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Antifouling biocides in German coastal & inland waters – How reliable are exposure prognoses of EU-scenario models for marinas?

Final Report

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Antifouling biocides in German coastal & inland waters – How reliable are exposure prognoses of EU-scenario models for marinas?

Final Report – English Translation

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Abstract

Reliable data on the inventory of leisure boats and marinas with their amounts of berths have to be used in the framework of the EU biocidal products regulation. For Germany, such area wide data were lacking so far. A comprehensive survey was initiated and funded by the German Federal Environment Agency (UFOPLAN 2011, FKZ 3711 67 432) in order to quantify the amount of leisure boats in marinas and other locations in both inland and inshore waters. The census of the number of leisure boats at their berths in German waters revealed a total of 206,279, of which 146,425 (71 %) boats were located in freshwater, 54,079 (26.2 %) boats in brackish waters (salinity <18 %), and 5,775 (2,8 %) boats in marine waters. The structure and characteristics of freshwater harbours were quite heterogeneous. Areas of high density of leisure boats were identified at the western Baltic Sea coast, the Lower Elbe around Hamburg, the Mecklenburg Lake District, Berlin with its surrounding waters, and Lake Constance with further pre-alpine lakes.

In the second work package, water concentrations of currently used antifouling biocides and some of their specific breakdown products were screened in 50 selected marinas in order to demonstrate the variety of antifouling active substances occurring in German leisure boat harbours.

Finally, in a third work package, measured antifouling concentrations in selected marinas were compared with those calculated using the MAMPEC model. With emphasis on freshwater sites, the reliability of MAMPEC turned out to be restricted in view of the actual antifouling exposure in German leisure boat harbours.

Kurzbeschreibung

Um modellbasierte Prognosen von Antifouling-Wirkstoffeinträgen durch Sportboote durchzuführen, müssen im Rahmen der EU-Biozidproduktzulassung belastbare Daten zum Bestand von Sportbooten und Häfen mit ihren Liegeplätzen vorliegen. Für Deutschland ware bisher solche repräsentativen Daten nicht verfügbar. Vor dieser Ausgangslage initiierte und förderte das Umweltbundesamt eine umfassende Studie (UFOPLAN 2011, FKZ 3711 67 432), um den Bestand an Liegeplätzen für Sportboote in Marinas und kleineren Häfen im Binnen- und Küstenbereich zu erfassen. Die bundesweite Bestandsaufnahme der Liegeplätze ergab eine Gesamtanzahl von 206,279 von denen sich 146,425 (71 %) im Süßwasser, 54,079 (26.2 %) im Brackwasser (Salinität < 18%) und 5,775 (2.8%) im Salzwasser befanden. Die Charakteristika und Formen der Sportboothäfen im Süßwasser waren sehr heterogen und entsprachen nicht dem klassischen Schema von offenen und geschlossenen Häfen. Die Anzahl der Boote an den Liegeplätzen variierte sehr stark in Abhängigkeit vom Revier und der Sportbootsaison. Als Gebiet mit hohen Liegeplatzzahlen erwiesen sich die Ostseeküste, die Unterelke ab Hamburg, die Mecklenburger Seenplatte, die Gewässer in und um Berlin und der Bodensee mit weiteren Voralpenseen.

In einem weiteren Arbeitsschritt wurden in 50 repräsentativen Sportboothäfen Wasserproben gezogen und auf die aktuell erlaubten Antifoulingbiozide und deren Abbauprodukte analysiert, um das Vorkommen von Antifoulingbioziden in der Wasserphase von Sportboothäfen im Küsten- und Binnenbereich zu dokumentieren.

Im dritten Schritt wurden die gemessenen Konzentrationen mit denen verglichen, die mittels der Computermodellierung mit MAMPEC errechnet wurden. Es stellte sich heraus, dass das MAMPEC-Modell im Gegensatz zu Küstenhäfen fur Süßwasserhäfen nur bedingt zuverlässig ist.

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List of Abbreviations

Abb.	Abbreviation written in full
AF	Antifouling
AP	Work Package
B	Overall width, total boat width
BMVBS	German Federal Ministry of Transport and Digital Infrastructure
BSH	German Federal Maritime and Hydrographic Agency
CEPE	European Association of the Paint, Printing Inks and Artists' Colour Industry
DT50	Disappearance time 50, time taken for half the amount of a material to disappear from a compartment, like for example water
ESD	Emission Scenario Documents
EU	European Union
FG	UBA Department
FKZ	Project number
R&D	Research and Development
HC5	Hazardous concentration for 5% of the species, concentration at which five percent of the species exhibit an effect
HH	Hamburg
HLUG	Hessian Agency for Nature Conservation, Environment and Geology
HSE	Health and Safety Executive
ICOMIA	International Council of Marine Industry Associations
KEMI	Swedish Chemicals Agency
LANU	State Agency for Nature, Environment and Consumer Protection of North Rhine-Westphalia
LLUR	State Agency for Agriculture, the Environment and Rural Areas of Schleswig-Holstein
LP	Berth
LoA/LüA	Length overall, total boat length
LWL	Length of waterline of the boat hull
LUNG	Agency for Nature Conservation, Environment and Geology of Mecklenburg-Western Pomerania
Max	Maximum
Min	Minimum
MW	Mean
N	Number
NDS	Lower Saxony
NLWKN	Lower Saxony Agency for the Water Industry, Coast and Nature Protection

NRW	North Rhine-Westphalia
P10	10th percentile
P50	50th percentile or median
PEC	Predicted Environmental Concentration
PNEC	Predicted No Effect Concentration
Px	x-th percentile
RIVM	Dutch National Institute for Public Health and the Environment
SD	Standard Deviation
SOP	Standard Operating Procedure
SH	Schleswig-Holstein
T	Draught of the boat in water
UBA	German Federal Environment Agency
UFOPLAN	Environmental Research Plan of the German Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety
UQN	Environmental Quality Standards
UWF	Underwater surface of the boat hull

Summary

In leisure boat coatings, highly effective antifouling biocides are widely used to prevent biofouling on the hull. Consequently, antifouling biocides are released into the water. High concentrations may particularly occur in marinas with high numbers of berths and low water exchange rates. Within the cruising range of boats around marinas, the active substances contained in antifouling products are spread out to adjacent waters and the aquatic organism living there.

The approval for antifouling products with biocidal ingredients is subject to the EU regulation No 528/2012. The first step in the two-step authorisation procedure is the risk assessment of the biocidal active substance. A key element of the environmental risk assessment, is among other aspects, the comparison between the predicted environmental concentration (e.g. in marinas) and the predicted no-effect concentration derived from standardised eco-toxicological tests with algae, small crustaceans, and fish. The active substance may be approved if the risk for both humans and the environment is regarded acceptable and if the biocidal active substance passes the efficacy testing. In the second step of the authorisation process the biocidal product, which contains additives beside the active substance(s), has to be approved. Here, the environmental risk assessment is based on product specific properties like the concentration of the active substance(s) and the leaching rate.

Predicted environmental concentrations are calculated by use of computer models like MAMPEC in order to coherently conduct the EU risk assessment, due to the lack of representative measured data of antifouling components in marinas. For the emission scenario *marina* a limited number of scenarios describing EU-wide marina types are available, which are predominantly characteristic for coastal areas. It had to be clarified if these marina types are also representative for the North Sea coast, brackish waters, and inland waters in Germany.

Therefore, the German Federal Environment Agency initiated a tri-annual research project. The objective was to carry out a nationwide inventory of marinas and their berths. Furthermore, additional information like surface size, geographic position, and infrastructure of the marinas had to be recorded.

Moreover, an analytical screening at 50 marinas had to be conducted in order to monitor the antifouling active substances currently in use on the German market, the boats currently at berth, and port specific infrastructure elements. These screening data gave an outline on the current pollution of antifouling active substances and provided detailed information on the last phase of the project.

Finally, the applicability of the prognostic model MAMPEC (V. 2.5) had to be demonstrated. Based on collected data from coastal and inland marina in Germany it had to be tested how reliably antifouling concentrations in the water can be predicted as a *realistic worst-case* by models as compared to measured data.

Nationwide about 206,000 berths were counted. Small leisure boats, like dinghies and rowing boats, were excluded since they are generally not antifouling coated. The amount of trailer boats without fixed mooring sites and berths at very small or single boat landing stages, which are not reliably detectable by aerial photos, were estimated to amount maximum 37,000 boats. The total stock of leisure boats in Germany determined is substantially smaller than reported in previous studies, e.g. the 500,000 motor and sailing boats stated in 2008. This discrepancy is caused by the use of different methods, namely: analysing nationwide aerial images or extrapolating total stock by use of polls and regionally delimited records. The actual census can be regarded more reliable and may represent a sound base for planning in the future.

Overall, the total stock of berths in freshwater amounted 146,000 (71.0 %), 54,000 (26.2 %) in brackish water like the Baltic Sea including fjords and inner bays as well as the river estuaries of the North Sea and only 5,800 mooring sites (2.8 %) in saltwater areas (North Sea coast). In total, 3,091 marinas

were monitored, 80 % of which were in freshwater, 18 % in brackish and 2 % in saltwater. This emphasizes the high relevance of inland waters for leisure boat activities in Germany.

Agglomerations with at least 10,000 berths were identified at the area of Berlin-Brandenburg (approx. 40,000) and along the Baltic Sea (approx. 43,000), followed by the Mecklenburg lake district with approx. 19,000 and the great pre-alpine lakes in Bavaria with approx. 23.000 mooring sites. Only 10,000 berths accounted each for the Rhine-Ruhr area, Hamburg with Lower Elbe and its estuaries as well as the North Sea coast with its further estuaries. Altogether, these agglomeration areas amounted about 76 % of the total stock.

The typical marina at the North Sea is the dyked *safe haven* with a median number of 70 berths and extensive infrastructure facilities. It is often multifunctional with a mixture of marina, ferry, fishing, and official harbour. The inland marinas are often undyked and therefore scarcely demarcated from the adjacent water body, having a median number of 40 berths and are used exclusively for water sport activities. The extent of infrastructure facilities is low. The sizes of marinas in freshwater and brackish waters may vary from single landing stages up to major marinas with more than 1,000 berths, whereas at the North Sea only 270 mooring sites were observed at maximum.

For the more detailed study, 50 marinas were selected according to the proportion of berths distributed over the three salinity classes. Additional selection criteria were open and dyked port basins with small to large water bodies, marinas with small and large amount of berths as well as sites with different water flows and tidal ranges. Furthermore, at sampling sites that gave reason to expect external pollution additional water samples were analysed as references outside the basins.

The active substances zineb, copper and zinc pyrithione as well as DCOIT (Sea-Nine 211) together with specific degradation products were always below the limit of quantification. Actually, Zineb and DCOIT are mainly applied by the commercial shipping industry and only a small number of antifouling products for leisure boats containing these biocides are available on the German market.

In contrast to the biocidal ingredients dichlofluanid and tolylfluanid, which rapidly degrade in water, their degradation products DMSA and DMST were identified in 70 % and 54 % of the analysed samples. However, the concentration levels of these degradation products were below threshold concentrations to cause adverse eco-toxicological effects on water organisms. The levels of the reference samples were usually below their limits of quantification, indicating that the active substances originate from the use of antifouling products.

For cybutryne (Irgarol) 78 % and its degradation product M1 46 % of the analysed samples were above the limit of quantification. The water concentration of this persistent antifouling active substance, monitored by singular sampling, indicated risk for water organisms at some sites. At 35 of 50 marinas, the actual concentrations were above the threshold value of 0.0025 µg/l given by the EU-directive 2013/39/EU, which should not be exceeded on annual average basis. At five marinas, concentrations were even above the maximum allowable concentration of 0.016 µg/L as stated by EU quality standards, which cannot be exceeded. The highest concentration of 0.119 µg/l was observed at an inland marina.

The metals copper and zinc were almost ubiquitously present in the samples. The highest levels were observed at brackish water marinas, where at maximum 20 µg Cu/l und 27 µg Zn/l were detected in filtered water samples. At sites where reference samples were taken, concentrations ranged between 2 and 20 µg/l for copper and 2 and 16 µg/l for zinc. This indicates that both metals were applied in antifouling-products for leisure boats and that they are also released into the environment by other applications.

Taking the predicted environmental effect concentration as so-called HC5 (according to the EU risk assessment) of 8 µg/l as a base, the exceeding of that threshold may result in risk for the aquatic environment depending on the actual pH-value and the chemical composition of the water. This threshold was exceeded at six sites for copper and at 9 of 50 sampled sites for zinc. Increased levels were observed in relatively large, well-embanked marinas. These concentrations were analysed by use of filtrated water samples without the metal fraction being bound at particles. It has to be assumed that metals bound to suspended matter may be deposited in medium-term and accumulate in the long-term in the sediments of the marinas.

Comparing the model derived prognoses with analytical findings of antifouling biocides determined in the screening, the selected dyked marinas of the North Sea were in good agreement. In contrast, only little correspondence was found between the outcome of the model MAMPEC and the measured values for almost non-embanked marinas of brackish and freshwater sites. This is not surprising since the model was originally designed for harbours at tidal coasts and not for open inland marinas with their complex flow conditions.

The study at hand underlines the high importance of German fresh waterways for leisure boat activities. Moreover, basic data are provided to generate scenarios for inland marinas in the EU risk assessment of antifouling active substances and products. Besides, existing prototypic models of coastal marinas can be checked for their suitability for use in Germany. Finally, the study may help to adjust models like MAMPEC to represent other more complex flow conditions.

1 Background and Aims of the Project

1.1 Biofouling and antifouling

Submerged surfaces are quickly colonised by numerous organisms in both fresh- and saltwater. This biofouling is comprised of microfouling — biofilm formation and bacterial adhesion — and macrofouling — attachment of larger organisms. Calcareous (hard) fouling organisms include barnacles, molluscs, tubeworms, and zebra mussels. Soft fouling organisms include seaweeds and algae.

Numerous antifouling (AF) systems, which are based on various different principles, are used to protect ships and submerged structures (aquaculture facilities, offshore sites, harbour and coastal protection constructions) against biofouling. These principles include:

- Active substances with biocidal effects that are released from the coating they are incorporated in
- Physically smooth surfaces or difficult to colonise surfaces (foul release coatings).

Numerous other principles have been and will be developed (electrochemical principle, ultrasonic, fibre-coating, cleanable resin coating), but to date none of these achieved a notable share of the market.

In shipping, AF systems contribute to material protection of the hull, to prevent friction and improve speed resulting in lower fuel consumption as well as increased intervals between in dock maintenance work (Dürr & Thomason, 2009).

If the AF products contain biocidal active substances, like those commonly used for leisure boats, these biocidal active substances are released gradually into the water at the hull-water interface. Eventually, these active substances also enter the surrounding surface water. Due to the persistent nature of these active substances, they accumulate in the aquatic environment and cause negative effects on aquatic organisms, especially those they are originally not aimed for (i.e. non-target organisms).

At the end of the 1980s, various research projects funded by the German Federal Environmental Agency (UBA) demonstrated that coastal marinas and inland waters show extremely high loads of organotin compounds in both the water column and the sediment (Kalbfus et al. 1991; Oehlmann et al. 1996). These compounds led to sex reversal, particularly in marine snails, which led to some snail populations off the German coast becoming endangered (Klingmüller & Watermann 2003; Bauer et al. 1995). In the following period, it could be shown that the EU-wide ban on the use of organotin based antifouling products in professional shipping and leisure boating substantially reduced contamination in the harbours. As a result, the adverse biological effect on aquatic organisms also diminished (Daehne & Watermann 2009).

Subsequently, it was demonstrated that organic biocides such as cybutryne (Irgarol 1051®) are supremely problematic in terms of aquatic pollution and have similar adverse ecotoxicological effects compared to organotin compounds. Surveys on Berlin-Brandenburg waterways and effect-fate studies using pond mesocosms conducted by the UBA (2007) have shown that pollution of the water and sediment in marinas is present in the surrounding waters, which already exceed the threshold values in open water for a range of water organisms. Since the manufacturers of AF products have partly replaced cybutryne in their coatings by other biocides, a reduction in the input and environmental concentrations can already be detected. However, concentrations are still seen as critical in terms of their risk assessment (Burkhardt & Dietschweiler 2013). Kahle and Nöh (2009) made a first estimate of the input of AF biocides into German surface waters in comparison to biocide inputs from other sources.

Germany has an extensive network of inland waterways, which also include some spatially limited and sensitive water bodies. Furthermore, within the last decades the extent of the network of German waterways has increased strongly due to the development of new areas for leisure boat activities to the east of the Elbe. Additionally, many of the freshwater water bodies in Germany have multiple uses (e.g.

leisure, commercial shipping, drinking water source, nature conservation area), so that for long-term use it is necessary to document the possible biocide loading as precisely as possible.

1.1 Antifouling products within the framework of the EU Biocidal Products Regulation

Throughout the EU, all preservatives, disinfectants and other pest controlling substances are classified as biocides. The EU Biocidal Products Directive (98/8/EC) has regulated the authorisation and placing on the market of biocides since 1998. Since September 2013, the EU Biocidal Products Regulation (528/2012/EU) replaces the Biocidal Products Directive.

New biocidal active substances may only be marketed in biocidal products after approval for the EU market. Within the framework of the first step in the authorisation procedure a risk assessment is performed. For the proposed intended use of the biocidal product, besides the efficacy of the active substance also the risks for humans and the environment is assessed. During this procedure, one of the member states takes the leading role, while all other EU member states are involved in the discussions and decision process. If there are no unacceptable risks and the efficacy is proven, the active substance is added to a positive list and in principle can then be used in biocidal AF products throughout the EU.

A second step in the approval process must be passed for marketing as a product. For this, an applicant must submit an application for authorisation of their product containing an active substance from the positive list in a specific EU member state. In this dossier, the efficacy of the product must be proven and it must be justified that the product has no unacceptable effects on human health and the environment when used as intended. Taking into account the results from the risk assessment, the respective Member State decides independently on the national product authorisation. To simplify authorisation in other Member States, an application for mutual recognition of the product authorisation by an additional Member State can be made, because there is already an extensive dossier available for the respective product.

The application for mutual recognition of a national authorisation can be done either sequentially to the primary assessment or parallel with the primary assessment. In case of sequential mutual recognition, the Member State in which the application is first submitted conducts the primary assessment and provides a Product Assessment Report. Based on the authorisation and underlying assessment a mutual recognition in other Member States can be requested, which then needs to be evaluated within 120 days. In case of parallel mutual recognition, the application for primary assessment and mutual recognition is submitted simultaneously. The authorisation processes for biocidal products takes place accordingly and without prejudice in all Member States receiving applications for mutual recognition of a national authorisation of a biocidal product.

A possible rejection of the application must be demonstrably justified and might be derived from the specific national situation of the Member State. This could mean, for example, that authorisation for an AF product for leisure boats is allowed in one Member State, as no unacceptable risks for the environment are expected due to low leisure boat numbers. In contrast, risks cannot be ruled out in other Member States with a considerably higher leisure boat density.

Emission scenarios are used for environmental risk assessment in the framework of the EU Biocidal Products Regulation, which are summarised in the *Emission Scenario Documents* (ESD). These emission scenarios describe the typical life cycle stages in which substances are released into the environment, production, processing or use. The parameters for these scenarios must be chosen in such a way that they represent a *realistic worst-case* scenario.

Therefore, especially in marinas a comparatively high local concentration of AF active substance is to be expected, because here numerous boats with AF coatings are moored and the AF active substance are released into the harbour basin. Consequently, the size and structure of a marina, the extent and type of the boats, and other environmental conditions are defined in the emission scenarios for marinas. These EU emission scenarios are applied in more complex models such as REMA, MAMPEC and EUSES (OECD 2004). With additional information on substance properties, rate of application of the AF product and the release rate of the active substance from the coating, the environmental concentrations in the marina water can be predicted using these models. Subsequently, the predicted environmental concentration (PEC) of an active substance is compared with the toxicity level for aquatic organisms by using a safety factor (Predicted No Effect Concentration, PNEC). Unacceptable risks are indicated if the PEC is greater than the toxicity threshold for which no detrimental effect is predicted (PEC/PNEC >1).

The structure and size of the marinas, the number and size of the boats, as well as the environmental conditions (tides, salinity, proportion of suspended solids, etc.) are, however, regionally very different and have a considerable influence on the outcome of the risk assessment. At present, there are four emission scenarios implemented in MAMPEC for risk assessments of coastal marinas and one for inland marinas (OECD 2004). None of them have been checked or adapted for German conditions. Currently only one harmonised scenario is used for risk assessment of coastal marinas, as agreed between the EU Member States.

1.2 State of knowledge regarding the total stock of leisure boats in Germany

Water sport activities are very popular in Germany, especially in the inland federal states containing numerous lakes. Currently, nationwide data regarding the distribution, number, position and structure of marinas and their total number of boats are not available for Germany. Isolated, local fleet figures are available at best.

Moreover, at present only selected AF active substances (like cybutryne; pers. comm. supervisory authorities NDS, HH, NRW, SH) are regularly investigated at a federal state level in the scope of monitoring programmes. A screening or monitoring of all the AF active substances in German surface waters does not take place at the moment, as this is not mandatory.

Therefore, AF active substance loads can be predicted neither by use of a specific prediction model designed especially for the German conditions, nor by analytical monitoring data of local waters. Thus, potential risks cannot be identified.

Whether the currently available EU scenarios (ESDs) for leisure boats, which were developed predominantly for coastal waters and their characteristics, are suitable for German brackish and freshwater areas, has not yet been investigated.

Therefore, to close these knowledge gaps, a three-year research project (FKZ 3711 67 432) in the framework of the UFOPLAN was publicly posted by the German Federal Environment Agency. This project covered three key areas with the following objectives:

1. A nationwide inventory of marinas and their fleet both inland and coastal (AP 1).
2. For this, the size, location and other marina infrastructure (shipyard, winter storage, slipways, and boatlifts) as well as the maximum number of berths were recorded. In addition to the total number of leisure boats and marinas, the proportion of saltwater, brackish and freshwater sites had to be itemised. Furthermore, regional (urban) agglomeration areas had to be identified.
3. In-depth surveys on 50 selected coastal and inland marinas (AP 2)
4. Site selection took place based on results gained from AP 1 (see above). Here, marina water samples were analysed for currently permitted antifouling active substances during a nationwide screening, and the boats present on site, including selected boat specifications, as well as additional harbour infrastructure facilities were recorded. This detailed information provided an initial overview of the current AF active substance load and formed the database for applying the exposition models.

5. Comparison of the leisure boat EU emission scenarios with the German situation at the coast and inland marinas, as well as model calculations of AF active substance concentrations in water adjusted to the selected marinas (AP 3).
6. The suitability of the available EU scenarios for risk assessment of the AF emissions from leisure boats in Germany was to be tested. Furthermore, the extent to which MAMPEC, adjusted to the characteristics of real harbours, could reliably predict the AF active substance concentrations in the water as *realistic worst-case* in comparison to real measurements was tested using four AF active substances. The required detailed information was taken from the AP 2 survey.

In 2011, the research laboratory LimnoMar (Hamburg, Norderney) was commissioned to run this project. In the framework of AP 2, the Institute Dr Nowak (Ottersberg) as a subcontractor performed the chemical analyses of the AF active substances, with the exception of cybutryne. In the framework of AP 2, the section IV 2.5 of the German Federal Environment Agency took part in the sampling. Additionally, the active substances cybutryne, terbutryn and the transformation product M1 as well as further chemical water parameters were analysed by section IV 2.5. The specialist supervision of the project was also performed by the section IV 2.5 in close collaboration with section IV 1.2, which is responsible for the approval of active substances and authorisation of biocidal products in the framework of the Biocidal Products Regulation.

The project ended in 2014 and results were presented within the framework of an expert discussion in Dessau in October 2014. Furthermore, results were also presented at the specialist trade fair *Hanseboot* in Hamburg.

2 Results

2.1 Nationwide inventory of marinas and their boats (AP 1)

Within the framework of this study, marinas are characterised as:

- Spatially well-defined harbours or marinas,
- Open pontoons for leisure boats with no or a very limited embankment to the open water, as well as
- Berth areas for leisure boats in industrial or communal harbours (*mixed use harbours*).

At least 80 % of the marina berths throughout Germany should be taken into account for the nationwide boat inventory. The focus of the survey was on large and middle-sized marinas. Smaller marinas or pontoon facilities were also recorded if they could be combined with nearby larger harbour clusters.

Sources for the survey were, among others, sea charts and navigational maps, regional tour and harbour guides, information about leisure boat organisations, as well as aerial images provided by geodata services.

The research was carried out nationwide, from Schleswig-Holstein in the north to Baden-Württemberg and Bavaria in the south, and covered the German North and Baltic Sea coasts with fjords, salt marshes, and lagoons, as well as flowing and stagnant inland freshwater (rivers, canals, natural and artificial lakes and river lakes).

Specific spatial characteristics of the marinas (e.g. size, structure) throughout Germany were also described (Chapter B.1). The naming of individual watercourses was based on the catchments main river, as assigned in the Water Framework Directive and the German Federal Ministry of Transport and Digital Infrastructure (Figure 2-1).

