

Grey Nurse Shark Issues and Questions Arising
Report of Julian Geoffrey Nicholson Pepperell
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1. I have been requested to review available information and to make comment specifically on population estimates of grey nurse shark (*Carcharias taurus*) along the coast of New South Wales and southern Queensland. These estimates have been presented in reports by Otway et al (2003) and Otway and Burke (2004). In doing so, I have read;
 - a) the Otway Reports mentioned above;
 - b) the statements of Dr Otway of 13 March 2007 and 4 April;
 - c) a copy of a letter dated 17 September, and attachment, from Adrienne Burke to Mr M Brown;
 - d) and a copy of a letter (undated) from Dr Steve Kennelly to the Minister for Primary Industries, Mr Ian McDonald.

I have also read other reports and material listed in the bibliography of this statement.

2. My curriculum vitae is attached. In brief, I hold a Bachelor of Science with First Class Honours and a Ph.D from Sydney University. Between 1975 and 1990, I held positions of Biologist and Senior Biologist with New South Wales Fisheries and have been Director of a research and consulting company since 1991. Throughout my career I have specialized in the biology of large oceanic fishes including billfish, sharks and tuna. Current research includes a study of movements of tiger sharks off NSW. I am currently a member of the Resource Assessment Group for the Eastern Tuna and Billfish Fishery and recently was a member of the Australian Government delegation to the second Scientific Committee Meeting of the Western & Central Pacific Fisheries Commission, Manila, Philippines August 2006.

Summary of main points in this statement

3. In reviewing the available information pertaining to estimates of the population of grey nurse shark off NSW and southern Queensland, I consider that there is reasonable doubt concerning the accuracy of these estimates, because:
 - While the surveys covered a defined part of the coast, limited to relatively shallow water depths, the true extent of the population of GNS off eastern Australia is considerably broader. As well as occurring to the north and south of the area surveyed, it is well known that GNS historically occurred in areas which are further offshore and in deeper water than the sites surveyed. It is quite possible that GNS, acclimatised to more offshore, deeper sites do not mix freely with the sharks in the 'traditional' GNS dive sites. If that were the case, then the true population size would be larger than that estimated.

- The methodologies of diver observation and reporting used for the derivation of population estimates may have introduced unknown problems or biases. For example, the reports of the surveys offered little information on quality control of data collection, including training of reporting divers, uniformity of reports, validation (ground truthing) of the reports or whether reporting was skewed towards any particular group of observers.
- In the tag-resighting study (Otway and Burke 2004), not all of the assumptions necessary for the Petersen estimate of the population of GNS appear to have been upheld. Of the seven assumptions, it is considered that three were not valid, two were probably valid, one was possibly valid, but unproven and one was valid. If any one assumption is not upheld, the resulting estimate of population size would not be valid.

Background

4. The grey nurse shark (GNS) has been declared critically endangered on the Australian east coast. On the west coast, it has been declared vulnerable. The classification in New South Wales and southeast Queensland is apparently on the basis of a series of diver surveys extending from the far south coast of NSW to Stradbroke Island in southern QLD. The initial surveys, which were based on counts of grey nurse sharks by many volunteer divers, and NSW DPI staff, estimated that the population of grey nurse sharks was very small (estimated at about 500 individuals, but commonly cited as about 350 – the lower end of the confidence limits) (Otway et al 2003).
5. The diver 'head count' survey (Otway et al 2003) has been questioned on a number of criteria, perhaps the most important being that of likely incomplete coverage of the distribution of GNS and non extrapolation of counts to the true population. Otway and Burke (2004) acknowledged that "it was not possible to identify what proportion of the total Grey Nurse Shark population was observed during the 10 coastwide surveys", and this was the reason for their instigating the tagging-resighting study in an attempt to estimate population size directly by the method of mark-recapture, or in this case, tag-resighting. The report from this work, based on tagging of 24 GNS, apparently confirmed the earlier population estimate (ie, of the order of 500 individuals) (Otway and Burke 2004).
6. There are some concerns about the methodology of this body of work, and also over a second mark-resighting exercise which apparently did not confirm the earlier work, but has remained unpublished.
7. This report considers several questions which cast some doubt on the validity of the estimates of the population size of GNS off eastern Australia.

