

1 **The third record of black-spotted porcupinefish *Diodon hystrix* Linnaeus, 1758 in the**
2 **Mediterranean Sea**

3 Short title: *Diodon hystrix* in Cyprus and Mediterranean

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14 **Acknowledgments**

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16 available for examination along with details of its capture.

17 **Introduction**

18 Marine ecosystems are becoming increasingly altered worldwide as a result of human activities
19 intensification and increasing synergistic pressures including climate change, habitat destruction,
20 over-exploitation, and biological invasions (Crain, Kroeker, & Halpern, 2008; Halpern et al., 2015).
21 The semi-enclosed Mediterranean Sea is at the forefront of ecosystem alterations, facing
22 unprecedented pressures, and being characterized as a basin “under siege” (Coll et al., 2010). The
23 spread of non-indigenous species (NIS), and ongoing shift of Mediterranean coastal species
24 assemblages cause an increasing impact over time, resulting in changes in trophic flows and
25 interactions between native species and NIS (Corrales, 2019). A large number of pufferfish species
26 (Diodontidae and Tetraodontidae) have invaded or expanded their ranges in the Mediterranean Sea
27 (Table 1). Monitoring of changes is critical towards effective adoption of management measures.

28 Here, we report the first confirmed record of the spot-fin porcupinefish *Diodon hystrix* Linnaeus,
29 1758 from the eastern Mediterranean, and the third from the entire region, after its report by a
30 spearfisher. The spot-fin porcupinefish is a circumtropical species, widely distributed in the Atlantic,
31 Indian and Pacific Oceans but rarely reported from the Mediterranean with only two confirmed

32 records; the first from the Gulf of Taranto, Italy (Torchio 1963) and the second from the Balearic
33 islands, Spain (Ordines et al. 2018) (Figure 1).

34 **Materials and Methods**

35 On February 4, 2017, a spot-fin porcupinefish was found drifting in the Akrotiri Peninsula (Limassol,
36 Cyprus) (32° 56.355'E, 34° 33.592'N) at 40m depth by a spearfisher (Figure 1, A). The specimen was
37 in relatively good physical conditions indicating a recent death (Figure 1, B). The fisher reported his
38 finding and donated the specimen for further examination. Visual and genetic studies were conducted.
39 DNA was extracted and the mitochondrial barcode gene CO1 (Cytochrome oxidase 1) was sequenced
40 following published protocols (Bariche et al., 2015). Phylogenetic reconstructions were performed
41 based on the Neighbor-Joining method generated in R (RCoreTeam, 2016) with the use of the ape
42 package (Paradis, Claude, & Strimmer, 2004). Genetic distances were based on the Kimura 2
43 parameter method. The maximum likelihood (ML) method was also used as a second phylogenetic
44 reconstruction approach, as implemented in GARLI (Zwickl, 2006). To estimate support for the
45 nodes, 1000 bootstrap replicates were performed and we retained only the values supporting the nodes
46 accounting for more than 50% of the bootstrap replicates.

47 **Results**

48 *Morphological analysis*

49 Morphological characteristics of the specimen were consistent with characters described in Leis
50 (2016) for *Diodon hystrix*. Its general colour was tan to brown with small dark spots along the body
51 that extended to cover most of its fins and a wide and blunt head. Its meristic characters were also
52 consistent with that species, with 23 pectoral-fin soft rays, 16 anal-fin soft rays, 14 dorsal fin rays
53 and no pelvic fins. Dorsal and anal fins were rounded. Morphometric measurements are presented in
54 Table 2.

55 *Genetic analysis*

56 The PCR amplification and sequencing of the cytochrome oxydase 1 resulted in a 658 bp fragment
57 (GenBank accession number MN498287). A BLAST comparison of this sequence with available
58 sequences in GenBank placed it in a cluster with 16 sequences, all identified as *Diodon hystrix*. Six
59 of those sequences were identical to the one obtained for our sample. These six sequences belonged
60 to samples collected worldwide, from the Caribbean, and both Pacific and Atlantic Oceans.

61 Phylogenetic analyses were performed by comparing our sequence to *Diodon hystrix* sequences
62 extracted from GenBank, using three sequences from the sister species *D. liturosus*, and one sequence
63 from *D. nichteremus* as outgroups following Santini et al. (2013). Maximum likelihood and
64 Neighbor-Joining methods resulted in identical tree topologies, therefore only the NJ tree is shown
65 here (Figure 2). As indicated above from the BLAST results, our sequence clustered with *Diodon*
66 *hystrix* samples, and was very well separated from outgroup sequences (bootstrap support was 100%
67 and 88% with NJ and ML methods, respectively).

