



**HAL**  
open science

# Historical trends in the species inventory of tintinnids (ciliates of the microzooplankton) in the Bay of Villefranche (NW Mediterranean Sea): Shifting Baselines

John R. Dolan

► **To cite this version:**

John R. Dolan. Historical trends in the species inventory of tintinnids (ciliates of the microzooplankton) in the Bay of Villefranche (NW Mediterranean Sea): Shifting Baselines. *European Journal of Protistology*, 2017, 57, pp.16-25. 10.1016/j.ejop.2016.10.004 . hal-01387404

**HAL Id: hal-01387404**

**<https://hal.sorbonne-universite.fr/hal-01387404v1>**

Submitted on 25 Oct 2016

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# **Historical trends in the species inventory of tintinnids (ciliates of the microzooplankton) in the Bay of Villefranche (NW Mediterranean Sea): Shifting Baselines**

John R. Dolan

Sorbonne Universités, UPMC Univ Paris 06, CNRS UMR 7093, Laboratoire d'Océanographie de Villefranche-sur-Mer, Station Zoologique, Villefranche-sur-Mer 06230, France

## **Abstract**

In the Bay of Villefranche, tintinnid ciliates have been studied since 1879 yielding a unique time series. The species inventory, excluding likely synonymous records, numbers 108. Temporal increases in the inventory appear linearly related to sampling effort up until the 2000's with a cumulative sampling effort of about 200 dates. Subsequently, with a large increase in sampling to currently over 460 dates, the rate of increases in species numbers declines. Surprisingly, the inventory is not highly inflated by unique occurrences, as species found but once are only 17 out of the 108. However, in recent years many previously recorded taxa have not been seen. Missing from a species list derived solely from intensive sampling from 2013 to 2016 are 38 previously recorded species. Most (26 out of 38) were recorded from a single year and thus may have been temporary residents. However, 12 species were found in multiple years by different investigators suggesting relatively common occurrence in the past. The substantial effort required to adequately sample a locality and possible historical changes in species inventories suggest that claims of a species as 'new' to a locality should be made with caution & caveats.

**Keywords:** Biodiversity Checklist; Plankton; Species Discovery; Species Diversity; Species Richness

## Introduction

Currently there is considerable interest in changes in species distribution related to climate change and the phenomenon of invasive species. Recent reviews include reports of 'new' marine protists in British waters (e.g. Minchin et al. 2013) and in the Adriatic Sea (Pecarevic et al. 2013; Langer and Mouanga 2016). With regard specifically to tintinnid ciliates, several species from the Mediterranean Sea have been catalogued as newly invasive species in the Black Sea (Shiganova et al. 2012; Nunes et al. 2014), and conversely, as potential new introductions into the Adriatic from Black Sea ballast water (David et al. 2007). Apparent changes in distribution in the North Atlantic over the past 50 years have been reported for some species of tintinnids (Hinder et al. 2012).

Obviously identification of a species as new to a given area requires near complete knowledge of the species inventory of the system or locality under consideration. However, species checklists, at least with regard to planktonic protists, are generally based either on a single time series of samplings, generally 1-3 years maximum, conducted with a single sampling protocol and acknowledged as provisional (e.g., Hoppenrath 2004) or alternatively are based on a wide-ranging literature review encompassing reports both historical and current, and are assumed to be comprehensive (e.g. Gomez and Boicenco 2004). In neither case is the possibility of historical changes addressed. To assess the possibility of a species being 'new' to a locality or indeed of any changes in species distributions a baseline for comparison is needed. To our knowledge, only reports of temporal changes in species inventories with regard to planktonic protists are that of Gavrilova and Dolan (2007) on Black Sea tintinnids based on reports from scattered locations and Modigh and Castalado (2002) for the Bay of Naples that compared recent sampling to that of Issel (1934). There appears to be a single study concerning historical trends from a single locale and it concerned macroinvertebrates from a large coastal embayment (Trott 2016). Here I report on historical changes in species inventory of tintinnid ciliates in a single location, the Bay of Villefranche, arguably the best-studied location with regard to tintinnid ciliates.

Studies of tintinnid ciliates in Villefranche began with the work of classic work of Fol (1881; 1883) who described new species based on sampling in 1879 and

1880. Fol's work, and the subsequent and current work summarized in Table 1, provides data allowing construction of a time-series of species lists and cumulative sampling effort (estimated as the number of samplings) of over 460 samplings over 137 years. Here I document the historical growth in the tintinnid species inventory, relate it to sampling effort, and examine apparent changes in community composition found in recent years compared to the historical record. The results suggest firstly that compiling a reasonable species inventory, i.e., species numbers approach a plateau with increased sampling effort, requires a very considerable sampling effort, and secondly that changes in species inventories with time apparently occur.

## **Methods**

### *Data Characteristics*

Literature reports (see Table 1) were the primary source of data. However, some unpublished data, i.e., continuations of 2 published temporal series (i.e., Dolan et al. 2006; Dolan 2016), were included as well. Over the course of 137 years, sampling methods and sample analysis varied considerably and indeed in some instances protocols were not specified. Here the study methods are briefly described.

For the earliest reports (Fol 1881, 1883) samples were collected from unspecified locations in the bay using a custom made silk net, preserved with an iron perchloride solution, and examined using an immersion lens. According to the texts (Fol 1881, 1883) observations were made over 2 consecutive winters, 1879-1880 (Fol 1881) and 1880-1881 (Fol 1883). An arbitrary value of 10 dates sampled for each of 1879 and 1880 were assigned. The report of Balech (1959) concerns 28 net samples obtained from 1928 to 1953, without details on the type of net used, only notations as to month and year of the sample, and occasionally depth strata. Balech gave no details as how samples were preserved nor analyzed. Posta (1963) analyzed samples obtained using a Phytoplankton Net (50  $\mu\text{m}$  mesh) at Point B, the now standard Villefranche sampling location; the net tow is described only as 'horizontal'. Net material was fixed with formol, concentrated by sedimentation, an aliquot poured into a Petri dish and transects examined until at least 100 cells were counted. No details on microscopy, sample volumes nor number of transects examined were reported. Data reported by Rassouzadegan for the year 1973

