Join our sampling campaign on pine forest fungi!

Project FunDive

In FunDive we work towards putting fungal diversity on the map to enhance European conservation efforts. Fungi are essential for our ecosystems but have often been neglected in monitoring efforts and conservation practices, leaving them vulnerable to threats and habitat loss. We would like to engage you to change this.

For more information, please visit https://fun-dive.eu/

FunDive is a pan-European initiative funded by Biodiversa+ that brings together 33 partners in 22 countries to improve fungal monitoring across the continent. The goal of FunDive is to close the knowledge gap dealing with fungal distributions to improve fungal conservation using the help from you and other citizen scientists.

Why is fungal monitoring important?

Fungi are generally under-studied. Their global distribution patterns are poorly resolved. Also in Europe, despite centuries of fungal research, there is a lack of the distribution patterns of many fungal species. However, this knowledge is very important for effective conservation practices. For example, assessments of species for the IUCN Red List require an understanding of the distribution of said species.

What can you do?

FunDive is structured in different projects, each focusing on a specific target group of fungi. You can engage in each project by documenting and collecting fungal specimens. The process is simple:

- find a representative of a target species from project list: https://fun-dive.eu/get-involved/current-projects/
- make a photo and record your specimen in PlutofGO app https://plutof.ut.ee/go following our instructions https://fun-dive.eu/get-involved/how-to-engage/
- send it to your national point of contact https://fun-dive.eu/get-involved/fundive-national-points-of-contact/
- your specimen will be processed and identified based on molecular information
- you can follow your fungus on FunDive records: https://fun-dive.eu/dataportal/.

For more information on how to document your records, please visit https://fun-dive.eu/get-involved/how-to-engage/

Pine forest ectomycorrhizal fungi

is one of the targets for the 2024 FunDive projects which aim to investigate fungal biodiversity and distribution patterns in Europe

Pine forests are rich habitat for a wide variety of ectomycorrhizal fungi, of which many are host specific or selective for Pines (*Pinus spp.*). Some even have specific associations with certain groups of pines, e.g. *Suillus placidus*, that only associate with *Pinus cembra* and closely related species. Here we focus on three important groups of ectomycorrhizal fungi differing in species diversity and knowledge-level, but all including species of relevance to conservation of pine forest ecosystems in Europa, i.e.

- Webcaps (*Cortinarius* s.lato)
- Stiptate thelephoroid hydnoid and poroid fungi
- Knights (*Tricholoma*)

In FunDive our main sampling focus is fungi associating with scotch pine (*Pinus sylvestris* and black pines (*Pinus nigra* complex), but we are also interested in samples associated with other pine species. Based on current knowledge, fungal species of conservation concern are mainly associated with older pine forest on strongly calcareous or extremely poor, sandy soils, and hence such communities are an important target for sampling within the project. For species groups emphasised as targets for collecting among the stipitate thelephoroid hydnoid and poroid fungi and in *Tricholoma* even collected found with other hosts are wanted, to help solve taxonomic issues.

Fig. 1. Representatives of our three target groups (from left): *Cortinarius fusisporus*, *Phellodon connatus* and *Tricholoma sudum* (photos Thomas Kehlet & Jens H. Petersen).

By reporting your findings, you will add to the knowledge of these species groups and your records will be important contributions to nature conservation.

Webcaps (*Cortinarius* end closely related genera)

Diversity and morphological characters

Webcaps comprise the largest and most diverse group of agarics worldwide, and also in Europe, where the estimated diversity exceeds 1000 species. Of these, several hundred species are associated with Pines. Despite the high diversity European species of *Cortinarius* s.lato are comparatively well resolved taxonomically, with a rich reference dataset of ITS sequences obtained from type material available in public databases (e.g. Liimatainen m.fl. 2014 & 2020).

Webcaps are characterised by a rusty brown spore print, ornamented spores and an ectomycorrhizal lifestyle, but otherwise vary widely in shape, colours, dimensions and cap and stem surface structure. Most species have a distinct cobwebby partial veil when young (hence the name web-caps), and many also possess an universal veil leaving more or less distinct fibrils, floccules, belts or patches on the cap margin and lower stipe in expanding sporocarps (on the margin of the bulb in species in which the cap expands before the stipe elongates and along the stipe in species in which the stipe elongates before the cap expands).