68 Discussion

69 The Eastern Mediterranean is the most invaded marine area of the world (Edelist et al., 2013) but the
70 number of recorded NIS for Cyprus is substantially lower than for neighbouring countries, mainly
71 due to the lack of targeted field studies (Crocetta et al., 2015). In the past years, however, citizen-
72 scientists have substantially contributed to the detection and monitoring of a relatively large number
73 of NIS in Cyprus waters (Giovos et al., 2019; Kleitou et al., 2019; Kousteni et al., 2019); and they
74 continue to prove essential for monitoring the drastic changes that the Mediterranean Sea is facing.
75 Visual and genetic results unambiguously identify the specimen reported here as a spot-fin
76 porcupinefish, *Diodon hystrix*. All three Mediterranean records for this species were found far from
77 each other and do not suggest a range expansion from the eastern Atlantic. Based on our genetic
78 results, it is difficult to determine if the Cyprus sample is an aquarium release or a Lessepsian
79 immigrant, because this species is found worldwide and shows little genetic differentiation at the COI
80 marker level. It is plausible that a careless aquarium hobbyist released the fish after it outgrew the
81 aquarium, as it is a relatively common practice (Semmens et al., 2004). Further work, sampling and
82 observations are therefore necessary to conclusively elucidate the introduction pathway.

83 References

- 84 Bariche, M., Torres, M., Smith, C., Sayar, N., Azzurro, E., Baker, R., & Bernardi, G. (2015). Red
85 Sea fishes in the Mediterranean Sea: a preliminary investigation of a biological invasion using
86 DNA barcoding. *Journal of Biogeography*, 42(12), 2363-2373.
- 87 Coll, M., Piroddi, C., Steenbeek, J., Kaschner, K., Lasram, F. B. R., Aguzzi, J., . . . Dailianis, T.
88 (2010). The biodiversity of the Mediterranean Sea: estimates, patterns, and threats. *PLoS one*, 5(8),
89 e11842.
- 90 Corrales Ribas, X. (2019). *Ecosystem modelling in the Eastern Mediterranean Sea: the cumulative*
91 *impact of alien species, fishing and climate change on the Israeli marine ecosystem*, Doctoral
92 dissertation. Universitat Politècnica de Catalunya, Barcelona, Spain. Retrieved from
93 <http://hdl.handle.net/2117/131431>
- 94 Crain, C. M., Kroeker, K., & Halpern, B. S. (2008). Interactive and cumulative effects of multiple
95 human stressors in marine systems. *Ecology letters*, 11(12), 1304-1315.