(Rassoulzadegan 1975) was based on weekly net samples, using the same net (50  $\mu\text{m}$  mesh) as Posta supplemented with whole water samples, both from Point B, fixed with Lugol's, settled in sedimentation chambers and examined using an inverted microscope. Sampling in 1998 (Cariou et al. 1999) consisted of 3 sets of whole water samples from 6 depths (0-75 m) collected on two dates from Point B. The water samples of 10 liters each were concentrated using a 20  $\mu\text{m}$  mesh concentrator and the all the concentrated material examined using an inverted microscope. Data from 2002-2003 (Dolan et al. 2006) were based on examination of all material from a 10 liter integrated whole water sample made from 6 discrete depth samples (0-75 m) from Point B. Data for the 2009 sample was from examination of material from a single 10 liter sample from 50m depth at Point B (Bachy et al. 2013). Data for 2010 was from 12 samples of 10 liters from 25 m depth at Point B (Dolan and Stoeck 2011). Data for 2013 to 2016 are from examination of phytoplankton net (50  $\mu\text{m}$ , 57 cm diam.) material taken at about weekly intervals from Point B (0-75 m depth vertical tow). The net tow material of 1 liter, assuming 100% filtration, represents 19 cubic meters sampled. Aliquots of net tow material, 1-3 ml, theoretically representing material from 19 – 58 liters, was examined using an inverted microscope. In addition, whole water samples were examined. A 50 or 100 ml whole water sample from combining aliquots from 6 discrete depth samples (0-75 m) were examined using an inverted microscope. These samples were examined at weekly to monthly intervals. In the text here, the June 2013 to September 2016 samplings represent the intensive modern effort (144 samplings).

### *Taxonomic Analysis*

Accounting for synonymy is an important problem in compiling species lists, especially with regard to tintinnids. The classic monographs of Kofoid and Campbell (1929, 1939) cited in all the studies of Villefranche tintinnids save those of Fol, list about 725 species. However, a large fraction of about 25%, were, previous to Kofoid and Campbell (1929, 1939), considered as morphological variants of other species. Kofoid and Campbell raised to full species status these morphological variants based on "minute deviations in lorica shape and size" (Agatha & Strüder-Kype 2013). Conversely, some species which apparently differ little in lorica morphology, e.g. certain species of *Tintinnopsis*, can differ considerably in DNA sequences (Zhang et

al. 2016). Different investigators may attribute different names to the same species depending upon their adherence or not to the species status attributed to many forms by Kofoid & Campbell as well their ability to recognize the 'minute deviations'. Balech (1959) was notably critical of the some of the species designations of Kofoid and Campbell. Another complicating factor is that only in recent years has the phenomenon and magnitude of polymorphism in tintinnids become apparent (Dolan 2016) and some species found in the Bay of Villefranche do appear to be polymorphic. *Favella ehrenbergii* has been revealed to be capable of producing distinct lorica associated with several species of distinct genera and families (Laval-Pueto 1981, 1983.) Bachy et al. 2013 found that several species of distinct genera and families had identical 18s RNA and ITS sequences justifying their fusion under one name, *Cyttarocyliis ampulla*. To minimize artificial or inadvertent inflation of the species inventory, the species list was examined to identify probable synonymous species, forms likely to be recorded under multiple names, most of which were originally described as morphological varieties, not distinct species. Table 2 lists the 'species' grouped under a single name. The listing is by its nature subjective and in the light of future work will likely require revision.

### *Data Analysis*

For each species, the sampling year in which the species was first found and all the years subsequently found were recorded in a spreadsheet with rows as species and columns for years (see supplementary data file). For species reported from a single year, that report was examined to determine if the occurrence was a unique event or if the species was found on more than one date within the year. A species found but once on a single date is herein termed a 'oncer', seen but once, and these species were noted as special cases. Sorting the entire listing by "sample year first found" allows plotting cumulative number of species by year of sampling. This was plotted along with cumulative number of samplings by year (see Table 1). The relationship between sampling effort and species discovery was examined by plotting cumulative number of samplings against cumulative number of species. It should be noted that the nature of the data, limited to species found by year and number of sampling within the year, precludes rarefaction analysis, which requires presence/absence data for each of the samplings. To identify species records as possibly new to the

Mediterranean Sea, for each species a literature search was conducted to determine the first sample year the species was found in the Mediterranean Sea. The species list from recent intensive sampling (2013-2016) was compared to the species list derived from all previous sampling to identify differences, especially with regard to species recorded from multiple years.

## **Results**

108 species, excluding probable synonyms have been found in the Bay of Villefranche in samples gathered over a span of 137 years (Table 3). Surprisingly, relatively few were encountered but one time, 17 out of the 108, and can so be considered as stray species. Other than the species first described by Fol (1881, 1883), the vast majority of species, 101, were found elsewhere in the Mediterranean Sea before being found in Villefranche. Thus not only have no species new to science been found since Fol's descriptions, but most were not even new records for the Mediterranean Sea. Of the few species first found in the Mediterranean Sea in Villefranche, 5 were also 'oncers', found but once, and likely members of the "accidental biosphere" out of their normal range due chance transport (e.g. Weisse 2014).

Temporal growth in the species inventory, both with and without 'oncers', along with sampling effort is shown in Figure 1a. Growth in the number of species appears to increase markedly in recent years. However, a different pattern is evident from the plot of changes in the species inventory as a function of sampling effort (Figure 1b). The log-log plot, similar to a Preston Species-Area curve relating sampling effort to species discovery (Preston 1962), shows a linear increase (log-log) up to about 100 samplings (approx 1960) followed by moderate increases in species from 100-300 samplings (early 2000's). Notably only minor increases in the species inventories resulted from recent intensive sampling from 300 to 461 samples (2013-2016).

Comparing the species list from recent (2013-2016) sampling to the previous inventory revealed some differences. Although a large number of previously recorded species have been found in recent sampling, 39 previously recorded species are absent and 9 new species have been found. Most species recorded previously but missing from recent sampling were either strays (oncers) or apparently temporary residents (found only during one year) representing 14 and 12 species, respectively.

However, 12 species were recorded from multiple years in previous sampling suggesting a relatively common occurrence in the past (Table 4). Likewise since 2013, among the species recorded as species new to the bay, 6 have been recorded from multiple years and can be considered as current resident species. In terms of gross morphology, there are no obvious characteristics distinguishing or uniting the apparently new nor absent species (Table 4). Both groups of species range widely in lorica dimensions. The majority of both groups of species are not unusual for Mediterranean waters as they are known from other coastal Mediterranean sites (Table 4).

## **Discussion**

The possibility of a systematic shift in the composition of microplankton in a given system due to environmental change is possible (e.g. Whyte et al. 2016). However, it is also evident that species inventories can only increase, as it is impossible to prove that a species, once recorded, is subsequently completely absent. Consequently, historical growth in a species inventory is to be expected. The questions addressed here focus-on how complete a listing does the cumulative historical record appear to provide compared to recent sampling and is there any evidence of large changes in the composition of the tintinnid assemblage?