What are the boundaries of the true 'population' of GNS on the east coast of Australia?

8. Estimating the size of a 'population' of animals requires that the true geographic range of the population is clearly known and defined (otherwise, one may be only estimating the number of animals in an unknown portion of the true population).
9. It is known that the GNS is a worldwide species (Compagno 2001, www.fishbase.org) but we are concerned here only with the species as it occurs along part of the east coast of Australia. GNS are found in all Australian states, with the possible exception of Tasmania (Last and Stevens 1994, Compagno 2001,). The distribution maps from each of these references show a continuous distribution of GNS around Australia (see attached map, from Compagno 2001). However, the diver surveys which were used to estimate the population of GNS off eastern Australia were confined to a coastal area between the Victorian/NSW border and Flat Rock in southern Queensland. As well, the depth range of the surveys only extended to about 25 metres of water (because of safe limits for scuba diving), in effect, a very narrow coastal strip. A 'population' of animals is widely understood to mean a genetically discrete group of animals which mix and interbreed.
10. The true extent or boundaries of the population of GNS off eastern Australia are presently unknown, so it is not possible to be certain what proportion of the true population is represented by animals encountered in the area surveyed (hereafter called the study area).
11. In the first diver count survey (Otway et al 2003), the population of GNS off eastern Australia was assumed to be restricted to habitat accessible by divers along the coastal strip described above. In the subsequent tag-resighting exercise (Otway and Burke 2004), the same coastal strip was the area surveyed for a) counts of untagged sharks and b) resightings of tagged sharks.
12. These north-south boundaries and depth restrictions are considered to be inadequate for the purpose of estimating the true size of the population of GNS for the following reasons:
13. As noted, the natural range of the GNS certainly extends beyond the north-south boundaries of the studies. In fact, one of the tagged GNS from the study of Otway and Burke (2004) was recaptured near Yepoon, some 680 km north of the northerly limit of the diver surveys. (Note that this shark was recaptured (and re-released), not resighted by divers). This single recapture would be sufficient to cast doubt on the validity of the choice of the boundaries of the study site and at the least, would strongly suggest that the tag resighting exercise should have extended continuously north to at least Yepoon, if not beyond.
14. Regarding the sites surveyed by divers, and noting that nearly all of these were most likely restricted to depths of 25 metres or less (although these details are not given in either Otway et al (2003) or Otway and Burke (2004)),

there is ample evidence that GNS naturally occur in greater depths, and at many offshore sites that were never surveyed by divers (see paragraphs 18-23 below). The literature states that GNS live in depths at least to 191 metres (Compagno and Niem 1998, as cited by www.fishbase.org) (Compagno (2001)) while Otway and Burke (2004) cite a more conservative maximum depth of 50 metres. Interestingly, recent studies by Dr Otway, using popup satellite technology, have shown that three tagged GNS recorded maximum depths of 61 to 96 metres and spent between 12% and 27% of their time at depths greater than 30 metres (statement of Dr Otway, 4 April 2007).

15. Off the central New South Wales coast, there is strong evidence that suitable GNS habitat extends to areas which are more seaward, and deeper than the surveyed sites. This evidence is in the form of capture records of GNS by organized Game Fishing Clubs, as published in their annual reports over a number of decades. Pepperell (1992) summarises these records with regard to captures of sharks (including GNS) since 1960. These reports list the date and location of capture and weight of individual fish, although location records of some clubs simply state the port of departure. In the latter cases, I have interviewed highly experienced fishers who actively fished for GNS in the 1960s and 1970s to ascertain the most likely capture grounds.
16. The following summarises the data regarding locations of capture of GNS.
- Between 1960 and 1977, 479 GNS are recorded as being captured by members of game fishing clubs between Port Stephens and Bermagui (a further 7 were recorded during the 1950s).
 - In 1977, the NSW Game Fishing Association removed the GNS from its list of species eligible for point score in fishing competitions and captures by game fishers virtually ceased after that year).