Figure 2-1

Federal waterways

Legend translation: Hoheitsgrenze = state border including territorial waters, Staatsgrenze = state border, Landesgrenze = national border, Seewasserstraßen des Bundes = territorial waters, Binnenwasserstraßen des Bundes = waterways used for shipping, nicht klassifizierte BinWaStr = not classified waterways, WaStr-Klasse I-III = regional (smaller) waterways class I-III, WaStr-Klasse IV-VI = main waterways class IV-VI
Source: © Federal Ministry of Transport and Digital Infrastructure; http://www.wsv.de/service/karten_geoin-formationen/bundeseinheitlich

In the saltwater of the North Sea, predominantly calcareous (hard) fouling organisms are found on the boat hulls. This marine fouling colonises every hard substrate available in the North Sea, including natural substances such as crags, rocks and wood, but also boat hulls and technical facilities. Hard fouling caused by barnacles and blue mussels is also found in the brackish water of the Baltic coast from Schleswig-Holstein to Rügen. The bay barnacle is widespread up to the Polish border (Peters et al. 1994). In the brackish salt marsh waters of the Baltic Sea, the zebra mussel is the only hard fouling organism found in the western region (Rödiger, 2003).

Based on the distribution of the hard fouling community, it can be assumed that AF products recommended for marine fouling are not used primarily at the North Sea, but also in the brackish Baltic Sea region. Other methodological details for this work package can be found in Chapter A.1 of the Appendix.

The species composition of the fouling community and its colonisation pressure, as well as the selection of antifouling systems are dependent on the local salt content. Therefore, for the selection of the sampling sites a distinction was made between saltwater (> 18 % salinity), brackish water (1-18 %) and freshwater (<1 %) marinas.

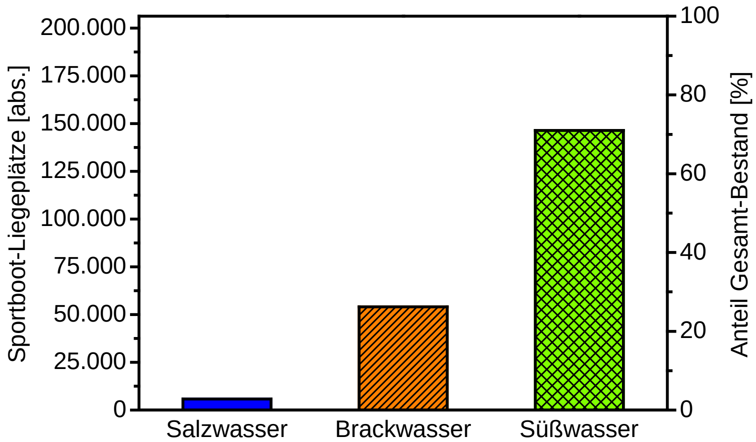
2.1.1 Distribution according to saltwater, brackish and freshwater sites

2.1.1.1 Number of leisure boat berths and marinas

By use of the digital aerial photos a total of 206,279 leisure boat berths were counted, of which 146,425 berths (71.0 %) were found in freshwaters, 54,079 (26.2 %) in brackish waters and only 5,775 berths (2.8 %) in saltwater areas (Figure 2-2).

Figure 2-2

Number of leisure boat berths in Germany and their distribution between fresh-, brackish and saltwater



Bottom axis: Salzwasser = saltwater, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: Sportboot-Liegeplätze = leisure boat berths. Right axis: Anteil Gesamt-Bestand = proportion of the total inventory.
Source: this study, LimnoMar.

In total, 3,091 marinas were found nationwide. The distribution of marinas and pontoons was similar to that of berths: 80 % of all marinas were found in freshwater, while 18 % were in brackish water and only 2 % in saltwater.

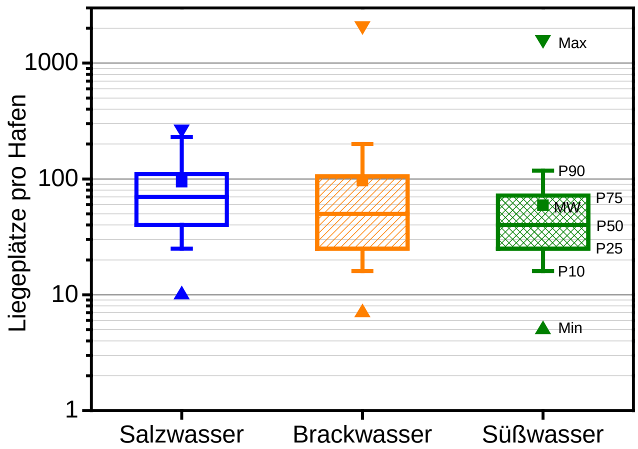
2.1.1.2 Berths and available space in marinas

The number of berths in saltwater marinas varied between 10 and 270, while in brackish and freshwater between 5 and over 1,000 berths per marina were determined (Figure 2-3, Table B-1). Therefore, the variance in berth numbers was considerably higher in brackish and freshwater areas than in saltwater areas. The median value (P50) represents the value separating the higher half of a data set from the lower half, i.e. the middle value of a data set. As with other percentiles, the median is not so much influenced by extreme large or small values. Subsequently, the median value for berths in saltwater was 70 and the value for brackish and freshwater dropped to 50 and 40 places, respectively.

The other percentiles behaved similar to the median (Figure 2-3). The arithmetic mean is more influenced by extreme values, so that the coastal marinas (both saltwater and brackish water) had a mean of about 96 berths, while the inland freshwater marinas had only a mean of 59 berths. This distribution for the three marina types is also presented in Figure B-1.

Figure 2-3

Statistical characteristics of the number of berths per marina in fresh-, brackish and saltwater

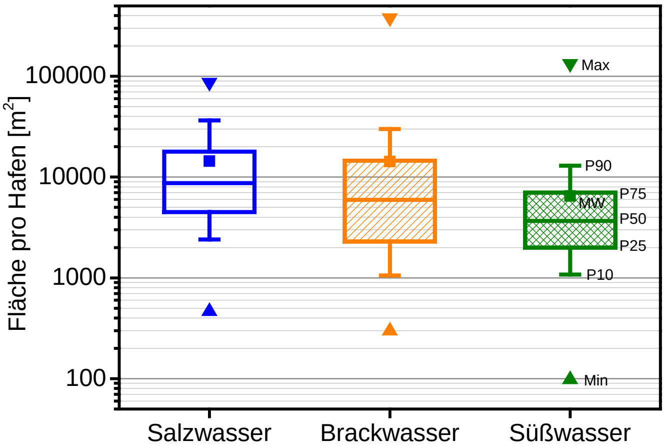


Bottom axis: Salzwasser = saltwater, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: Liegeplätze pro Hafen = berths per marina. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

In saltwater, the extreme values of the harbour surface area ranged between 465 and approximately 87,000 m². However, for brackish and freshwater, surface areas were much larger reaching nearly 300 - 380,000 and 100 - 133,000 m², respectively (Figure 2-4, Figure B-2, Table B-3). Analogue to the number of berths, the median of the surface area also dropped considerably from saltwater harbours with about 8,700 m², to brackish and freshwater harbours with ca. 6,000 and 3,700 m², respectively.

Figure 2-4

Statistical characteristics of the surface area per marina in fresh-, brackish and saltwater

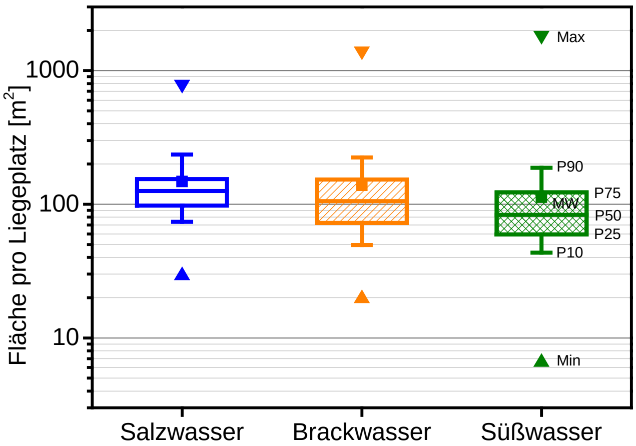


Bottom axis: Salzwasser = saltwater, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: Fläche pro Hafen = surface area per marina. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

The available surface area per berth reflects the same trend as the number of berths and the harbour surface area (Figure 2-5, Table B-5, Figure B-3): the surface area per berth was greatest in saltwater with a median of 126 m^2, which dropped in brackish and freshwater to 108 and 83 m^2, respectively.

Figure 2-5

Statistical characteristics of the surface area per berth in fresh-, brackish and saltwater



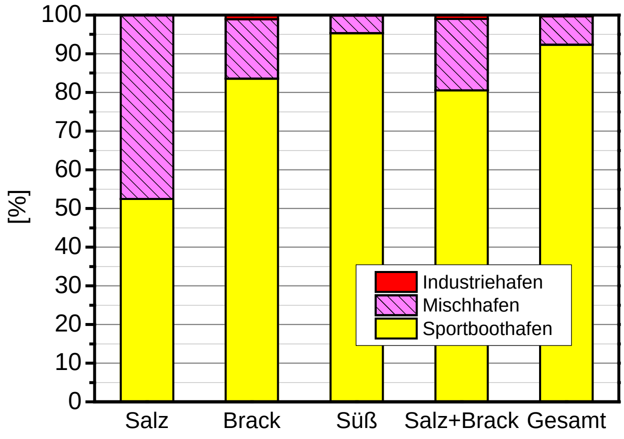
Bottom axis: Salzwasser = saltwater, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: Fläche pro Liegeplatz = surface area per berth. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

2.1.1.3 Harbour use

The use of a harbour can be divided as follows: a marina is exclusively used by leisure boats, a so-called *mixed use harbour* has besides recreational uses also municipal-commercial uses, and an *industrial harbour* is a classical harbour mainly for professional shipping, which also has moorings areas for leisure boats.

Figure 2-6

Percentile distribution of marinas, mixed use and industrial harbours in salt-, brackish and fresh-water



Legend translation: Industriehafen = industrial harbour, Mischhafen = mixed use harbour, Sportboothafen = recreational marina. Bottom axis: Salz = salt, Brack = brackish, Süß = fresh, Salz+Brack = salt + brackish, Gesamt = total.
Source: this study, LimnoMar.

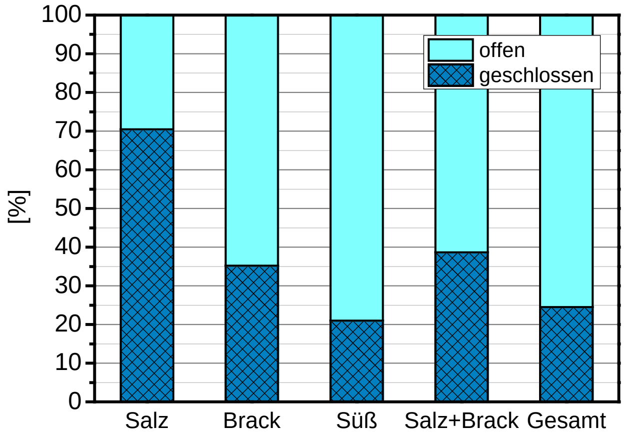
In saltwater almost half of the harbours were used as *mixed use* harbours (Figure 2-6). Ferries and cruise boats, fishing boats as well as official vessels such as e.g. coast guard, buoy tenders or work-boats have their berths in these harbours. The proportion of *mixed use* harbours in brackish water was considerably lower at 15 %, and in freshwater even only 4.6 %. Leisure boats rarely share the use of industrial harbours. Only a few harbours were found near coastal towns (brackish water) where the mixed use of leisure boats and professional shipping occurred.

2.1.1.4 Extent of the harbour embankment

The degree of embankment of a marina was determined in a simplified and manageable manner to cover the large structural diversity. A harbour was defined as *closed* if its boundaries were given by embankment or harbour facilities at three sides (cf. Chapter A.1.3.2). All other cases were defined as *open*.

Figure 2-7

Percentile distribution of open and closed harbours in salt-, brackish and freshwater



Legend translation: offen = open, geschlossen = closed. Bottom axis: Salz = salt, Brack = brackish, Süß = fresh, Salz+Brack = salt + brackish, Gesamt = total.
Source: this study, LimnoMar.

Closed harbours dominated at saltwater sites with more than 70 % (Figure 2-7). Harbours classified as *open* are situated at the coast, for example protected behind locks such as in Wilhelmshaven and Cuxhaven, or are part of a larger inner harbour with mixed use. The proportion of closed harbour systems decreased considerably to 35 % in brackish waters and to 21 % in freshwater.

2.1.1.5 Harbour infrastructure

Boatlifts or slipway facilities, dockyard and winter boathouse berths were determined as infrastructure characteristics in the immediate vicinity of the harbour. These characteristics allow to gain insight whether additional inputs of paint residues and AF active substances released by cleaning, repair or maintenance activities can be expected to enter the harbour basin (Figure 2-8). Open-air dry berths on land were difficult to identify and therefore not recorded here.

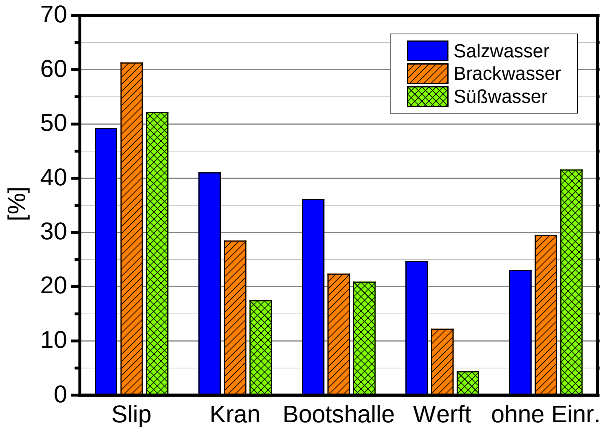
Slipways are widely distributed and found at 61 % of all the brackish water harbours, 52 % of all the freshwater harbours and 41 % of all the saltwater sites. Crane facilities for boatlifting were found mostly in saltwater harbours (41 %) due to the ship sizes, multiple usage e.g. by dockyards, and the presence of trained personnel. Here also the most dockyards were also recorded with almost 25 %. In contrast, dockyards in brackish and particularly in freshwater are usually spatially separated from the marinas, or they are so small that they cannot be determined on aerial pictures or other sources. Their proportions were 12 % for brackish water harbours and 4.3 % for freshwater harbours.

At saltwater sites, around 36 % of all the harbours had winter storage in a boathouse. In fresh- and brackish waters, the value was around 20 %. In all the areas, a large proportion of the boats were moved further away for storage in winter if they did not remain anchored.

Harbours without any of these infrastructure characteristics were present in lowest numbers in saltwater areas with 23 % and occurred most frequently in freshwater areas with 42 %.

Figure 2-8

Harbour infrastructure facilities in salt-, brackish and freshwater



Legend translation: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Bottom axis: Slip = slipway facilities, Kran = crane facilities, Bootshalle = boathouse, Werft = dockyard, ohne Einr. = without any facilities. Facilities: boathouse for winter storage, without facilities: Proportion of harbours without slipway, crane, boathouse or dockyard.
Source: this study, LimnoMar.

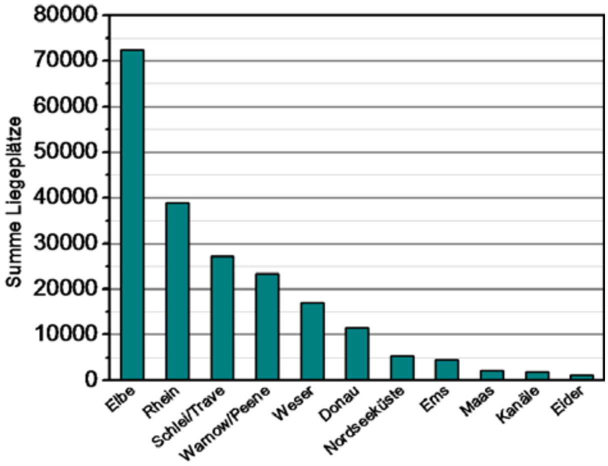
2.1.2 Distribution according to river catchment areas

Considering the distribution of berths according to the river basin districts, about 35 % of all the berths (72,339 berths) are found in the Elbe catchment area (Figure 2-9).

This area covers not only the berths on the Elbe but also the tributaries Havel, Spree and Dahme, which drain the Berlin area and also the Mecklenburg lake area to a large extent. In the catchment area of the Rhine, including its German section of Lake Constance, around 19 % of the total berths were recorded. Followed by the areas Schlei/Trave with about 13 % and Warnow/Peene with about 11.3 %.

Figure 2-9

Number of berths according to river basin districts and other regions



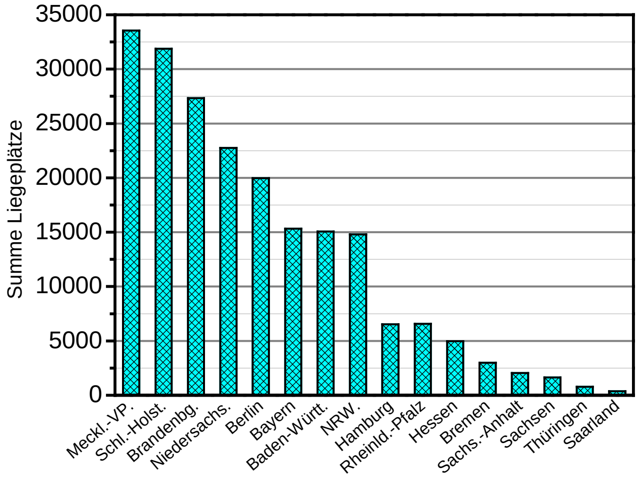
Bottom axis: Elbe = Elbe, Rhein = Rhine, Schiel/Trave = Schiel/Trave, Warnow/Peene = Warnow/Peene, Weser = Werser, Donau = Danube, Nordseeküste = North Sea coast, Ems = Ems, Maas = Meuse, Kanäle = channels, Elder = Elder. Left axis: Summe Liegeplätze = total number of berths. Catchment area according to Directive 2000/60/EC, with the exception that the North Sea coast and large canals are given separately.
Source: this study, LimnoMar.

2.1.3 Distribution according to federal state

The largest number of leisure boats are found in northern Germany, corresponding to the availability of coastal and inland water (Table 2-1, Figure 2-10). The highest number of leisure boats was found in Mecklenburg-Western Pomerania, followed by Schleswig-Holstein, Brandenburg, Lower Saxony and Berlin. These five federal states have approximately 66 % of all the berths within Germany and 68 % of the harbours.

Figure 2-10

Number of berths in Germany according to federal state



Bottom axis: Meckl.-VP. = Mecklenburg-West Pomerania, Schl.-Holst. = Schleswig-Holstein, Brandenbg. = Brandenburg, Niedersachs. = Lower Saxony, Berlin = Berlin, Bayern = Bavaria, Baden-Württ. = Baden-Württemberg, NRW. = North Rhine-Westphalia, Hamburg = Hamburg, Rheinld.-Pfalz = Rhineland-Palatinate, Hessen = Hesse, Bremen = Bremen, Sachs.-Anhalt = Saxony-Anhalt, Sachsen = Saxony, Thüringen = Thuringia, Saarland = Saarland. Left axis: Summe Liegeplätze = total number of berths.
Source: this study, LimnoMar.

Table 2-1

Number of berths in Germany according to federal state

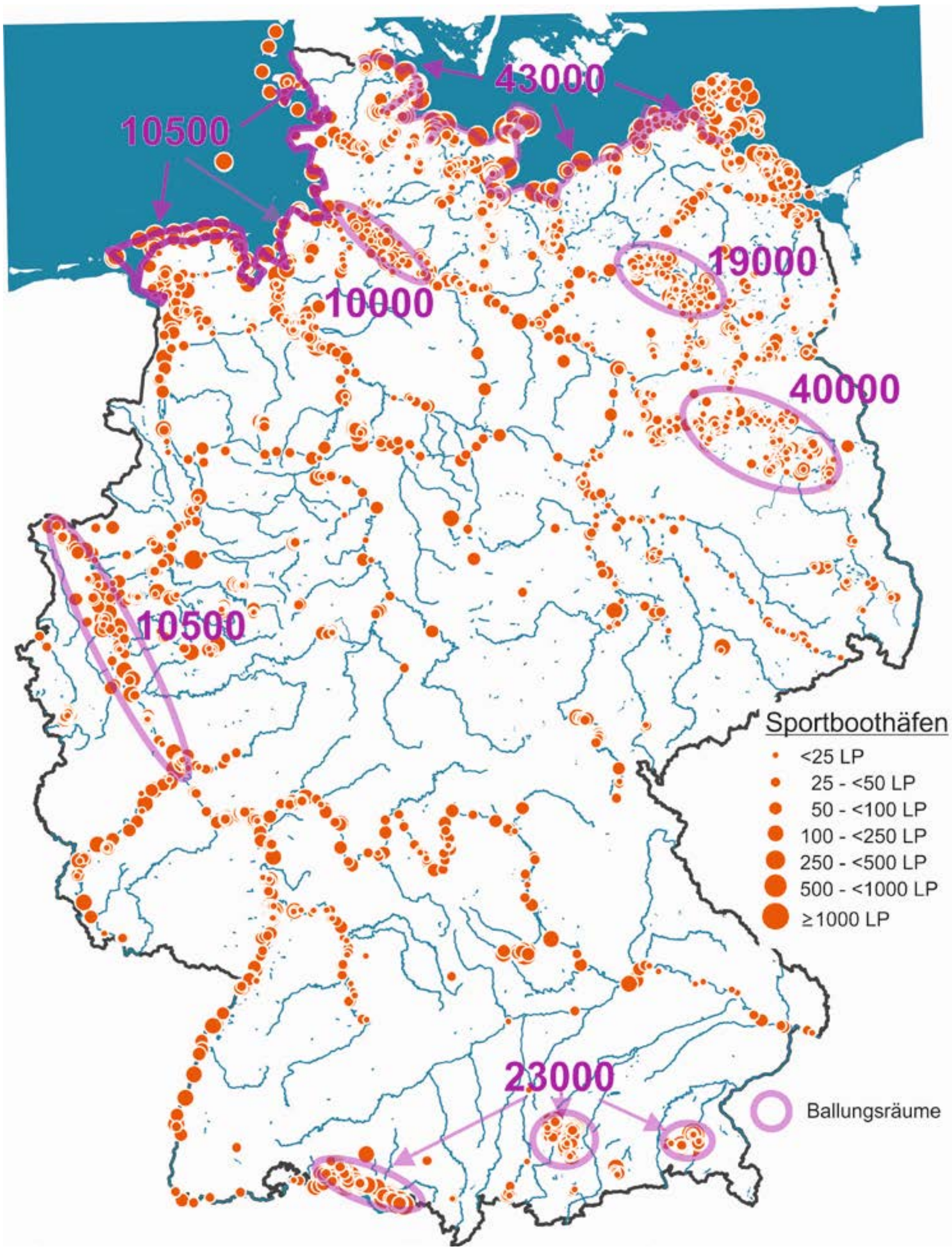
Federal State	Berths	Proportion (%)	Harbours
Mecklenburg-Western Pomerania	33,547	16.3	567
Schleswig-Holstein	31,878	15.5	332
Brandenburg	27,330	13.2	571
Lower Saxony	22,739	11.0	319
Berlin	19,954	9.7	319
Bavaria	15,304	7.4	212
Baden-Württemberg	15,041	7.3	141
North-Rhine-Westphalia	14,777	7.2	231
Hamburg	6,506	3.2	68
Rhineland-Palatinate	6,544	3.2	103
Hesse	4,957	2.4	63
Bremen	2,958	1.4	37
Saxony-Anhalt	2,020	1.0	64
Saxony	1,610	0.8	45
Thuringia	763	0.4	14
Saarland	351	0.2	5
Total	206,279	100	3091

2.1.4 Distribution according to berth density

For Germany, regional hot spots of berths can be identified in north and northeast Germany (Figure 2-11). For this reason, different sized areas were grouped together as densely populated areas, in which at least 10,000 berths are present. The areas with the highest number of berths were found within the Berlin-Brandenburg region as well as along the Baltic Sea coast with approximately 40,000 and 43,000 berths, respectively. Further agglomerations are identified in the Mecklenburg lake area with approximately 19,000 berths and the Bavarian lakes of the alpine foothills and Lake Constance with together 23,000 berths. Only 10,000 to 10,500 boats are found in each of the high population areas of the Rhine-Ruhr area, Hamburg with the Lower Elbe and Elbe estuary as well as the North Sea coast with its estuaries. Overall, around 76 % of the berths recorded throughout Germany were found in the above-mentioned high population areas.

Figure 2-11

High concentration area of leisure boat berths in Germany



Legend translation: Sportboothäfen = leisure craft marinas, LP = berths, Ballungsräume = agglomeration.
Source: Federal Environment Agency 2013, Geodatabase DLM1000 © BKG 2013

2.1.5 Distribution according to marina size

The smallest size class of marinas, with a maximum of 24 berths, represents 23.6 % of the total number of berths. They were found predominantly in the upper reaches of the Elbe, Spree, Rhine, Mecklenburg lake area and the eastern part of the German Baltic Sea. The following size class of marinas with 25 - 49 berths contained 976 harbours, which make up the largest portion of just under one-third, followed by the next biggest size class with 50 - 99 berths which contained 806 harbours. Both size classes were represented throughout all the regions in Germany. The proportion of large harbour facilities with 100 - 250 berths was only 15.7 % of the total number of berths. They were found as groups in the regions with high leisure boat density (Figure 2-11). Harbours with between 250 and 499 berths made up 2.1 % of all the harbours and were found predominantly on the North Sea and Baltic Sea coasts, in Berlin and on Lake Constance. Twelve harbours on the Baltic coast and on the south German lakes had between 500 and 999 berths. Four harbours with over 1,000 berths were found at the Baltic Sea, in the Hamburg area and at Lake Constance.