As noted previously, sampling methods and frequencies varied considerably over the past 137 years. Plankton net mesh size, bottle vs net sampling, and season of sampling varied. Thus one might expect a very weak relationship between cumulative sampling effort and increases in the numbers of species encountered. Interestingly, there is a strong relationship between cumulative sampling effort, varied as it was, and increases in the species inventory (Fig. 1a). Furthermore, the increases in the species inventory of Villefranche corresponding with increases in cumulative sampling effort (Fig. 1b) suggest that substantial sampling effort (hundreds of dates) are needed to provide a near complete species list (as indicated by a plateau). However, as the historical series includes any changes in the species composition it may be useful to compare it with a similar sampling effort curve derived from only the recent intensive sampling (2013-2016). Figure 2 shows cumulative number of species encountered as a function of the cumulative number of samplings



for both the periods 1879-2010 and 2013-2016. The two curves reach a similar value at about 100 samples, corresponding to multiple year coverage for the recent sampling. Subsequent increases in both series may then be attributable to year to year variability. As nicely remarked by Haeckel (1891), time-series data are needed to capture changes in composition and inter-annual variability can be considerable:

*"To obtain a complete and more certain survey of the temporary variations of plankton composition requires an unbroken series of observations, carried on at one and the same place at least for the space of a full year—still better for several successive years—to obtain from the yearly and monthly oscillations a general average. .... As there are good and bad wine and fruit years, so there are rich and barren plankton years".*

Comparing the species list from recent sampling (2012-2016) to the historical list (1879-2010) some differences are evident. Of the species previously found, but not noted in recent years, none were described as abundant and likewise among species first noted in recent years, none were abundant. There are no obvious morphological characteristics distinguishing either group of recently absent or recently new. Most of the species of both groups are distributed widely in the Mediterranean (Table 4). The differences in the species lists of recent versus previous years may represent a change in the species composition of the tintinnid assemblage. However, the more likely explanation is that the differences are due to chance detections of species intermittently present in low concentrations.

Previous studies of seasonal changes in the assemblage of tintinnid species in Villefranche have yielded distinct descriptions. Rassoulzadegan (1975) noted that in his 1973-1974 series common was *Steenstrupiella steenstrupii* and rare was *Proplectella claparedei*, in contrast with the data of Posta who found found *P. claparedei* abundant and found no *S. steenstrupii* (1972) from her sampling in 1960-1962. He attributed the difference to sampling methods. However, a comparison of the presence of the most common species in 2014 and 2015, sampled using the same methods, shows that a species found often one year may be relatively rare another year, i.e., the conspicuous species *Stenosomella ventricosa* and *Tintinnopsis campanula* (Table 5). While we have no data on historical concentrations, the recent temporal variabilities in the presence of *Stenosomella ventricosa* or *Tintinnopsis*

*campanula* (2014 vs. 2015) are in regard to detection limits in range of 1 cell in 20 l. Thus species inventories may differ due not only to sampling methods but also large inter-annual variability in relatively abundant and common species, as pointed out long ago by Haeckel (1891). It should be noted that data on possible historical changes in the physical and chemical characteristics is lacking. However data from the late 1960's to the present suggests that periodic oscillations of sea surface temperature exists on a 10-15 year scale and may influence zooplankton abundances (Howes et al. 2015).

### **Conclusions**

Data presented here show historical growth in the species inventory of tintinnid ciliate species in the Bay of Villefranche. Temporal increases in species inventories are to be expected in any open or semi-open system, as with time inter-annual variability will be captured and occasional species are more likely to be found. Remarkable for Villefranche is the magnitude of diversity recorded, over 100 species after accounting for likely synonymous records. The comparison of recent and historical sampling in Villefranche suggests a very large sampling effort, weekly sampling over multiple years, is required to provide an inventory representing the majority of species currently found in the Bay. Based upon data from Villefranche, a species checklist of tintinnids is at best an approximation, an incomplete list of species possibly to be found. Consequently, claims of a tintinnid species as 'new' to a locality should be made with caution & caveats.

### **Acknowledgements**

This work was supported by the Centre National de la Recherche Scientifique and the Université Pierre et Marie Curie, Paris VI. Our thanks to the sailors of the Observatoire Océanologique de Villefranche-sur-Mer, in particular Jean-Yves Carval. Comments, questions, and observations of the 3 reviewers of a previous version of the manuscript led to significant improvements.

## References

- Abboud-Abi Saab, M., 2002. Annual cycle of the microzooplankton communities in the waters surrounding the Palm Island Nature Reserve (north Lebanon) with special attention to tintinnids. *Medit. Mar. Sci.*, 3, 55-76.
- Abboud-Abi Saab, M., 1989 Distribution and ecology of tintinnids in the plankton of Lebanese coastal waters (eastern Mediterranean). *J. Plank. Res.* 11, 203-222.
- Agatha S., Strüder-Kype, M., 2013. Systematics and evolution of tintinnid ciliates. In J.R. Dolan, D. J.S. Montagnes, S. Agatha & D.K. Stoecker (eds), *The Biology and Ecology of Tintinnid Ciliates: Models for Marine Plankton*. Wiley-Blackwell, Oxford, pp 43-85.
- Bachy, C., Gómez, F., López-García, P., Dolan, J.R., Moreira, D., 2012. Molecular phylogeny of tintinnid ciliates (Tintinnida, Ciliophora). *Protist* 163, 873-887.
- Bachy, C., Dolan, J.R., López-García, P., Deschamps, P., Moreira, D., 2013. Accuracy of protist diversity assessments: morphology compared to cloning and direct pyrosequencing of 18S rRNA genes and ITS regions using the conspicuous tintinnid ciliates as a case study. *ISME J.* 7, 244-255.
- Balech, E., 1959. Tintinnoinea del Mediterraneo. *Trab. Inst. Español Oceanogr.* 28, 1-88.
- Balkis, N., & Koray, T. 2014. A Check-List of Tintinnids (Protozoa: Ciliophora) in the Coastal Zone of Turkey. *Pakistan J. Zool.* 46, 1029-1038.
- Brandt, K., 1906. Die Tintinnodeen der Plankton-Expedition. Tafelerklärungen nebst kurzer Diagnose der neuen Arten. In: *Ergebnisse der Plankton-Expedition der Humboldt-Stiftung 3 La* (ed. V. Hensen), Lipsius and Tischer, Kiel, pp. 1-33.
- Cariou J.-B., Dolan J. R., Dallot S., 1999. A preliminary study of tintinnid diversity in the N. W. Mediterranean. *J. Plank. Res.* 21, 1065-1075.
- Claparède, É., Lachmann J., 1858. Études sur les infusoires et les rhizopodes. *Mémoires de l'Institut National Genevois*, 5 (year 1857), 1-260.
- Cleve, P.T., 1900. Some Atlantic Tintinnodea. *Ofversigt Kongl. Vetenskaps-Akademiens Förhandlingar*, 56, 969-975.
- Daday, E. von, 1887. Monographie der Familie der Tintinnodeen. *Mitt. Zool. Stn. Neapel* 7, 473-591.
- David, M., Gollasch, S., Cabrini, M., Perkovič, M., Bošnjak, D., Virgilio, D., 2007. Results from the first ballast water sampling study in the Mediterranean Sea – the Port of Koper study. *Mar. Poll. Bull.*, 54, 53-65.

