Asian Journal of Fisheries and Aquatic Research

Volume 24, Issue 3, Page 9-22, 2023; Article no.AJFAR.104680
ISSN: 2582-3760

The Saddleback Deformity in Teleost Fish: Identification of a Unique Global Hotspot in Eastern Australia

Barry Pollock [a*]

[a] *Sunfish Queensland, 25 Uther Street, Brisbane, Queensland-4152, Australia.*

Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/AJFAR/2023/v24i3633

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/104680

Review Article

Received: 01/06/2023
Accepted: 04/08/2023
Published: 10/08/2023

ABSTRACT

The saddleback deformity, an abnormality of the dorsal fin and profile, lacking one to all of the dorsal spines, accompanied by shape, number and position abnormalities of associated pterygiophores, has been reported in teleosts under culture conditions and in the wild in many locations throughout the world, including North and South America, Asia, Australia, Europe, India and the Middle East. A unique global hotspot for saddleback deformities in wild teleosts is the southeast Queensland Australia coastal region between 26° S and 28° S. At this location the incidence of saddleback has been relatively stable but very high at about 10% of individual teleosts taken in the associated fishery since 1997. Opinions on causation have focused on two possibilities, a developmental defect associated with water pollution or a physical injury. The range of skeletal deformities is vastly different in cultured teleosts compared with those occurring in the wild. There is now mounting evidence that physical injury is causing saddleback in teleosts in southeast Queensland Australia. Such injury could be caused by predatory behaviour of piscivorous fish or birds, parasites, or escapement or release from fishing nets and other fishing gear. Population mortality rates associated with saddleback in southeast Queensland are unknown, but expected to be high. The high level of occurrence of saddleback in teleosts in southeast Queensland Australia together with the good understanding of their fisheries biology

**Corresponding author: Email: br_pollock@yahoo.com.au;*

(age and growth rates, reproductive biology, habitat dependence) and stock assessments of the associated fisheries provide excellent opportunities for further research which would add to the scientific understanding of the saddleback deformity in teleosts throughout the world. A recommendation from this review is that support should be sought by research providers (universities and Government research agencies) from routine annual funding offers from the Australian and Queensland Governments to achieve an increase in the scientific understanding of the saddleback deformity.

Keywords: Deformity; developmental defect; injury; mortality; Southeast Queensland; teleosts.

1. INTRODUCTION

The definition of the saddleback syndrome in teleost fish is an abnormality of the dorsal fin and profile, lacking one to all of the dorsal spines, accompanied by shape, number and position abnormalities of associated pterygiophores [1]. The term saddleback has been applied to teleost fish under culture and those taken in the wild [2].

Saddleback deformities have been reported in many species of wild teleosts from locations throughout the world (North and South America, Asia, Australia, Europe, India, the Middle East). Most of these reports are based on a single specimen or small numbers of a species, giving descriptions of the deformity and commenting on causation in some cases [3-8]. Saddleback in wild populations of teleost fish has been attributed to several causes including physical injuries [9-12], developmental defects associated with unsuitable water conditions including chemical contamination [3-8] and an inherited abnormality [13]. The saddleback deformity also commonly occurs in teleosts under culture conditions. In these cases saddleback is attributed to developmental defects associated with water quality, nutrition, crowding and genetic anomalies [14,15]. Initial studies of saddleback in wild teleosts throughout the world often discounted causation by physical injury [2].

The present paper reviews the incidence and causation of the saddleback deformity in teleosts taken from the wild and those under culture for comparisons. The review draws attention to the unique situation in southeast Queensland Australia where saddleback deformities have been occurring at very high levels in several teleost species taken in local fisheries since the early 1990s. The associated fisheries for teleosts with saddleback deformities in eastern Australia are relatively large and important for both the commercial net and trap sector and a large recreational line fishing sector [16]. The very high levels of saddleback deformities in southeast Queensland provide good opportunities to further examine causation of saddleback in wild teleosts.

2. STUDIES OF SADDLEBACK IN TELEOSTS UNDER CULTURE

Research on the causes of saddleback deformities and descriptions of associated abnormalities in cultured teleosts have been the subject of many studies [14,15,17,18]. As a result saddleback syndrome and its cause in cultured teleosts is better understood in comparison to this deformity in wild teleosts. The range of skeletal deformities is very different in cultured teleosts compared with those in the wild. For example the occurrence of spinal abnormalities such as lordosis and scoliosis commonly occur in teleosts under culture [14,15]. A case-study of two sparids (F. Sparidae), sharpsnout sea bream *Diplodus puntazzo* and pandora *Pagellus erythrinus*, found skeletal abnormalities are more common and severe in reared juveniles compared with wild juveniles [19]. Teleosts with saddleback syndrome raised under aquaculture conditions are subject to vastly different environmental conditions (culture facilities, water quality, water conditions such as temperature and salinity, nutrition, crowding) to saddleback teleosts in the wild. Causation of saddleback and other skeletal deformities in teleosts under culture conditions have commonly been attributed to developmental defects. Reviews of the morphologies and incidences of abnormalities of teleosts under culture conditions describe a wide range of abnormalities to the skeleton of teleosts. These reviews have concluded that causative pathways resulting in skeletal abnormalities are not well understood [14,15].

3. WORLD STUDIES OF SADDLEBACK IN TELEOSTS IN THE WILD

Saddleback deformities have been reported in several species of wild teleosts from locations throughout the world. Two studies report the saddleback deformity in clusters of different species of wild teleosts [20,21]. The study of a cluster of teleosts in Biscayne Bay, Florida, United States identified 61 individual specimens from 11 species in a sample of 43,000 teleosts with saddleback syndrome and scale pattern deformities caught by fishers. The level of occurrence in that study was very small (0.14%). That study concluded that the saddleback and scale pattern deformities were developmental defects associated with chemical contamination in Biscayne Bay. Another study examined saddleback deformities in a cluster of marine teleosts on the Arabian Gulf Coast of Saudi Arabia [21]. The occurrence of saddleback specimens in that study was also very low (eleven saddleback specimens from seven families). Teleost samples were obtained from local fishers during an extended time period from February 2013 to September 2016. The total sample size examined was not provided, but it is expected to be very large. The study concluded that the occurrence of similar deformities across such a spectrum of fishes from the same location suggests the deformity was induced by something in the environment common to all these species, most likely the same environmental contaminant or group of contaminants is adversely affecting a common developmental pathway [21]. The study concludes that saddleback in teleosts on the Arabian Gulf Coast is a developmental defect associated with poor water quality. Neither of the two studies [20,21] of the saddleback deformity in clusters of marine teleosts examined possible mechanisms of how saddleback deformities are caused by water pollution or whether sampled teleosts had traces of chemical contaminants in their tissues. It is therefore concluded that studies of saddleback in wild teleosts which attribute causation to developmental defects due to water pollution are speculative at this stage, with no direct scientific evidence to support such claims [2,22,23]. Further research to examine for possible direct pathways between the saddleback deformity in wild teleosts and water pollution are necessary at present.