2.1.6 Distribution according to region

2.1.6.1 Saltwater

The harbours on the islands and at the coast of the North Sea are subject to tidal change. The average tidal difference on the East Frisian coast is 2.3 m in the West (Borkum) and 3.0 m in the East (Scharhörn), and on the North Frisian coast, it is between 1.7 and 2 m on Sylt and 3.6 m at Husum (BSH 2013).

Depending on the inner harbour depth, there are many North Sea harbours that are almost or completely dry during low tide, this means an enormous water exchange takes place in the harbour basin twice a day. Regarding the East Frisian Islands, only Norderney and Borkum can be reached by boat at low tide.

These harbours represent marinas and harbours with mixed uses in equal proportions. In the latter, ferries and fishing boats are moored next to the leisure boats. Two-thirds of these harbours are embanked and act as port of refuge, the other third consists of open harbours in protected sites, such as behind locks like in Wilhelmshaven (Figure 2-12).

Figure 2-12

North Sea coast of Germany

Source: Geodatabase DLM1000 © BKG 2013

During the summer the island and coastal harbours are heavily frequented by touring boats, so that more boats of visitors than of residents (e.g. club boats) are anchoring in the harbour. By *raft mooring* (multiple rows of adjacent mooring) the number of leisure boats during this period can be considerably greater than the indicated berth capacity.

In total, eight harbours with 1,402 leisure boat berths were found in the East Frisian Islands and 13 harbours with 1,013 berths in the North Frisian Islands (including Helgoland). This amounted to 5,775 berths with sites at the East and North Frisian North Sea coast, and the saltwater sites in the estuaries (Table 2-2).

Table 2-2

Harbours and leisure boat berths in saltwater

Region	Number harbours	Number berths	Proportion berths (%)	Median berths
East Frisian Islands	8	1,402	24.3	156
North Frisian Islands	13	1,013	17.5	62
East Frisian North Sea Coast	20	1,965	34.0	70
North Frisian North Sea Coast	5	255	4.4	50
Ems Estuary	1	77	1.3	77
Weser Estuary	4	293	5.1	52.5
Elbe Estuary	10	770	13.3	55
Total	61	5,775	100	-

2.1.6.2 Brackish water

In total, the present study identified 54,079 leisure boat berths in brackish water. The individual areas are itemised in Table 2-3.

Figure 2-13

German Baltic Sea coast

Legend translation: Flensburger Förde = Flensburg Firth, Schlei = Schlei, Eckernförder Bucht = Eckern-förder Bay, Kieler Förde = Kiel Fjord, Hohwachter Bucht = Hohwachter Bay, Fehmarn Sund = Fehmarn Strait, Lübecker Bucht = Bay of Lübeck, Wismarer Bucht = Bay of Wismar, Warnemünder Bucht = Bay of Mecklenburg, Darss-Zingster Bodden = Darss-Zingster Bodden, Kubitzer Bodden = Kubitzer Bodden, Jasmunder Bodden = Jasmunder Bodden, Strelasund = Strela Sound, Greifswalder Bodden = Bay of Greifswald, Achterwasser = Achterwasser, Stettiner Haff = Szczecin Lagoon/ Bay of Szczecin.
Source: Geodatabase DLM1000 © BKG 2013

Table 2-3

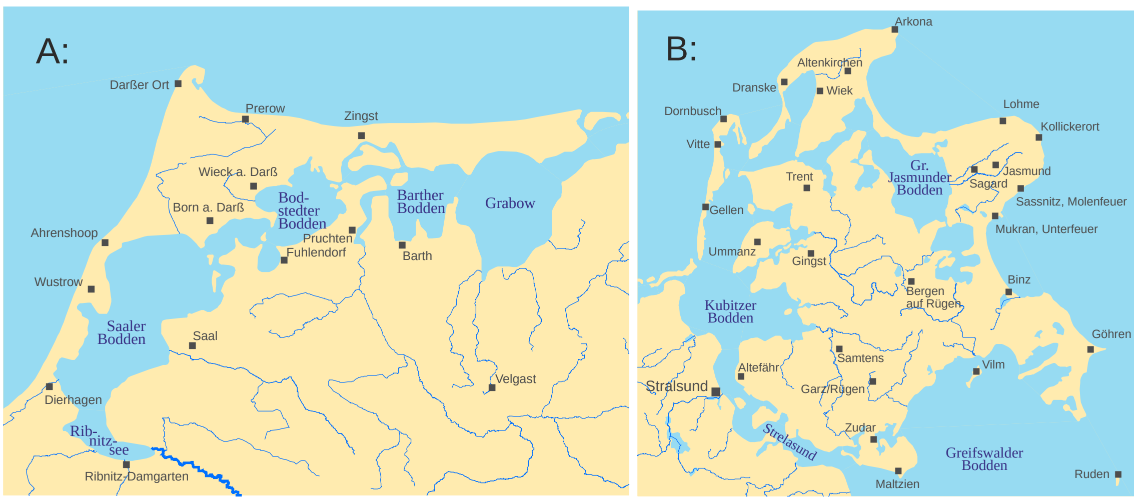
Harbours and leisure boat berths in brackish water

Region	Number harbours	Number berths	Proportion berths (%)	Median berths
Baltic Sea with fjords and salt marsh lagoons	408	42,741	79	57
Kiel Canal	7	466	0.9	40
East Frisian North Sea Coast	7	1,008	1.9	100
North Frisian North Sea Coast	22	1,252	2.3	46
Ems Estuary	4	267	0.5	41
Lower Ems	14	782	1.4	38
Weser Estuary	7	1,276	2.4	162
Lower Weser	19	1,156	2.1	42
Lower Elbe	67	4,894	9.0	31
Peene	5	237	0.4	47
Total	560	54,079	100	-

Almost 80 % of the berths are found at the Baltic Sea coast. These harbours stretch ribbon-like along the coast (Figure 2-13). Here many middle-sized harbours with ca. 150 - 400 berths in the bays (*Bodden*) are situated, especially in the Schlei fjord. The largest harbours, with more than 1,000 berths, are the marinas Heiligenhafen, Hohe Düne Warnemünde and Ancora Neustadt. Four harbours with around 800 berths are found in the Kiel Fjord, Grömitz and Warnemünde. The coast from Flensburg to Lübeck should be designated as one of the largest centres for leisure boats. An additional agglomeration of harbours is situated to the east in the Rostock/Warnemünde area. A special morphological characteristic of the Baltic Sea coast are the bays (*Bodden*) at Darss-Zingst and around Rügen and Greifswald (Figure 2-14). In these protected areas, a large number of smaller harbours is present.

Figure 2-14

Salt marsh lagoon waters - A: Darss-Zingster Bodden Chain with the most significant marinas. B: Salt marshes around Rügen.



Source: Geodatabase DLM1000 © BKG 2013

As in case of the North Sea, *closed* harbours are found predominantly at the Baltic Sea coast, offering protection against wind and waves. Here, closed harbours only represent about 30 % of the recorded harbours. The remaining two-thirds are *open* harbours, especially in bays, fjords and protected salt marsh areas.

From the 408 harbours at the Baltic Sea, the majority (86 %) was classified as marinas, whereas only 14 % of the harbours was classified as *mixed-use* harbours, which also included commercial dockyards, ferries or fishing vessels.

The brackish regions of the North Sea are comprised of the estuaries of rivers or near coast lakes with saltwater inflow. In brackish regions, the harbours have very different structures:

- The Seaport Emden situated in the Ems estuary has a saltwater outer harbour open to the North Sea and a protected brackish inner harbour.
- At the East Frisian coast, harbours are protected but have open tidal gates (Chapter B.1.2.1). Half of them have more than 100 berths. At the North Frisian coast and at the tidal Eider the harbours are also open and have a median of 46 berths. Generally, the sizes of the harbours at the Lower Ems, Lower Weser and Lower Elbe were also small, with median values of 38, 42 and 31 berths, respectively. In Bremerhaven and the Weser estuary the marinas and mixed-use harbours are situated behind locks and are much larger (median value: 162 berths) compared to harbours at other brackish sites.
- Two-thirds of the harbours on the Lower Ems have open structures, while only one-third at the Lower Weser and half at the Lower Elbe are open. The total number of berths is largest at the lower section of the Elbe, with about 4,900 berths. At Wedel, the largest German marina is situated, with approximately 2,100 berths.

2.1.6.3 Freshwater

By far the largest portion of the German marinas is found at freshwater sites, approximately 71 %. The marinas are predominantly located at rivers (approx. 40,000 berths) and lakes (approx. 29,000 berths). At lake-like river sections (river lakes), around 67,000 berths were recorded. A regional focus for these river lakes is the Mecklenburg lake area as well as the Spree-Dahme-Havel region in Berlin and Brandenburg, where small lakes, rivers and canals form a dense network of waterways and therefore represent a popular leisure boat area. The berth numbers of the individual regions and main river sections are summarised in Table 2-4.

Due to the nature of things, sailing boats are predominantly found at lakes and river lakes, while motorboats dominate at rivers and canals. At rivers, either closed harbours in natural bays or backwaters, man-made marina basins or open pontoons along the bank can be found. There, the leisure boats are often packed close together.

Table 2-4

Marinas and leisure boat berths in freshwater

Region	Number harbours	Number berths	Proportion berths (%)	Median berths
Lower Rhine	165	10,656	7.3	50
Middle Rhine	62	3,804	2.6	45
Upper + Higher Rhine	186	11,043	7.5	48
Baden-Württemberg lakes	6	284	0.2	42
Rur Dam	32	2,238	1.5	62
Ems Estuary	15	852	0.6	50

Region	Number harbours	Number berths	Proportion berths (%)	Median berths
Lower Ems	16	479	0.3	30
Upper Ems	16	977	0.7	34
Lower Saxony lakes	50	4,995	3.4	80
Lower Weser	46	2,913	2.0	40
Middle Weser	32	2,308	1.6	41
Upper Weser	39	3,031	2.1	60
Lower Elbe	73	4,569	3.1	40
Middle Elbe	127	4,905	3.3	30
Upper Elbe	12	319	0.2	21
Schleswig-Holstein lakes	72	2,911	2.0	34
Peene	11	485	0.3	42
Lower Oder	12	194	0.1	15
Mecklenburg lake area	433	18,846	12.9	31
Middle + Lower Havel	382	23,096	15.8	47
Berlin water bodies	185	10,550	7.2	50
Brandenburg water bodies	125	6,521	4.5	42
Lausitzer lakeland	18	648	0.4	28
Danube	28	1,203	0.8	29
Lakes of the alpine foothills	126	10,393	7.1	59
Lake Constance	77	12,630	8.6	112
Dortmund-Ems Canal	21	1,289	0.9	35
Mittelland Canal	21	1,098	0.7	39
Grand Canal d'Alsace	10	494	0.3	40
Rhine-Main-Danube Canal	10	409	0.3	36
Oder-Havel Canal	62	2,285	1.6	24
Total	2,470	146,425	100	-/-

Open marina facilities are usually situated at lakes. In some areas, they are packed close together, like in Berlin. In the immediate vicinity of marinas, also single pontoons are found at single water properties.

This study tried to identify and separate single marinas and pontoon facilities as commercially or association units (water sport clubs, private or municipal ownership). However, this was not always successful based on the available data and without additional on-site checks. Particularly in areas with a high marina density, which have small waterside properties, open pontoons were situated so close to each other that it was not always possible to separate them accurately based on aerial photos or other data sources. These areas were therefore grouped together, so that the number of the smallest marinas has been underestimated in favour of somewhat larger harbours. The number of total berths in a region is however, not affected. From the median values, it is clear that the harbours with the largest number of available berths can be found on Lake Constance (Table 2-4).

2.2 Detailed survey of 50 selected marina (AP 2)

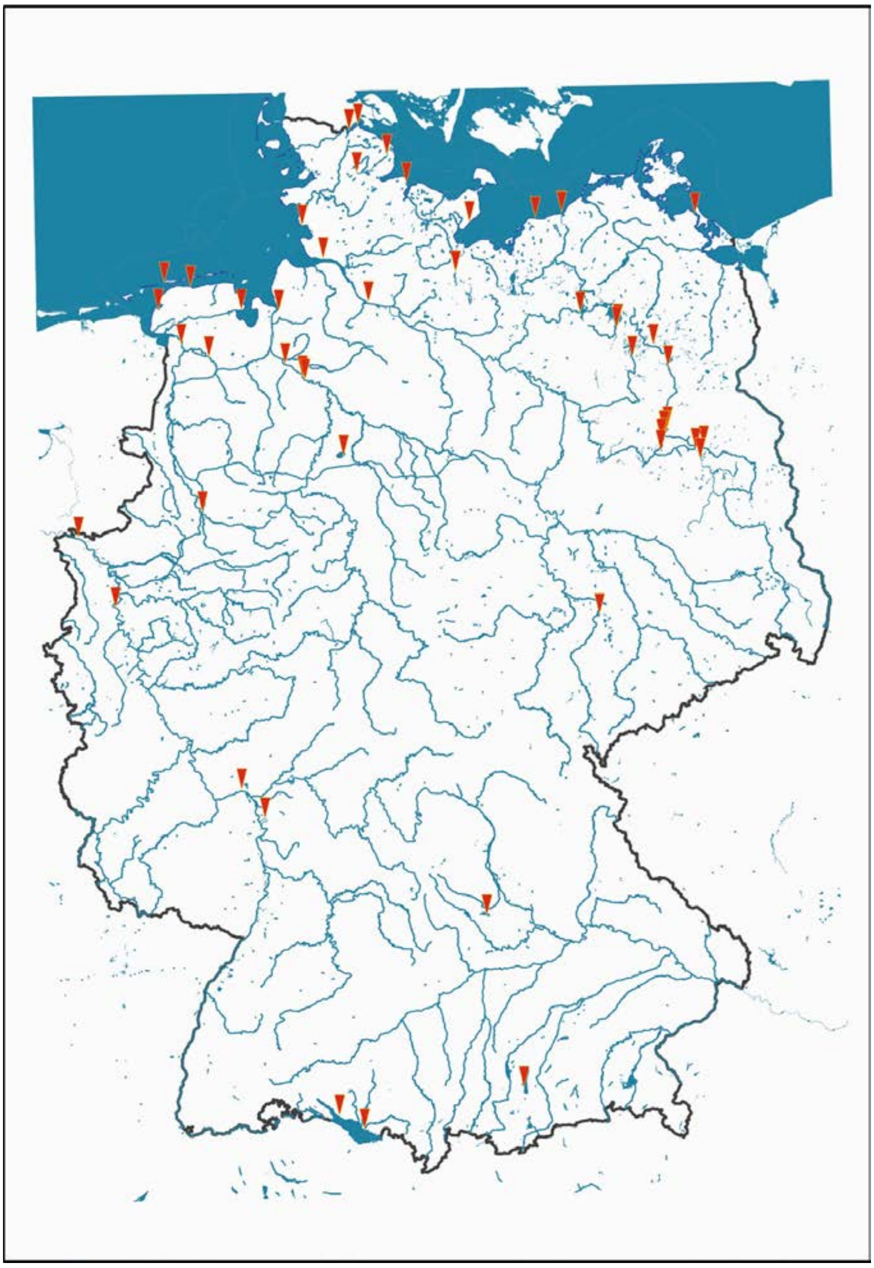
Based on the results in work package AP 1, the following criteria were used when selecting marinas for the detailed survey and water-chemical screening in work package AP 2:

- Open and closed marina
- Marinas with small to large water volumes
- Marinas with few up to many berths
- Marinas with high and low water flow.

In total, 50 harbours were selected for the detailed survey, whereby the regional distribution of the harbours in fresh-, brackish and saltwater was also in line with the results of AP 1. For the screening, 34 sites in freshwater, 11 in brackish water and 5 in saltwater were selected (Figure 2-15).

Figure 2-15

Location of the marinas selected for AP 2



Source: Federal Environment Agency 2013, Base map: Geodatabase DLM1000 © BKG 2013

Table 2-5

Harbours selected for AP 2

Nr.	Datensatz AP1	Koordinaten N,E		Name des Hafens	Bundesl.	Salinität	offen	geschlossen	Gewässer	LP AP1	Hafentyp	Stegplan	Referenz-probe
1	6	53°42'09.37"	7°09'57.27"	Seglerverein Norderney	NI	1		x	Nordsee	270	Sportboothafen	x	
2	14	53°40'49.20"	7°29'20.31"	Yachtclub Accumersiel, Dornumersiel	NI	1		x	Nordsee	250	Sportboothafen	x	
3	26	53°30'35.29"	8°07'03.56"	Marina Cramer, Wilhelmshaven	NI	1	x		Jadebusen	70	Sportboothafen		
4	718	53°53'38.18"	9°07'32.38"	Brunsbütteler Segelvereinigung, Brunsbüttel	SH	1		x	Elbästuar	115	Sportboothafen		+
5	52	54°07'23.86"	8°51'51.43"	Büsumer Seglerverein, Büsum	SH	1		x	Nordsee	100	Sportboothafen	x	+
6	571	53°30'34.27"	8°34'42.10"	Nordsee Yachting Kuhlmann, Bremerhaven	NI	2	x		Weserästuar	280	Sportboothafen		
7	796	53°34'23.69"	9°40'38.88"	Yachthafen Wedel, Hamburg	HH	3		x	Unterelbe	2100	Sportboothafen	x	+
8	84	54°48'39.17"	09°27'14.38"	Marina Sonwik, Flensburg	SH	2	x		Ostsee, Flensburger Förde	370	Sportboothafen	x	+
9	89	54°51'27.36"	09°34'16.84"	Club Nautic, Glücksburg	SH	2		x	Ostsee, Flensburger Förde	169	Sportboothafen	x	
10	113	54°38'00.53"	09°55'50.14"	Wassersportgemeinschaft Arnis	SH	2	x		Schlei (nördl.)	275	Sportboothafen	x	
11	148	54°30'26.22"	09°32'58.08"	Wiking Yachthafen, Schleswig	SH	2	x		Schlei (südl.)	360	Sportboothafen	x	
12	164	54°25'49.84"	10°10'16.00"	Olympiahafen Kiel- Schilksee, Kiel	SH	2		x	Kieler Förde, Schilksee	860	Sportboothafen	x	
13	204	54°08'08.48"	10°56'49.26"	Yachthafen Grömitz	SH	2		x	Ostsee, Lübecker Bucht	786	Sportboothafen	x	
14	261	54°09'09.79"	11°46'11.31"	Bootshafen Kühlungsborn	MV	2		x	Ostsee	400	Sportboothafen	x	
15	265	54°10'53.15"	12°05'56.54"	Yachthafen Hohe Düne, Warnemünde	MV	2		x	Ostsee,Warnow Mündung	772	Sportboothafen		+
16	414	54°07'19.53"	13°45'32.97"	Marina Kröslin	MV	2		x	Peenestrom, Krösliner See	500	Sportboothafen		
17	2223	51°50'14.33"	6°13'30.32"	Yachthafen Emmerich	NW	3		x	Rhein	420	Sportboothafen		+
18	546 & 547	53°10'08.03"	7°43'59.84"	WSC Soeste und Bootshafen Barßel	NI	3	x		Unterems	30	Sportboothafen		
19	648	53°00'35.81"	8°54'07.74"	Wieltsee Hafen, Dreye	NI	3		x	Mittelweser	450	Sportboothafen	x	
20	2233	51°20'11.86"	6°41'32.05"	Crefelder Yachtclub, Krefeld	NW	3		x	Rhein	110	Sportboothafen	x	+
21	2732	52°02'46.31"	7°41'14.06"	Alte Fahrt Yachthafen Marina Fuestrup, Greven	NW	3		x	Dortmund-Ems-Kanal	150	Sportboothafen		
22	646	53°02'13.03"	8°52'10.24"	Wassersport-Zentrum Oberweser, Bremen	HB	3		x	Weser	240	Sportboothafen		
23	2838 & 2840	52°27'41.49"	9°21'50.43"	Segelclub Salzdetfurth & Steinhuder Seglervereinigung	NI	3	x		Steinhuder Meer	705	Sportboothafen		
24	632	53°07'24.16"	8°39'59.52"	Yachthafen Hasenbüren, Bremen	HB	3		x	Weser	560	Sportboothafen		
25	530	53°15'52.03"	7°23'33.43"	Luv up, Jemgum	Ni	2		x	Unterems	59	Sportboothafen		
26	519	53°30'08.80"	7°06'00.41"	Yachtclub Greetsiel	NI	3	x		Emsästuar	80	Sportboothafen	x	
27	2781 & 2786	53°46'46.66"	10°45'35.48"	Segler-Verein Wakenitz & o. Steganlage Schanzenberg2, Ratzeburg	SH	3	x		Ratzeburger See	195	Sportboothafen		
28	1986	52°25'12.68"	13°34'54.74"	Bootsservice Dross, Berlin	BE	3	x		Spree-Oder-Wasserstraße	50	Sportboothafen		
29	2020	52°26'09.13"	13°40'53.38"	SV Rahnsdorf 1926 , Berlin-Rahnsdorf	BE	3	x		Müggelsee-Die Bänke	70	Sportboothafen		
30	1907	52°21'04.71"	13°38'02.11"	Bootshaus Roll, BB-Zeuthen	BB	3	x		Zeuthener See, Dahme	136	Sportboothafen		
31	1748	52°35'33.84"	13°15'53.24"	Seglervereinigung Tegel, Berlin	BE	3	x		Große Malche, Tegeler See	65	Sportboothafen		+ '+
32	1771	52°33'35.06"	13°14'19.99"	Bootsstände Lahe, Berlin	BE	3	x		Tegeler See	130	Sportboothafen		
33	1675	52°30'37.26"	13°12'14.15"	Bootscenter Keser , Berlin	BE	3		x	Pichelssee	84	Sportboothafen		+
34	1667	52°30'37.90"	13°11'21.43"	Seglerverein Scharfe Lanke, Berlin	BE	3	x		Scharfe Lanke, Havel	70	Sportboothafen		
35	1626	52°25'19.37"	13°10'14.35"	Potsdamer Yachtclub, Berlin Wannsee	BE	3	x		großer Wannsee	147	Sportboothafen		+'+
36	1690	52°30'33.42"	13°12'36.70"	Yachthafen Stößensee Captain`s Inn (nur Verein), Berlin	BE	3	x		Havel	80	Sportboothafen		+
37	1782	52°34'17.28"	13°13'20.00"	Wannseaten 1911	BE	3	x		Aalemannkanal/ Tegeler See	126	Sportboothafen		
38	1317	53°01'55.38"	13°18'41.90"	Alter Hafen Mildenberg, Zehdenick	BB	3		x	Havel	28	Sportboothafen		
39	1277 & 1278	53°11'17.73"	13°08'54.74"	Stadtanleger Fürstenberg & Fürstenberger Yachtclub	BB	3	x		Havel	115	Sportboothafen		
40	986	51°15'48.08"	12°20'38.09"	Cospudener Yachtclub, Cospuder See, Leipzig	SN	3	x		Cospudener See	215	Sportboothafen		+
41	1346	53°06'57.96"	12°53'17.67"	Hafendorf Rheinsberg	MV	3		x	Rheinsberger See	282	Sportboothafen		
42	1143 & 1144	53°19'49.92"	12°42'55.72"	Müritz, Rechlin (2 Vereine + Bootsschuppen)	MV	3	x		Müritz	201	Sportboothafen	x	
43	1141 & 1142	53°21'20.09"	12°43'40.54"	Hafendorf Müritz & Bootsschuppen, Claassee	MV	3		x	Classee	439	Sportboothafen		
44	1080	53°27'15.43"	12°16'35.60"	Segelschule Plau, Plau	MV	3		x	Plauer See	140	Sportboothafen		
45	2455 - 2461	50°02'24.15"	8°11'41.17"	Schiersteiner Hafen, 7 Vereine zusammengefasst, Wiesbaden	HE	3		x	Rhein	571	Sportboothafen		
46	2477 & 2478	49°50'16.40"	8°27'15.95"	Yachtclub Erfelden u. Yachtclub Darmstadt	HE	3		x	Rhein, Altrhein	115	Sportboothafen		
47	2912	47°52'11.26"	11°17'36.40"	Marina Bernried, Starnberg-Bernried	BY	3	x		Starnberger See, Voralpensee	234	Sportboothafen		
48	2897	49°07'28.64"	10°55'45.53"	Hafen Ramsberg	BY	3		x	Brombachsee, Voralpensee	420	Sportboothafen		
49	3022	47°35'16.46"	9°33'33.56"	Ultramarin Meichle Mohr Marina Kressbronn, Obersee	BW	3		x	Bodensee	1599	Sportboothafen		+
50	3017	47°40'58.63"	9°17'22.43"	Yachtclub Meersburg	BW	3		x	Bodensee	80	Sportboothafen		

Salinity: 1=salt, 2=brackish, 3=fresh

The operators or owners of the marinas were asked for their approval before sampling. They received assurance that single analytical results of the screening are published without specific site data.