Dolan, J.R., 2016. Planktonic protists: little bugs pose big problems for biodiversity assessments. *J. Plank. Res.*, 38,1044-1051.

Dolan, J. R., Marrase, C., 1995. Planktonic ciliate distribution relative to a deep chlorophyll maximum: Catalan Sea, N. W. Mediterranean, June 1993. *Deep-Sea Research I*, 42, 1965-1987.

Dolan, J.R, Stoeck, T., 2011. Repeated sampling reveals differential variability in measures of species richness and community composition in planktonic protists. *Environ. Microbiol. Rep.*, 3, 661-666.

Dolan, J.R., Lemée, R., Gasparini, S., Mousseau, L., Heyndrickx, C., 2006. Probing diversity in the plankton: using patterns in tintinnids (planktonic marine ciliates) to identify mechanisms. *Hydrobiologia*, 555, 143-157.

Dolan J. R., Claustre H. & Vidussi F., 1999. Planktonic ciliates in the Mediterranean Sea: longitudinal trends. *Deep-Sea Research Part I*, 46, 2025-2039.

Duran, M., 1951. Contribución al estudio de los tintínidos del plancton de las costas de Castellón (Mediterráneo occidental). *Publ. Instit. Biolog. Aplic.*, 5, 101-122.

Duran, M., 1953. Contribución al estudio de los tintínidos del plancton de las costas de Castellón (Mediterráneo occidental). Nota II. *Publicaciones del Instituto de Biología Aplicada (Barcelona)* 12, 79-95.

Ehrenberg, C.G., 1854. Die systematische Charakteristik der neuen mikroskopischen Organismen des tiefen atlantischen Oceans. *Ber. Akad. Wiss.*, Jahre 1854, 236-250.

Entz, G., Sr. 1884. Über Infusorien des Golfes von Neapel. *Mitt. Zool. StN. Neapel*, 5, 289-444.

Entz, G., Sr. 1885. Zur näheren Kenntnis der Tintinnoden. *Mitt. Zool. Stn. Neapel*, 6, 185-216.

Entz, G. jr. 1909. Studien über Organization und Biologie der Tintinniden. *Archiv. Protistenk.* 15: 93-226.

Fol, H., 1881 Contribution a la connaissance de la famille des Tintinnodea. *Arch. Sci. Phys. Nat.* 5, 5-24.

Fol, H., 1883. Sur la famille des Tintinnodea. *Recueil Zool. Suisse* 1, 27- 64.

Gavrilova, N., Dolan, J.R., 2007. A note on species lists and ecosystem shifts: Black Sea tintinnids, ciliates of the microzooplankton. *Acta Protozool.*, 46, 279-288.

Gómez, F., Boicenco, L., 2004. An annotated checklist of dinoflagellates in the Black Sea. *Hydrobiologia*, 517, 43-59

Hada, Y. 1932. Description of two new neritic Tintinnoinea, *Tintinnopsis japonica* and *Tps. kofoidi* with a brief note on unicellular organisms parasitic on the latter. Zool. Inst., Fac. Sci. Hokkaido Imp. Univ., Sapporo, 30, 209–212.

Haeckel, E. 1873. Ueber einige pelagische Infusorien. Jen. Zeit. Medizin Naturwis., 7,561-568,

Haeckel, E. (1891) Plankton-Studien. Jenaische Zeitschrift für Naturwissenschaft 25: 232-336. (English translation: Report of the U.S. Commissioner of Fish and Fisheries for 1889 to 1891 (1893) pp 565-641)

Hinder, S.L., Manning, J.E., Gravenor, M.B., Edwards, M., Walne, A.W., Burkill, P.H., Hays, G.C., 2012. Long-term changes in abundance and distribution of microzooplankton in the NE Atlantic and North Sea. J. Plank. Res., 34, 83-91.

Hoppenrath, M., 2004. A revised checklist of planktonic diatoms and dinoflagellates from Helgoland (North Sea, German Bight). Helgol. Mar. Res., 58, 243-251.

Howes, E.L., Stemmann, L., Assailly, C., Irisson, J.-O., Dima, M., Bijma, J. Gattuso, J.-P. 2015. Pteropod time series from the North Wester Mediterranean (1967-2003): impacts of pH and climate variability. Mar. Ecol. Prog. Ser. 53, 193-206.

Issel, R., 1934. Ciclo annuale del microplancton di superficie nel golfo di Napoli (golfo interno). Publ. Staz. Zool. Naploi 14,1-50.

Jørgensen, E., 1924. Mediterranean Tintinnids. Report on the Danish Oceanographical Expeditions 1908-10 2 J.3. (Biology),1-110.

Kofoed, C.A., Campbell, A.S., 1929. A Conspectus of the Marine and Freshwater Ciliata Belonging to the suborder Tintinnoinea, with Descriptions of New Species Principally from the Agassiz Expedition to the Eastern Tropical Pacific 1904-1905. Univ. Calif. Publ. Zool., 34, 1-403.

Kofoed, C.A., Campbell, A.S., (1939) Reports on the scientific results of the expedition to the Eastern Tropical Pacific, in charge of Alexander Agassiz, by U.S. Fish Commission Steamer "Albatross" from October 1904 to March 1905. Lieut. Commander L.M. Garrett, U.S.N. commanding. 37. The Ciliata: The Tintinnoinea. Bull. Mus. Comp. Zool., Harvard, 84, 1-473.