The locations of all recorded captures of GNS are shown in the following Table:

Number of GNS	Location	Vicinity	Dist from Coast	Depth (shallowest)
2	AVOCA	Nth of Broken Bay		
3	BERMAGUI	NSW far south coast		
14	BOULTONS REEF	Off Broken Bay	3 n.miles	40 mtrs
1	COLLARROY	Nth of Sydney		
179	LONG REEF (Wide)	Nth of Sydney	2-3 n.miles	31 mtrs
2	MORNA POINT			
110	THE PEAK	Sth of Sydney	~6 n.miles	64 mtrs
165	THE GIBBER/THE 'V'	Nth of Port Stephens	3-4 n.miles	38 mtrs
1	SEAL ROCKS	Nth of Port Stephens		
1	TERRIGAL	Central NSW coast		
4	THE BANKS	Off Greenwell Pt	~7n.miles	36 mtrs
1	TUGGERAH	Central NSW coast		
1	ULLADULLA	Sth NSW coast		
1	WAVERLEY	Nth of Sydney		
1	THE WHALE	Central NSW coast		
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17. This table clearly indicates that the great majority of GNS captured in the past by gamefish anglers were caught over offshore reef areas, three of which (highlighted) account for 93% of all captures. The depths of these reef areas, **at their shallowest points**, are deeper than the great majority of sites surveyed by divers. It should also be clearly noted that none of the locations of captures of GNS (with the possible exception of Seal Rocks) were included in the diver surveys.
18. These data strongly suggest that, at the times of the surveys and tag-resighting study, GNS would have existed in these same areas, as well as many other similar areas along the coast, possibly in reasonable numbers, but because the areas were not surveyed this possibility was left out of the population equation.
19. It might be argued that the tag-resighting study took this possibility of a cryptic population of GNS into account. However, no GNS were tagged on these or other similar sites, and it is quite possible that GNS, acclimatised to more offshore, deeper sites (and perhaps not disturbed by divers), do not mix freely with the sharks in the 'traditional' GNS dive sites. This is a critical problem for both the head count survey and the tag-resighting survey, and in the writer's opinion, has not been adequately addressed.

How were the diver surveys conducted?

20. The initial diver surveys were conducted by NSW Fisheries staff, and also by receiving solicited reports of counts from volunteer divers (Otway et al 2003). During a four week period, the divers were asked to spend specific lengths of time (15 minutes) looking for and counting GNS, either on specific dives, or while conducting dives for other purposes.
21. There are some concerns about this methodology since the reports (Otway et al 2003, Otway and Burke 2004) offer little information on quality control of data collection, including training of reporting divers (if any) as to searching routines and routes, uniformity of reports, any validation (ground truthing) of at least a subset of the reports or whether reporting was skewed towards any particular group (eg, scuba divers vs spear fishers).
22. The tag-resighting study was done in much the same way, with divers asked via posters to report tags on GNS, including the location sighted and the tag number. Resightings were presumably more random than the original survey, in that there was no stipulation about how long to search for GNS. The GNS 'head count' (313) derived during this survey was taken over half the time of the previous survey (2 weeks vs 4 weeks). In addition, no information was presented on probable difficulties with reading numbers on tags, caused by algal growth, or on multiple resightings of the same tags. Lastly, the fact that selection of dive sites did not include offshore, deeper sites leads to the likelihood of not encountering, and therefore not counting, sharks which were not mixing with those sighted.