4. SADDLEBACK IN TELEOSTS IN SOUTHEAST QUEENSLAND AUSTRALIA

The incidence of teleosts with the saddleback deformity taken in coastal fisheries in southeast Queensland, Australia (26° S and 28° S, a latitudinal distance of 140 km, extending from coastal estuaries eastward offshore to the continental shelf to depths exceeding 60 m) was very high and concerns were raised by fishers and other stakeholders [2]. Three sparid species, yellowfin bream *Acanthopagrus australis*, snapper *Chrysophrys auratus* and tarwhine *Rhabdosargus sarba* were of particular concern. In the case of yellowfin bream, the incidence was reported to be consistently high at approximately 10% of affected teleosts with the deformity in catches where fish exceeded the minimum legal length (25cm Total Length). Another example is a catch of snapper in southeast Queensland containing 17.6% of individual fish with saddleback [23]. The population mortality rates associated with saddleback in the southeast Queensland teleosts are not known, but expected to be high.

A literature review and stakeholder workshop was funded by the Australian Government as an initial approach to determining stakeholder views and available scientific information [2]. The report on this workshop favoured a developmental defect as the likely cause of the saddleback deformity in southeast Queensland, and discounted the possibility of causation by physical injury. The Australian Government and the Queensland fisheries agency were unable to provide funding for the recommended follow-up research. One of the key stakeholder groups, Sunfish, representing the recreational fishing sector in Queensland, implemented an independent research project to examine the nature of the deformity and identify causation [24]. The Sunfish study found that physical injury was the most likely cause of saddleback deformities in southeast Queensland. This finding was disputed (See editor's note [24] and commentaries [23,25]). A second research study by Sunfish [26] into yellowfin bream with saddleback in southeast Queensland examined several common features associated with this deformity (lateral line fracture, abnormalities of scale patterns, normal and replacement scales associated with the saddleback site including scales taken from the lateral line, skeletal X-rays, microscopic slide tissue examinations of wounding of the dermis, connective tissue and muscle tissues in normal and saddleback individuals). Examinations of X-ray images of saddleback teleosts in southeast Queensland found no examples of spinal curvature deformities such as lordosis and scoliosis which are common in teleosts raised under culture [15], indicating major differences in causative factors. The incidence of saddleback deformities of teleosts in southeast Queensland remains high at present, providing good opportunities for studies of saddleback injuries in wild teleost populations and associated fishery. All teleosts with saddleback in this area have legal minimum sizes applied by the Queensland fisheries agency. Fishers are required to release undersized teleosts. This review provides images of the deformities associated with saddleback in teleosts in southeast Queensland. In addition to saddleback, deformed teleosts have one or more associated abnormalities, indicative of physical injury.

Details are taken from a single snapper *Chrysophrys auratus* (Total Length 68cm) with a physical injury, caught on 10 July 2021 by a line fisher, held in an ice slurry and given to the author one day after capture (Figs. 1, 2, 3). The snapper was caught at Jew Shoal on the Australian east coast (26° - 22ˈ S, 153° - 07ˈ E) , a natural reef rising out 20m to a depth of 6m, and popular ground for offshore fishing vessels.

Soft tissue abnormalities associated with the saddleback deformity in teleosts taken in southeast Queensland (Fig. 4) have been described. These abnormalities to soft tissue (dermis, connective tissue and muscle) are indicative of deep wounding [26].

Examples of yellowfin bream with saddleback taken by fishers in southeast Queensland, and reported in the recent study [26] are given in Fig. 5.

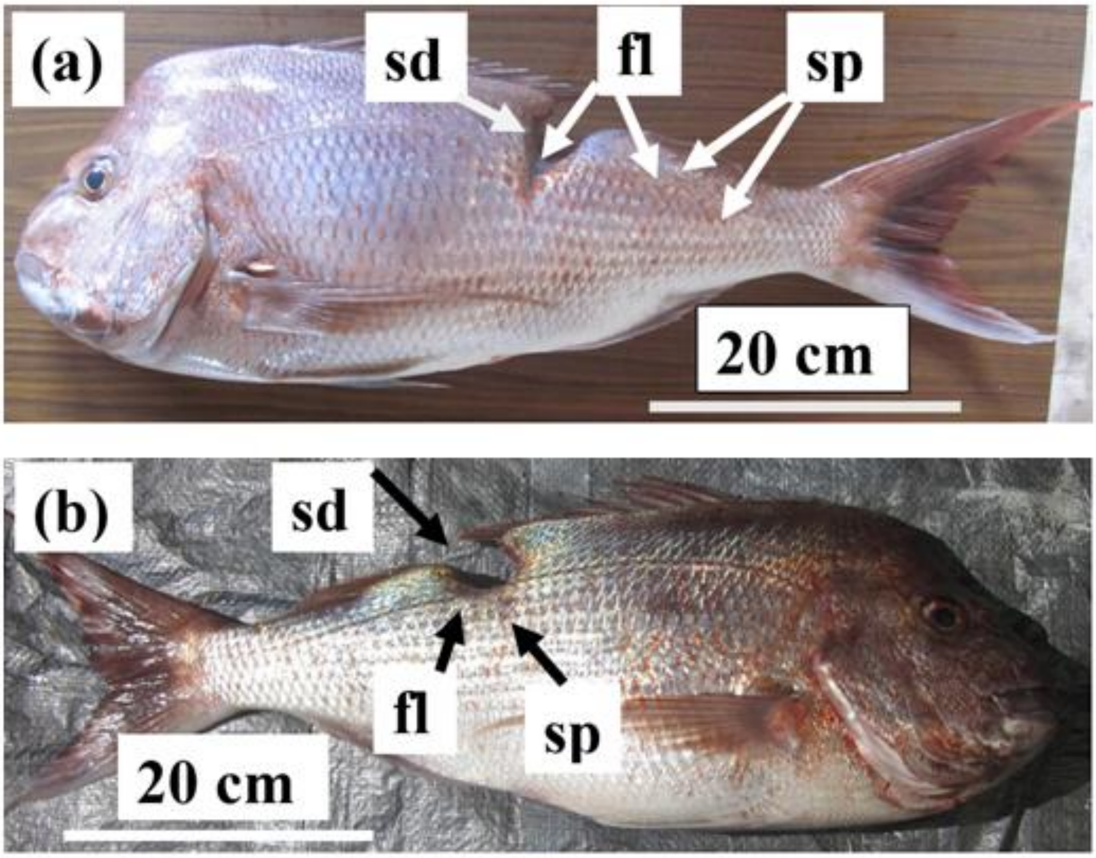


Fig. 1. Photographic images of a snapper *Chrysophrys auratus* taken by line fishing offshore in southeast Queensland showing abnormalities due to physical injury. (a) Left side of whole fish. (b) Right side of whole fish. sd – saddleback deformity. fl – fractured lateral line. sp – scale pattern deformity