These marinas were subject of an additional on-site survey on number of berths, number of leisure boats actually at berth and harbour infrastructure. Water samples were taken and analysed for the active substances currently in use in antifouling products as well as for further water quality parameters. Sampling and mapping took place nationwide from June to August 2013.

Using aerial photos, further possible emission sources for pollutants were identified on some sites near the harbour, which could represent possible sources of AF active substances. Therefore, additional reference samples were taken at these sites in order to obtain measurements outside of the examined marinas and if necessary to identity biocidal inputs from other emission sources. Additional water samples were also taken in the middle of the water bodies in four bays of Berlin waterways where many water sports take place. An overview of the selected marinas for AP 2 is given in Table 2-5.

2.2.1 Detailed data for harbour infrastructure

During the detailed investigation of the marinas in AP 2, the number of berths was locally registered again and, if possible, a distinction was made between berths reserved for residents, for guests or for short time anchoring, in order to determine the number of used berths at the sampling day. For a few marinas plans of the jetties were available, to identify residents at berth. Rarely also size data of the leisure boats was available. In most marinas, type and length of boat were registered by local inspection. All locally registered information was documented in specific marina data sheets.

In 35 of the 50 marinas, the number of berths counted in AP 2 was similar to the number of moorings counted in AP 1 with a maximum difference of 5 %. In 14 marinas, the number of berths deviated downwards by more than 5 %, in some up to 16 - 50 %. In some of these marinas, current changes in the mooring structure were apparent compared to the aerial photographs interpretation conducted in the previous year. Compared to the previous year, finger pontoons or whole pontoon parts were removed. According to the operators, the number of boats was decreasing, in parts due to the competition with new marinas, such as in Schleswig. Instead of using finger pontoons, the boats were now moored along the pontoons. In four of the 14 marinas, other published berth data (e.g. regional sources, ADAC guide) led to a higher berth number. Only the number of berths in the Schiersteiner Hafen (Wiesbaden) turned out to be higher in the on-site count than in AP 1, with an additional 56 berths. The operator had recently built additional moorings there.

The marinas Luv up Jemgum and Marina Kramer were still classified as *mixed use* marinas in AP 1. Locally it turned out that the marina in Jemgum is now used only by leisure boats. The Marina Cramer is also solely used as a marina for leisure boats. In AP 1, neighbouring pontoons were counted as well, which are used commercially by third parties for commercial shipping purposes. For further evaluation in the working package AP 2, only Marina Cramer was included.

At Steinhuder Meer, Ratzeburger See, Lake Constance and waters around Berlin, individual pontoons were identified, where small sailing boats (dinghies) and leisure crafts are stored in boatlifts within the mooring box above the water line. Using aerial photography, it is impossible to differentiate this type of storage from water moorings. Interestingly, it was noted that these boats were also painted with antifoulant. This was most striking in the Marina Ultramarin (Lake Constance), where approx. 50 larger yachts were also stored in boatlifts, although they had antifouling coatings.

It was not possible to detect seasonal differences in the occupancy rate of the marinas using aerial photography. Local inspection did not lead to definite results in all marinas regarding the extent of utilisation. Moreover, during the inspection over the day many leisure boats were in use outside the marina. However, the occupancy rate of berths varied between 41 and 100 %. Especially in the tourist relevant yachting areas with many visitors, e.g. the Baltic and North Sea coast, there are large daily fluctuations in the number of boats (e.g. by approx. 25 %).

2.2.2 Measurements in the field and other water chemistry parameters

Besides the analysis for the biocides from the antifoulants, water samples were used to determine further water quality parameters. The breakdown and dispersion of the active substances are influenced by water parameters such as pH, DOC and TOC and suspended matter content. Furthermore, these parameters are also required by models such as MAMPEC to calculate exposure scenarios.

The methodology of the analyses carried out is described in Chapter A.2.2.

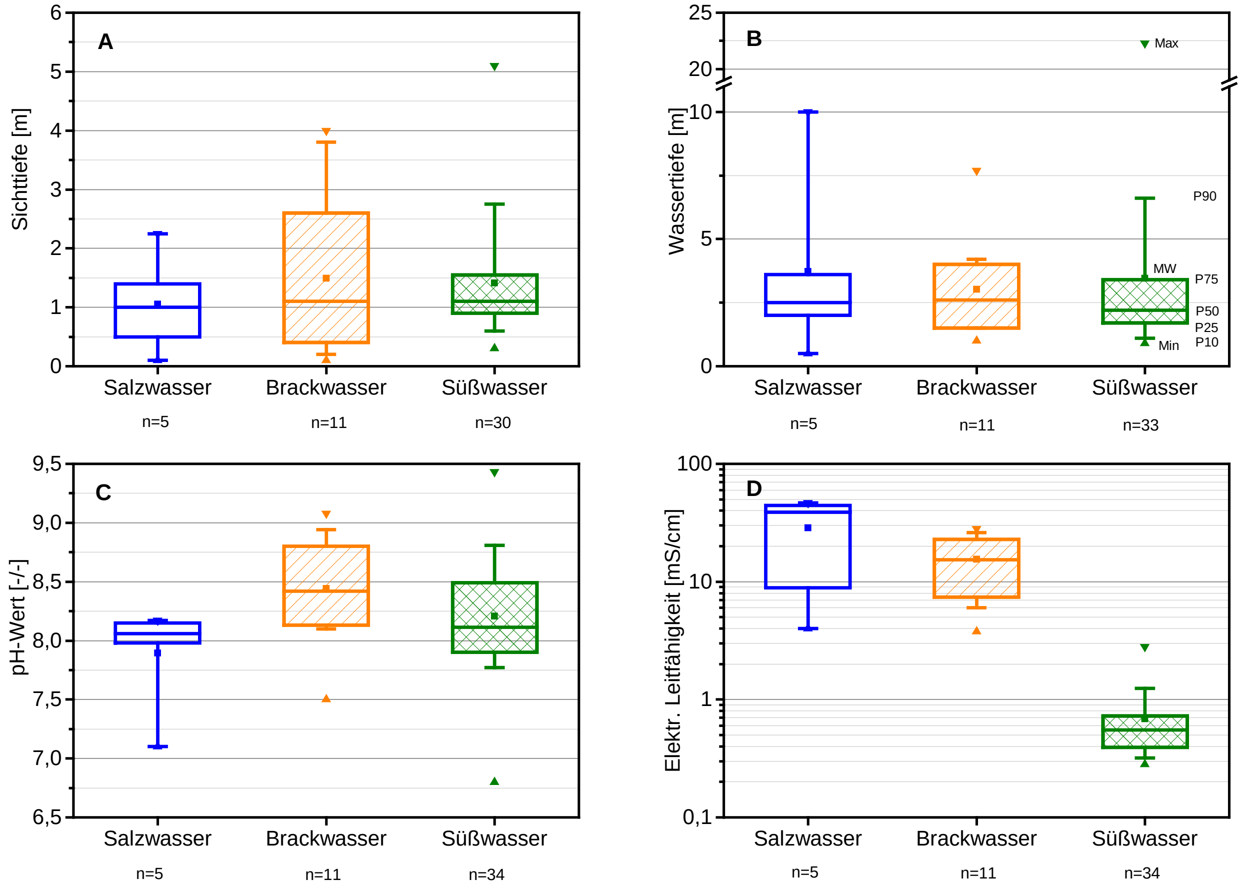
The visibility depth measured in the water of the sampled marinas at salt-, brackish and freshwater sites were overall between 0.4 and 2.5 m (percentile P25, P75), with the greatest variances in brackish water areas (Figure 2-16 A). The water depths at the sampling sites (directly at the pontoons) were between 2 - 3.5 m (Figure 2-16 B). The pH-values differed according to the salinity. In saltwater, the median was 8.06, in brackish water 8.42 and in freshwater 8.14 (Figure 2-16 C).

The electrical conductivity measurements resulted in considerably lower values than expected in some brackish and saltwater marinas (Figure 2-16 D). Due to the fresh water inflow at these sites, e.g. from drainage (tidal outlets), the salt content periodically drops during low tide. Additionally, intense rainfall, as witnessed during one sampling session, can reduce the salinity in a short time. Therefore, a second measurement was carried out during high tide in June 2014, which gave a very similar result. Furthermore, many estuaries show great variation in their salinity. In freshwater, at the time of sampling, conductivity values were determined between 0.3 and 1.7 mS/cm (Cospudener See, a residual lake from opencast brown coal mining) and 2.8 mS/cm (Greetsiel, at the North Sea, behind the dyke with ditch water and water inflow from tidal outlets).

The amount of suspended solids (dry matter (DM) content) was highest in saltwater with a median of 18.4 mg DM/l and dropped in brackish water to 8.1 and 5.7 mg DM/l (Figure 2-17). The highest value was measured in brackish water in the marina Jemgum (tidal area of the lower Ems) with 276 mg DM/l. As expected, larger amounts of suspended solids above 20 mg DM/l were found in the estuaries of the Ems, Weser and Elbe as well as on the sites on the North and Baltic Sea. The freshwater values were between 0.1 und 38.5 mg DM/l. The difference in the medians of fresh- and saltwater was statistically significant (Table B-11, Table B-12).

Figure 2-16

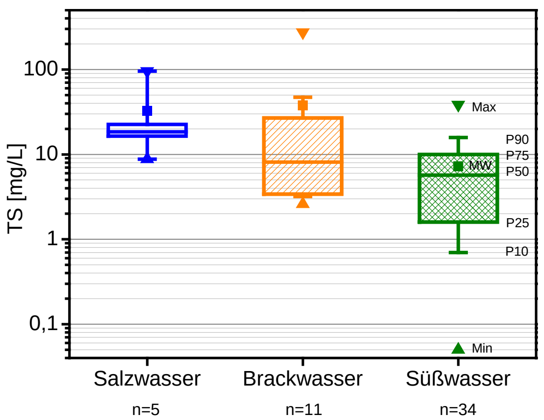
Main statistical data for degree of visibility depth [m] (A), water depth [m] (B), pH-value (C) and electrical conductivity [mS/m] (D) in fresh-, brackish and saltwater marinas



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: Sichttiefe = visibility depth, Wassertiefe = water depth, pH-Wert = pH-value, Elektr. Leitfähigkeit = electrical conductivity. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

Figure 2-17

Main statistical data for total suspended solids [DM/l] in fresh-, brackish and saltwater marinas

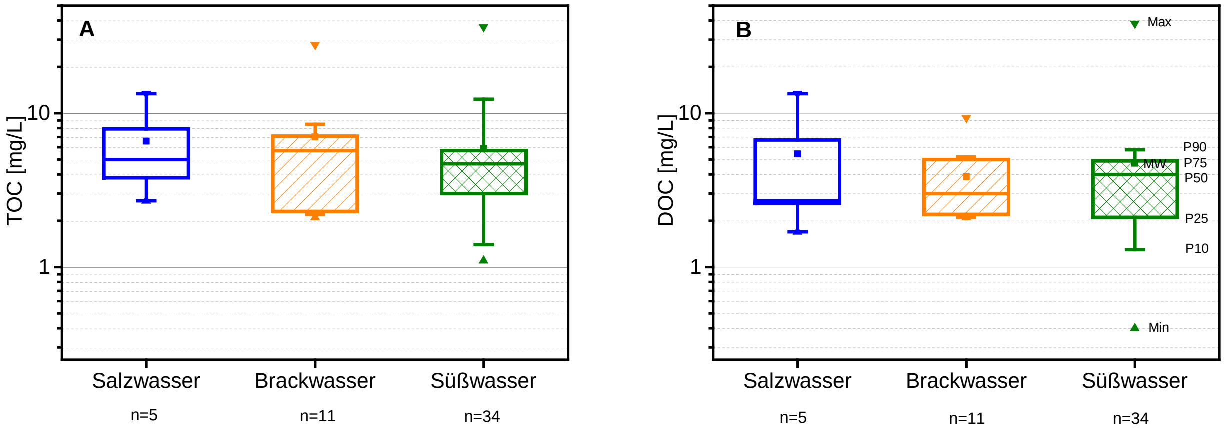


Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: TS = total suspended solids. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

Compared to dissolved organic carbon (DOC) (Figure 2-18 B), the concentrations of total organic carbon (TOC) (Figure 2-18 A) were slightly higher. In saltwater, the median for TOC was at 5.0 mg/l, in brackish waters 5.7 mg/l and in freshwater at 4.7 mg/l (Table B-15). The highest value for TOC/l was in freshwater at 36.3 mg TOC/l.

Figure 2-18

Main statistical data for total organic carbon TOC [mg/l] (A) and dissolved organic carbon DOC [mg/l] (B) in fresh-, brackish and saltwater marinas



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: TOC = total organic carbon, DOC = dissolved organic carbon. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

The concentrations of dissolved organic carbon (DOC) in saltwater were between 1.7 and 13.4 mg/l, in brackish water between 2.1 and 9.3 mg/l and in freshwater between 0.4 and 38.2 mg/l (Figure 2-18 B, Table B-13). The medians of salt-, brackish and freshwater varied between 2.7 mg/l and 4.0 mg/l (Table B-14).

2.2.3 Active substance concentrations

The water samples were analysed for the following active substances of antifoulants:

- Transformation product ETU and EU of the active substance zineb
- Dichlofluanid and its transformation product DMSA
- Tolylfluanid and its transformation product DMST
- DCOIT (Sea-Nine 211®) with its transformation products NNOA, NNOMA and NNOOA
- Pyrithione as sum of zinc and copper pyrithione with its transformation product PSA
- Cybutryne (Irgarol 1051®) with its transformation product M1 (GS26575)
- Terbutryn (not an approved active substance for antifoulants, is used in the terrestrial area for protection against algal growth, e.g. in facade paints, indicator for incoming rain and waste water)
- Copper and zinc

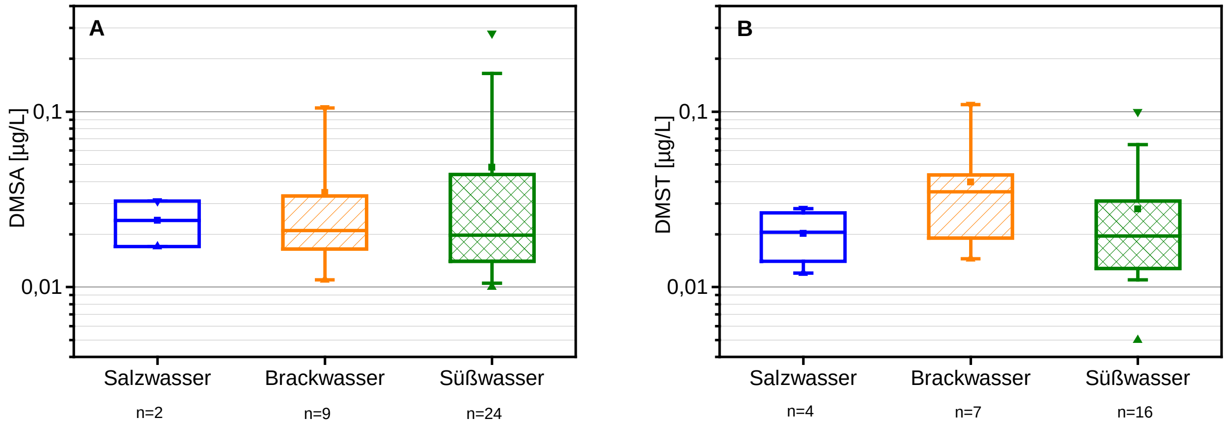
The transformation products ETU and EU of zineb, pyrithione, as well as DCOIT (Sea-Nine 211®) with its transformation products NNOA, NNOMA and NNOOA were below the respective analytical detection limits in all samples (Table A-2, Table A-3).

While the concentrations of dichlofluanid and tolylfluanid were below the analytical detection limit, the concentrations of their transformation products DMSA and DMST were above 0.01 µg/l in 70 % and 56 % of all the marinas respectively (Figure 2-19). In saltwater, DMSA was detected at two sites with 0.031 µg/l and 0.017 µg/l (Table B-19). In brackish water, a maximum of 0.1 µg/l and in freshwater 0.28 µg/l was detected. The medians in general were 0.02 µg/l in brackish water. DMST reached the highest concentration with 0.11 µg/l and the highest median with 0.028 µg/l (Table B-20). In freshwater concentrations of up to 0.10 µg/l were also reached, though the median was only 0.022 µg/l.

The additional sample taken from reference sites were, with one exception, all below the limit of quantification.

Figure 2-19

Main statistical data for DMSA (A) and DMST (B) [µg/l] in fresh-, brackish and saltwater marinas



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Left axis: DMSA = transformation product of dichlofluanid, DMST = transformation product of tolylfluanid. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

In freshwater, cybutryne was detected at 25 of the 34 sites, with a concentration of >0.001 µg/l (Figure 2-20 A). The highest value of 0.110 µg/l was measured in a marina with stagnant water condition. There, the transformation product M1 (Figure 2-20 B) was measured with the highest value of 0.071 µg/l. In total, the M1 concentrations were above the detection limit in 14 of the tested 34 marinas.

In brackish water, cybutryne was detected in 10 marinas in maximum concentrations of 0.029 µg/l. The median was 0.006 µg/l.

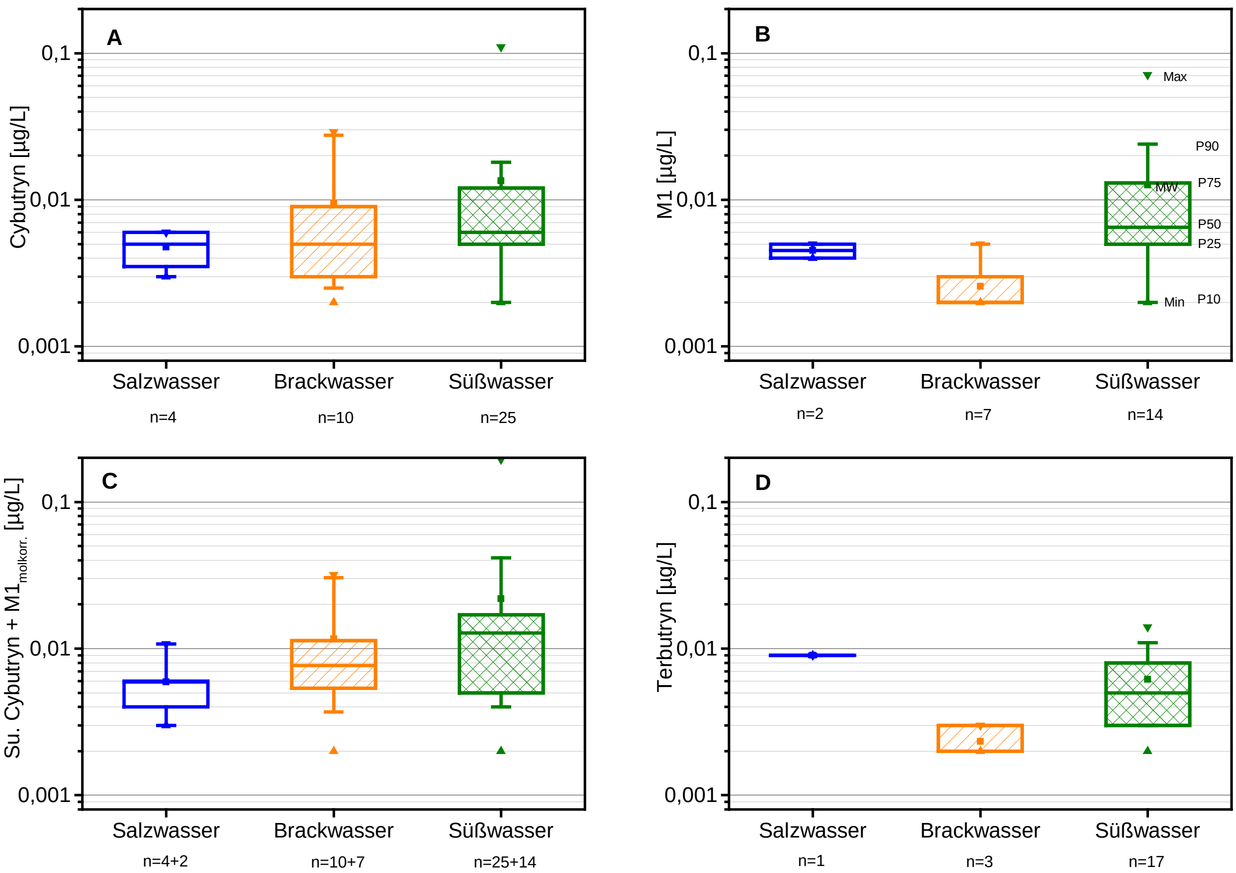
In saltwater the concentrations were only slightly above the limit of quantification with a median of 0.005 µg/l. M1 was also detected at one of the sites with 0.004 µg/l.

M1 is an important and persistent transformation product of cybutryne in surface waters. If the concentrations of cybutryne and M1 are added for the different areas (Figure 2-20 C), the theoretical minimum concentration of cybutryne released by the hulls is calculated. Accordingly, the medians and the 75 and 90 percentiles increase from saltwater to freshwater.

Terbutryn (Figure 2-20 D) could only be identified at a few marina sites. The concentrations of the median values were 0.009 µg/l in saltwater, 0.002 µg/l in brackish water and 0.005 µg/l in freshwater. Interestingly, samples taken at reference sites showed equal or similar concentrations of terbutryn.

Figure 2-20

Main statistical data for cybutryne (A) and M1 (B), sum of cybutryne and M 1 (C) and terbutryn (D) [µg/l] in fresh-, brackish and saltwater marinas

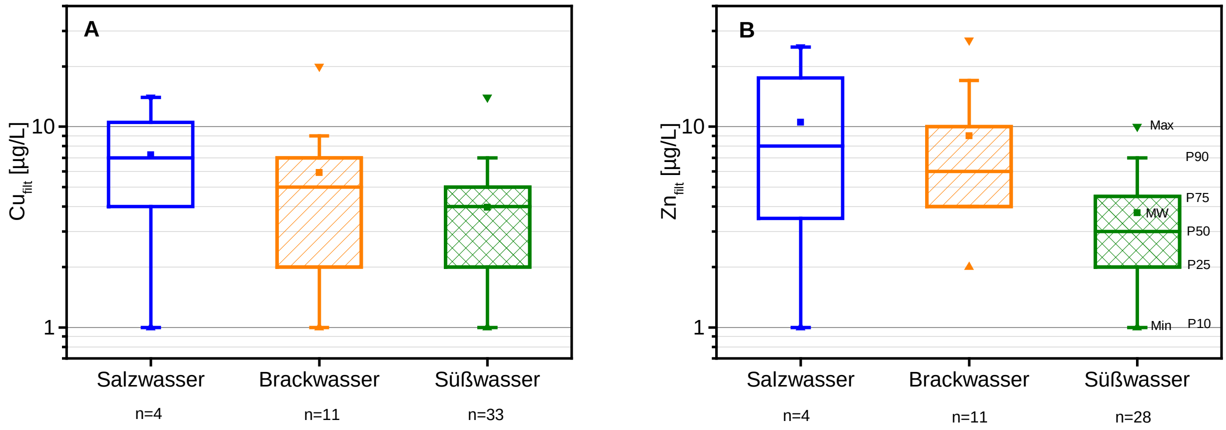


Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Box-Whisker-Plot: Min: Minimum, Max: Maximum, P10, P25, P50, P75, P90: Percentiles, mean value: arithmetic mean, part figure A, B, D: n: Number of marinas with active substance concentrations > BG, C: n: Number of marinas with active substance concentrations > BG differentiated according to cybutryne and M1.
Source: this study, LimnoMar.

The concentrations of the metals copper (Figure 2-21A) and zinc (Figure 2-21B) were highest in saltwater and lower in brackish water and lowest in freshwater, as demonstrated by the comparison of medians, means and percentiles P25 - P75. The copper contents were above the respective quantification limits in nearly all marinas. Zinc could be determined in nearly all the salt- and brackish water sites but only in approx. 80 % of the freshwater sites. Maximum values for copper were 20 µg/l in brackish water and 14 µg/l in salt- and freshwater. The maximum values for zinc in salt- and brackish water were at about 26 µg/l and in freshwater at 10 µg/l. The reference site also had concentrations in the range of 2 - 20 µg/l for copper and 2 - 16 µg/l for zinc, and shows a general background concentration in the water bodies.

Figure 2-21

Main statistical data for copper (A) and zinc (B) [µg/l] in fresh-, brackish and saltwater marinas



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

In four selected centres of Berlin bays, all the biocides had similar concentrations as their adjacent marinas.

2.3 MAMPEC modelling of selected marinas (AP 3)

2.3.1 MAMPEC application for German marinas

It was not intended to evaluate the biocide emissions under the criteria of an environmental risk assessment within this research project. Rather, it was aimed to test to what extent model predictions of the release of antifouling active substances in different marinas at the coast and in inland marinas matched the analytical findings. Therefore, the data of selected exemplary marinas chosen in AP 2 were used as input parameters to run MAMPEC 2.5 for selected biocidal active substances. The position of the marinas was anonymised to assure anonymity.