23. In summary, in the absence of more detail, the field methodologies of both the head count survey and the tag-resighting study are somewhat questionable in their ability to provide accurate estimates of the population of GNS because of:
- Lack of quality control over the training and actual field counting and sighting by volunteer divers
 - Possible biases caused by different searching routines in different areas
 - Possible biases caused by untruthful, or inaccurate reporting
 - Possible misreading or inaccurate reporting of tag numbers (especially since it was admitted that tags became fouled quite quickly)
 - Possible lack of encountering other sharks within the true population

Assumptions of the Petersen tag-resighting study

24. In the following section, the assumptions required for a valid Petersen estimation of a population of animals, as listed in Otway and Burke (2004), are repeated. As well, the explanation of Otway and Burke as to how each of the assumptions was presumed to be upheld are given in quotes, followed by the writer's comments in this regard, in bold italic. It should be noted that if any of the assumptions are not upheld, then the estimates of population size would be invalid.
25. (Assumption 1) **Tagged individuals are unaffected by the tagging process and behave in the same manner as untagged animals**

"Twenty of the 24 tagged sharks were re-sighted on numerous occasions within 1 year of tagging. Video footage of Grey Nurse Sharks showed that tagged and untagged displayed similar behaviours. Moreover, observations of untagged (but recognisable individuals) and tagged sharks moving between the same sites also indicated that tagging had had little effect on the animals. These lines of evidence are qualitative, but suggest that the sharks are unaffected by the tagging process and thus this assumption appears valid".

Comment: Tagged animals may appear to be 'behaving normally' via casual observation, but various sublethal effects may affect them compared with untagged animals. For example, some studies have shown that tagged fish may have retarded growth compared with untagged fish, tagged fish may not move as extensively as untagged fish and tagged fish may absorb eggs. Whether or not such sublethal effects occurred in the tagged GNS is impossible to say. Also, tags became fouled with algae and created wounds on tagged animals (which caused the tagging program to be curtailed). (Otway and Burke 2004). Assumption valid? Possibly, but not proven.

26. (Assumption 2) **Tagged individuals disperse throughout the untagged**

population

“The tagged individuals moved over a range of sites within the known range of the SE Australian population of Grey Nurse Sharks, and were re-sighted at many sites distant from the site where the sharks were originally tagged. These observations suggest that the tagged individuals have dispersed throughout the untagged population and thus this assumption also appears valid”.

Comment: The tagged sharks did indeed move over a range of selected sites within the known range of the population, but did not necessarily disperse throughout the whole, untagged population. As noted, it is quite possible that the tagged sharks, coming from shallow inshore sites, did not disperse throughout the true population, either to more offshore, deeper sites, or to areas north and south of the study area (the fact that one tagged shark was recaptured well to the north of the study area casts considerable doubt that the whole true population was being surveyed). Also, tagged sharks were not seen at many locations, even though untagged sharks were in those sites, casting doubt over whether the tagged sharks were indeed mixing randomly. Assumption valid? Probably not.

27. (Assumption 3) All animals have the same probability of being tagged initially

“Sharks of a particular size or sex were not targeted when the tagging was done at a range of sites. The particular animals tagged comprised a random sample of the sharks present at any given site. Given this approach, it is highly likely that this assumption is valid”.

Comment: Probability of all animals being tagged is unlikely to be the same. On the sites where tagging took place, baited hooks were positioned in front of sighted sharks. Unconscious selection bias may have come into play. But more importantly, if GNS occurred on the sites where historic game fishing activities caught large numbers of them, something that was simply not checked, then the probability of all animals being tagged initially is not the same at all. In fact, the probability of any sharks in the ‘cryptic’ group being tagged may well be nil Assumption valid? No.

28. (Assumption 4) Tags are not lost in the time between the two samples

“All the sharks were double tagged and none of the 20 sharks re-sighted over the period of the study had lost either of their tags. Given this result, it is unlikely that tag shedding prevented the remaining 4 sharks from being re-sighted. Hence, for the purpose of this study we have assumed that this assumption is valid”.

Comment: Given the double tagging results, tag shedding would indeed appear to be negligible. Assumption valid? Yes.