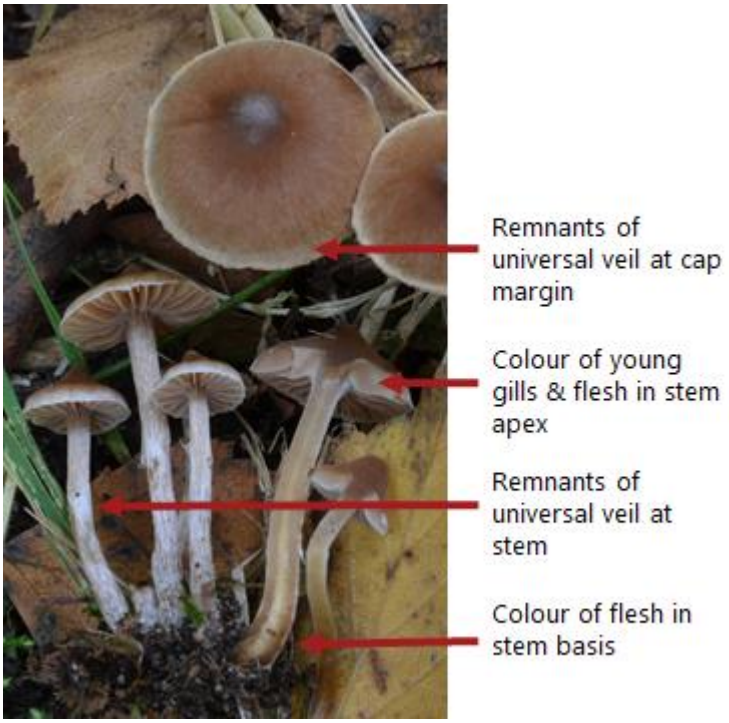

Fig. 2. Important, but often overlooked field characters in web-caps (*Cortinarius minusculus*, photo Jacob Heilmann-Clausen).

Taxonomy

Traditionally, webcaps were all assigned to one genus *Cortinarius*, but a recent study has suggested to split the genus in ten genera, which to some extent can be distinguished also based on morphological characters (Liimatainen m.fl. 2022). The split is still somewhat controversial, but is followed here. Based on the most recent phylogenetic analysis all genera

are monophyletic, but not all of them receive full support (Gallone m.fl. 2024). Eight of the ten genera occur in Europe: Four of them are species-rich, *Cortinarius, Phlegmacium, Calonarius,* and *Thaxterogaster,* whereas the remaining four *Aureonarius, Cystinarius, Hygronarius,* and *Mystinarius* only include one to few species in Europe. Of the species-rich genera the genus *Cortinarius* includes almost all telamonioid and most cortinarioid and myxaciod species and some phlegmacioid species (*C. subtortus* and Infracti). The genus *Phlegmacium* includes most of the species traditionally included in the *Cortinarius* subgenus *Phlegmacium*, the genus *Calonarius* includes the species earlier recognized as *Calochroi* s. lato, and *Thaxterogaster* the phlegmacioid *Multiformes*, *Scauri*, *Riederi*, *Turmales*, and *Variegati* and myxacioid *Vibratiles* as well as *T. pinophilus, T. leucophanes* and *T. lustratus*..

Purpose of mission and how to contribute

The main purpose of the sub-project is to get an improved understanding of the ecological requirements and distribution patterns of the often poorly known species across all genera, including host association, soil-preference and sensibility to forest management. In addition we are interested in mapping the diversity of yet undescribed species. For this reason, we are interested in collections of all groups of webcaps. However, collections of high quality, and with good documentation will be preferred for sequencing, i.e.

- Collections including young as well as ripe sporocarps.
- With good documentation by photos showing
    - young and ripe sporocarps in moist condition
    - the colour of young gills
    - the colour and distribution of the universal veil (if present)
    - the colour of flesh of cut specimens.
- Notes on the smell of fresh specimens
- Notes or photos of soil- and forest type

Additional info that is most welcome include:

- Spore photos and measurements, including assessment of dextrinoid reactions in Melzer's reagent (none or somewhat dextrinoid/moderately dextrinoid/strongly dextrinoid)
- Details on other microscopical characters, including pigmentation or colour reactions of hyphae of lamellae or pileipellis in 3-10% KOH and encrustation of lamellar trama or pileipellis hyphae (often best observed in Melzer's reagent). Only a few groups of *Cortinarius* s. lato have distinct cystidia (*Cortinarius violaceus* and allies, *C. subtortus*, *C*. sect. *camphorati*, *C.* subgenus *Iodolentes*, *C.* sect. *bicolores* and *Cystinarius crassus/rubicundulus*)
- Colours under UV-light

Stipitate, thelephoroid hydnoid and poroid fungi (*Boletopsis, Hydnellum, Phellodon* and *Sarcodon*)

This group of fungi encompass members of the hydnoid genera *Hydnellum, Phellodon* and *Sarcodon,* and the poroid genus *Boletopsis*. All are characterised by ornamented brownish spores and belong to the same family, the *Bankeraceae* within the *Thelephorales*. In total the mentioned genera encompass around 50-60 species in Europe, of which at least half associate with pines. Despite the rather low diversity, several species groups are poorly resolved taxonomically, and a number of undescribed species are known to exist. Members of the species group are considered indicators of high habitat quality in pine forest, related to their preference for older pine forests with high continuity and growing on nutrient poor or calcareous soils.Several species are considered threatened globally according to the IUCN red-list (https://www.iucnredlist.org).

Stipitate thelephoroids all have an ectomycorhizal lifestyle, and produce annual, but slow-growing and long-lasting sporocarps. Most species are short-stemmed and some have caps that may fuse into larger multi-stemmed conglomerates as they grow. Identification by morphological characters usually require fresh and young sporocarps where important characters, including colours of stem base and cap margin and cap surface structure are still not weathered.

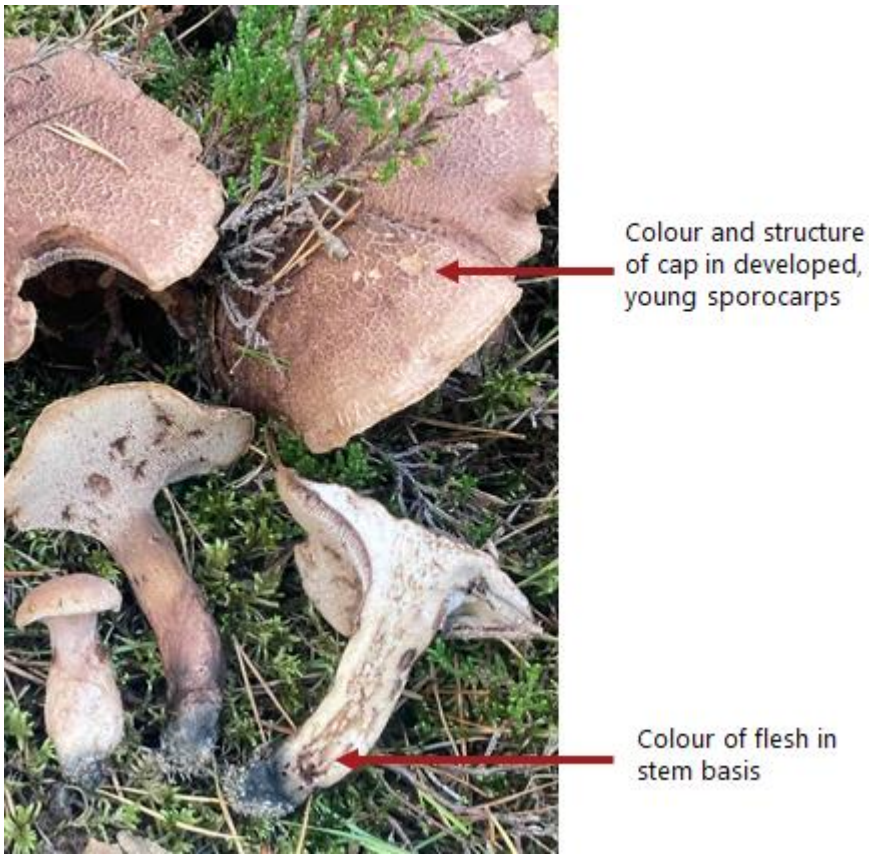

Fig. 3. Important field characters in stipitate thelephoroids (*Hydnellum scabrosum*, photo Michael Sonniks).