The following scenarios given in MAMPEC 2.5 were used: a close-to-coast marina (*estuarine marina*), a closed yacht marina at the coast (*marina*) and a yacht marina with inflow from the mainland (*marina 400 m poorly flushed*). In each case, the default values of the model marinas were adjusted to the physical data of the selected marinas. For modelling the environmental conditions, a number of parameters regarding the marina structure and the numbers of boats, the water body and the environmental fate behaviour and degree of application of the various active substances had to be set. These input parameters are described in the Appendix Materials and Methods, Chapter A.3.

2.3.2 Results of the modelling and comparison with AP 2

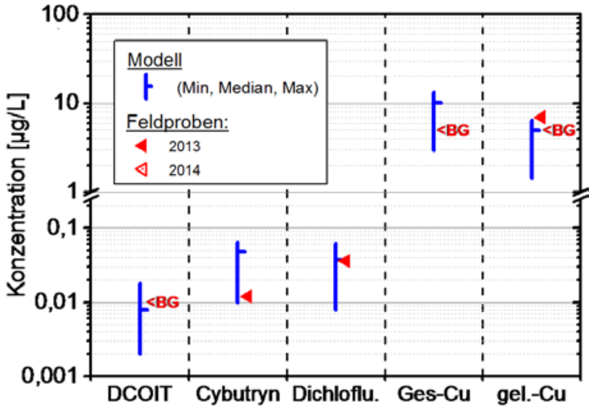
2.3.2.1 Saltwater sites

Two different coastal marinas were selected for the modelling as seawater sites. Marina Sa_1 has a closed inner marina, but the water body has a high exchange rate due to tides. In marina Sa_2, a freshwater stream runs into the marina from the hinterland, during low tide the inner marina is nearly dry. Therefore, the modelling for both marinas resulted in a water exchange rate of more than 200 % per tide.

For marina Sa_1 emissions of 4,158 g/d copper, 41.5 g/d dichlofluanid, 21.6 g/d cybutryne and 20.9 g/d DCOIT were calculated. The predicted freely dissolved concentrations in MAMPEC were between 6.50 µg/l max and 1.44 µg/l min, with a median of 4.93 µg/l for freely dissolved copper, while the measured concentration of the filtered water sample was 7 µg/l, which is beyond the prediction range (Figure 2-22, Table B-25). The predicted total copper concentrations were about twice as high as the freely dissolved copper content, so that the real measurement of <5 µg/l was between median and minimum. The predicted freely dissolved concentrations of dichlofluanid were between 0.008 µg/l and 0.061 µg/l and a median of 0.037 µg/l. This was in line with the measured value of 0.036 µg/l. The predicted freely dissolved concentrations of cybutryne were between 0.01 µg/l and 0.064 µg/l, with a median of 0.048 µg/l. The measured concentration was slightly higher than the minimum reaching 0.012 µg/l. For DCOIT, MAMPEC calculated freely dissolved concentrations ranging between 0.002 µg/l and 0.018 µg/l, with a median of 0.008 µg/l. Here, the measured the value was below the limit of quantification of 0.01 µg/l.

Figure 2-22

Marina Sa_1 - predicted freely dissolved concentrations [µg/l] by MAMPEC (blue) compared to analytical results obtained during the survey in AP 2 (red)

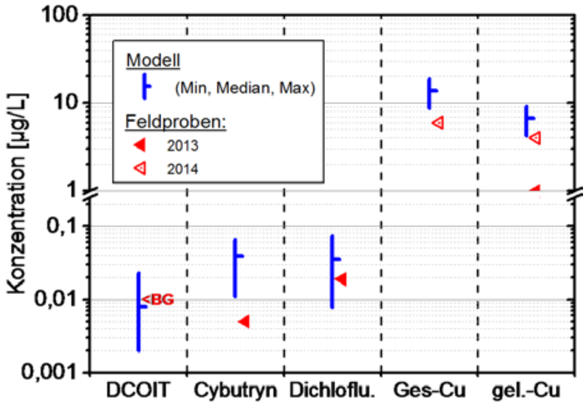


Legend translation: Modell = model results, Feldproben = samples. Left axis = Konzentration = concentration.
Source: this study, LimnoMar.

In marina Sa_2 total emissions of 1,839 g/d copper, 18.3 g/d dichlofluanid, 9.9 g/d cybutryne and 9.3 g/d DCOIT were calculated. The MAMPEC model predicted a freely dissolved concentration range between 4.20 µg/l and 9.21 µg/l, with a median of 6.74 µg/l for copper. In the model predictions, the background values of the reference standard sample were taken into account (Figure 2-23, Table B-26). Both, the measured values of the survey and an additional measurement in 2014 were below the predicted minimum, reaching 1 µg/l and 4 µg/l, respectively. The measured total copper concentration was 6 µg/l, therefore, well below the predicted total copper concentration range of 8.62 µg/l to 18.9 µg/l. For dichlofluanid, a freely dissolved concentration range between 0.074 µg/l to 0.008 µg/l was predicted, with a median of 0.036 µg/l. The measured concentration was within this range reaching 0.019 µg/l. For cybutryne a freely dissolved concentration range between 0.011 µg/l and 0.066 µg/l was predicted, whilst the analytical finding was below this range reaching only 0.005 µg/l. The modelled freely dissolved concentration spanned for DCOIT from 0.002 µg/l to 0.023 µg/l, whereas the real measurement was within this range of values at <0.01 µg/l.

Figure 2-23

Marina Sa_2 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



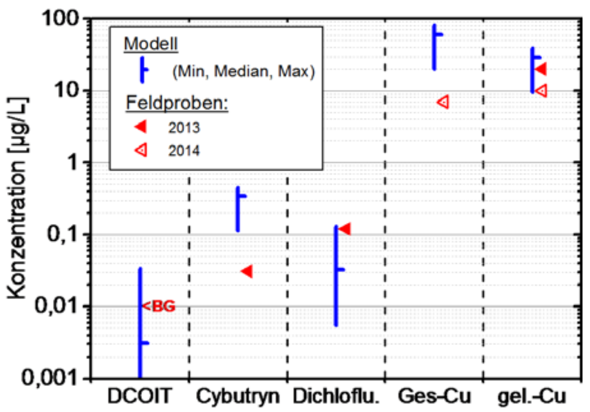
Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

2.3.2.2 Brackish water sites and sites influenced by tides

The marina Br_1, situated in brackish water, formed a closed marina with a water exchange rate of 35 % and a relatively high number of boats compared to its water volume. The MAMPEC predictions of total emissions were 10,973 g/d for copper, 109.6 g/d for dichlofluanid, 56.8 g/d for cybutryne and 55.1 g/d for DCOIT. The predicted range of the total copper concentration was between 19.7 µg/l and 81.1 µg/l, with a median of 60.2 µg/l (Figure 2-24, Table B-27). The measured concentration was below this range. The predicted concentrations for freely dissolved copper were between 9.6 µg/l and 39.5 µg/l. The water analyses revealed 20 µg/l and was therefore between the minimum and the predicted median of 29.4 µg/l. For dichlofluanid, the model predicted a freely dissolved concentration range between 0.006 µg/l and 0.131 µg/l. Here, the measured concentration nearly equalled the predicted maximum. In contrast to this, a measured concentration for cybutryne of 0.031 µg/l was below the predicted freely dissolved concentration range of 0.113 µg/l to 0.455 µg/l. For DCOIT, the predicted freely dissolved concentration range was between 0.0002 µg/l and 0.034 µg/l, while the concentration in the water sample of the marina was below the limit of quantification of 0.01 µg/l.

Figure 2-24

Marina Br_1 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)

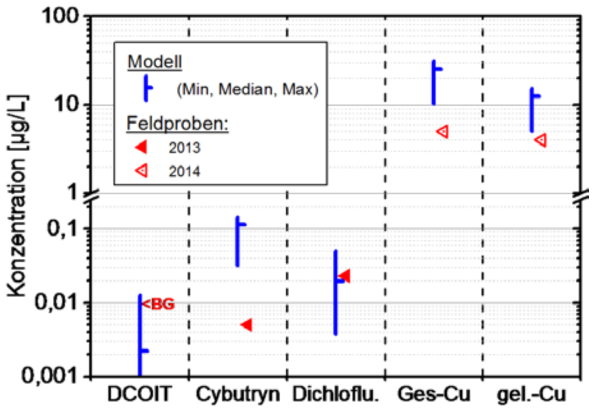


Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

Like Br_1, the marina Br_2 was highly occupied by leisure boats but due to tidal differences, the water exchange volume per tide reached nearly 72 %. Due to the very high number of berths, there were very high daily emissions for marina Br_2 with 19,824 g copper, 197.4 g dichlofluanid, 108.9 g cybutryne and 100.2 g DCOIT. The predicted freely dissolved concentrations for all considered biocides were, however, lower than in marina Br_1 (Figure 2-25, Table B-28).

Figure 2-25

Marina Br_2 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



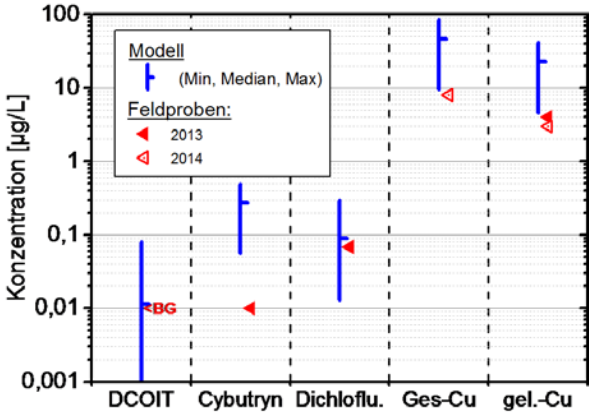
Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

A total copper concentration between 0.3 µg/l and 31.2 µg/l was predicted for marina Br_2, with a median of 25.3 µg/l, while the measured concentration was 5 µg/l and therefore below the predicted minimum. Nearly half of the total copper concentration was predicted as freely dissolved copper, whereas the measured concentration of 4 µg/l was just below the calculated minimum. The measured concentration for dichlofluanid of 0.023 µg/l was just above the predicted median of 0.020 µg/l. For cybutryne, the predicted freely dissolved concentration was between 0.032 µg/l and 0.15 µg/l (median 0.114 µg/l). In this case, the measured concentration was one order of magnitude smaller than the prediction. For DCOIT, the maximum predicted freely dissolved concentration was 0.013 µg/l, which was slightly above the limit of quantification, which was not determined during the survey.

Both, the marinas Br_3 and Br_4 are designed as open marina. However, due to the different water flow regime, the exchange rates were higher in marina Br_3 (33 %) than in Br_4, which was situated behind a sluice gate. Furthermore, the predicted daily total emissions were approx. five times higher due to the higher number of berths in marina Br_3 compared to marina Br_4.

Figure 2-26

Marina Br_3 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



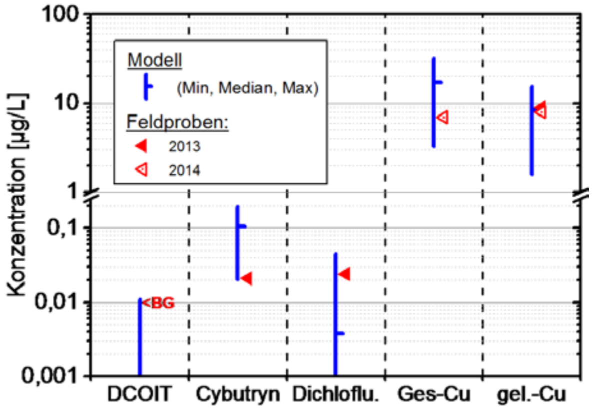
Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

For marina Br_3, a total emission of 3,718 g copper, 37.0 g dichlofluanid, 20.5 g cybutryne and 18.8 g DCOIT per day was predicted by MAMPEC. For total copper, a concentration range between 9.5 µg/l and 85. µg/l min was calculated, with a median of 46.5 µg/l, while the measured concentration of 8 µg/l was still below the minimum (Figure 2-26, Table B-29). For freely dissolved copper, a concentration range between 4.6 µg/l and 41.5 µg/l was predicted, with a median of 22.7 µg/l. Here as well, the measured concentration of 4 µg/l was quite low. The measured concentration of dichlofluanid was 0.067 µg/l and ranged between the predicted minimum and median freely dissolved concentration. The model derived maximum freely dissolved concentration for dichlofluanid was 0.3 µg/l. For cybutryne, considerably high freely dissolved concentrations were predicted, between 0.056 µg/l and 0.495 µg/l, compared to the real measured value of 0.010 µg/l. For DCOIT, a predicted freely dissolved concentration range was between 0.001 µg/l and 0.081 µg/l and a median of 0.011 µg/l. In comparison, the analytical limit of quantification was <0.01 µg/l.

In marina Br_4, the predicted total emissions were 766 g/d copper, 7.6 g/d dichlofluanid, 4.6 g/d cybutryne and 3.9 g/d DCOIT. The maximum predicted total concentrations were 32.0 µg/l for copper and 0.19 µg/l for cybutryne. The measured concentrations of both biocidal active substances ranged between the predicted median values and the minimum concentrations, with 7 µg/l for total copper and 0.021 µg/l for cybutryne (Figure 2-27, Table B-30). The measured dissolved concentration for copper equalled with the predicted median freely dissolved concentration. The DCOIT concentrations in the marina were below the analytical detection limit. The predicted freely dissolved concentrations were also very low with 0.011E-6 - 2E-6 µg/l. Dichlofluanid, however, was measured in the marina with a concentration of 0.024 µg/l, which ranges between predicted median and maximum. The predicted freely dissolved concentration range was between 0.0002 µg/l and 0.050 µg/l.

Figure 2-27

Marina Br_4 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

2.3.2.3 Freshwater sites

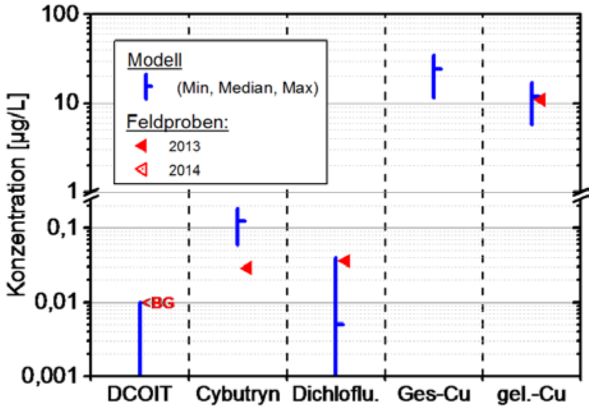
For modelling in freshwater, the selection criteria focussed on marinas with a relevant size and high number of moored boats or with a well-dyked water body matching the existing scenarios implemented in MAMPEC.

The marina Sü_1 is as a former quarry with a very large water volume. For this well-embanked marina with a narrow entrance, a low water exchange rate of 3 % per 12.4 hours was calculated. The high user number of leisure crafts also resulted in high predicted daily emissions of 14,125 g copper, 140.6 g dichlofluanid, 77.9 g cybutryne and 71.4 g DCOIT.

The model outcome for total copper concentrations was between 11.7 µg/l and 35.0 µg/l, with a median of 24.4 µg/l (Figure 2-28, Table B-31), whereas for freely dissolved copper concentrations a range between 5.7 µg/l and 17.1 µg/l was predicted. Here, the calculated median of 11.9 µg/l almost equals the measured concentrations in the marina. For cybutryne, a freely dissolved concentration range between 0.059 µg/l and 0.181 µg/l was predicted, whereas only 0.029 µg/l were measured in the water. However, for dichlofluanid, the measured concentration of 0.036 µg/l was slightly below the maximum predicted freely dissolved concentration of 0.04 µg/l. For DCOIT the predictions were below the analytical limit of quantification.

Figure 2-28

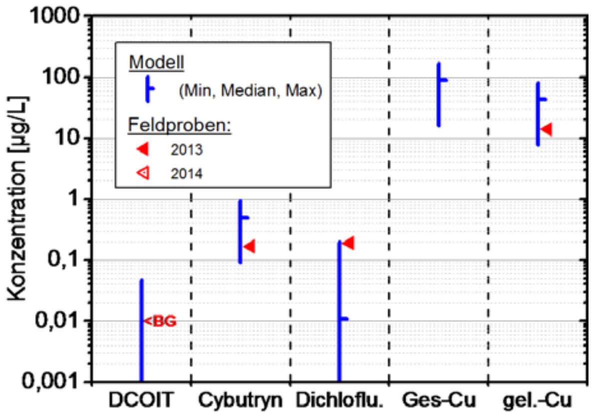
Marina Sü_1 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

Figure 2-29

Marina Sü_2 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

For marina Sü_2, a low water exchange rate of 7.8 % per 12.4 hours was calculated by use of MAMPEC, which corresponded to the low-flow condition in a dead-ending side arm of a canal. For this marina, daily emissions of 1,405 g copper, 14 g dichlofluanid, 7.8 g cybutryne and 7.1 g DCOIT were calculated.

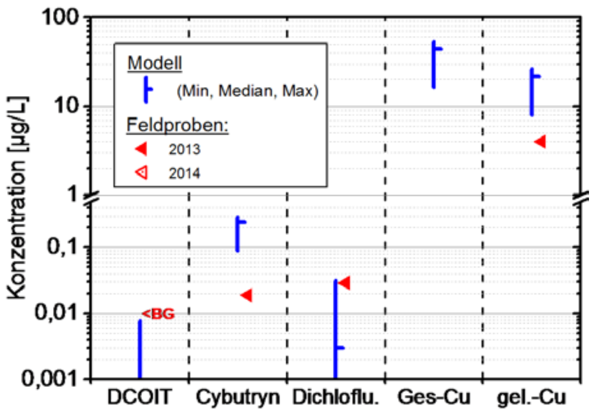
Due to a special local situation, MAMPEC modelled high concentrations of total copper (16 - 168 µg/l), freely dissolved copper (7.8 - 81.9 µg/l) and dissolved cybutryne (0.091 - 0.945 µg/l) (Figure 2-29, Table B-32). The measured concentrations of cybutryne and freely dissolved copper were slightly above the predicted minima. Here, again, the measured concentration of dichlofluanid was slightly below the predicted maximum of 0.20 µg/l, whereas the predicted minimum was only 0.0004 µg/l. The predicted concentration range of DCOIT was between 1.84E-6 and 0.047 µg/l, whereas the measured concentration was below the limit of quantification.

The marina Sü_3 is the home for several leisure boat clubs and is situated at the river Rhine. For this marina, a water exchange of 14.8 % per 12.4 hours was calculated. The predicted emissions per day were 5,460 g copper, 54.3 g dichlofluanid, 30.9 g cybutryne and 27.7 g DCOIT.

For total copper a concentration range between 16.5 µg/l and 53.8 µg/l was predicted, with a median of 44.2 µg/l (Figure 2-30, Table B-33). The measured concentration of dissolved copper was 4 µg/l and was below the predicted freely dissolved concentration range of 8.0 - 26.3 µg/l. For cybutryne, the measured concentration of 0.019 µg/l was also below the minimal predicted concentration of 0.090 µg/l. The maximum predicted concentration was 0.296 µg/l cybutryne. The concentrations for dichlofluanid ranged from 0.0003 to 0.036 µg/l. Here again, the measured concentration was slightly below the predicted maximum concentration (0.029 µg/l). The predicted concentration of DCOIT was very low with 0.008 µg/l (max), and in the marina, the values of the biocidal active substance were below the limit of quantification.

Figure 2-30

Marina Sü_3 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



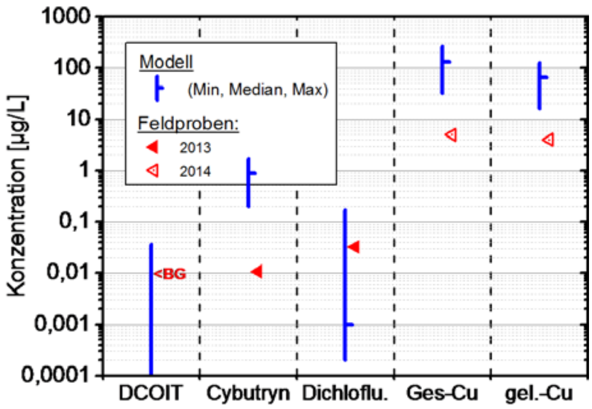
Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

A bight of a river-lake in Berlin with its many small leisure boat clubs was taken as a unit for modelling (Sü_4). The lake receives fresh water through a small inflow. A tongue that narrows the bay to approx. 180 m width was chosen as the lower end of the bay. Therefore, the lake section cannot be seen as a closed marina. The model run revealed a low water exchange rate of 2.1 % per 12.4 hours for this bight. The predicted emissions were 5,378 g/d copper, 53.4 g/d dichlofluanid, 31.3 g/d cybutryne and 27.4 g/d DCOIT.

Compared to all other sites, highest copper and cybutryne concentrations were predicted in this marina. They ranged between 32.4 and 264 µg/l for total copper, between 15.8 and 129 µg/l for freely dissolved copper and between 0.20 and 1.71 µg/l for cybutryne (Figure 2-31, Table B-34). In comparison, the measured concentrations from samples taken in the middle of the lake were all far below the predicted minima, especially for cybutryne. The predicted concentration for dichlofluanid ranged between 0.0002 and 0.17 µg/l, whereas the measured concentration of 0.033 µg/l was between the predicted mean and maximum. The DCOIT concentration ranged between 3E-9 and 0.036 µg/l, covering the analytical limit of quantification of 0.01 µg/l.

Figure 2-31

Marina Sü_4 - predicted water concentrations [µg/l] by MAMPEC (blue) compared to analytical results detected during the survey in AP 2 (red)



Legend translation: Modell = model results, Feldproben = samples. Left axis: Konzentration = concentration.
Source: this study, LimnoMar.

3 Discussion

3.1 Nationwide census of leisure boats in Germany

3.1.1 Initial situation

In Germany, there is no obligatory central registration for leisure boats. A registration can take place locally at the Water- and Shipping Authorities. However, on this level there are regional registration and identification obligations, which are laid down in specific shipping ordinances. Examples are the Bavarian lakes, the Lake Constance, the Ratzeburger See and Berlin waterways.

Often, the registration data are not updated so that vessels that are no longer in use are still registered. Furthermore, the registered address of the boat owner does not indicate the location of the vessel mooring.

Existing surveys about the numbers or estimates of the numbers only exist for certain regions (PLANCO 2008, IGKG 2011), or are based on extrapolated surveys (Chapter 3.1.2). Therefore, this project focussed on aerial photography for the nationwide analysis.

For the nationwide survey at hand, boats at berth were counted as well as unused berths, because aerial photographs from the winter half year were also analysed, when only a few boats were moored. In addition, it was impossible to differentiate clearly between guest and resident berths. While doing so, it was assumed that all the berths were in use by leisure boats during the high season. This should be the case for marinas with a high number of resident berths as well as for marinas with a high number of guest berths. For the latter, the occupancy rate can be considered lower during the low season.

The number of cruising boats, which were on the way during season sometimes even outside German waters, could not be determined. However, it was assumed that during this period, guests from other regions used the locally vacant berths.

Berths clearly identified as moorings for rowing boats, small sailing dinghies, etc., were not counted in this study. In addition, dinghies stored onshore during the season where excluded from the census. For those boat types, it was assumed that antifoulants were normally not applied.

Locally at individual pontoons, small boats such as dinghies or fishing boats are stored in boatlifts within the mooring box above the water surface. By use of aerial photography only, it is impossible to identify this type of storage. Leisure boats stored outside marinas and launched by trailer and slipway could also not be registered. Overall, it is assumed that their share of the total number is relatively low.

At the North Sea and Baltic coast and the adjacent estuaries, the marinas are quite well registered and documented by the maps of the BSH or marina guides. Furthermore, they could be easily identified and analysed using aerial photography. It can be assumed that all these sites were registered, and all the berths were recorded quantitatively. In the inland, it was difficult to identify and quantify the smallest marinas, single pontoons or *one-boat-marinas*, which are scattered throughout the region. Therefore, at least 1000 moorings or boats have not been identified. Single moorings at lake and river riparian zones covered with trees were difficult or impossible to identify on aerial images. It was also difficult to assess the number of moorings inside boathouses (cf. Chapter B.1.2.9).

In some places, it is also common to store boats outside on private grounds and to trail them to water bodies at weekends and during holidays. The number of the so-called *trailer captains* is difficult to assess. On a request at the Kraftfahrzeug-Bundesamt (Federal Motor Vehicle Transport Authority), about 16,911 boat trailers were registered in the year 2011, 16.640 in 2012 and 16.525 in 2013 (Jürgensen, pers. com.). Thus, about 16,000 - 17,000 additional trailer boats were assumed as a maximum theoretical number, which is probably an overestimation.

Overall, the approach of berth counting is a very good approximation of the inventory of leisure boats. On the one hand, there are certainly too few boats registered, as in some marinas there are more boats than moorings and because some isolated boat moorings were not counted, on the other hand, not every marina has an occupancy of 100 %. To assess the amount of unregistered moorings, the statistical distribution of the marina sizes was analysed (berth numbers). Using this approach, the error can be set at between 6,800 (approx. 3 %) and 20,000 (approx. 10 %) berths.

