery of this species has improved from collapsed to depleted status, showing signs of recovery after 20 years.

Average time for recovery of the families Ariidae and Carcharhinidae was observed to be 16 and 12 years respectively, which is comparatively slow. The family Squillidae which, in recent years forms a major component of fish meal, was noted to recover in 12 years and this needs to be carefully monitored. Stock recovery times of documented finfish and invertebrate ranged from 3 to 30 years, with demersal recoveries generally being longer than pelagic ones<sup>44</sup>. Clupeids, such as herring and sardines, have shown more rapid recovery within 5–10 years after depletion, whereas gadoids showed no, or slow, recovery within 15 years after depletion<sup>41</sup>. It has been shown that 95% of recoveries of exploited marine species in estuarine and coastal regions were enabled by reduced or banned exploitation; 72% by habitat protection, especially of breeding colonies and feeding grounds; and 8% by pollution controls<sup>45,46</sup>. In most cases (78%), these measures were most successful when implemented in combination<sup>14</sup>. For locally extirpated species, assisted re-introduction has enabled some successful re-establishments of wild populations<sup>47,48</sup>. However the recoveries observed in the present study are those which have happened with limited management or regulations and no targeted reductions in effort.

In India, recent stock assessment of exploited fisheries has indicated that most fish stocks are being exploited close to maximum sustainable yield level, many over-exploited and few underexploited<sup>49,50</sup>. For many of the local, small, tropical, short-lived species, short-term fluctuations are not significant, even if it is caused by excessive fishing pressure. The depleted and declining stocks (particularly those close to the threshold of depleted status) need to be carefully monitored and their conservation and rebuilding plans need to be made. As a first step for rebuilding stocks, fishing effort has to be reduced and strict implementation of the legal mesh sizes and net dimensions would particularly help in preventing growth of overfishing and help in restoration of stocks. As a developing country with multiple stakeholder compulsions, India has found it difficult to implement basic fisheries management principles. It is clear that small and short-lived species could recover fast but in the case of large and long-lived species such as the catfish and blacktip shark, it is more than 20 and 25 years since the species has collapsed. The catfish stocks are improving in recent years, and care must be taken to see that recruitment overfishing is not allowed to happen again by restricting its capture during the breeding period by seiners. The most obvious drivers of recovery are the reduction of those human impacts that caused the depletion or degradation in the first place<sup>14</sup>.

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