29. (Assumption 5) The second sample is a random sample

"The mark-recapture (re-sighting) survey was done following established techniques (Otway et al. 2003). The sharks counted were observed at 44 sites over a two-week period. The observation of tagged and untagged sharks in this survey comprised a random sample of the population at sites within the sharks' known range. Thus, it appears that this assumption is valid".

Comment: *Although this was an apparently random sample within the a range of selected sites, these were certainly not spread throughout the known range of the true the population. As noted, the true population almost certainly included animals north and south of the study area, and perhaps more importantly, in deeper, more offshore locations. A further question in relation to this assumption relates to the likelihood of seeing a tagged shark in the same area it was tagged. Given that GNS are known to home to some extent, there would presumably be a higher chance of seeing tagged sharks at release sites. This important point is not addressed in the report of the study. Assumption valid? No.*

30. (Assumption 6) **The effects of emigration, immigration, mortality and recruitment are negligible**

"The sampling covered almost the entire range of the population (see Otway & Parker 2000, Otway et al. 2003) and thus emigration and immigration would likely not be evident and hence not affect the population estimate. The mark-recapture (re-sighting) survey was done in excess of a year after the first Grey Nurse Shark was tagged. This was done to enable sufficient time for the tagged animals to disperse amongst the untagged population by participating in the migratory movements along the SE Australian coast. A single period of recruitment would have occurred in late winter – early spring, 2002. However, tagging did not finish until after the period of recruitment. Any effect of recruitment, if present, would lead to an over-estimation of the true population size (Seber, 1982)."

Comment: *Again, the proposition that the sampling covered 'almost' the entire range of the population is not upheld. The possibility of unsampled animals occurring outside the study area has already been discussed, and in this case, the effects of emigration and immigration are not accounted for. Assumption valid? No.*

31. (Assumption 7) **All tagged animals seen in the second sample are reported**

"Sixteen individual, tagged sharks were reported during the mark recapture survey in June 2003. Numerous, independent reports of the same shark were made by divers on the same dive. Divers also reported seeing tagged sharks with the tag numbers obscured by algae. These data suggest that all tagged sharks were seen and were also reported. It is important to note that under-reporting of tagged animals will give a total population estimate greater than the true population. This is not likely to be a problem in this study."

Comment: *This is a problem in that it is clearly stated in a number of reports*

that tags became fouled with algae, making them difficult to read. How were such tags dealt with? Were numerous reports of the same shark by divers on the same dive made for all resightings, or just some? There is a question mark over the accurate reading of tag numbers under water, in all cases, which could affect the results. Assumption valid? Probably, but needs resolution.

Second resighting survey

32. Mention needs to be made of some additional data collected from divers' observations in August 2003, two months after the June 2003 survey, the latter being the only data used for the estimate of population size. In a document attached to a letter dated 22 September 2003 from NSW Fisheries (A. Burke) to M Brown, it is stated that a second resighting survey was carried out over the last 2 weeks of August 2003. It was stated that this survey covered the whole coast, from Eden in the far south to Tweed Heads in the north, and extending up to the Queensland coast of Bundaberg. In that survey, 162 GNS were sighted over 27 sites but no tagged sharks were sighted.
33. NSW DPI Chief Scientist, Dr Steve Kennelly, in a letter to the Minister of Primary Industries, comments that the data from the August diving observations came mainly from northern NSW and southern Queensland (not the whole coast, as stated in the attachment to the letter to M. Brown dated 22 September 2003) and that because no tags were seen, the requirement of at least 7 resightings within a short period (note that the August period was the same as the June period) was not met for the purposes of a population estimate.
34. I agree with Dr Kennelly's interpretation of why these data could not be used in a population estimate, but the fact that no tagged sharks were seen at all must be cause for some questions regarding the assumptions relating to full mixing of tagged sharks with untagged sharks throughout the whole population. This is especially pertinent because, in August (winter), a high proportion of GNS would be expected to have moved to northern sites.

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WORLD DISTRIBUTION OF GNS