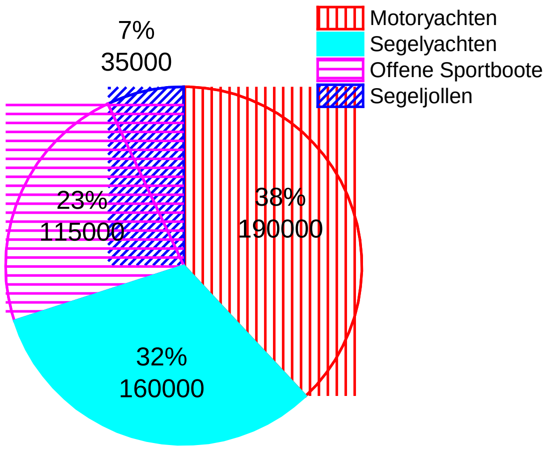
3.1.2 Nationwide total number of berths compared with other studies

Within the framework of this study, a total number of 206,000 berths was determined, which equals approximately the number of leisure boats nationwide (Chapter 2.1.1.1). These findings were taken from aerial photographs that originated mainly from 2009 to 2012.

The number mined here is considerably below the published numbers of leisure boats in Germany to date. Mell (2008) published extrapolations based on interviews, according to which Germany has an inventory of around 500,000 leisure boats in 2008 (Figure 3-1), of which about 300,000 represented motor boats and 200,000 sailing boats. Nationwide about 320,000 berths were extrapolated by Mell, who compared his figure with the outcome of 150,000 counted berths from official sources such as the Wassertourismus-Guide (www.vivawasser.de).

Figure 3-1

Number of leisure boats and number according to boat type based on surveys and approximations



Source: Mell 2008

In the study at hand, berths clearly used by smallest boats (like rubber dinghies, dinghies without antifoulant) were not taken into account. Furthermore, an unknown but small number of German boats are moored outside of Germany during the season, e.g. in the Netherlands or the Mediterranean Sea. Furthermore, it can be assumed that some marinas have more boats than berths. If only the sum of motor crafts and sailing yachts from Figure 3-1 are taken, this already amounts to 350,000 boats requiring mooring sites. Therefore, it can be assumed that this total number has to be considered as an overestimation due to the methodology used (see above).

In addition, the Federal Ministry of Transport (2014) stated a much larger number of leisure boats with an estimated 750,000 leisure crafts in its yearly report on traffic investment. There is no references given as to what those estimates are based on.

According to the Federal Water- and Shipping Authorities, there are about 4.8 million people practicing water sports, of which 1 million are sailors and 1.2 million motor boat drivers (www.wsv.de, BMVI, 2011).

However, the marinas recorded in the ADAC Marina Guide (2010) only had approx. 67,000 berths. Other sources, such as the WTG Törnplaner also present a limited selection of harbours and marinas.

Furthermore, in recent years some regions are showing a decline in the number of leisure boats, especially in boats <7.50 m length, whereas the number of boats >12 m has increased slightly. The reason for this, among others, is the demographic aging of the water sportsmen (PLANCO 2008).

Conclusion: The data at hand differs considerably from data presented in other known studies, which seems to base on overoptimistic extrapolation. This study publishes a well-founded census of the berths in Germany for the first time.

3.1.3 Situation in other countries

Table 3-1

Berths and number of boats in selected European countries

Country	Berths	Leisure craft	Motor boats	Sailing boats
Germany	206,279(1)	approx. 500,000(7)	300,000(7)	200,000(7)
The Netherlands	38,941(2)	n.d	n.d	n.d
Denmark	46,082(3)	n.d	n.d	n.d
Switzerland	93,018(4)	n.d	n.d	n.d
France	117,848(2)	n.d	n.d	n.d
Italy	n.d	608,000(5)	503,000(5)	n.d
Greece	n.d	154,666(5)	132,000(5)	3,800(5)
Sweden	n.d	881,000(6)	660,000(5)	105,000(5)
Finland	48,000(6)	737,000(5)	102,000(5)	247,650(5)
Norway	n.d	600,000(6)	n.d	n.d
Great Britain	n.d	694,000(5)	n.d	n.d
Croatia	n.d	205,786(5)	n.d	n.d

Source: (1) this study, (2) ADAC Marinaführer 2010, (3) PLANCO 2008, (4) Vereinigung der Schifffahrtsämter Schweiz 2013, (5) Fritsch, YACHT pers. com. (6) Gerstrøm, Danish sailor association, pers. com., (7) Mell 2008, n.d.: no data

A comprehensive listing of leisure craft and the berths in yacht marinas and on pontoons are only available from other European countries or worldwide as internet files, where individual marinas can be selected, such as: http://www.portbooker.com. This lists numerous marinas, however, it offers no overview of the total number of berths or boats in the individual countries. Only Switzerland has good documentation of their number of boats. According to this, the number of boats has risen until 1988 and since then is falling slightly again, whereby the number of motor boats constantly increases against the sailing boats. For 2012, in total 93,000 leisure boats are registered, excluding rowing boats and pedal boats (Vereinigung der Schifffahrtsämter Schweiz 2013). For Denmark, own rough counting of the berths within the framework of this study resulted in a sum of 45,000, PLANCO (2008) states 46,082 berths for 2003 (Table 3-1).

Reliable data for France and the Netherlands could not be found. An unproven source states 180,000 berths for the Netherlands. The sum of all listed berths in marinas from the ADAC marina guide (2010) stated for the Netherlands only 38,941. Similar to Germany, the actual number will be far higher, as only ADAC member marinas are listed. The basis of the data for other European countries is also considered as not reliable. The data on the inventory of leisure boats for Scandinavia, Great Britain and the southern European countries are enormously high in comparison to the berths in Germany and should be interpreted with great caution.

In summary, the impression arises that, like Germany, other European countries also have insufficient databases regarding their national number of boats and that numbers of berths, and boats may be based on projections.

3.1.4 Regional comparison with other studies

3.1.4.1 Greater Berlin

Table 3-2

Comparison of the boat numbers in Greater Berlin using aerial photographs from 2003/2006 and 2012

Section of water ways	1st count	2nd count
Upper Havel	4,580	4,474
Lower Havel	7,735	7,890
Spree (mouth to Schleusendamm)	5	60
Spree (Schleusendamm to Dahme / Müggelspree	613	793
Müggelspree / Oder to Spree canal	3,283	3,394
Dahme from Spree mouth to Neue Mühle	6,149	6,602
Total	22,365	23,213

Source: Count 1: German Environment Agency, unpublished, Count 2: this study.

An inventory on leisure boats of the greater area of Berlin was also done in 2010 (German Environment Agency, unpublished). Apart from moorings also the boats were recorded according to their current position (marina, on waterways, on-shore) and size. Geo-information services freely available in the internet were used, whereby aerial images dated from the years 2003 to 2006. In Table 3-2, these results are compared with those collected as part of the current project. Therefore, the area of Berlin was separated into six sections. Both counts are based on aerial photographs and were carried out by different persons using different image material but applying a similar method. Compared to the elder census, the recent one identified a surplus of about 850 berths, which is an increase of 3.8 %. This growth could be seen as a method error. However, it cannot be excluded that, by use of more current image material, the number of boats has slightly increased in this subsequent period of 5 - 6 years. As there were slight differences in the design of the borders between the sections of waterways, here the counts of individual sections differ more than those of the total count.

To summarize, by using the same method for this greater area with approx. 22,000 leisure boats, the error or difference is less than 4 %.

3.1.4.2 Region on the East Frisian North Sea coast

For the East Frisian coast, there have been only two investigations so far regarding the number of leisure boats and their activity. Grünewälder (1979) counted 2,486 berths in 24 marinas between Weser and Ems in 1978. The Deutsche Küsteninformation e.V. (1994) gave detailed information regarding berths in marinas along the North Sea coast in a short overview in 1994. A comparison of the berth numbers from 1978 with those of 1994 and the present survey (Table 3-3) demonstrates the development of this area over time. Many marinas were extended and restructured, so that the number of berths increased to nearly double the amount (4,595 berths).

Table 3-3

Numbers of berths along the East Frisian coast over time from 1979 to 2012

Harbour	1979 (Grünwälder 1979)	1994 (Küstenkalender 1994)	2012 (own survey)
Ditzum	20	25	20
Emden outer harbour	83	86	77
Greetsiel	24	50	80
Borkum	116	150 (+ 110 GB)	360 (2 sites)
Juist	44	44	182
Norddeich	80	270	270
Norderney	184	300 (+150 GB)	270
Neßmersiel	70	60 (+5 GB)	59
Baltrum	56	30 (+20 GB)	110
Accumersiel	230	200 (+30 GB)	250
Langeoog	170	202 (+115 GB)	240
Bensersiel	181	186	220
Neuharlingersiel	0	12	35
Spiekeroog	10	120 (+80 GB)	130
Harlesiel	110	140 (+30 GB)	192
Wangerooge	36	120	110
Horumersiel / Wangersiel	150	200	200
Hooksiel (2 sites)	220	400 (+50 GB)	680
Rüstersiel (3 sites)	123	No information	172
Wilhelmshaven (6 sites)	250	100 (+10 GB)	442
Dangast	64	60 (+5 GB)	76
Varel	110	135 (+20 GB)	240
Fedderwardersiel (2 sites)	137	142	160
Eckwardersiel	18	No information	20
Total berths	2486	3657	4595

GB = guest berths

3.1.5 Special features of marinas at the coast

The majority of the marinas on the coast are designed as *port of refuge*, sheltering the boats from wind and waves. Therefore, with more than 70 % *closed harbours*, with a considerable amount of dyking, dominated the saltwater sites at the North Sea (Figure 2-7). Thus, their amount was considerably larger than those of the brackish (35 %) or freshwater sites (21 %). Equally, the share of marinas with special infrastructure (e.g. lifts, wharfs) with 77 % (Figure 2-8), and the share of mixed use with fisheries or ferries with 47 % (Figure 2-6) was considerably higher than in brackish or freshwater sites.

Due to this protective character, the tidal range and the larger vessels, the marinas of the mid- range (P10 - P90) were considerably larger (2,400 - 36,500 m^2), and offered more berths (25 - 230), and a larger theoretical water surface per leisure boat (74 - 236 m^2 per boat) than brackish or freshwater sites (Table B-1, Table B-3, Table B-5). In particular, small and extremely large marinas were only found in brackish and freshwater sites.

3.1.6 Berth distribution

One reason for the large amount of berths on freshwater sites is most likely the very large network of German waterways, which can also be used by leisure boats. The federal and national waterways have a length of approx. 10,000 km and are navigable by leisure boats. This network makes Germany one of the most interesting water sport areas in Europe. These waterways also interconnect with other European waters, including the North Sea and Baltic Sea as well as the Black Sea and Mediterranean Sea. The Berlin area stands out in particular as a large leisure craft area, since here a high population density meets a landscape rich in rivers and lakes, which can be optimally used for water sports. The same can be said for the area around Lake Constance and the lakes of the alpine foothills, forming a recreational area for the nearby large cities.

In comparison to the urban areas, the population density on the coast is sparse. Furthermore, the North Sea is a difficult area for sailing. This explains the low number of berths at saltwater sites. However, the marinas profit highly from boat tourism (Chapter 3.1.7).

In contrast to the North Sea, the Baltic Sea offers excellent sailing conditions. There is a tight network of marinas in Schleswig-Holstein, which is also very interesting for sailors exploring inland and coastal waterways. The distances to the neighbouring marinas are very easy to manage with a maximum distance of 20 nautical miles. Furthermore, within this area there are plenty of alternative marinas available (PLANCO 2008). New berths have been created mainly in Mecklenburg-Western Pomerania. A site concept for marinas at the Baltic Sea coast of Mecklenburg-Western Pomerania that is in place since 1995 (Ministerium für Arbeit, Bau und Landesentwicklung Mecklenburg-Vorpommern, 2004) played an important part in this. In the concept for 2003, an existing number of 14,566 berths were determined in a detailed survey of the marinas and berths on the Baltic Sea coast of Mecklenburg-Western Pomerania. In order to fulfil the forecast, additional requirements for berths and to create further stage marinas to close gaps in the network, some marinas were enlarged or newly built, such as the yacht marina Kühlungsborn with 400 berths. The regional census in the present study determined 18,684 berths for the year 2012. Thus, the current number is below the expected requirement of 21,625 berths for the year 2015 as pinpointed in the site study by the state Mecklenburg-Western Pomerania, it shows however an enormous growth in the last decade. Furthermore, new marina constructions are planned on the Baltic Sea coast, such as the marina Olpenitz on the mouth of the Schlei fjord planned for 2,500 vessels.

3.1.7 Boat tourism during the water sport season

Recording the berths, as was done in this study, does not equal the number of boats in the respective clubs. Many clubs have a low number of available guest berths. On the Baltic Sea coast and especially on the North Sea coast, the permanent berth holders represent the minority of the boats. The marina Norderney, for instance, has 90 permanent berths as opposed to 270 berths in total. In peak times during summer holidays, even this number is insufficient and the boats are raft moored, fixed at sheet piling or moored near to other commercially used vessels.

During the summer months, the Baltic Sea in particular is a popular holiday destination for boat tourism, with vessels even coming from far away such as the Ruhr area and Berlin. Especially the coast of Mecklenburg-Western Pomerania has experienced a positive development. Until 1990, Schleswig-Holstein had an undisputed top position in this market segment, where the demand could never be met by the available supply. With the German reunification, Mecklenburg-Western Pomerania has been made available as a new water sport area. As a result, the diversity of the marinas on offer has improved, on the one hand, but on the other hand, it has created new internal German competition for guest skippers and permanent berth holders (PLANCO 2008).

Internationally, Germany's Baltic Sea coast has regained lost ground in the water tourism sector. This is seen in the declining number of German water sport enthusiasts in Danish marinas and the slowly rising number of Scandinavian visitors in German marinas (PLANCO 2008). Alone in the first ten years following re-unification, the number of Scandinavian visitors dropped by more than 10,000 guest boat nights. Also in the last few years, the number of German water sports enthusiast visitors in Denmark has dropped, although not as strongly. Visitors from Schleswig-Holstein increasingly visit Mecklenburg-Western Pomerania instead of Denmark. That means: the gains of Mecklenburg-Western Pomerania were largely losses for Denmark and Sweden.

3.1.8 Boat types and their use

Using aerial images to identify berths for pleasure boats, it is impossible to differentiate between berths for residents or guests. Therefore, it is helpful to take a closer look at the different habits and behaviours of the water sport enthusiasts. The following aims at making this clearer by differentiating between motorboat and sailing boat skippers.

3.1.8.1 Motor boats

During a meeting in November 2011 (Deutsche Bundesstiftung Umwelt, Osnabrück), which highlighted the question of cleaning leisure boat hulls as an alternative to biocidal antifouling coatings, the environment officer of the Deutsche Motor Yacht Verband (DMYV) Dr Utzelmann (Utzelmann, 2011) attempted to typecast motor boat enthusiasts into the following categories:

- Regatta and race boats without berths, the boats are only launched for the regattas and are not coated with antifoulants.
- Trailer boats are only launched on the weekends or for the holiday and are not protected by antifouling systems.
- Glider and semi-planer are moored during the entire season; these boats are mostly moved little and are protected with antifouling coatings.
- Displacer, type *holiday apartment*. These boats have a fixed berth and are used as a holiday home, terrace and in holiday time as a travel boat. The sailing frequency, however, is relatively low and a number of these boats are also in the water in winter. They regularly have antifouling coatings.
- Displacer, type *travel boat*. These boats are used for travel in changing water bodies. They do not have a fixed berth but they are commonly in the water over winter. Without exception, they have antifouling coatings.
- Travel boat with permanent berth in club marina.

3.1.8.2 Sailing boats

From our own perspective and experience of the authors, it is possible to create comparable profiles and typecasting. Here the following subgroups can be differentiated:

- Dinghies, catamarans, skiffs and racing yachts are not on berths but rather in dry berths or on trailers. They are not treated with antifouling systems. Usually, their activity is high.
- Sailing boats, type *tea time boat* of all size classes, mostly as common yachts from 7 - 14 metres. They are moored in the water to berths like pontoons or buoys for the entire season (March to November). They move around relatively little, are used as weekend home and for sociable gatherings. Without exception, they have antifouling coatings.
- Sailing boat type *regatta participant, travel boat*. Here, boats of all size classes are found, the majority, however, has a length between 7 - 14 m. A smaller share is boats of 15 to more than 25 metres length. They are frequently moved for club or class regattas. Furthermore, especially during summer months, they are used as travel boats and can leave their berths for a longer period. This switch between resident and guest berths can take place at the weekend, but also during holiday travel time. Often boats switch between fresh-, brackish to seawater areas. Examples are the Baltic

coast with special focus points on the Schlei, the bays of Kiel and the areas of Lübeck, Rostock and around Rügen. During the summer months, there are sometimes so many guests in the marinas that they surpass the number of permanent berth holders. This type of boat is also usually antifoulant coated, and in the water from March to November. Winter storage is usually dry storage on land.

It has to be added to the above rough description of the behavioural differences of people in water sports, that a growing proportion of the boats is chartered out, especially sailing boats. Charter boats therefore have an untypically high level of activity and are less often bound to the charter marina.

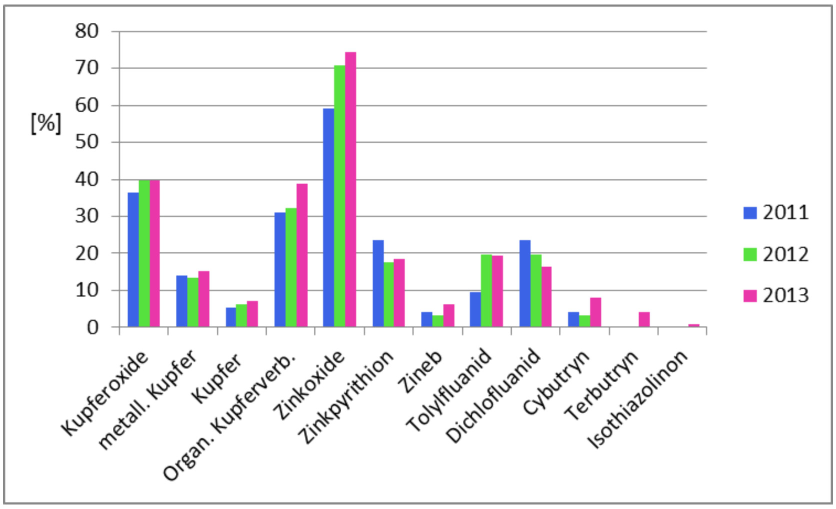
3.2 Detailed survey of 50 selected marinas (AP 2)

3.2.1 Antifouling biocides in marinas

As described in Chapter 2.2.3, the water concentrations of some antifouling biocides were below the analytical limit of quantification. The results for the biocide DCOIT (= isothiazolinone) and the transformation products of zineb are not surprising, as these biocides are used mainly in antifoulants for commercial shipping and have not yet been used in leisure boat products, as can be seen in Figure 3-2 (LimnoMar 2013).

Figure 3-2

Share of different antifouling biocides in [%] of the number of antifouling products available on the German market in 2011, 2012 and 2013



Bottom axis: Kupferoxide = copper oxide, metall. Kupfer = metallic copper, Kupfer = copper, Organ. Kupferverb. = organic copper compounds, Zinkoxide = zinc oxide, Zinkpyrithion = zinc pyrithion, Zineb = zineb, Tolylfluanid = tolylfluanid, Dichlofluanid = dichlofluanid, Cybutryn = cybutryne, Terbutryn = terbutryn, Isothiazolinon = isothiazolinon.
Source: Bewuchs-Atlas 2011, 2012, LimnoMar 2013

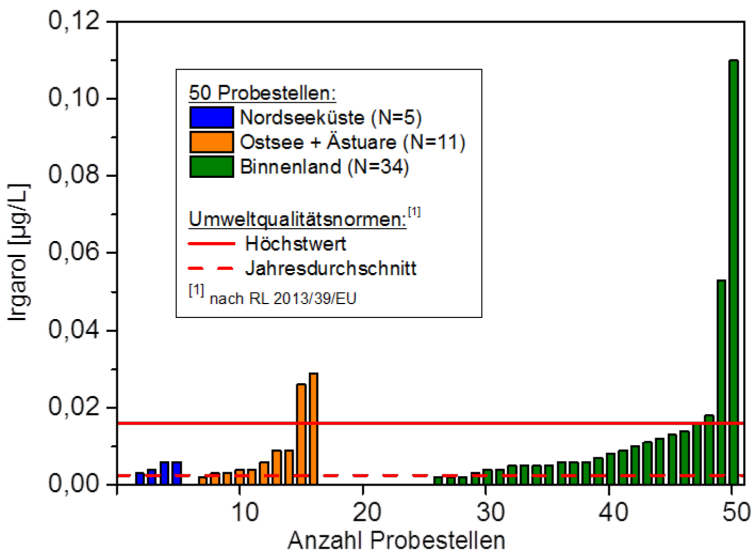
An annual product list records the antifoulants available on the German market for the leisure boat area (Bewuchs-Atlas 2012; LimnoMar 2013). Using these lists, an attempt has been made to represent the share of active substances in antifoulants on the total number of biocidal antifoulant products. In most products between two to four biocides are present.

In water, dichlofluanid and tolylfluanid have a short half-life (DT50: approx. 3 h - 2 d and 1.6 - 6 h) and were not detected above their limits of quantification. The transformation products DMSA and DMST, however, could be detected as they are relatively stable in water (DMST: DT50 42.1 - 75.8 d) and therefore point to recent emissions in 2013. The transformation products DMSA and DMST were observed at all salinity ranges. These degradation products, however, are not ecotoxicologically relevant in the concentration ranges found. Similarly, the analytical proofs of copper and zinc in the filtered samples are representative for their use in antifoulants of leisure boats (Chapter 3.2.5). However, these metals could also enter the aquatic environment by many other emission sources. If an effect threshold value (PNEC: Predicted Environmental Effect Concentration) of about 8 µg/l for both zinc and copper, known as the so-called HC5 according to the EU risk evaluation (ECI 2008, EU 2010), is exceeded, risks for the aquatic environment can be indicated depending on the current pH-value and the water composition on-site. Here, the HC5 was exceeded at six of 50 sites for copper and at nine for zinc. Increased concentrations were mainly found inside relatively large and well embanked marinas, and reached maximum values of 20 µg Cu/l and 27 µg Zn/l. Each of these values are analysed from the filtered water samples without the fraction bound to the suspended matter. It is to be expected that the metal fraction bound to the suspended solids will sediment out in the medium-term and accumulate in the marina's sludge in the long-term. Unfortunately, there are no data of the metal load of dredging material from marinas available.

For the persistent active ingredient cybutryne, dissolved concentrations were determined that may indicate risks for the aquatic environment on some sites, namely in 35 of the 50 marinas. In these 35 marinas, the measured concentrations were above the annual average environmental quality standard (AA-EQS) of 0.0025 µg/l from the recent EU Directive 2013/39/EU, which may not be exceeded permanently. At five sites, concentrations were above the maximal acceptable concentration (MAC-EQS) of 0.016 µg/l of the EU quality norm, which may not be exceeded once. The highest concentration of 0.110 µg/l was measured in an inland marina (Figure 3-3).

Figure 3-3

Cybutryne concentrations in the water of 50 marinas, sized and sorted by region and the levels of the EU environmental quality norm according to Directive 2013/39/EU



Legend translation: Probestellen = sample locations, Nordseeküste = Nord Sea coast, Ostsee + Ästuare = Baltic Sea + estuaries, Binnenland = inland, Umweltqualitätsnormen = environmental quality standards, Höchstwerte = maximum concentration, Jahresdurchschnitt = annual average concentration. Bottom axis: Anzahl Probestellen = number of sampling sites. The gaps with missing bars represent concentrations below the analytical limit of quantification.
Source: this study, LimnoMar.

Note that in this study the concentrations of copper and zinc decrease from salt- over brackish to freshwater, while in contrast the concentrations of cybutryne, M1 and DMSA increase towards freshwater. This does not mean that more biocides are transferred into freshwater but rather that the biocides introduced by leisure craft are probably less dispersed due to a lower flow and water exchange.

By analysing available data on the German market supply of antifouling products offered for leisure boats (LimnoMar 2013), it can be seen that more than 90 % of the products are recommended for use in salt- and brackish water areas. Products recommended only for the use in freshwater, which have a correspondingly lower amount of biocides, occupy less than 10 % of the market. Therefore, the measured concentrations represent also the use of certain antifouling biocides in freshwater, which are predominantly only required in salt- and brackish water (Daehne et al. 2012). This means that the use of these antifoulants resembles *a sledgehammer to crack a nut* as the effective share of the boats in freshwater makes up over 70 %, of which possibly 10 - 20 % should be deducted for vessels that pass also through brackish or saltwater areas during summer. Currently, within a DBU project biocide-free coatings in freshwater are tested that have to be cleaned mechanically (Daehne et al. 2014).

It remains unclear, how the use of biocidal antifouling systems at freshwater sites is communicated to the boat owner community of the marinas and the water sport clubs and whether the use of low biocide or biocide-free antifouling coatings is aimed for. The *Bewuchs-Atlas* (fouling-atlas), sponsored by the Deutsche Seglerverband (DSV), offers free information regarding the local fouling conditions and the local fouling pressure (www.bewuchs-atlas.de). This data source offers the opportunity to boat owners, to select the most environmentally friendly and most effective antifouling coating.