Taxonomy

The stipitate thelephoroids have been separated in several genera for decades, but recent phylogenetic studies have shown the traditional segregation of genera to be partly wrong. Thus several species earlier assigned to *Sarcodon* in fact belong in *Hydnellum* (Larson et al. 2019), while *Bankera* belong in *Phellodon* (e.g. Song et al. 2022). Molecular studies have indicated the presence of several species complexes, still remaining to be resolved, and overall species richness appear to be higher than traditionally accepted (Parfitt et al. 2007; Ainsworth et al. 2010)

Purpose of mission and how to contribute

The main purpose of the sub-project is to get an improved understanding of the ecological requirements, conservation needs and distribution patterns of species in the group, including host association, soil-preference and sensibility to forest management. In addition we are interested in exploring and resolving the taxonomy of several species complexes. Hence, we are interested in records of all included species, and of collections within the following species groups (even with other hosts):

- *Boletopsis leucomeleana* s.lato
- *Hydnellum concrescens* s.lato (incl. *H. cumulatum, scrobiculatum*)
- *Hydnellum ferrugineum* s.lato
- *Hydnellum scabrosum* s.lato
- *Phellodon connatus* s.lato
- *Phellodon niger* s.lato

Collections of high quality, and with good documentation will be preferred for sequencing, i.e.

- Collections including young as well as ripe sporocarps.
- With good documentation by photos showing
    - the structure, zonation patterns and colours of the cap
    - The colour, shape and dimensions of the stem
    - the colour of the flesh in cut specimens, including the stem base
- Notes on the smell and taste of fresh specimens
- Notes or photos of soil- and forest type

Knights (*Tricholoma*)

Diversity and morphological characters

The genus Tricholoma includes around 70-90 species in Europe, of which many associate with pine forests. Members of the genus are characterised by a white spore print, emarginate gills, smooth hyaline spores, lack of true, well differentiated cystidia and the ectomycorrhizal lifestyle. A distinct partial veil is present in some species. Species identification is in most cases possible based on macroscopical characters alone, but see below. Most species are associated with older forests, and among the pine-associated species several species have preference for stands on nutrient poor sandy or calcareous soil. Several species are considered good indicators of high natural value in such environments, and two species, viz *Tricholoma apium* and *T. matsutake* are considered globally vulnerable according to IUCN (https://www.iucnredlist.org/).