Koray, T. (1987). One-celled microplankton species of Izmir Bay (Aegean Sea): a species list and a comparison with the records of adjacent regions. Turk. J. Biol, 11, 130-146.

Langer, M.R., Mouanga, G.H. 2016. Invasion of amphisteginid foraminifera in the Adriatic Sea. Biol. Invasions,185,1335-1349.

Laval-Peuto, M., 1981. Construction of the lorica in Ciliata Tintinnina. In vivo study of *Favella ehrenbergii*: variability of the phenotypes during the cycle, biology, statistics, biometry. *Protistologica*, 17, 249-272.

Laval-Peuto, M., 1983. Sexual reproduction in *Favella ehrenbergii* (Ciliophora, Tintinnina). Taxonomical implications. *Protistologica*, 19, 503-512.

Minchin, D., Cook, E.J., Clark, P.F., 2013. Alien species in British brackish and marine waters. *Aquat. Invasions*, 8, 3-19.

Modigh, M., Castalado, S., 2002. Variability and persistence in tintinid assemblages at a Mediterranean coastal site. *Aquat. Microb. Ecol.* 28, 299-311.

Monti, M., Minocci, M., Milani, L., & Umani, S. F. (2012). Seasonal and interannual dynamics of microzooplankton abundances in the Gulf of Trieste (Northern Adriatic Sea, Italy). *Estuarine, Coastal and Shelf Science*, 115, 149-157.

Moscatello, S., Rubino, F., Saracino, O. D., Fanelli, G., Belmonte, G., & Boero, F. 2004. Plankton biodiversity around the Salento Peninsula (South East Italy): an integrated water/sediment approach. *Scien. Mar.*, 68, 85-102.

Nunes, A.L., Katsanevakis, S., Zenetos, A., Cardoso, A.C., 2014. Gateways to alien invasions in the European seas. *Aquat. Invasions*, 9, 133-144.

Pecarevic, M., Mikus, J., Cetinic, A. B., Dulcic, J., Calic, M., 2013. Introduced marine species in Croatian Waters (eastern Adriatic Sea). *Medit. Mar. Sci.*, 14, 224-237.

Pérez M.T., Dolan J. R., Vidussi F., Fukai E., 2000. Diel vertical distribution of planktonic ciliates within the surface layer of the NW Mediterranean (May 1995). *Deep-Sea Res. Part I*, 47, 479-503.

Polat, S., Toklu, B., Sarihan, E. 2002. Seasonal distribution of protozooplankton in İskenderun Bay: Northeastern Mediterranean. In: Yilmaz, A. (ed), *Oceanography of the Eastern Mediterranean and Black Sea: Similarities and Differences of Two Interconnected Basins*, Tübitak, Istanbul, pp 839-844.

Posta A., 1963. Relation entre l'évolution de quelques tintinnides de la Rade de Villefranche et la température de l'eau. *Cah. Biol. Mar.* 4, 201-210.

Preston, F.W., 1962. The canonical distribution of commonness and rarity: Part I. *Ecology* 43,185–215.

Rampi, L., 1948. I tintinnoidi delle acque di San Remo. *Boll. Pesca, Piscicoltura Idrobiologia*, 3, 50-56.

Rassoulzadegan, F., 1975. Ecologie et relations trophiques du microzooplancton dans un écosystème nértique. Thèse Doctorale, Océanographie Biologique, Université Pierre et Marie Curies (Paris VI).

Schmidt, J., 1902. Some tintinnodea from the Gulf of Siam. *Viden. Meddel. Naturhist. Foreng Kjøbenhavn for Aaret 1901*, 63, 183-190.

Shiganova, T.A., Musaeva, E.I., Lukasheva, T.A., Stupnikova, A.N., Zas'ko, D.N., Anokhina, L. L., Bulgakova, Y.V., 2012. Increase in findings of Mediterranean nonnative species in the Black Sea. *Russ. J. Biol. invasions*, 3, 255-280.

Travers, A., Travers, M., 1971. Catalogue des tintinnides (Cilies Oligotriches) recoltés dans le Golfe de Marseille de 1962 a 1964. *Tethys*, 2, 639-646.

Trott, T.J. 2016. Century-scale species incidence, rareness and turnover in a high-diversity Northwest Atlantic coastal embayment. *Mar. Biodiv.* 46, 33.  
doi:10.1007/s12526-015-0313-0

Whyte, C., Davidson, K., Gilpin, L., Mitchell, E., Moschonas, G., McNeill, S., Tett, P., 2016. Tracking changes to a microplankton community in a North Atlantic sea loch using the microplankton index PI (mp). *ICES J. Mar. Sci.*, in press.

Weisse T. 2014. Ciliates and the rare biospher- community ecology and population dynamics. *J. Eukaryot. Microbiol.* 61, 419–433.

Zhang, Q., Agatha, S., Zhang, W., Dong, J., Yu, Y., Jiao, N., Gong, J. 2016. Three rDNA Loci-Based Phylogenies of Tintinnid Ciliates (Ciliophora, Spirotrichea, Choreotrichida). *J. Eukaryot. Microbiol.*, in press, doi: 10.1111/jeu.12354

Table 1. Summary data of tintinnid studies in the Bay of Villefranche.

<b>Year</b>	<b># samplings</b>	<b>Method</b>	<b>Reference (Table 2 number)</b>
1879	10	net	Fol 1881 (1)
1880	10	net	Fol 1883 (2)
1929	5	net	Balech 1959 (3)
1938	1	net	Balech 1959 (3)
1939	2	net	Balech 1959 (3)
1948	5	net	Balech 1959 (3)
1949	1	net	Balech 1959 (3)
1951	2	net	Balech 1959 (3)
1953	12	net	Balech 1959 (3)
1960	6	net	Posta 1963 (4)
1961	50	net	Posta 1963 (4)
1962	40	net	Posta 1963 (4)
1973	52	net & bottle	Rassoulzadegan 1975 (5)
1998	6	bottle	Cariou et al 1999 (6)
2002	47	bottle	Dolan et al. 2006 (7)
2003	18	bottle	This study (8)
2009	1	bottle	Bachy et al. 2013 (9)
2010	12	bottle	Dolan & Stoeck 2011 (10)
2013	29	net & bottle	Dolan 2016 (11)
2014	50	net & bottle	Dolan 2016 (11)
2015	57	net & bottle	This study (8)
2016	37	net & bottle	This study (8)