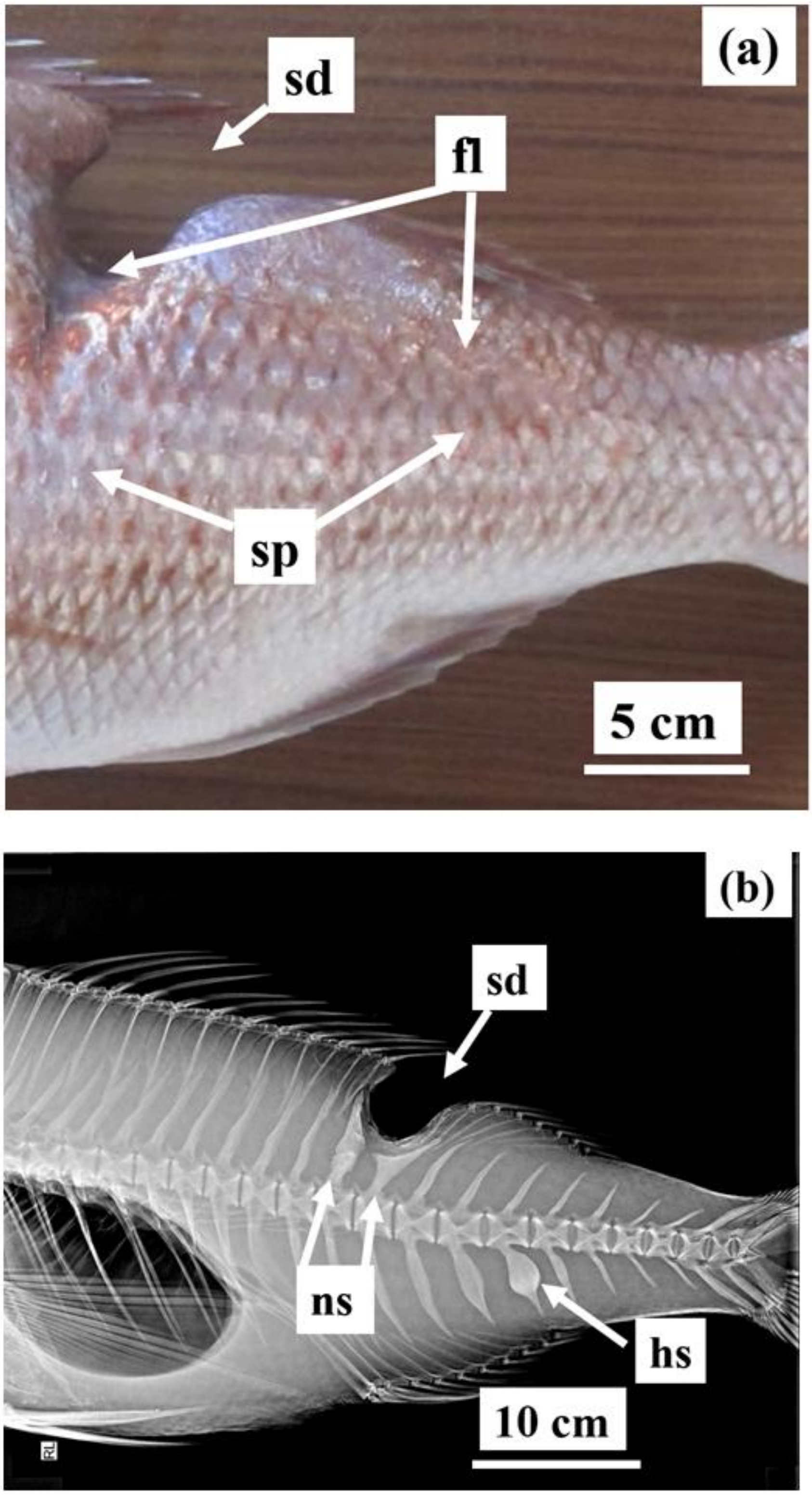
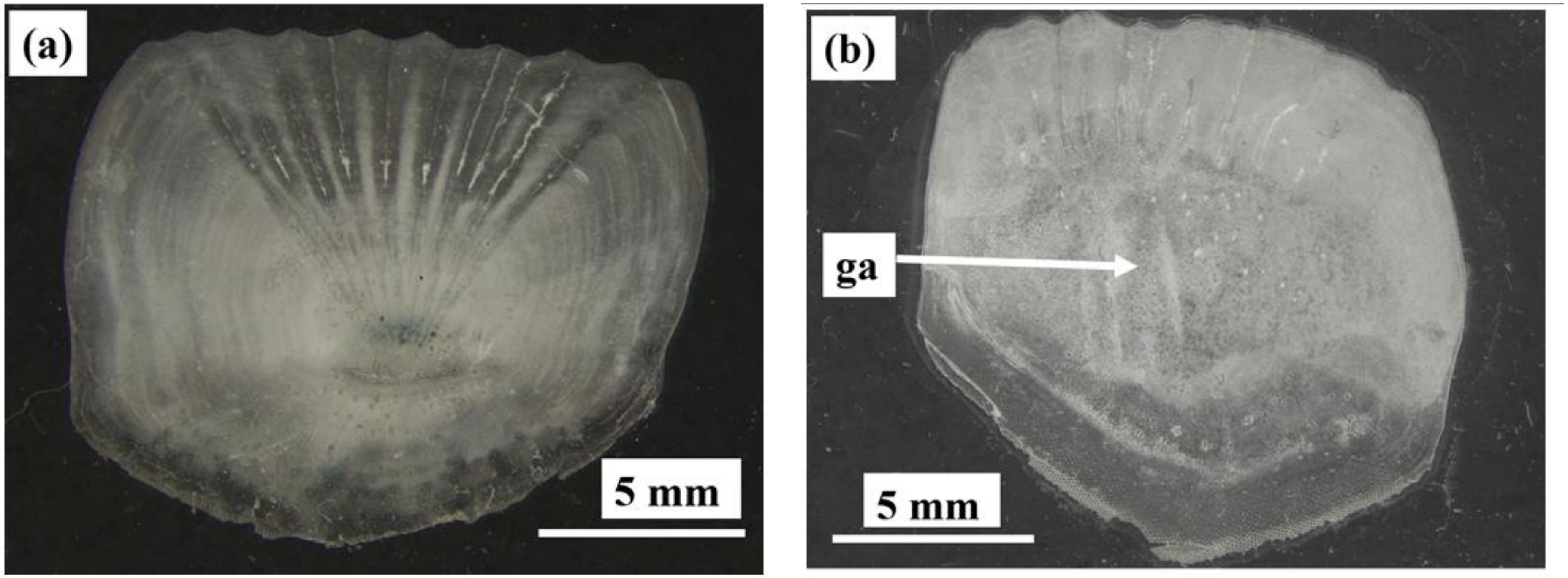