In various publications of the water police and the Motorbootverband Bayern (www.bmyv.de), information is provided to check whether an antifouling coating is even necessary. If an antifoulant is necessary, if possible a biocide-free coating (e.g. silicone paints or Teflon® paints) should be selected (Bayerisches Landesamt für Wasserwirtschaft, 2005). According to personal communication given by the trade, around the pre-alpine lakes the majority of the antifouling coatings in use are Teflon based, which are predominantly provided with copper. It would be very interesting to know whether and in how far skippers of sailing and motor boats waive to use biocidal coatings. From this survey, the results were unremarkable for two selected marinas. In a further marina, it was demonstrated that tolylfluanid is used as an antifoulants. However, tolylfluanid is not exclusively present in any product but generally combined with zinc oxide, copper thiocyanate and copper oxide, and in some other products additionally in combination with dichlofluanid. In a further marina, the increased concentrations of DMSA, DMST, cybutryne and M1 as well as copper and zinc indicated clearly the use of antifouling products.

The only German leisure boat area where the use of biocidal antifouling products is explicitly forbidden is the Ratzeburger See and the Wakenitz area. Only the use of biocide-free systems is allowed since 2000 according to the *Wakenitz-Ordinance* (GVO-Schleswig-Holstein, 2000). Here, eroding products are frequently in use, with a high proportion of zinc oxide (up to 30 %). Zinc oxide is not registered as a biocide, however, has proven toxicity. In this survey, we were able to detect cybutryne, M1, and very low concentrations of zinc and copper in the Ratzeburger See.

3.2.2 Background exposure of the water bodies

As already described above (screening in AP 2), increased concentrations were often detected at the reference sites, especially for copper and zinc. Thus, for these substances a general background load of the waters is indicated (Kahle & Nöh, 2009).

If terbutryn was found inside the marina, a similar concentration level could be detected also outside in the reference sample. This indicates that terbutryn could originate from different emission sources into the water. Terbutryn is, for example, also used in facade paints, and could enter surface waters by washing-out processes, and subsequently appeared also in marinas (Burkhardt & Dietschweiler 2013).

A search on the preload of the examined sites in terms of antifouling biocides did not yield satisfactory results. It turned out that none of the affected federal states carries out a specific antifoulant-based biocide monitoring. Sometimes, concentrations of copper and zinc are monitored. Some individual results for cybutryne and M1 are also available. The focus of screening activity at the flowing waters is more set on the possible emissions by plant protectants, wood preservatives, industrial chemicals and organic solvents, as demonstrated by a comprehensive survey carried out between 2007 and 2011 in Mecklenburg-Western Pomerania (LUNG 2012).

The detected biocide concentrations collected outside the examined marinas in AP 2 are used as input parameters to run the model MAMPEC in the framework of AP 3.

3.2.3 Comparable organic antifouling concentrations in Germany and Europe

The cybutryne and M1 concentrations measured in salt- and freshwater in this study are relatively low in contrast to previous surveys, and also compared to the concentrations published by other countries with respect to marinas.

Additional data was published by Biselli et al. (2000), who analysed water and sediment samples for cybutryne taken from the coasts of the German North and Baltic Sea between March 1997 and January 1998. The detection limit was 4 ng/l for water and 0.05 ng/g wet weight for sediment (Table 3-4). During this period, the station *Husumer Segler Verein*, which is not directly connected to the North Sea, had the highest values, whereas the lowest values were observed at the stations *Sylt Hörnum*, *Sylt Munkmarsch* and *Cuxhaven*, which have a complete water exchange within 48 hours due to the tides. The Baltic Sea marinas revealed far higher concentrations, especially in the marinas with a high boat density. Overall, those levels were much higher than the concentrations found in the present study.

Also for cybutryne, additional survey data is available from several studies. Outside the marinas, the concentrations were generally low on the Lower Saxony coast. Between 2007 and 2008, the currently recommended annual environmental quality standard (AA-EQS; EU water framework directive) of 2.5 ng/l cybutryne were exceeded at the Elbe near *Grauerort* (Table 3-5). Here the maximum values reached 8 ng/l in 2008. Lower values were measured at the Ems estuary below 1 ng/l for the annual average with peak values of 2.1 ng/l. The conditions were similar at a measuring station in front of island Norderney, with a median of <1 and a maximum value of 1.7 ng/l (Steffen & Bülow 2009). Schulz (2014) also detected the same range in a time series study. Furthermore, Schulz observed a sharp decline of the concentrations at all stations between 2006 and 2012. In comparison, in the Berlin waters, higher values were measured (UBA 2010).

Table 3-4

Cybutryne concentrations in the water and sediment at sampling sites of the North Sea and Baltic Sea coast in August / September 1997

Sampling site	Water (ng/l)	Sediment (ng/g ww)	Sediment (ng/g dw)
Sylt Hörnum	29	9	14
Sylt Munkmarsch	11	15	25
Cuxhaven	12	<LOD	<LOD
Büsum	33	<LOD	>LOD
Husum town	n.d	2	3
Husum Segler Verein	170	5	8
Kiel Schilksee	320	3	4
Heiligenhafen	440	17	40
Flensburg	440	5	5
Kappeln	80	2	4
Warnemünde yacht marina	190	2	4
Warnemünde	90	80	220
Niendorf	320	40	70

WW = wet weight / DW = dry weight / LOD = below limit of detection
Source: Biselli et al. 2000

Table 3-5

Cybutryne concentrations (ng/l) from different surveys outside marinas and in adjoining waters

	U-Elbe Grauer-ort	U-Elbe Blanken ese	Ems es-tuary	Nor-derney	Berlin waters(1)	Main, Erla-brunn	Main, Kahl	Rhine, Koblenz	Saale, Wettin
Mean	2.8	2.7	< 1.0	< 0.1	3.0 - 30	0.65	0.8	0.48	1.2
Max	8.0		2.1	1.7	22 - 58				
min-max		0.8 - 4.6				0.2 - 1.1	<0.1 - 1.5	0.1 - 0.96	0.1 - 3.4

(1) Multiple sampling sites.
Source: Steffen & Bülow, 2009; Umweltbundeamt, 2010; Sengl, 2012, Schulz, 2014.

In a special study at Lake Starnberg carried out by the Bayerisches Landesamt für Umweltschutz, 6 - 10 ng/l were measured in closed marinas and 0 - 1 ng/l in open marinas. In 2012, the sediment load in the marinas reached peak values of up to 120 µg/kg DW (Sengl 2012). For one marina concentrations levels above 1 ng/l cybutryne could not be proofed, however 3 ng/l M1 were observed during this survey.

In the years 1996 and 1997, measurements of cybutryne were carried out in Denmark, in the Aarhus bay in the area of the marina Ega with approx. 800 boats, and in two further marinas with 400 boats. The observed levels were between 1000 and 2300 ng/l, while below 10 ng/l in the outer Aarhus bay (Jensen & Heslop 1997a). For the marina Ega, in 1997 a clear gradient was measured for cybutryne, with rising distance from the marina with the following values (Table 3-6).

Table 3-6

Cybutryne concentration [ng/l] in the area of the marina Ega

Sampling site	Cybutryne [ng/l]
Marina	750
90 m distance	71
150 m distance	51
250 m distance	50
500 m distance	13

Source: Jensen & Heslop 1997b

In a further Danish study of marinas and reference areas, the following cybutryne concentrations were measured (Table 3-7):

Table 3-7

Cybutryne concentration [ng/l] in the area of selected marinas

Sampling site	Number of leisure boats	Cybutryne [ng/l]
Silkeborg	250	350
Skanderborg	130	58
Ebeltoft	330	430
Grena	300	340
Ega	700	540
Randers	100	530
Århus commercial port		<10
Grena fishing port	50	120
Grena inner marina in front of wharf		27
Århus bay		<10
Hevring bay		<10

Source: Jensen & Heslop 1997b

These Danish studies clearly demonstrate that water concentrations of cybutryne decreased from the marinas to adjacent water bodies. Furthermore, a positive correlation between the boat density and the water concentration was found. It also became clear, that long-time berthing of the leisure boats in the marinas have a reinforcing effect compared to commercial harbours. This can also be demonstrated based on results gained from sediments. Readman (2002) analysed water and sediment samples from Danish harbours, marinas and open coastal waters for diuron and cybutryne between 2000 and 2001. Compared to industrial harbours, highest concentrations of cybutryne and diuron were found in the sediments of the marinas.

Further intensive investigations were carried out in marinas and adjacent reference areas at the Swedish East coast between 1994 and 1997. In waters near Stockholm, between 20 and 130 ng/l cybutryne were measured in the area of a marina with 800 boats and between 4 and 40 ng/l in a marina with 1250 boats. In the adjacent water bodies outside the marinas, the concentrations were between 4 and 6 ng/l. In sediment samples, cybutryne was only found near the marina. The concentrations were between 2 and 10 ng/l dry weight (Haglund & Pettersson 1997). In 1994 and 1997 at the Swedish West Coast and in the Gullmarsfjord, cybutryne concentrations were detected in the range of 30 - 480 ng/l inside the marina with 300 leisure boats at berth. Water concentrations nearby the marina were between 99 and 400 ng/l. In two reference areas, concentrations were between 6 and 22 ng/l (Dahl & Blanck 1996). Here the detection limit of cybutryne was 4 - 5 ng/l.

It has be noted that in Sweden, Denmark and also Finland the use of biocidal antifouling coatings is prohibited in inland waters, as well as in parts of the Baltic Sea coast. In Sweden, there is also a separate approval for biocidal products for the West Coast with high marine fouling pressure and for the Baltic Sea with low fouling pressure.

Table 3-8

Concentrations of organic biocidal active substances in [ng/l] in European countries given as minimum and maximum as well as median

Active substance	S (10)	DK (21)	NL (26)	UK (168)	F (35)	SP (112)	GR (58)
Cybutryne [ng/l]	2 – 364 61	4 – 9 2	<1 – 87 20	<1 – 621 52	3 – 491 46	<1 – 670 80	<1 – 90 18
Diuron [ng/l]	<1 – 35 5	37 – 174 27	<1 – 1129 328	<1 – 685 62	n/a	<1 – 2190 190	n/a
Dichlofluanid [ng/l]	<1	n/a	n/a	<1 – 390 8	<1	<1 – 760 30	<1 – 284 61
Chlorothalonil [ng/l]	<1	n/a	n/a	<1 – 30 1	<1 – 27 6	<1	<1 – 63 16
Seanine [ng/l]	<1 – 3 <1	n/a	n/a	<1	n/a	<1 – 3700 110	<1

Countries (with number of marinas): S = Sweden, DK = Denmark, NL = The Netherlands, UK = Great Britain, F = France, SP = Spain, GR = Greece; n.a. = not analysed.
Source: Ferrer & Barceló 1999, Boxall et al. 2000, Voulvoulis et al. 2000, Martinez et al. 2001, Albanis et al. 2002, Readman 2002, Sakkas et al. 2002

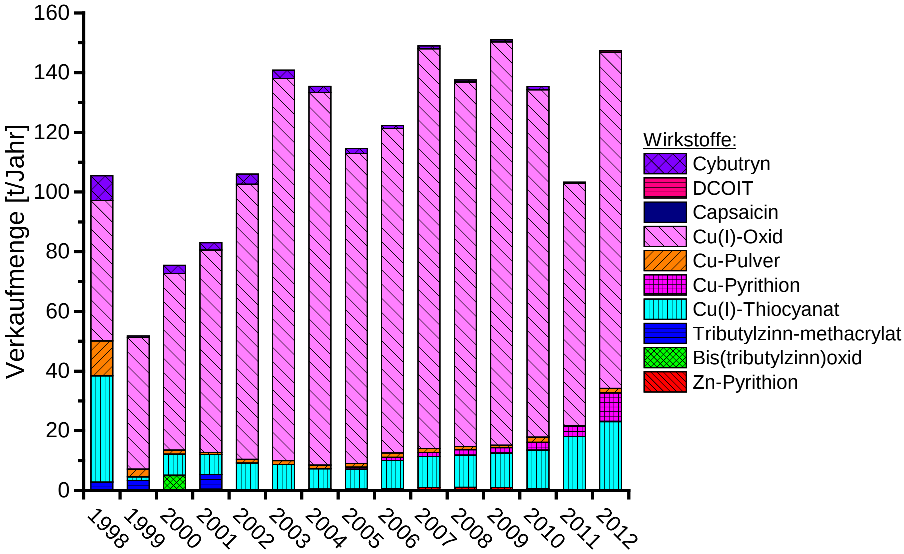
A comprehensive study on organic antifouling biocides in marinas and their adjacent water bodies was carried out in the framework of the EU research project ACE (Readman 2002). The results (Table 3-8) reveal, as well as in the present study, that cybutryne reached higher concentration levels, whilst the other biocides (with the exception of diuron) very likely degrade rapidly, thus only some of their transformation products may be detected in the marinas. In parallel to the above cited time series analyses for cybutryne in Germany, further studies document the decline of concentrations after the ban of cybutryne, for instance in 2001 in the UK (Thomas et al. 2001; Gatidou et al. 2007; Cresswell et al. 2006). In the framework of this ACE project, water and sediment samples from Danish harbours, marinas and open coastal waters were analysed for diuron and cybutryne. Compared to industrial harbours, the highest concentrations of cybutryne and diuron appeared inside the marinas.

3.2.4 Comparable copper and zinc concentrations in Germany and Europe

Zinc and in particular copper are present in different chemical compounds in most antifouling products. A few products contain metallic copper, which, even though it is embedded into an epoxy coating at the hull surface, still releases ions into the water. All the other inorganic and organic copper compounds act the same way by a slowly releasing from the coating into the water (leaching). Especially, the Scandinavian countries keep national products registers to be used for statistics on the use and consumption of biocides including antifoulants. In the last years, the consumption of antifoulants for leisure boats has increased considerably (Figure 3-4).

Figure 3-4

Sales volumes in tonnes of antifouling biocides on the Swedish market between 1998 and 2012

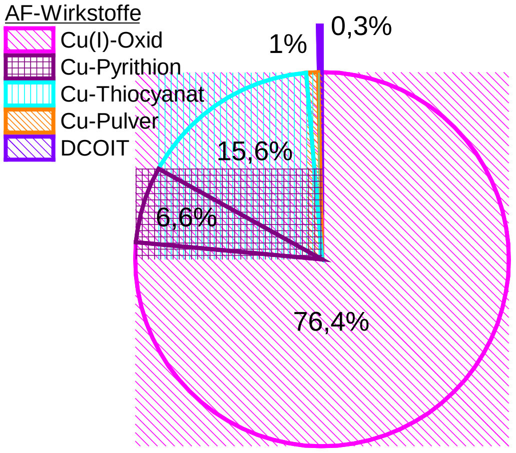


Legend translation: Wirkstoffe = biocidal active substances. Left axis: Verkaufmenge = sale volume.
Source: KEMI 2009 – 2013

In 2012, approx. 148 tonnes of the active substances in antifoulants were sold in Sweden, of which approx. 100 t accounted for industrial use and 48 t for private consumers. The shares of the individual biocides in Figure 3-5 (www.kemi.se) demonstrate that metallic copper and copper compounds are clearly dominant. It can be assumed that a similar market share is also present in other European countries and freshwater dominated regions.

Figure 3-5

Share of biocidal active substances in antifoulants on the Swedish market in 2012



Legend translation: AF-Wirkstoffe = antifouling (AF) active substances.
Source: KEMI 2013

Below, some background concentrations for copper in fresh- and saltwater areas (Table 3-9) are given. Especially for inland waters, it can be assumed that the concentrations listed below reflect to some extent an anthropogenic-driven increase.

Table 3-9

Background concentration of copper in water

Type of water	Area	Copper conc. [µg/l]
freshwater		1 – 3 0.4 - 0.6 2.0
saltwater (36 PSU)	NE-Atlantic (Median) Northern North Sea NE-Atlantic	0.2 - 0.3 0.099 0.066 - 0.070

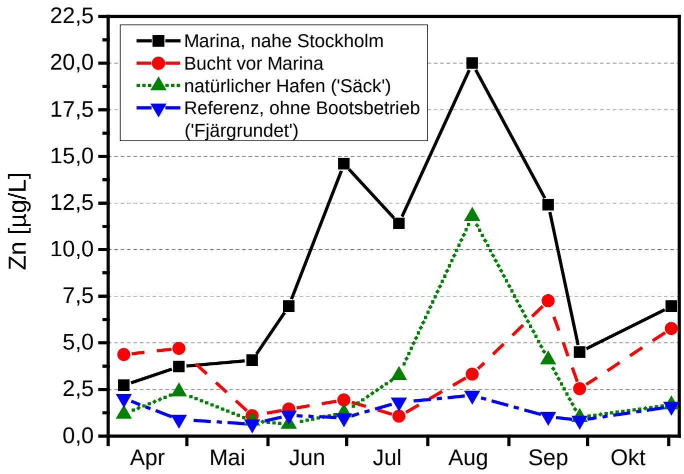
Source: Haarich, 1994

An interesting Swedish survey carried out from April to October revealed that highest concentrations of copper and zinc appeared in late summer. This can be explained by maximum occupancy rate of berths for residents, highest boat activity and an increased number of guest boats at berths in the marinas. Figure 3-6 and Figure 3-7 show exemplarily the dissolved concentrations of zinc and copper during the season, with pronounced peaks in August and September. The following four sampling stations are used (KEMI 2006):

- A marina close to Stockholm (Marinan),
- The bay in front of this marina (Utanför marinan),
- A natural marina in Säck, often used by leisure boats and
- A reference station (Fjärgrundet), located offside from marinas and navigation routes.

Figure 3-6

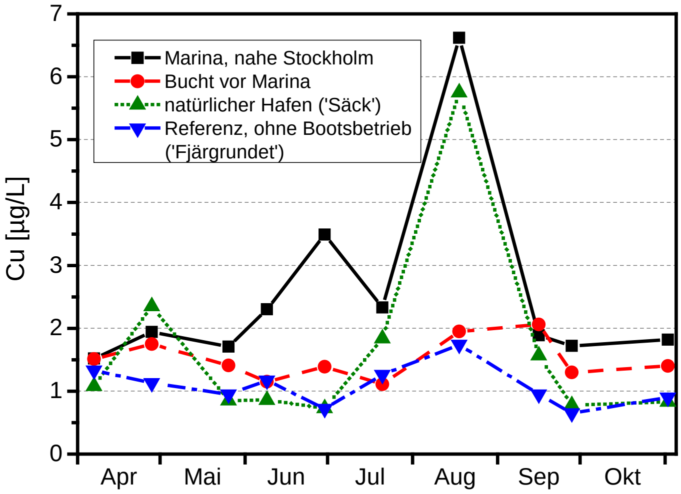
Seasonal curve of the zinc concentration in marinas and adjoining waters



Legend translation: Marina, nahe Stockholm = marina near Stockholm, Bucht vor Marina = bay in front of marina, näturlicher Hafen (Säck) = natural marina (dead end branch of river), Referenz, ohne Bootsbetrieb = reference, without leisure craft.
Source: KEMI 2006

Figure 3-7

Seasonal curve of the copper concentration in Swedish marinas and adjoining waters



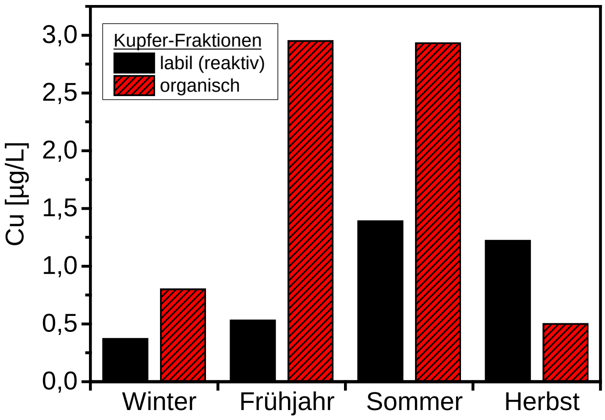
Legend translation: Marina, nahe Stockholm = marina near Stockholm, Bucht vor Marina = bay in front of marina, näturlicher Hafen (Säck) = natural marina (dead end branch of river), Referenz, ohne Bootsbetrieb = reference, without leisure craft.
Source: KEMI 2006

Recent studies from Sweden have also shown that the soils of the marina plots onshore are considerably contaminated with antifouling biocides and further hazardous substances. The soil concentrations in 34 marinas exceeded the Swedish environmental quality standards for copper, zinc, lead, mercury, cadmium, TBT, PAHs and PCBs by a factor of 10 - 20,000 (Eklund et al. 2014, Eklund & Eklund 2014).

A British study by Jones & Bolam (2007), who analysed the proportions of reactive copper (instable bound) and organically bound copper, demonstrated an increase of total copper as well as an increase of the reactive copper in the Milford Marina during the summer (Figure 3-8).

Figure 3-8

Concentrations of organically bound and instable bound reactive copper from filtered surface water samples of Milford Marina over a year



Legend translation: Kupfer-Fraktionen = copper species, labil (reaktiv) = labile (reactive), organisch = organic bound.
Source: Jones & Bolam 2007

3.2.5 Paint use for antifouling coatings

The quantity of antifouling coating paints used for the submerged boat hull depends on the size of the boat. Paint manufacturers of underwater coatings published simplified calculation formulas for motor and sailing boats, which give some guidance to the boat owners to estimate the paint consumption. They are summarized in Table 3-10. Here paint consumption is calculated by use of the calculated underwater surface of the hull (UWF) divided by the yield of the paint. Usually two paint coats are recommended (Yachtpaint 2015).

Table 3-10

Calculation formulae for the underwater hull surface according to various coating manufacturers

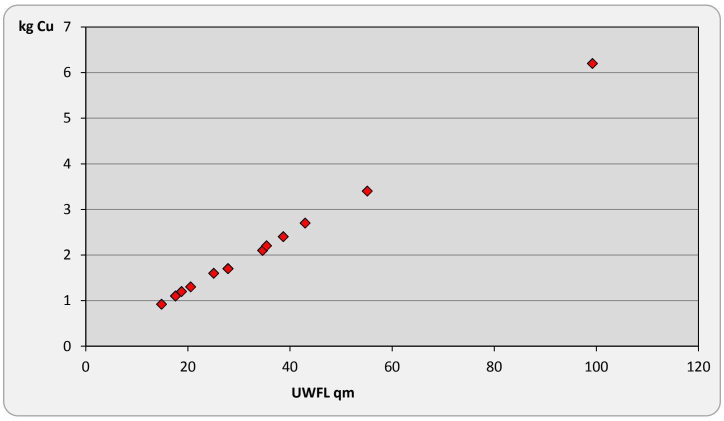
	Manufacturer 1	Manufacturer 2
General approximate formula	UWF = 0.85 * LoA * B	- / -
Motor boat	UWF = LWL * (W + D)	UWF = LWL * (W + D)(1)
Long-keel boat	UWF = 0.75 * LWL * (W + D)	UWF = LWL * (W + D)(1)
Short-keel boat	UWF = 0.5 * LWL * (W + D)	UWF = 0.75 * LWL * (B + D)

Abbreviations: UWF = under water surface, LoA = total boat length, B = boat width, beam, D = draft, LWL = length of waterline. (1): Full-bottomed boats: motor yachts, dinghies, sailing yachts.
Source: Manufacturer 1: Yachtpaint 2015, manufacturers 2: Wohlert 2015

Despite the recommendations given by the manufacturers, the consumed amounts of copper or other biocides can only be roughly estimated. For example, for a motor boat with a length of 9.1 m a paint consumption of 7 l is calculated. The concentrations of the active substances can vary from one AF product to another, thus only a minimum-maximum ratio can be derived. Further calculation factors may vary, too, such as the specific density of the AF product. A standard copper coating paint with a weight proportion for copper of 22 - 44 % and a physical density of 1.7 kg/l would result in a copper consumption of 2.6 to 5.3 kg applied to the submerged hull surface. Moreover, how much of this biocide enters the aquatic environment is depending on several factors like the leaching behaviour of the antifouling coating, the driving behaviour and the berthing time, as well as the lifetime of the coating staying on the UW surface. In Florida, the total yearly copper release was calculated in 14 marinas, by summing up the underwater surfaces of the total boat stocks (Srinivasan and Swain 2007). Boat specific mooring periods were recorded and a leaching rate of 17 $\mu g/cm^2/d$ assumed. According to this, a boat with approx. 28 m^2 underwater area (equivalent to a motor boat with a length of 8 - 10 m) releases approximately 1.7 kg of copper per year into the water (Figure 3-9).

Figure 3-9

Release of copper in [kg] in relation to the underwater surface [m²] of leisure boats, based on calculations from 14 marinas in Florida, USA



Bottom axis: UWFl = underwater surface area.
Source: Srinivasan and Swain 2007

An interesting study regarding the use of biocidal antifouling products in freshwater was carried out by the British registration board HSE (2001). By poll information, the use of biocidal products in freshwater areas of Britain with low fouling pressure was investigated. The study aimed to identify areas with high number of boats as well as whether and which biocides are used in order to evolve strategies for future monitoring. It turned out that 92 % of the owners in the region Norfolk Broads used biocidal antifoulants. However, it must be mentioned that there are partly brackish conditions in this region due to tides. In the Lake District and the Midlands lakes, only 51 % of the owners use biocidal antifoulants, which was mainly caused by a lower fouling pressure in the freshwater. Copper based antifouling products were most in use.