Table 2. Species grouped as likely synonyms. Reference number refers to the Villefranche reports given in Table 1. Species description reference abbreviations: K & C 1929 for Kofoid & Campbell 1929; C & L 1858 for Claparède & Lachmann 1858

Main Species	Known & Likely Synonym (s)	Reference
<i>Acanthostomella minutissima</i> (K. & C. 1929)	<i>A. obtusa</i> (K. & C. 1929)	6
<i>Amphorella laackmanni</i> (Jorgensen 1924)	<i>Salpingella laminata</i> (K. & C. 1939)	6
<i>Amphorides quadrilineata</i> (C. & L. 1858)	<i>A. minor</i> (K. & C. 1939)	6
<i>Climacocylis scalaria</i> (Brandt 1906)	<i>C. elongata</i> (K. & C. 1929)	7
<i>Codonellopsis morchella</i> (Cleve 1900)	<i>C. schabi</i> (K. & C. 1929)	3,4,5,6,
	<i>C. lata</i> (K. & C. 1929)	6
<i>Codonellopsis pusilla</i> (Cleve 1900)	<i>C. inornata</i> (K. & C. 1929)	7
<i>Cyttarocylis ampulla</i> (Fol 1881)	<i>C. brandti</i> (K. & C. 1929)	5
	<i>C. cassis</i> (Haeckel 1873)	4,5
	<i>C. eucrycephalus</i> (Kofoid 1912)	4
	<i>C. magna</i> (K. & C. 1929)	4
	<i>Petalotricha major</i> (K. & C. 1929)	4,5
<i>Dadayiella ganymedes</i> (Entz 1884)	<i>D. curta</i> (K. & C. 1929)	6
<i>Dadayiella pachytoecus</i> (Jorgensen 1924)	<i>D. cuspis</i> (K. & C. 1929)	6
<i>Dictyocysta entzi</i> (Jorgensen 1924)	<i>D. extensa</i> (K. & C. 1929)	3
<i>Dictyocysta lepida</i> (Ehrenberg 1854)	<i>D. polygonata</i> (K. & C. 1929)	8
	<i>D. speciosa</i> (K. & C. 1929)	6
	<i>D. duplex</i> (K. & C. 1929)	7
<i>Dictyocysta mitra</i> (Haeckel 1873)	<i>D. minor</i> (K. & C. 1929)	7
<i>Favella ehrenbergii</i> (C. & L. 1858)	<i>F. campanula</i> (Schmidt 1902)	3
<i>Salpingella acuminata</i> (C. & L. 1858)	<i>S. glockentogeri</i> (K. & C. 1929)	4,5
<i>Salpingella attenuata</i> (Jorgensen 1924)	<i>S. gracilis</i> (K. & C. 1929)	6
<i>Steenstrupiella steenstrupii</i> (C. & L. 1858)	<i>S. robusta</i> (K. & C. 1929)	7
	<i>S. gracilus</i> (Jorgensen 1924)	8
<i>Tintinnopsis cylindrica</i> (Daday 1887)	<i>T. kofoidi</i> (Hada 1932)	6
	<i>T. levigata</i> (K. & C. 1929)	6

Table 3. Tintinnid species found in the Bay of Villefranche. First and last year denotes sample year of first and last records, respectively. First year found in the Mediterranean Sea shown as First Medit Yr with the corresponding reference. Species in bold are 'oncercs', recorded only once. For a complete listing of all years found for each species see the supplementary data file.

Villefranche Species	First year	Last Year	1 <sup>st</sup> Medit Yr	1st Medit Yr Ref
<i>Acanthostomella conicoides</i>	1998	2015	1995	Perez et al. 2000
<i>Acanthostomella lata</i>	2002	2002	1950	Duran 1951
<i>Acanthostomella minutissima</i>	1998	2010	1997	Modigh & Castalado 2002
<b><i>Amphorellopsis acuta</i></b>	1998	1998	1998	Monti et al. 2012
<i>Amphorellopsis tetragona</i>	2013	2015	1950	Duran 1951
<b><i>Amphorides amphora</i></b>	1953	1953	1886	Daday 1887
<i>Amphorides laackmanni</i>	1998	2015	1886	Daday 1887
<i>Amphorides quadrilineata</i>	1952	2016	1886	Daday 1887
<i>Ascampbelliella armilla</i>	1998	2015	1950	Duran 1951
<i>Ascampbelliella oxyura</i>	1998	2002	1909	Jørgensen 1924
<i>Ascampbelliella tortulata</i>	1998	2016	1909	Jørgensen 1924
<i>Cantheriella pyrimidata</i>	1998	2015	1909	Jørgensen 1924
<i>Climacocylis scalaria</i>	2003	2016	1909	Jørgensen 1924
<i>Climacocylis scalaroides</i>	1998	2016	1938	Rampi 1948
<i>Codonaria cistellula</i>	1880	2016	1880	Fol 1883
<i>Codonella amphorella</i>	2014	2016	1909	Jørgensen 1924
<i>Codonella aspera</i>	1929	2003	1921	Issel 1934
<i>Codonella elongata</i>	1998	2016	1886	Daday 1887
<i>Codonella galea</i>	1880	2014	1880	Fol 1883
<i>Codonella nationalis</i>	1960	2016	1909	Jørgensen 1924
<i>Codonella perforata</i>	2003	2015	1884	Entz 1884
<i>Codonellopsis lagenula</i>	2002	2002	1886	Daday 1887
<i>Codonellopsis morchella</i>	1929	2016	1909	Jørgensen 1924
<i>Codonellopsis orthoceras</i>	1929	2016	1909	Jørgensen 1924
<i>Codonellopsis pusilla</i>	1929	2015	1909	Jørgensen 1924
Villefranche Species	First year	Last Year	1 <sup>st</sup> Medit Yr	1st Med Year Ref