Fig. 2. Magnified images from a snapper *Chrysophrys auratus* taken by line fishing offshore in southeast Queensland showing abnormalities due to physical injury. (a) Colour photograph of exterior left side. (b) X-ray of skeletal deformities. sd – saddleback deformity. fl – fractured lateral line. sp – scale pattern deformity. ns – deformed neural spines. dh – deformed hemal spine


(a)
5 mm
(b)
ga
5 mm

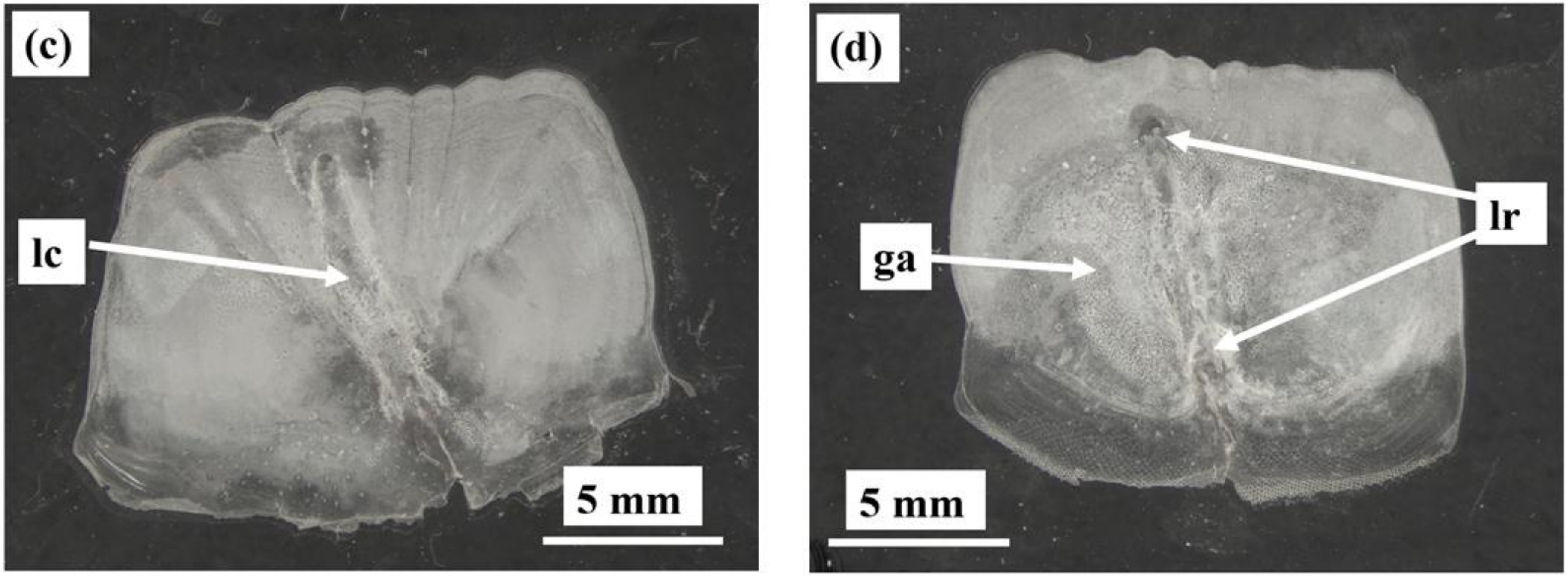


Fig. 3. Photographic images of normal and replacement scales taken from an injured snapper *Chrysophrys auratus* caught by line fishing offshore in southeast Queensland. (a) Normal ctenoid scale. (b) Replaced scale with a central rapid-growth granular interior resulting from the loss of the normal scale, (c) Normal lateral line scale with central cavity. (d) Replacement lateral line scale with a rapid-growth granular interior and replacement cavity. ga – granular (replacement) area. lc – lateral line canal. lr – lateral line replacement canal