- 96 Crocetta, F., Agius, D., Balistreri, P., Bariche, M., Bayhan, Y., Çakir, M., . . . El Zrelli, R. (2015).
97 New Mediterranean Biodiversity Records (October 2015). *Mediterranean Marine Science*, 16(3),
98 682-702.
- 99 Giovos, I., Kleitou, P., Poursanidis, D., Batjakas, I., Bernardi, G., Crocetta, F., . . . Keramidas, I.
100 (2019). Citizen-science for monitoring marine invasions and stimulating public engagement: a
101 case project from the eastern Mediterranean. *Biological invasions*, 1-15.
- 102 Edelist, D., Rilov, G., Golani, D., Carlton, J. T., & Spanier, E. (2013). Restructuring the Sea: profound
103 shifts in the world's most invaded marine ecosystem. *Diversity and Distributions*, 19(1), 69-77.
- 104 Halpern, B. S., Frazier, M., Potapenko, J., Casey, K. S., Koenig, K., Longo, C., . . . Selkoe, K. A.
105 (2015). Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature*
106 *communications*, 6, 7615.
- 107 Kleitou, P., Giovos, I., Wolf, W., & Crocetta, F. (2019). On the importance of citizen-science: the
108 first record of *Goniobranchus obsoletus* (Rüppell and Leuckart, 1830) from Cyprus (Mollusca:
109 Gastropoda: Nudibranchia). *BioInvasions Records*, 8(2), 252-257.
- 110 Kousteni, V., Bakiu, R., Benhmida, A., Crocetta, F., Di Martino, V., Dogrammatzi, A., . . . Gokoglu,
111 M. (2019). New Mediterranean Biodiversity Records (April, 2019). 20(1), 230-247. doi:doi:
112 10.12681/mms.19609
- 113 Leis J.M. 2016. Diodontidae. Porcupinefishes (burrfishes, spiny puffers). Pp. 3074–3079. In:
114 Carpenter K.E., de Angelis N. (eds.) The living marine resources of the Eastern Central Atlantic.
115 Volume 4. Bony fishes part 2 (Perciformes to Tetradontiformes) and Sea turtles. FAO Species
116 Identification Guide for Fishery Purposes. FAO, Rome
- 117 Ordines, F., Deudero, S., Sintes-Vila, J., Sbragaglia, V., Fricke, R., & Azzurro, E. (2018). A new
118 record of *Diodon Hystrix* (Actinopterygii: Tetraodontiformes: Diodontidae) in the Mediterranean
119 Sea *Acta Ichthyologica et Piscatoria*, 48(4), 403.
- 120 Paradis, E., Claude, J., & Strimmer, K. (2004). APE: analyses of phylogenetics and evolution in R
121 language. *Bioinformatics*, 20(2), 289-290.
- 122 RCoreTeam. (2016). R: A language and environment for statistical computing. R Foundation for
123 Statistical Computing, Vienna, Austria. URL <http://www.R-project.org>.
- 124 Santini, F., Nguyen, M. T. T., Sorenson, L., Waltzek, T. B., Lynch Alfaro, J. W., Eastman, J. M., &
125 Alfaro, M. E. (2013). Do habitat shifts drive diversification in teleost fishes? An example from the
126 pufferfishes (Tetraodontidae). *Journal of Evolutionary Biology*, 26(5), 1003-1018.
- 127 Semmens, B. X., Buhle, E. R., Salomon, A. K., & Pattengill-Semmens, C. V. (2004). A hotspot of
128 non-native marine fishes: evidence for the aquarium trade as an invasion pathway. *Marine Ecology*
129 *Progress Series*, 266, 239-244.
- 130 Torchio, M. (1963). Accertata presenza di un rappresentante della famiglia Diodontidae in
131 Mediterraneo. [The established presence of a representative of the family Diodontidae in the
132 Mediterranean.] *Atti della Società Italiana della Scienze Naturali*, 102(3): 277–281. [In Italian.]
- 133 Zwickl, D. J. (2006). *Genetic algorithm approaches for the phylogenetic analysis of large biological*
134 *sequence datasets under the maximum likelihood criterion*.

136 **Table 1.** Pufferfish species (Diodontidae and Tetraodontidae) reported in the Mediterranean to date.

Family	Scientific name	Origin	Establishment success
Diodontidae	<i>Diodon hystrix</i> Linnaeus, 1758	Alien or Range expanding	Casual
Diodontidae	<i>Cylichthys spilostylus</i> (Leis & Randall, 1982)	Alien	Casual
Diodontidae	<i>Chilomycterus spinosus mauretanicus</i> (Le Danois 1954)	Range expanding	Single record
Tetraodontidae	<i>Lagocephalus guentheri</i> Miranda Ribeiro, 1915	Alien	Established
Tetraodontidae	<i>Lagocephalus sceleratus</i> (Gmelin, 1789)	Alien	Established
Tetraodontidae	<i>Lagocephalus suezensis</i> Clark & Gohar, 1953	Alien	Established
Tetraodontidae	<i>Torquigener flavimaculosus</i> Hardy & Randall, 1983	Alien	Established
Tetraodontidae	<i>Tylerius spinosissimus</i> (Regan, 1908)	Alien	Established
Tetraodontidae	<i>Lagocephalus lagocephalus</i> (Linnaeus, 1758)	Native	Established
Tetraodontidae	<i>Ephippion guttifer</i> (Bennett, 1831)	Range expanding	Casual
Tetraodontidae	<i>Sphoeroides marmoratus</i> (Lowe, 1838)	Range expanding	Casual
Tetraodontidae	<i>Sphoeroides pachygaster</i> (Müller & Troschel, 1848)	Range expanding	Established
Tetraodontidae	<i>Sphoeroides spengleri</i> (Bloch, 1785)	Range expanding	Single record

138 **Table 1.** Morphometric measurements collected from the caught *Diodon hystrix* specimen

Morphometric measurements	Absolute value (mm)	% TL
Standard Length	60.77	-
Head Length	8.61	0.14
Head Width	16.87	1.96
Head Depth	8.98	0.53
Eye diameter	1.27	0.14
Body depth	12.56	9.89
Postorbital length	8.18	0.65
Pectoral fin height	5.02	0.61
Pre-pectoral length	6.35	1.26
Pectoral fin base length	3.5	0.55
Dorsal fin base length	4.91	1.40
Dorsal fin height	8.23	1.68
Pre-anal length	24.96	3.03
Anal fin base length	2.89	0.12