<i>Dadayiella ganymedes</i>	1929	2016	1884	Entz 1884
<i>Dadayiella pachytoeus</i>	2002	2016	1909	Jørgensen 1924
<i>Daturella gaussi</i>	2002	2016	2002	This Study
<b><i>Daturella stramonium</i></b>	2014	2014	1993	Dolan & Marrasé 1995
<i>Dictyocysta elegans</i>	1960	2016	1886	Daday 1887
<i>Dictyocysta entzi</i>	1953	2009	1909	Jørgensen 1924
<i>Dictyocysta lepida</i>	1880	2016	1880	Fol 1881
<i>Dictyocysta mitra</i>	1938	2016	1909	Jørgensen 1924
<i>Epipliocylis acuminata</i>	1929	2016	1909	Jørgensen 1924
<i>Epipliocylis undella</i>	2002	2015	1909	Jørgensen 1924
<i>Eutintinnus apertus</i>	1880	2016	1880	Fol 1883
<i>Eutintinnus elongatus</i>	2002	2015	1938	Rampi 1948
<i>Eutintinnus fraknoi</i>	1929	2016	1909	Jørgensen 1924
<i>Eutintinnus lusus-undae</i>	1929	2016	1885	Entz 1885
<i>Eutintinnus macilentus</i>	1929	2010	1950	Duran 1951
<i>Eutintinnus permintus</i>	2013	2016	1938	Rampi 1948
<i>Eutintinnus pinguis</i>	2015	2015	1984	Koray 1987
<i>Eutintinnus stramentus</i>	2013	2016	1950	Duran 1951
<i>Eutintinnus tenuis</i>	1998	1998	1993	Dolan & Marasé 1995
<i>Eutintinnus tubulosus</i>	1953	2015	1950	Duran 1951
<i>Favella azorica</i>	1948	2013	1909	Jørgensen 1924
<i>Favella ehrenbergi</i>	1929	2016	1909	Jørgensen 1924
<i>Favella serrata</i>	1929	2002	1909	Jørgensen 1924
<b><i>Helicostomella subulata</i></b>	1973	1973	1886	Daday 1887
<i>Metacylis jørgensenii</i>	1953	2002	1930	Issel 1934
<i>Metacylis mediterranea</i>	2002	2013	1886	Daday 1887
<b><i>Metacylis mereschkowskii</i></b>	2002	2002	1909	Jørgensen 1924
<i>Niemarshallia aperta</i>	2002	2002	2002	This Study
<b>Villefranche Species</b>	<b>First year</b>	<b>Last Year</b>	<b>1<sup>st</sup> Medit Yr</b>	<b>1st Med Year Ref</b>

<b><i>Ormosella bresslaui</i></b>	2002	2002	2002	This Study
<i>Parundella aculeata</i>	1953	2016	1909	Jørgensen 1924
<b><i>Parundella caudata</i></b>	2002	2002	1909	Jørgensen 1924
<b><i>Parundella lohmanni</i></b>	1939	1952	1909	Jørgensen 1924
<i>Petalotricha ampulla</i>	1879	2016	1879	Fol 1881
<i>Proplectella amphora</i>	2013	2015	2013	This Study
<i>Proplectella claparedei</i>	1929	1998	1886	Daday 1887
<i>Proplectella fastigata</i>	2002	2016	1909	Jørgensen 1924
<i>Proplectella subacuta</i>	2003	2003	1909	Jørgensen 1924
<b><i>Proplectella subcaudata</i></b>	2003	2003	1909	Jørgensen 1924
<i>Protohabdonella curta</i>	1998	2010	1909	Jørgensen 1924
<i>Protohabdonella simplex</i>	2002	2002	1909	Jørgensen 1924
<b><i>Rhabdonella amor</i></b>	2003	2003	1904	Entz 1909
<i>Rhabdonella elegans</i>	2003	2015	1909	Jørgensen 1924
<i>Rhabdonella spiralis</i>	1879	2016	1879	Fol 1881
<i>Salpingella accuminata</i>	1951	2016	1909	Jørgensen 1924
<i>Salpingella attenuata</i>	1973	2016	1909	Jørgensen 1924
<i>Salpingella curta</i>	2003	2016	1981	Balkis & Koray 2014
<i>Salpingella decurtata</i>	1951	2016	1909	Jørgensen 1924
<i>Salpingella faurei</i>	2002	2016	1996	Dolan et al. 1999
<i>Salpingella minutissima</i>	2002	2002	1993	Dolan & Marrasé 1995
<i>Salpingella rotundata</i>	1951	1953	1951	Balech 1959
<i>Steenstrupiella intumescens</i>	2002	2003	1909	Jørgensen 1924
<i>Steenstrupiella steenstrupii</i>	1953	2016	1886	Daday 1887
<i>Stenosemella nivalis</i>	1929	2016	1938	Rampi 1948
<i>Stenosomella ventricosa</i>	1880	2016	1880	Fol 1883
<i>Tintinnopsis acuminata</i>	2002	2016	2000	Moscatello et al. 2004
<i>Tintinnopsis beroidea</i>	1952	2014	1909	Jørgensen 1924
<b>Villefranche Species</b>	<b>First year</b>	<b>Last Year</b>	<b>1<sup>st</sup> Medit Yr</b>	<b>1st Med Year Ref</b>

<i>Tintinnopsis campanula</i>	1879	2016	1879	Fol 1881
<i>Tintinnopsis compressa</i>	1953	2002	1909	Jørgensen 1924
<i>Tintinnopsis cylinidrica</i>	1929	2015	1887	Daday 1887
<i>Tintinnopsis everta</i>	2002	2002	1980	Abboud-Abi-Saab 1989
<i>Tintinnopsis fimbriata</i>	2003	2003	1992	Abboud-Abi-Saab 1992
<i>Tintinnopsis lobiancoi</i>	1998	1998	1938	Rampi 1948
<b><i>Tintinnopsis major</i></b>	2002	2002	2002	This study
<i>Tintinnopsis minuta</i>	2002	2002	1938	Rampi 1948
<i>Tintinnopsis nana</i>	1952	1952	1952	Balech 1959
<i>Tintinnopsis nucula</i>	1880	1880	1880	Fol 1883
<i>Tintinnopsis radix</i>	1929	2016	1909	Jørgensen 1924
<i>Tintinnopsis tocantinensis</i>	2002	2002	2002	Polat et al 2002
<b><i>Tintinnopsis turbo</i></b>	2003	2003	2003	This Study
<b><i>Tintinnopsis urnula</i></b>	2003	2003	2003	This study
<i>Undella attenuata</i>	1973	1973	1909	Jørgensen 1924
<i>Undella clevei</i>	1951	2015	1909	Jørgensen 1924
<i>Undella hyalina</i>	1951	2016	1886	Daday 1887
<i>Undellopsis marsupialis</i>	1929	2016	1909	Jørgensen 1924
<i>Xystonella clavata</i>	2009	2009	1909	Jørgensen 1924
<i>Xystonella lanceolata</i>	2013	2016	1909	Jørgensen 1924
<i>Xystonella lohmanni</i>	2010	2015	1909	Jørgensen 1924
<i>Xystonella longicaudata</i>	1973	2016	1909	Jørgensen 1924
<i>Xystonella treforti</i>	1938	2016	1886	Daday 1887
<b><i>Xystonellopsis spicata</i></b>	2016	2016	1909	Jørgensen 1924
<b><i>Xystonellopsis brandti</i></b>	1973		1909	Jørgensen 1924
<i>Xystonellopsis paradoxa</i>	1973	2016	1909	Jørgensen 1924