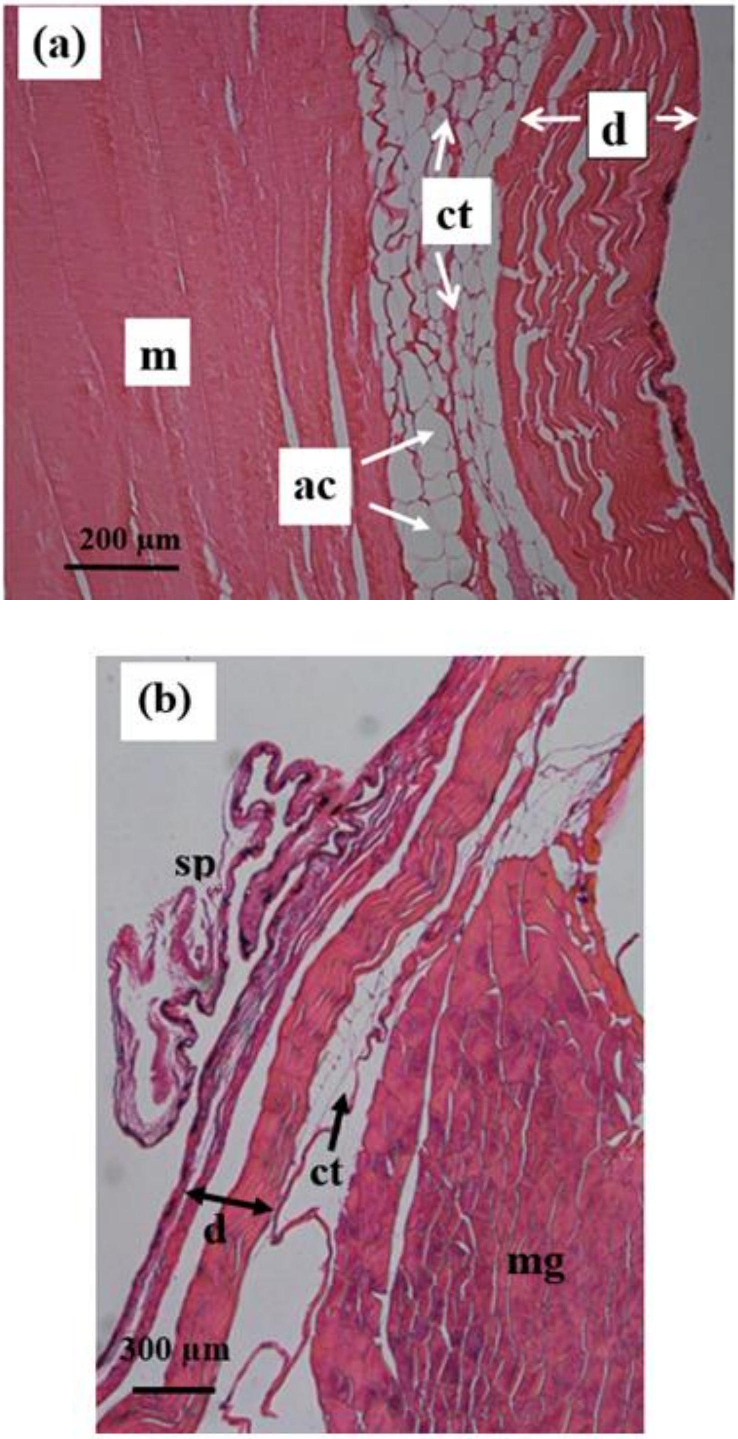


Fig. 4. Tissue structure associated with the saddleback deformity in yellowfin bream *A. australis.* Haematoxylin and eosin stained histological sections. (a) Tissue sample from a normal fish at the location where the saddleback deformity is usually present, showing a thick connective tissue layer with adipose cells and striated skeletal muscle. (b) Tissue sample from the saddleback site of a fish with saddleback deformity, showing a thin connective tissue layer with few adipose cells and muscle granulation tissue. ac – adipose cell, ct – connective tissue, d – dermis, m – skeletal muscle striated, mg – granulation muscle tissue, sp – scale pocket with scale removed. (From previous study by author [26])

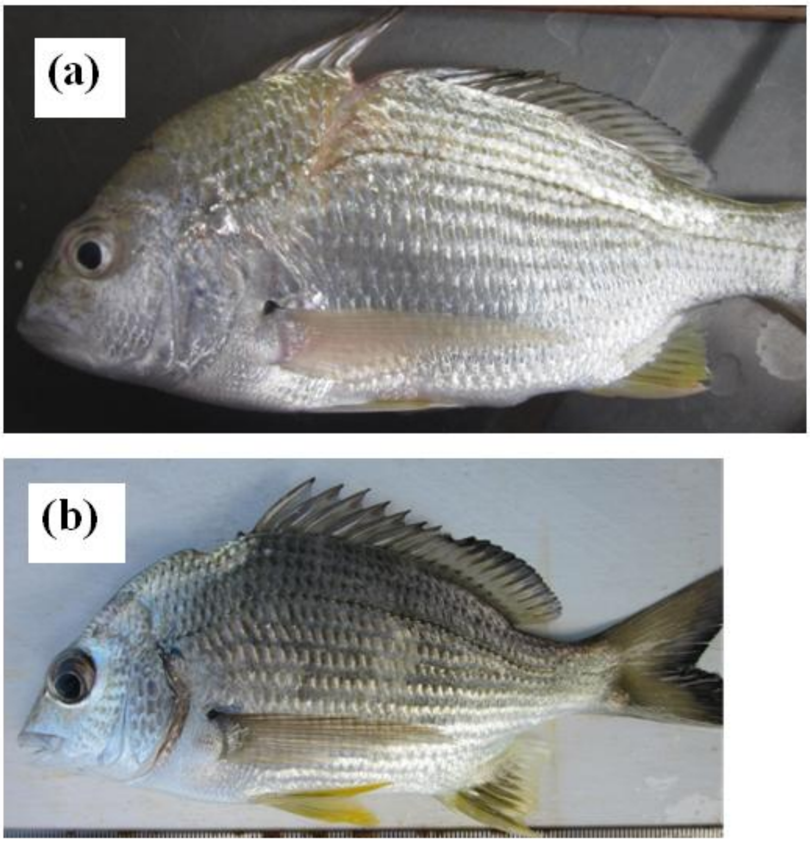


Fig. 5. Photographs of yellowfin bream *Acanthopagrus australis* with saddleback deformities taken in southeast Queensland during June - July 2020. A sample of 161 yellowfin bream were examined with 17 (10.5%) having saddleback. (a) Specimen with saddleback deformity, soft tissue damage below the saddleback and fractured lateral line, 29 cm Total Length. (b) Specimen with saddleback deformity and fractured lateral line at the caudal peduncle, 18 cm Total Length [26]

5. DISCUSSION AND CONCLUSIONS

The teleost species in which saddleback commonly occurs, yellowfin bream *Acanthopagrus australis*, snapper *Chrysophrys auratus* and tarwhine *Rhabdosargus sarba* in southeast Queensland, have a similar reproductive biology and early life history. They are highly fecund broadcast spawners with serial spawning over a protracted period annually. Spawning occurs in oceanic waters, and the larvae are planktonic in offshore waters before they migrate, becoming benthic juveniles in coastal habitats such as estuaries and sheltered embayments [27-29].

The variety of skeletal deformities and the aquatic environments in cultured teleosts are vastly different to those occurring in wild teleosts. The causes of saddleback in the wild and those under culture are consequently different and unrelated [14,15]. However the studies of morphological abnormalities in early life stages of teleosts under culture conditions have influenced predictions of the possible cause of saddleback and other abnormalities in wild teleosts [2,26]. Studies of wild teleosts have speculated that causation of saddleback deformities is due to developmental defects in early life stages associated poor water quality including chemical contamination [5-7,20,21]. This was also the case in initial studies of the saddleback deformity in wild teleosts in southeast Queensland [2,22] where causation due to physical injury was rejected in favour of developmental defects of early life stages associated with poor water quality.

Detailed examinations [24 26] of anomalies associated with saddleback in teleosts in the southeast Queensland cluster have now been completed, and these indicate causation by physical injury. Teleosts with saddleback in southeast Queensland were provided to the Queensland Health Department for chemical contaminant screening in tissues of saddleback and normal fish [26]. The screening found no abnormally high levels of tissue contamination in saddleback teleosts, compared with samples taken from specimens lacking the saddleback deformity. A range of chemical contaminants associated with domestic, agricultural and industrial sources have been identified in a river which flows into the site of the unique global hotspot for saddleback in southeast Queensland [30]. There is a clear gradient in contaminant concentrations with maximum levels in the upper river reduced to very low levels in samples taken from west to east as mixing with oceanic waters increases. That study also found traces of a range of chemical contaminants in yellowfin bream in the more heavily polluted area of the river, but that study did not examine for associations between chemical contaminants and the saddleback deformity [30]. It is relevant that wild teleosts with saddleback in southeast Queensland, yellowfin bream, snapper and tarwhine, have early life stages of planktonic eggs and larvae, and post larval migration in oceanic waters where the level of chemical pollution is lowest [30].