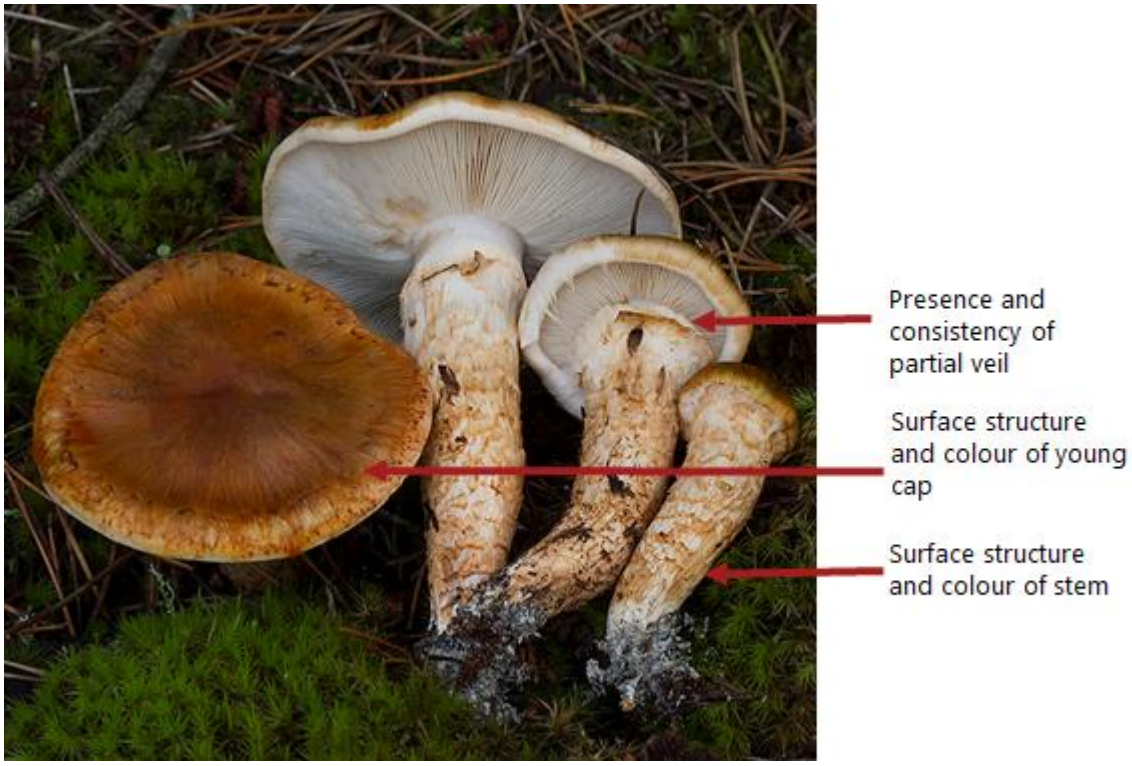

Fig. 4. Important field characters in Tricholoma (*Tricholoma focale*, photo Thomas Kehlet).

Taxonomy

The taxonomy of the genus is relatively well resolved and for many species the European distribution and ecology is well understood - at least in Northern Europe (Christensen & Heilmann-Clausen 2013). However, taxonomic traditions in southern and northern Europe have been quite different, and several species complexes are known in the genus (Heilmann-Clausen et al. 2017). Thus, additional studies incorporating collections from all over Europe are crucial to get the taxonomy of the genus resolved.

Purpose of mission and how to contribute

The main purpose of the mission is to get an improved understanding of the ecological requirements and distribution patterns of species in the group, expanding to all parts of Europe. In addition some species complexes are still poorly understood and are a main target for DNA sequencing within this subproject. Target taxa for sampling include:

- *Tricholoma caligatum and T. illkai*
- *Tricholoma focale (*incl. *T. robustum)*
- *Tricholoma batschii (*incl. *T. striatum & T. fracticum ss.auct)*
- *Tricholoma albobrunneum*
- *Tricholoma stans + T. cedretorum and T. tridentinum*
- *Tricholoma pessundatum*
- *Tricholoma vaccinum + T. inodermeum*
- *Tricholoma roseoacerbum*
- *Tricholoma arvernense*
- *Tricholoma joachimii*
- *Tricholoma equestre,* inkl. *T. ulvinenii*
- *Tricholoma atrosquamosum*
- *Tricholoma bonii and T. triste (+ more)*
- *Tricholoma sudum*
- *Tricholoma saponaceum s.lato*

High quality collections with good documentation will be preferred for sequencing, i.e.

- Collections including young as well as ripe sporocarps.
- With good documentation by photos showing
    - The structure and colours of the cap
    - The colours, surface and shape of the stem
    - The colour of the young gills
- Notes on the smell and taste of fresh specimens, both before and after cutting
- Notes of colour reactions in the gills, stem and cap surface and stem base
- Notes or photos of soil- and forest type

Additional information, identification keys and more:

Web-caps (*Cortinarius* s.lato):

Recent taxonomic advances have made old keys obsolete, while new keys still need a lot of testing and development to be truly trustworthy. Hence identification to species level is often difficult, with final ID requiring molecular data.

- Gallone, B., Kuyper, T.W. & Nuytinck, J. 2024. The genus Cortinarius should not (yet) be split. – bioRxiv, 2024-05.
- Kibby, G. & Tortelli, M. 2022. *The Genus Cortinarius in Britain*
- Liimatainen, K., Niskanen, T., Dima, B., Kytövuori, I., Ammirati, J.F. & Frøslev, T.G. 2014. The largest type study of Agaricales species to date: bringing identification and nomenclature of Phlegmacium (Cortinarius) into the DNA era. – Persoonia 33(1): 98-140.
- Liimatainen, K., Niskanen, T., Dima, B., Ammirati, J.F., Kirk, P.M. & Kytövuori, I. 2020. Mission impossible completed: unlocking the nomenclature of the largest and most complicated subgenus of Cortinarius, Telamonia. – Fungal diversity 104: 291-331.
- Liimatainen, K., Kim, J.T., Pokorny, L., Kirk, P.M., Dentinger, B. & Niskanen, T. 2022. Taming the beast: a revised classification of Cortinariaceae based on genomic data. – Fungal Diversity 112: 89-170.
- Petersen, J.H., Frøslev, T.G. & Heilmann-Clausen, J. 2024. Slørhatte i Danmarks basidiesvampe (In Danish): https://drive.google.com/file/d/1duF5nhS3vHrE7UFQzgwTPK1uFKyT0nZy/view

Stipitate thelephoroids (*Boletopsis, Hydnellum, Phellodon* and *Sarcodon*):

Overall species identification in stipitate thelephoroids is rather easy based on morphological and ecological characters, if good material is available. However some species complexes remain to be resolved, and in these species separation is still unclear.