Table 4. Characteristics of “New Species” and “Species Absent in Recent Years” (2013-2016). The list excludes 'oncers' and species recorded from a single year. Morphological characteristics given are lorica oral opening diameter (LOD), overall length lorica length (LL). Occurrences in other coastal Mediterranean sites are (arranged in order of increasing distance from Villefranche): SR = San Remo, Italy (Rampi 1948), M = Marseille, France (Travers and Travers 1971), CS = Catalan Sea, Spain (Dolan and Marassé 1995), C = Castellon, Spain (Duran 1951, 1953), N = Naples, Italy (Modigh & Castalado 2002), T = Trieste, Italy (Monti et al. 2012), JB = Jounieh Bay, Lebanon (Abboud-Abi Saab 1989), PI = Palm Island, Lebanon (Abboud-Abi Saab 2002).

<b>New Species</b>	<b>LOD (<math>\mu\text{m}</math>)</b>	<b>LL (<math>\mu\text{m}</math>)</b>	<b>Last year</b>	<b>Mediterranean Sites</b>
<i>Amphorellopsis tetragona</i>	45	110	2015	C, T, JB
<i>Eutintinnus permintus</i>	34	162	2016	SR
<i>Eutintinnus stramentus</i>	28	145	2016	M, C, T, JB
<i>Proplectella amphora</i>	29	59	2015	
<i>Xystonella lanceolata</i>	55	245	2016	
<i>Codonella amphorella</i>	44	89	2016	JB, PI
<b>Missing Species</b>				
<i>Acanthostomella minutissima</i>	24	33	2010	N
<i>Ascampbelliella oxyura</i>	28	40	2002	
<i>Codonella aspera</i>	50	75	2003	M, T, JB
<i>Dictyocysta entzi</i>	38	48	2009	N
<i>Eutintinnus macilentus</i>	48	233	2010	SR, M, C, JB, PI
<i>Favella serrata</i>	116	264	2002	M, N, T
<i>Metacylis jørgensenii</i>	47	55	2002	SR, N, T, JB, PI
<i>Proplectella claparedei</i>	35	85	1998	M, C, N, T, PI
<i>Salpingella minutissima</i>	34	106	2003	CS
<i>Salpingella rotundata</i>	43	334	1953	M, N, T
<i>Steenstrupiella intumescens</i>	36	205	2003	JB, PI
<i>Tintinnopsis compressa</i>	56	69	2002	M, T, PI

Table 5. Presence (as % dates sampled) of the most common species in 2014 and 2015. The species listed were found on at least 25% of the dates sampled in either the 50 dates sampled in 2014, or the 57 dates sampled in 2015. Note the high variability in detection of some species such as *Stenosomella ventricosa* and *Tintinnopsis campanula*

<b>Species</b>	<b>2014</b>	<b>2015</b>
<i>Amphorella quadrilineata</i>	54	48
<i>Codonaria cistellula</i>	34	18
<i>Codonella elongata</i>	58	44
<i>Codonella nationalis</i>	40	23
<i>Codonellopsis morchella</i>	72	67
<i>Dictyocysta lepida</i>	18	25
<i>Eutintinnus apertus</i>	30	42
<i>Proplectella fastigata</i>	50	40
<i>Rhabdonella spiralis</i>	34	37
<i>Salpingella acuminate</i>	54	42
<i>Salpingella attenuata</i>	28	32
<i>Steenstrupiella steenstrupii</i>	18	37
<i>Stenosemella nivalis</i>	54	16
<i>Stenosomella ventricosa</i>	60	16
<i>Tintinnopsis campanula</i>	26	4

## Figures

Figure 1a. Temporal changes in the cumulative number of species recorded from the Bay of Villefranche and the cumulative number of samplings. Cumulative number of species (pooling probable synonymous records, see Table 2) are shown both with (# Spp All) and without species recorded but once (# Spp No Oncers). Figure 1b.

Cumulative number of species recorded from the Bay of Villefranche as a function of sampling effort.

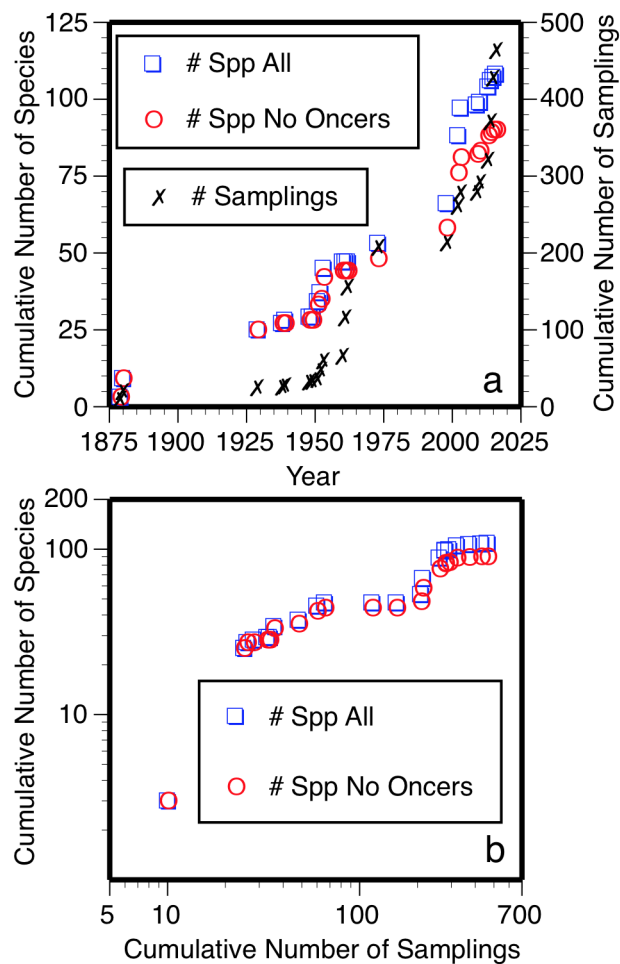




Figure 2. Comparison of cumulative number of species recorded from the Bay of Villefranche as a function of sampling effort for recent intensive sampling (2013-2016) and the preceding historical sampling (1879-2010).