Productive commercial net and recreational line fisheries for yellowfin bream, and commercial and recreational line fisheries for snapper have a long history in southeast Queensland [31,32]. Juvenile and adult teleosts, less than the legal minimum size, are caught in large numbers in southeast Queensland especially in estuaries, embayments and other coastal habitats but must be released, [33]. The legal minimum sizes are yellowfin bream and tarwhine 25cm Total Length, and snapper 35 cm Total Length. A common method for commercial gill net fishers to remove undersized teleosts is to grip the caudal peduncle and extract the fish backwards before releasing it [33]. The injuries to teleosts release in this way have not been examined or described. Examination of these injuries is an important subject for further research. Studies of teleosts in the wild in southeast Queensland which implicate causation to developmental defects are speculative with no direct evidence provided [2,22,23]. Further research is also needed to determine the cause of saddleback and associated abnormalities in affected teleosts taken in the southeast Queensland fishery such as escapement or discarding teleosts under the legal minimum size from gill nets or sub-lethal injury by predators (sharks, other piscivorous fish, piscivorous birds).

In addition to the saddleback deformity in wild teleosts in southeast Queensland, the associated deformities [24,25] are:

- Scale pattern abnormalities both above and below the lateral line
- Scale replacement, including replacement of lateral line scales
- Lateral line fractures
- Tissue histology (dermis, connective tissue and muscle) examination indicative of deep wounding
- Skeletal abnormalities using X-ray examinations

An important finding from the present review of saddleback deformities in teleosts in the wild is the high level of occurrence of saddleback in southeast Queensland. Teleosts with saddleback are vastly more abundant in southeast Queensland compared to the levels of abundance in other locations throughout the world. For example yellowfin bream *Acanthopagrus australis* in southeast Queensland has saddleback at about 10% in catches from 1997 to the present, and snapper *Chrysophrys auratus* has saddleback levels as high as 17.6% in a catch. In comparison saddleback in clusters of teleosts in Biscayne Bay, Florida and the Arabian Gulf coast off Saudi Arabia have saddleback incidence at extremely low levels. Saddleback in teleosts in the wild in other countries, based on single or small numbers of teleosts, also indicate the presence of this deformity at very low levels of abundance. This review has termed the area in southeast Queensland a unique global hotspot for teleosts with the saddleback deformity.

Saddleback-like deformities in teleosts have been recently reported in catches from locations north and south of the southeast Queensland hotspot on the east coast of Australia (Fig. 6). In such cases the incidence of the deformity is relatively low, according to fishers and other stakeholders. Examples of the locations of such reports are the Clarence River estuary and the Burrill Lake estuary both south of the southeast Queensland hotspot for distances of 200 km and 800 km respectively. No examinations of teleosts outside the southeast Queensland hotspot have been carried out to determine the extent, characteristics or cause of the deformity.

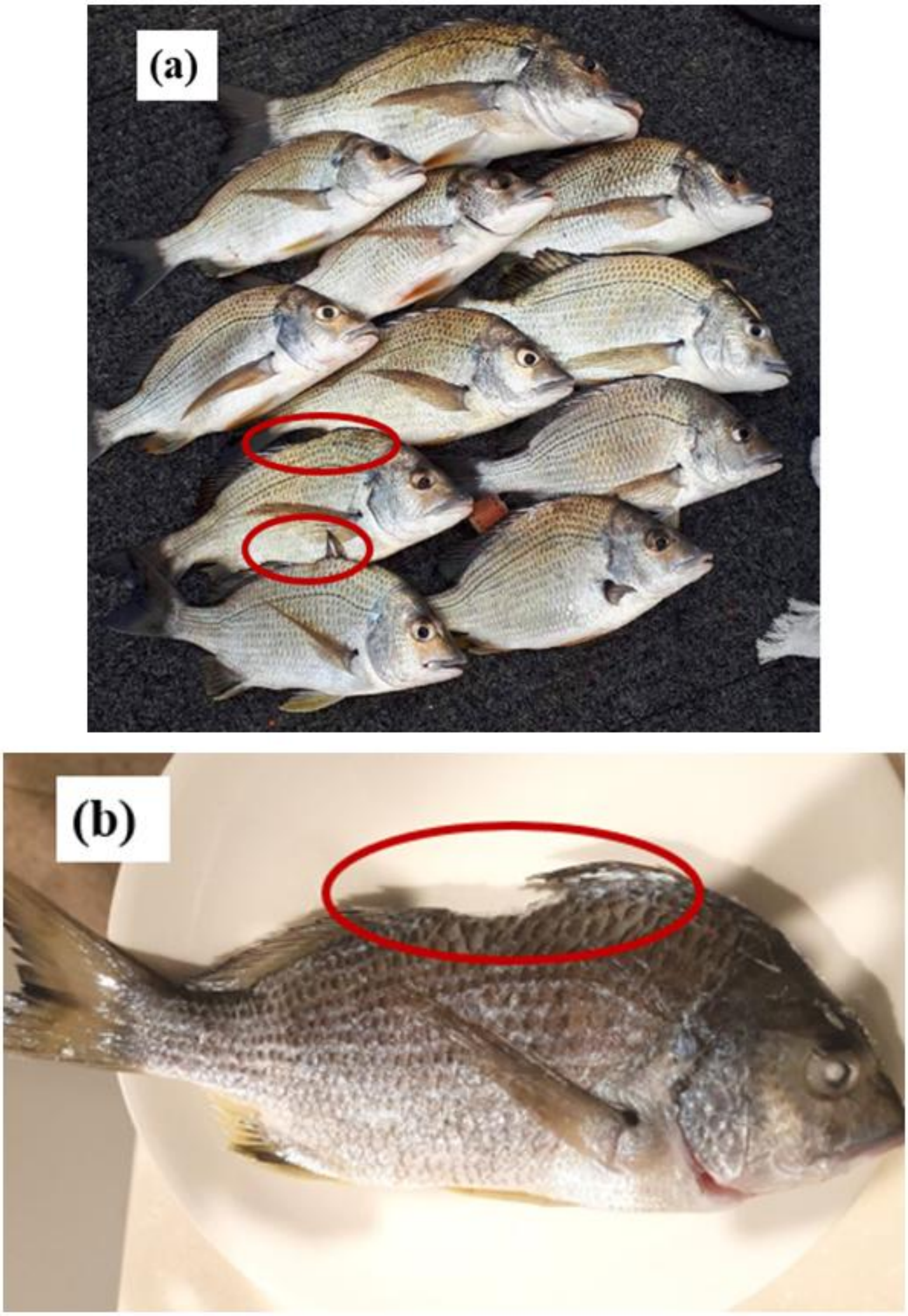


Fig. 6. Examples of yellowfin bream *Acanthopagrus australis* with saddleback-like deformities reported at low occurrence levels by fishers south of the southeast Queensland hotspot. (a) From the Clarence River, 200 km south. (b) From Burrill Lake, 800 km south. Photographs were provided by recreational fishers