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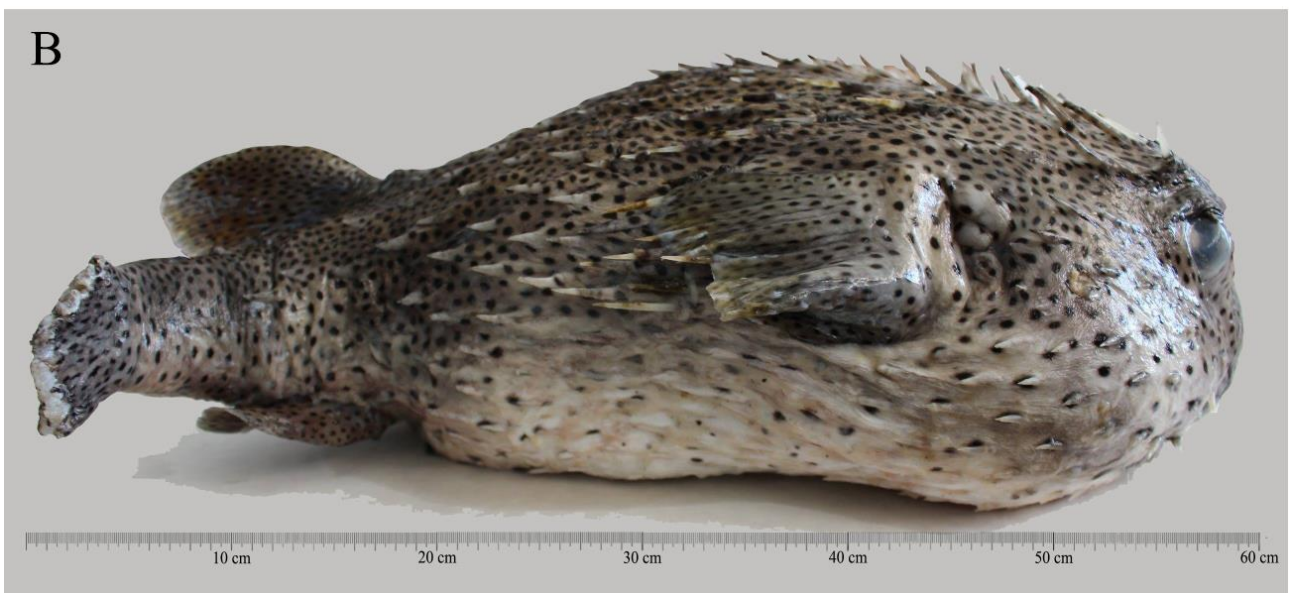
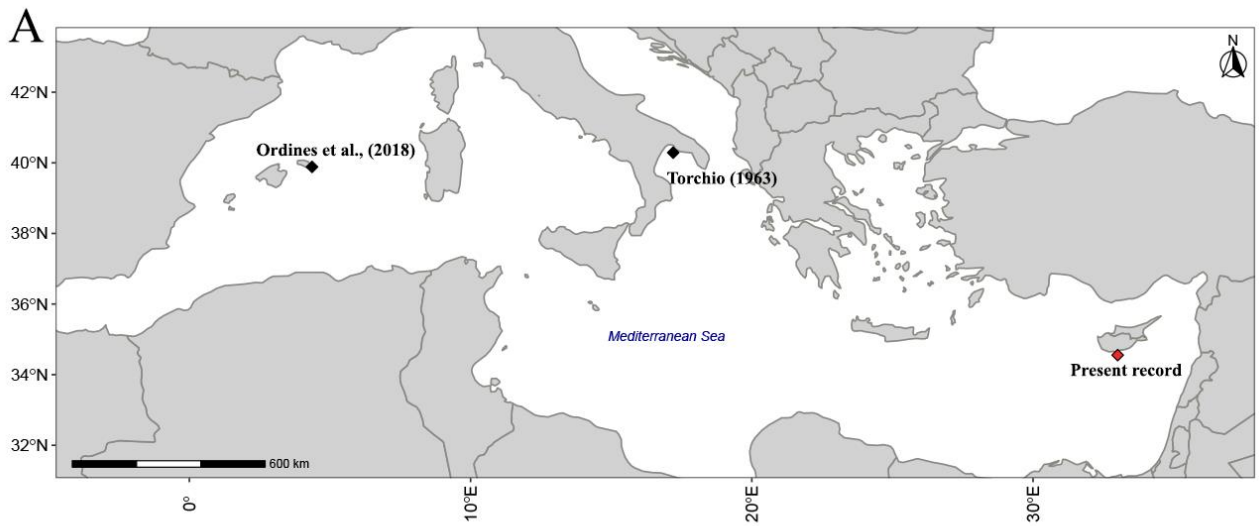
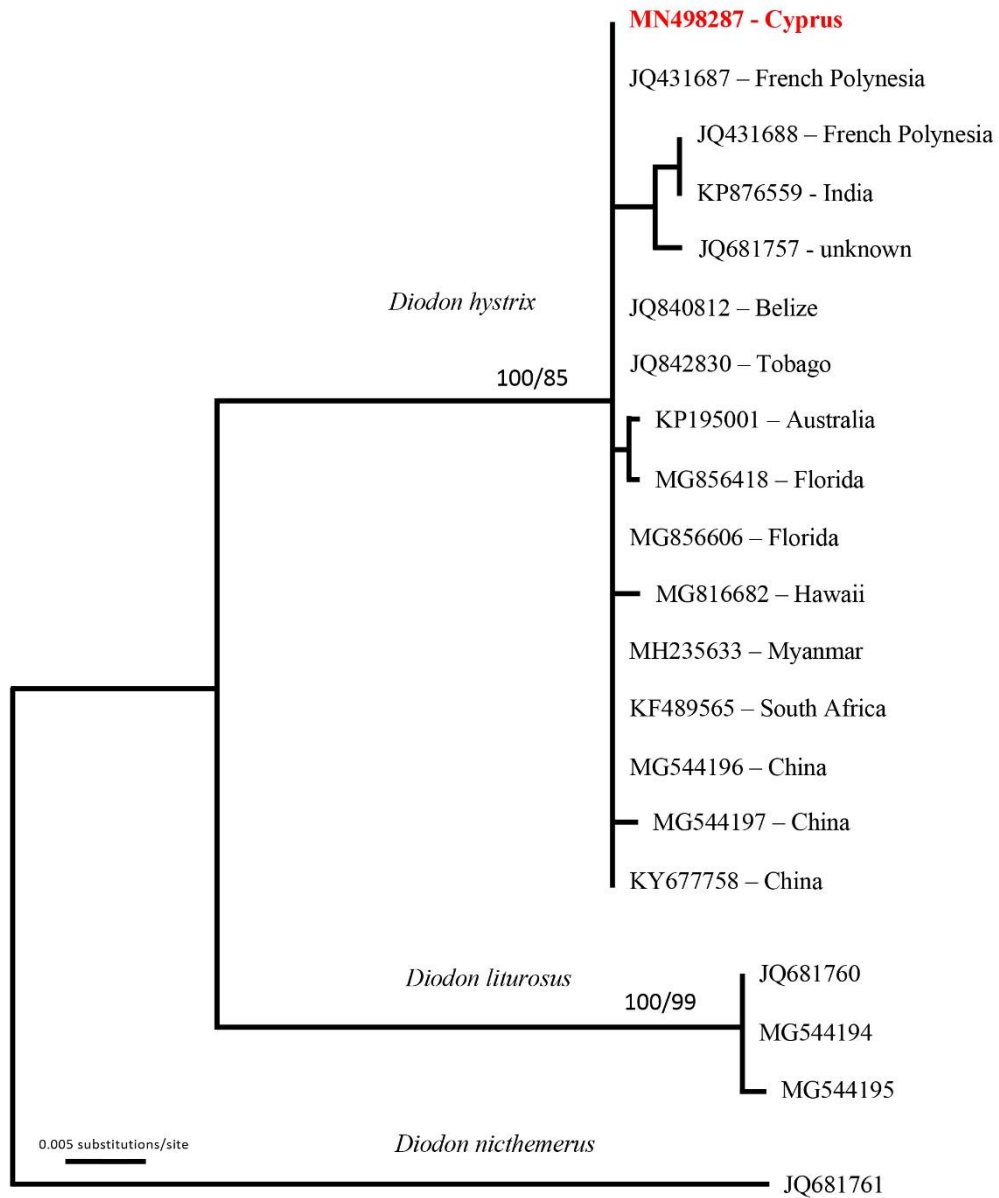


Figure 1. (A) Map with the confirmed records of *Diodon hystrix* in the Mediterranean, (B) Caught specimen reported in this study.

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 144 **Figure 2.** Phylogenetic reconstruction of *Variola* groupers based on the cytochrome oxidase marker.
 145 Tree topology is based on the Neighbour-Joining, NJ, method (identical to Maximum Likelihood,
 146 ML, topology), numbers on nodes are bootstrap values derived from 1000 replicates (only numbers
 147 above 50% are shown). First number is for NJ, second number for ML. Mediterranean sample is from
 148 Cyprus and is in red. All other sequences are from GenBank and are in black. Their sample origin is
 149 indicated after their accession number.