- Ainsworth, A. M., Parfitt, D., Rogers, H. J., & Boddy, L. (2010). Cryptic taxa within European species of Hydnellum and Phellodon revealed by combined molecular and morphological analysis. *Fungal Ecology*, *3*, 65-80.
- Holec, J., & Kučera, T. (2018). Hydnoid fungi of the family Bankeraceae–their assemblages and vegetation ecology in Central Europe, Czech Republic. *Fungal ecology*, *32*, 40-48.
- Larsson, K. H., Svantesson, S., Miscevic, D., Kõljalg, U., & Larsson, E. (2019). Reassessment of the generic limits for Hydnellum and Sarcodon (Thelephorales, Basidiomycota). *MycoKeys*, *54*, 31.
- Loizides, M., Ševčíková, H., Rossi, C., & Moreau, P. A. (2020). Taxonomic challenges posed by the genera Hydnellum and Phellodon highlighted by two interesting collections on the Atlantic coast of Spain. Myco-Liébana: 81–96.
- Nitare, J., Ainsworth, A. M., Larsson, E., Parfitt, D., Suz, L. M., Svantesson, S., & Larsson, K. H. (2021). Four new species of Hydnellum (Thelephorales, Basidiomycota) with a note on Sarcodon illudens. *Fungal Systematics and Evolution*, *7*(1), 233-254.
- Parfitt, D., Ainsworth, A. M., Simpson, D., Rogers, H. J., & Boddy, L. (2007). Molecular and morphological discrimination of stipitate hydnoids in the genera Hydnellum and Phellodon. *Mycological research*, *111*, 761-777.

- Petersen, J.H. & Læssøe, T. 2024. Key to thelephoralean, stipitate hydnoid fungi (http://www.mycokey.com/keys/FunDiveStipitateThelephoraceae.pdf)
- Song, C. G., Chen, Y. Y., Liu, S., Xu, T. M., He, X. L., Wang, D., & Cui, B. K. (2022). A phylogenetic and taxonomic study on Phellodon (Bankeraceae, Thelephorales) from China. *Journal of Fungi*, *8*, 429.

Tricholoma:

Overall species identification in *Tricholoma* is rather easy based on morphological and ecological characters, if good material is available. However some species complexes remain to be resolved, and in these species separation is still unclear.

Christensen, M., & Heilmann-Clausen, J. (2013). The genus Tricholoma. Fungi of Northern Europe vol 4, Svampetryk (http://www.mycokey.com/Downloads/TheGenusTricholoma.pdf)

Heilmann-Clausen, J., Christensen, M., Frøslev, T. G., & Kjøller, R. (2017). Taxonomy of Tricholoma in northern Europe based on ITS sequence data and morphological characters. *Persoonia 38*, 38-57.

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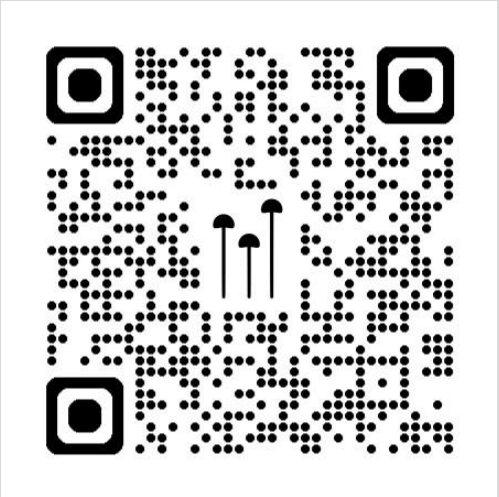
For more information on FunDive, please visit
https://fun-dive.eu/get-involved/



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Phellodon connatus **(photo Jens H. Petersen).**