Given the incidence of the saddleback deformity in wild teleosts throughout the world, the unique global hotspot in southeast Queensland provides good opportunities for further research aimed at increasing the scientific understanding of the saddleback deformity. The Queensland and Australian Governments have annual funding programmes for priority research on fisheries within their jurisdictions. Research providers from universities and Government agencies could be encouraged to make funding applications for further scientific studies of saddleback in teleosts at this unique global hotspot and elsewhere on the Australian east coast. Caution should be exercised in future research into the saddleback deformity in southeast Queensland. Suggestions involving the culturing of saddleback and normal teleosts from southeast Queensland in waters of varying quality taken at locations in southeast Queensland where saddleback teleosts are abundant, or assessing the effects of temperature, pH and dissolved oxygen in saddleback as possible causations have been suggested [2,22,23]. Such proposals are dependent on the culture of teleost, which in itself leads to a wide range of skeletal and other deformities [14,15,34]. A simpler and more direct proposal is to test saddleback and normal teleosts for levels of chemical contaminants in tissues, which has already done with small samples, showing low levels of contamination and no differences between saddleback and normal teleosts [2,26]. An advantage of testing for chemical contaminants in tissues of saddleback and normal teleosts in southeast Queensland is the ease of obtaining teleost samples from this unique global hotspot.

ETHICAL APPROVAL

This study did not require official or institutional ethical approval. Fish were captured by fishers in accordance with fisheries legislation and killed or treated humanely by them in accordance with the Australian national recreational fishing code of practice. The fishers allowed the author to take photographs and X-ray images of their fish.

ACKNOWLEDGEMENTS

Since saddleback deformities in teleost fish were first reported in southeast Queensland, Australia in 2007 many have contributed to Sunfish studies at no cost. Numerous specimens were obtained by members of the Queensland Amateur Fishing Clubs Association and affiliated bodies. Those who made contributions to specimen collection were Martin Cowling, Ken Davis, Charles Lanskey, Ken Orme, Bob Pearson and David Pollock. Staff at the Ecosciences Precinct in Brisbane kindly provided bench space for the author and assisted with photographs of scales. Microscope slides of tissue samples were prepared by Darryl Whitehead, Histology Facility, University of Queensland. X-ray images were taken and provided by Shibly Mustapha. Figures were prepared for publication by Glenys Pollock. Bob Pearson reviewed some manuscripts prior to submission. I acknowledge the many scientists, editors, referees and stakeholders who have taken the time to provide comments and criticisms on causation of the saddleback deformity of teleosts in southeast Queensland since 2007. I thank the Sunfish Management Committee members for their continuing support. The AJFAR editorial board agreed to fast-track the review process, given the urgency of the need for further research to be undertaken on the saddleback deformity in teleosts in southeast Queensland, a unique global hotspot.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Koumoundouros G, Divanach P, Kentouri M. The effect of rearing conditions on development of saddleback syndrome and caudal fin deformities in *Dentex dentex* (L.). Aquaculture. 2001;200: 285-304.
2. Campbell M, Landers M. Tactical research fund: Incidence and possible causes of saddleback syndrome in the fish species of south east Queensland. Queensland Department of Agriculture, Fisheries and Forestry. Fisheries Research and Development Corporation, Project Number 2010/070. 2013;53.
3. Alavi-Yeganeh MS, Razavi S, Egan JP. Taillessness and skeletal deformity in striped piggy *Pomadasys stridens* (Osteichthyes: Haemulidae) from the Persian Gulf. Diseases of Aquatic Organisms. 2019;213:209-213. Available:https://doi.org/10.3354/dao03322
4. Koumoundouros G. First record of saddleback syndrome in wild parrotfish *Sparisoma cretense* (L., 1758) (Perciformes, Scaridae). Journal of Fish Biology. 2008;72:737-741. DOI:10.1111/j.1095-8649.2007.01714.x
5. Jawad LA, Akyol O, Aydin I. First records of saddleback syndrome and pughead deformities in the common pandora *Pagellus erythrinus* (Linnaeus, 1758) (Teleostei: Sparidae) from wild population in the northern Aegean Sea, Turkey. International Journal of Marine Science. 2017;7:183-187.

DOI: 10.5376/ijms.2017.07.0019
6. Jayaprabha N, Purusothaman S, Srinivasan M. First record of saddleback syndrome in wild species, *Etroplus suratensis* (Bloch, 1790) from Southeast coast of India. Indian Journal of Geomarine Sciences. 2016;45:1536-1539.
7. Almatar S, Chen W. Deformities in silver pomfret *Pampus argenteus* caught from Kuwait waters. Chinese Journal of Oceanology. 2010;28:1227–1229.
8. Jawad LA, Al-Mamry J. Saddleback Syndrome in wild silver promfret, *Pampus argenteus* (Euphrasen 1788) (Family:Stromatidae) from the Arabian Gulf Coasts of Oman. Croation Journal of Fisheries. 2012;70:3.
9. Aguilar-Perera A, Quijano-Puerto L. Saddleback syndrome in the lionfish, *Pterois volitans* (Linnaeus 1758) (Scorpaenidae), in the southern Gulf of Mexico. Cahiers de Biologie Marine. 2018;59:301 – 304.
10. Vinothkumar R, Rajkumar M, Thirumalaiselvan S, Saravanan R, Remya L, Sikkander SS, Batcha SM, Siklander Nazar AK Abdul. First record of deformity in Chinese Pomfret, *Pampus chinensis* (Euphrasen, 1788) from Indian waters. Indian Journal of Geomarine Sciences.. 2020;49:95-98.
11. James PSBR, Badrudeen M. On certain anomalies in the fishes of the family Leiognathidae. Journal of the Marine Biological Association of India. 1968;10:107-113.
12. Jayaprabha N, Purusothaman S, Srinivasan M. First record of saddleback syndrome in wild species, *Etroplus suratensis* (Bloch, 1790) from Southeast coast of India. Indian Journal of Geomarine Sciences. 2016;45:1536-1539.
13. Tave D, Bartles JE, Smitherman RO. Saddleback: A dominant, lethal gene in *Sarotherodon aureus* (Steindachner)(=*Tilapia aurea)*. Journal of Fish Diseases. 1983;59-73.
14. Boglione C, Gavaia P, Koumoundouros G, Gisbert E, Moren M, Fontagné S, Witten PE. Skeletal anomalies in reared European fish larvae and juveniles. Part 1: normal and anomalous skeletogenic processes. Reviews in Aquaculture. 2013; 5:S99-S120.
Available:https://doi.org/10.1111/raq.12015
15. Boglione C, Gisbert E, Gavaia P, Witten E, Moren PM, Fontagné S, Koumoundouros G. Skeletal anomalies in reared European fish larvae and juveniles. Part 2: main typologies, occurrences and causative factors. Reviews in Aquaculture. 2013;5:S121-S167.
Available:https://doi.org/10.1111/raq.12016
16. Toby Piddocke, Crispian Ashby, Klaas Hartmann, Alex Hesp, Patrick Hone, Joanne Klemke, Stephen Mayfield, Anthony Roelofs, Thor Saunders, John Stewart, Brent Wise, James Woodhams (eds), Status of Australian fish stocks reports 2020, Fisheries Research and Development Corporation, Canberra; 2021.
17. Sfakianakis DG, Katharios P, Tsirigotakis N, Doxa CK, Kentouri M. Lateral line deformities in wild and farmed sea bass (*Dicentrarchus labrax* , L .) and sea bream (*Sparus aurata* , L .). Journal of Applied Ichthyology. 2013;29:1015-1021.
DOI:10.1111/jai.12248
18. Izquierdo MS, Socorro J, Roo J. Studies on the appearance of skeletal anomalies in red porgy: effect of culture intensiveness, feeding habits and nutritional quality of live preys. Journal of Applied Ichthyology. 2010;26:320-326.
DOI:10.1111/j.1439-0426.2010.01429.x
19. Boglione C, Gisbert E, Gavaia P, Witten E, Moren P, Fontagné M, Koumoundouros G. Skeletal anomalies in reared European fish larvae and juveniles. Part 2: main typologies, occurrences and causative factors. Reviews in Aquaculture. 2013;5:121-167.
20. Browder JA, McClellan DB, Harper DE. Kandrashoff MG. A major developmental defect observed in several Biscayne Bay, Florida, fish species. Environmental Biology of Fishes. 1993;37:181–188.
21. Jawad LA, Ibrahim M. Saddleback deformities in fish species collected from the Arabian Gulf Coast of Jubail City, Saudi Arabia. Journal of Ichthyology. 2018;58:401–409.
Available:https://doi.org/10.1134/S0032945218030049
22. Diggles BK. Saddleback deformities in yellowfin bream *Acanthopagrus australis* (Gunther) from South-East Queensland. Journal of Fish Diseases. 2013;36:521-527.
23. Diggles BK. Reply to Pollock. Comments on 'Saddleback deformities in yellowfin bream, *Acanthopagrus australis* (Günther), from South East Queensland' by Diggles.

Journal of Fish Diseases. 2014;38(3):331-333.
DOI: 10.1111/jfd.12339. PMID: 25594432.
24. Pollock BR. Saddleback syndrome in yellowfin bream [Acanthopagrus australis (Günther, 1859)] in Moreton Bay, Australia: its form, occurrence, association with other abnormalities and cause. Journal of Applied Ichthyology. 2015;31: 487-493.
25. Pollock BR. Comments on 'Saddleback deformities in yellowfin bream, Acanthopagrus australis (Günther), from South-East Queensland' by Diggles (2013). Journal of Fish Diseases. 2014; 38(3):329-330.
DOI: 10.1111/jfd.12334. PMID: 25594243
26. Pollock B. Causation of saddleback deformities in the yellowfin bream Acanthopagrus australis fishery: Evidence of physical injury. Asian Journal of Fisheries and Aquatic Research. 2021;10(4):35-48.
27. DM Parsons, CJ Sim-Smith, M Cryer, MP Francis, B Hartill, EG Jones, A Le Port, M Lowe, J McKenzie, M Morrison, LJ Paul, C Radford, PM Ross, KT Spong, T Trnski, N Usmar, C Walsh, J Zeldis. Snapper (*Chrysophrys auratus*): a review of life history and key vulnerabilities in New Zealand. New Zealand Journal of Marine and Freshwater Research. 2014;48:2:256-283.
DOI: 10.1080/00288330.2014.892013
28. Hughes JM, Stewart J, Kendall BW, Gray CA. Growth and reproductive biology of tarwhine *Rhabdosargus sarba* (Sparidae) in eastern Australia. Marine and Freshwater Research. 2008;59(12):1111-1123.
29. Pollock BR, Weng H, Morton RM. The seasonal occurrence of postlarval stages of yellowfin bream, *Acanthopagrus australis* (Gunther), and some factors affecting their movement into an estuary. Journal of Fish Biology. 1983; *22*(4):409-415.
30. Shaw M, Tibbetts IR, Müller JF. Monitoring PAHs in the Brisbane River and Moreton Bay, Australia, using semipermeable membrane devices and EROD activity in yellowfin bream, *Acanthopagrus australis*. Chemosphere. 2004;56(3):237-246.
31. McGilvray J, Conran S, Broadhurst M. Yellowfin bream *Acanthopagrus australis.* Status of Australian fish stocks report 2018*.* Fisheries Research and Development Corporation, Canberra. Australia; 2018.
32. Fowler A, Stewart J, Roelofs A, Garland A, Jackson G. Snapper (2020) *Chrysophrys auratus.* In Piddocke T, Ashby C, Hartmann K, Hesp A, Hone P, Klemke J, Mayfield S, Roelofs A, Saunders T, Stewart J, Wise B, Woodhams. Status of Australian fish stocks reports 2020. Fisheries Research and Development Corporation, Canberra; 2021.
33. Halliday I, Ley J, Tobin A, Garrett R, Gribble N, Mayer D. Effects of net fishing; Addressing biodiversity and bycatch issues in Queensland inshore waters. Fisheries Research and Development Cooperation, Australia. Final Report 97/206; 2001.
34. Eissa AE, Abu-Seida AM, Ismail MM, Abu-Elala NM, Abdelsalam M. A comprehensive overview of the most common skeletal deformities in fish. Aquaculture Research. 2021;52 (6):2391-2402.

Peer-review history:
The peer review history for this paper can be accessed here:
https://www.sdiarticle5.com/review-history/104680