Similar results were reported by a study in the Cardiff Bay (UK). There, it turned out that biocidal antifoulants with high copper contents were used for leisure boats although they were situated in a freshwater area. Consequently, the copper concentration exceeded the environmental quality standard of 12.5 µg/l in the inner harbour of the marina (Bartlett 2006).

In summary, it can be assumed that even in freshwaters biocidal antifouling products for leisure boats are applied very frequently, although these products are actually designed for use in salt- or brackish water areas. It can also be assumed that the buying behaviour of German water sports enthusiasts is not so much different to that in Great Britain.

Due to the very high number of boats in German freshwaters, biocide-free antifouling techniques should be tested, for example by regular cleaning of the underwater hull in selected regions to reduce the release of antifoulants and thus improve the water quality of inland waters (c.f. www.dbu.de/OPAC/fp/DBU-Abschlussbericht-AZ-29523-01.pdf). Several projects are still ongoing focusing on biocide-free coatings and their cleaning techniques such as BMWi-FOULPROTECT (www.ifam.fraunhofer.de/de/Presse/Biozidfreie_Beschichtungen.html) and EU-CHANGE (www.changeantifouling.com) in the Baltic Sea area.

3.3 Scenarios and Modelling (AP 3)

3.3.1 MAMPEC in comparison with other EU emission scenarios

As there are usually insufficient measuring data of antifouling active substances for marinas, the environmental concentrations necessary for the risk assessment are calculated using computer models such as MAMPEC. They depict a simplified model of the harbour situation (size, water exchange rate, number and type of moored boats, water composition, etc.) and simulate the environmental behaviour of the active substance. For the risk assessment, no real harbours are used; instead, the conditions of a fictitious harbour are set in such a way that they represent a realistic worst-case scenario.

For the forecast or predicted concentrations of biocides in water, sediment and soils, several models were developed a few years ago and were tested for their suitability. After the EU-Biocide directive has passed, the CEPE (European Association of the Paint, Printing Inks and Artists' Colour Industry) commissioned the Dutch Health and Environmental Authorities (RIVM, Rijksinstituut voor Volksgezondheid en Milieu) to develop a specific model for the exposure estimation of biocides from antifoulants. This was later on supported by the EU and led in 1999 to the development of MAMPEC (Marine Antifoulant Model to Predict Environmental Concentrations), which since then has been improved and amended several times.

When developing the model MAMPEC, the following main requirements were defined:

- Definition of harbour prototypes
- Ability to take into account the typical emission routes from shipping
- Integration of standard degradation rates and behaviour of organic and inorganic substances
- Compatibility with EU agreed risk assessments
- Can be used on commercially available computer systems

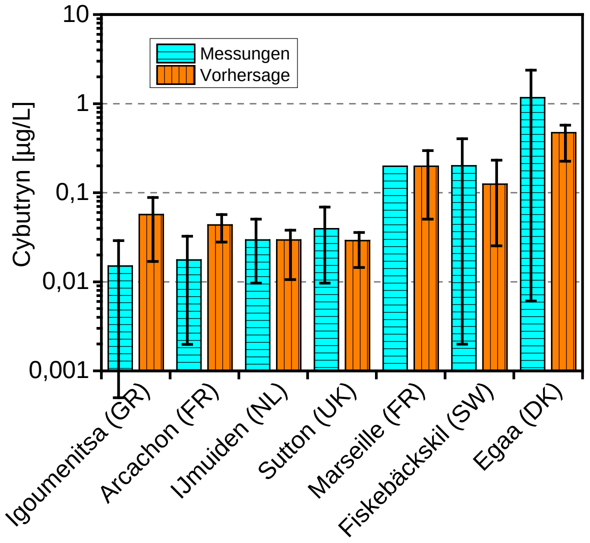
The developed model generates concentrations for the previously named marine environmental conditions. The five main harbour types (environments) defaulted in MAMPEC are commercial harbours, estuarine harbours, marinas, open harbours and open sea. The model assumes that these five harbour types are representative for most of the important situations on the coast. MAMPEC tries to take into consideration emission parameters such as leaching rates, degrees of boat activity, mooring times, underwater surfaces, etc. by connecting these parameters to the physical-chemical properties of the respective biocidal active substance. Defined scenarios are given for every harbour type, which have previously been assessed as representative. It is possible, to save own scenarios in MAMPEC, which turned out to be necessary for each of the selected marinas in this study, as the given scenarios did not represent reality, and there were no scenarios for freshwater at all.

3.3.2 Validation of MAMPEC by previous studies

For each harbour type (environment), the output of the model was compared with measured concentrations or in a few cases with published measurement results. Here, data mined during the EU-project ACE showed good agreement (Figure 3-10). A validation until now was only carried out for coastal marinas (Readman 2002, Hattum et al. 2002).

Figure 3-10

Measured (light blue) and calculated (orange) water concentrations (averages in µg/l) in selected European coastal marinas



Variance as min-max for measurements and predictions. Legend translation: Messungen = measured concentrations, Vorhersage = predicted concentrations.
Source: Readman 2002

Comparisons of references and calculations for the marina prototype in MAMPEC 1.4 clearly show a wide variation of measured values, which are mostly observed in the minimum to maximum values of the modelled concentrations for the various European marinas (Table 3-11).

Table 3-11

Comparison of measured concentrations of TBT, copper and cybutryne (values from literature, in µg/l) in the water of various European marinas with concentrations modelled by MAMPEC 1.4 (predicted environmental concentrations PEC in µg/l) for the prototype marina, assumption application to a 100 %

	MAMPEC – PEC Mean (MIN-MAX)	References
TBT [µg/l]	0.161 (0.035 - 0.233)	0.04 - 0.35
Cybutryne [µg/l]	0.101 (0.022 – 0.147)	0.03 - 1.70
Cybutryne [µg/l] (marina with inflow)	1.14 (0.514 – 1.61)	0.03 - 1.70
Copper (µg/l)	1.99 (0.434 – 2.896)	0.30 - 6.68*

Source: Hattum et al. 2002, * Thomas & Brooks 2009

Until now, the focus of the MAMPEC scenarios was clearly in the salt and brackish water area. For freshwater marinas, the suitability of MAMPEC was tested using the modelled calculation for a Swiss marina (OECD 2004). This scenario, however, is very country-specific and was not seen as representative for European freshwater marinas, so that there are no standard scenarios in MAMPEC representing freshwater marinas at present.

The current version is MAMPEC, version 3.0, which is optimised for the modelling of introduced pollutants from commercial shipping. These take place continuously throughout the year, just as the repairs (removal of coating and recoating), and the entries from maintenance and repairs and removal are calculated as annual mean values.

It is obvious that these assumptions cannot be applied to the leisure boat sector in countries with a six-month water sport season, where the boats are stored on land during the winter months. There, a removal and repair activity of 3 months is more likely. This behaviour is easier to adapt and calculate in version 2.5. Therefore, during an EU-meeting for biocide risk assessment (Technical Meeting, September 2013) the member states voted to keep MAMPEC version 2.5 for the modelling of leisure boat related exposure estimates.

3.3.3 Comparison of the MAMPEC prognoses with individual measurements in summer in selected German marinas

In total, 10 marinas situated in salt-, brackish and freshwaters were used for the modelling and compared with the active substance analysis carried out once in summer (July, August 2013). Particularly due to the single measurements, the extent of the short- and medium-term fluctuations cannot be determined. Among others, it is known that particularly high concentrations occur in spring when boats are launched that have been repaired shortly before launching. Wind and waves can in the short-term increase the water exchange rate also in otherwise weakly exchanged fjords, lagoons and inland waters, and thus lower the harbour concentrations. This leads to a large variation of local concentrations during the season. Furthermore, the application quota for individual active substances of an antifoulant can differ considerably from the current national market share of the sold antifoulant products. Therefore, a statistically founded statement cannot be made, however some trends and conclusions can be drawn.

For DCOIT**,** the measured concentration, which was below the limit of detection in every marina, always fitted into the concentration range calculated by MAMPEC, which was a maximum of 0.08 µg/l and was way below the limit of detection (Figure 3-11). Due to its difficult handling, DCOIT is mainly used in commercial shipping.

All measured concentrations of the transformation product DMSA, expressed as its parent dichlofluanid (see Chapter A.3.1), were within the modelled value ranges for dichlofluanid. In both saltwater marinas, the measured concentrations were close to the median. In brackish water, the measured values were in the area between mean and the 95 % percentile, in the open marina of Br_3 between median and minimum. In freshwater, the measured values equalled the modelled maximum values or were slightly below. The selected application factor of 20 % is higher than the one for the other copper-based biocides with 10 % due to the higher number of antifouling products containing dichlofluanid on the German market. The weight per cent was set low, as 2.5 % dichlofluanid in the antifouling coating. Besides, antifouling products with a weight share of 1 - 2.5 % for dichlofluanid, there are also two products for which the manufacturer states a percentage of 2.5 - 10 % (LimnoMar 2013). Overall, the variation of the settings for the manufacturers' statements are too great to be able to perform precise approximations of the active substance contents. In addition, there are other sources of entries of dichlofluanid, such as wood protectants from treated boardwalks near the sampled marinas.

For cybutryne (Irgarol), it was clear from the measured concentration in the different marinas that MAMPEC had a tendency to overestimate. In seven of the ten marinas, the measured concentrations were lower than calculated ones and the remaining three marinas had measured concentrations close to the predicted minimum concentrations. The manufacturers' statement for cybutryne in the safety data sheets is also very imprecise, stating a share of 2.5 - 10 % by weight.

Table 3-12

Weight shares [%] of cybutryne in antifouling paints in Sweden

	Approval expired (2010).	Approval (1994 - 2007)	Total (1994 - 2010)
Mean	1.88	2.39	2.32
SD	1.05	0.96	0.97
No of products	6	39	45
Min.	0.60	0.30	0.30
Max	3.50	3.90	3.90
Median	2.00	2.41	2.40

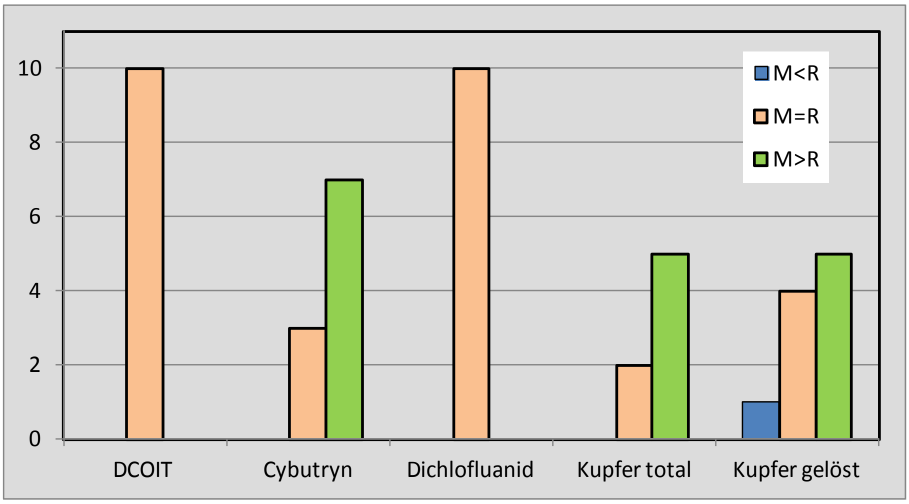
Source: www.kemi.se, last visit 23.03.2010

Therefore, in this study a *worst-case* of 10 % was used. In the KEMI data (2010) for Sweden, Irgarol in antifouling paints only had per cent weight of on average 2.32 % (median 2.4 %) with a spread of 0.3 - 3.9 % (Table 3-12). Possibly, the currently low number of antifouling products on the market containing cybutryne explains the higher concentration from the modelling with MAMPEC. The application factor of 10 % was set quite low.

Similar conclusion can be drawn for copper: in five of seven harbours, the measured concentration of total copper was below the predicted concentration, in two harbours it was close to the minimum concentration. For three harbours, there was no usable measurement for total copper. The measured dissolved or filtered copper concentrations yielded a slightly higher agreement with MAMPEC in four harbours. In five harbours, MAMPEC again predicted higher concentrations, and in one harbour the measured concentration was above the predicted MAMPEC concentration range. An explanation could be that a worst-case leaching rate is assumed for copper in MAMPEC, which normally only occurs in the first two weeks of launching the boats. Furthermore, overestimation could appear due to the extreme variation of the copper contents in the safety data sheets used for the project. For the modelling, a 100 % application factor was assumed for copper, which is possibly correct for salt- and brackish water, but is possibly only 80 % in freshwater. The modellers realized quite early that the missing exact concentration data for the antifouling products and the missing information about the market share of the products and biocides for the harbour led to a systematic error (Hattum et al. 2006).

Figure 3-11

Number of harbours with the different active substances of antifoulants, in which the prediction by the model (M) equals the measured concentration (R) (M=R), higher (M>R) or lower (M<R) concentrations were predicted



Bottom axis: DCOIT = DCOIT, Cybutryn = cybutryn, Dichlofluanid = dichlofluanic, Kupfer total = total copper, Kupfer gelöst = dissolved copper.
Source: this study, LimnoMar.

Independently of the degree of agreement between the modelled predictions by use of MAMPEC 2.5 with the measured concentrations in summer 2013, the suitability of MAMPEC should be tested under different conditions, and is discussed below.

3.3.3.1 Location: Coast- Inland waters

Generally, the harbours of the North Sea coast could be modelled well, as the present and pre-entered scenarios were designed for coastal sites. The brackish water harbour Br_2 coincided with the scheme of the *estuarine harbour*, which shortly after flows into the sea. The two saltwater harbours coincided with the prototype *marina*, Sa_2 opening into the estuary of a river, Sa_1 opening into the open sea. The site Br_1 on the Baltic Sea coincided structurally with the prototype *marina* without mentionable tides. A study by Baart (2005) demonstrated for Finnish Baltic harbours, without the influence of tides, that non-tidal daily water height differences, horizontal flows and water exchange through wind gain in importance and the exchange rate in the harbour increases under the influence of these factors. From MAMPEC 2.0, this type of harbour can also be modelled adapted to the real conditions. In the non-tidally influenced coastal harbours Br_1, Br_3 and Br_4 it was demonstrated that depending on the winds, the input parameter wind has a large effect on the water exchange volume and therefore is a sensitive parameter for the whole model. Small differences in the input in the wind force result in large differences in the exchange volume. A precise description, as what percentage of the year (or sailing season) the wind blows perpendicularly to the harbour entrance and with what force, is not easy to derive despite the available wind statistics (e.g. www.windfinder.com). The example calculation for the Harbour Br_3 in Table 3-13 clearly shows how sensitive the exchange volume in MAMPEC is with regard to the determining factor wind. For the modelling in AP 3, the value 0.5 m/s was taken for the region (see also LWKSH 1978).

Table 3-13

Example calculation in MAMPEC with different entries for wind speed

Wind velocity [m/s]	Exchange volume [m³/tide]	Exchange volume [% harbour volume]
0	2,671	4.06
0.5	21,467	32.6
1	41,355	62.9

Input of the wind frequency perpendicular to harbour mouth: 6.2 %

For inland harbours, the standard *marina* harbour type was used and the tide was set to *zero*, similar to the Swiss scenario (OECD 2004). The calculated exchange volumes were low with 2 to 15 %. Misleading is that the exchange volumes are always relating to a 12.4 hour period, which makes no sense at all for freshwater. This problem should definitely be addressed during the future development of a freshwater scenario.

3.3.3.2 Grade of embankment to the surrounding water bodies

It turned out that all closed harbours are classified as *MAMPEC-suitable*. Optimal for data entry were the closed harbours, where the moorings nearly filled the inner harbours, such as in Br_1, Br_2 Sa_2, and Sü_1.

Less definite were harbours, where the moorings only constituted part of the inner harbour, such as in Sa_1, Br_4, and Sü_2. For calculation in MAMPEC, only this part of the harbour, in which the marina was situated, was taken into consideration. In Sa_1 and Br_4, the harbour area not included contained commercially used boats as further biocide sources, which could not be taken into consideration. In Br_4, it can be assumed that the leisure boat emissions are not distributed throughout the entire harbour area but instead probably sediment close to the mooring. The measured and modelled concentrations in harbour Br_4 correlate closely, while the measured concentrations were higher than the model. In harbour Sa_1, considerable water movement takes place due to the tides. Due to the other commercial ships in the front part of the inner harbour, only the back part of the harbour, used as marina, was looked at for the calculation in MAMPEC. For Sa_1, good results in terms of agreement between model and reality were obtained using this approach, despite all the doubts regarding the external AF sources.

In the harbours Sü_3 and Sü_4, several harbour operators and clubs with open marinas were situated together in one closed bay. Therefore, it made sense to treat them in MAMPEC as one unit. Comparison of the model and reality showed for both harbours a high degree of diversity for the individual biocides and only agreement between measured and predicted concentrations was found for DCOIT and dichlofluanid. Interestingly, the results for Sü_4 demonstrated that the concentration of the real measurements directly in the harbour differed very little from those in the middle of the bay. Therefore, not restricting the harbour volume to the volume just around the moorings, but to include the whole bay seems to be justified for those harbours.

These examples show how important it is in MAMPEC to select the *correct* harbour volume, in which the emissions are presumably distributed. The open harbour structures in some areas do not allow a clear conclusion to be drawn, so it is important to decide according to the characteristics of the respective harbour, as different selected harbour volumes lead to different concentrations.

There is no open harbour scenario in MAMPEC up to now. There is the *shipping lane* as an open system, but this is seen as an area with passing commercial shipping traffic and is unsuitable for marinas. Open harbours such as Br_3 cannot be realistically modelled, as the present scenarios always assume a water exchange at or through the harbour mouth. In an open undyked harbour, its total basin is completely subject to the flow. In Br_3, it was assumed that during certain times, there is a high drift of the emissions due to the wind-driven currents of the Schlei. The measured concentrations were, with the exception of dichlofluanid, lower than the predicted MAMPEC minimum value. In analogy to Table 3-13 as an example, the modelling was also carried out for a wind speed of 1 m/sec. Using this higher emissions drift, lower concentrations for copper and cybutryne were predicted, which fitted better to the measured concentrations. The concentration range became narrower for DCOIT and dichlofluanid, while the minimum concentration increased. Sedimentation could also lead to a reduction in the dissolved concentration.

Concluding, it can be summarised that when modelling with MAMPEC, more often higher dissolved concentrations are predicted than are found in reality. Therefore, the model can be assessed as more *conservatively* in the framework of this study. This is also the case for harbours with a very specific harbour structure. Nevertheless, the reliability of these model predictions should be further tested with measurements in selected harbours - if possible throughout the entire boating season.

3.3.4 Deficits of MAMPEC for the modelling marinas

From the concept and the present scenarios in MAMPEC, it is clear that the original focus of the modelling was aimed at the risk assessment requirements in professional shipping. The selected marinas showed often peculiarities that could not be easily implemented in the standard harbour types and the scenarios of MAMPEC. Furthermore, normally marinas are much smaller than harbours for commercial shipping, which are often open and in the low-flow freshwater areas and they influence themselves due to their spatial proximity to each other in high density areas, such as in Berlin and its surrounding areas. Particularly problematic is the modelling in mixed harbours with, for instance a ferry service and additional fishing and marina area.

As this project aimed to assess whether MAMPEC can reliably predict concentrations of active AF active substances in water in comparison with measured concentrations, the parameters from MAMPEC were adjusted to reflect the peculiarities of the individual harbours as much as possible.

In the following, a few critical points are listed that came up while modelling German marinas using MAMPEC.

3.3.4.1 Hydrological and chemical factors

Background concentrations of AF active substances

It is possible to enter active substance background concentrations of a site in MAMPEC. It was shown in this project that possible background concentrations, specifically as a result of antifouling active substances, is insufficiently registered by the monitoring authorities as a rule, and is generally restricted only to copper, zinc and cybutryne. As monitoring of biocidal active substances is not obligatory, only sparse data from specific problems are available but no well-founded data on background concentrations.

Transformation products of AF active substances

The organic antifouling active substances in the model section *compounds* are only modelled using the original substance, although the substance-specific degradation rate is considered. However, some active substances breakdown rapidly. Their degradation products are not taken into consideration in the MAMPEC program. As the measured concentrations have shown, these transformation products can possibly persist considerably longer in the water than the original substances. The transformation products such as M1 from cybutryne can also be ecotoxicologically relevant to a certain extent. Modelling of these transformation products would also be desirable in individual cases.

Hydrology

From the technical document for MAMPEC (Hattum et al. 2002) it can be concluded that complicated exchange processes such as those that occur in coastal harbours under the influence of different salinities and temperatures must be taken into consideration. However, it is unclear whether hydrological processes in freshwater, such as seasonal water level changes in the lakes of the alpine foothills, can be calculated. Spring floods regularly occur here (see also Chapter B.1.2.15). Hydrological condition in urban areas, such as those found in the Berlin water bodies of the rivers Spree and Havel are also extremely complicated due to outlets of sewage plants and the numerous run-offs of urban areas. Furthermore, bays often include many harbours and therefore should be considered as a single hydrological unit. Here it should be possible to set the balance of the inflow and outflow of the lakes as input parameters, as they were for example presented by the UBA (2010). The same is also relevant for Lake Constance. These long-term water level changes could not be entered into MAMPEC to date. Instead, there is the input *non-tidal daily water level change*. However, daily data on non-tidal water level changes are - if at all - very difficult to determine or are not available.

Even for freshwater sites, the time unit of the exchanged water volume in the section *environment*, which has to be set, is the period of the tide and a tidal range set to zero.

3.3.4.2 Structure of the harbours

The harbours in freshwater are generally open harbours. In MAMPEC 2.5, this situation can be difficult to model for marinas. In the available scenarios, the program assumes closed harbours with a port entrance, which is mostly only applicable for coastal sites.

Open harbours are among the calculated example harbours, which have at least one natural border like the Berlin Lake Sü_4 as a complete bay, or the Harbour Br_3 which lies protected behind a headland. Individual harbour systems, separated only by a one-sided quay wall, open pontoons on a river or the open buoy fields of the lakes of the alpine foothills cannot be realistically represented in MAMPEC 2.5.

In the MAMPEC Version 3.0 there is in the section *environment*, a mask for *open harbour*, however, no exchange volumes can be entered or calculated. The results of the comparative measurements from reality with this scenario are not yet available.

Tidal gate harbours

On the German North Sea coast, there is the peculiarity that many harbours are tidal gate harbours with inflow from the hinterland, which is regulated by the seasonal agricultural requirements. At the same time, the outflow amount through the tidal gate is not uniform, and the outflow and substance load are not recorded. The inflow through such tidal gates influences just as strongly the extent of the exchange volume in the harbour. MAMPEC can incorporate one inflow into a harbour and different densities because of the fluctuating salt content, but it is unclear what effect a strongly fluctuating inflow has and how this can be taken into consideration in MAMPEC.

Wind

It was noticeable that the influence of wind was always set to zero in the available MAMPEC scenarios. From the hydrological conditions in both the North Sea and the Baltic Sea, it emerges that wind is a strong factor influencing water movement and water levels. This is particularly clearly documented for the Schlei estuary and the region of Grömitz (LWKSH, 1978; Ohlendieck, 2009).

The influence of wind is taken into consideration in MAMPEC from Version 2.0, as it was discovered that the exchange volume was calculated too low in harbours without tide with low current without density differences (Baart 2005). In order to correct this, the wind factor was considered, which creates a certain current close to the surface and in doing so raises the exchange volumes in the harbour (Boon et al. 2008). The wind factor was only included in the MAMPEC scenarios when modelling for harbours with little or no tidal influence. In order to reach the most realistic representation of the German harbours in the harbours selected in AP 3, in this project the specific wind situation was considered for each harbour.

3.3.4.3 Specific factors of leisure boat handling

Current market share of antifouling active substances

A huge range of antifouling products is used in the leisure boat sector. For the year 2013, 21 copper antifouling products and over 60 antifouling products with copper and organic co-biocides were found on the market for German leisure boats. Which products are used in a marina and to what extent they are used is unknown. Furthermore, the concentration data in the safety data sheets always covers a wide range. Therefore, the data for the *application factor* and *concentration of active substance* can only be considered approximations. Considerably more data that are reliable could be used for modelling with MAMPEC if every boat owner had to carry on board a certificate regarding his applied antifouling product and would give a copy to the harbour master or association, as is also intended in a similar manner for leisure boats in the IMO AF Convention.

Intensity of use during the year

MAMPEC assumes constant shipping traffic throughout the entire year for its calculations. This only applies to the leisure boat area in the Mediterranean region to a certain extent, and for example to charter boats. In the northern European countries like Germany, the Netherlands and Scandinavia it is common for boats to be taken out of the water in winter, to be worked on, and then returned to the water again in spring. This means that the *service life* in reality only stretches over half a year. However, there is no possibility to enter a time range for the *service life* in MAMPEC. For the *maintenance & repair* phase and the *removal* phase for professional treatment of the boats, a time period of six months is set, and for non-professional treatment, a period of three months is set. However, this selected period has no influence over the *service life* period.

Ratio of guest to permanent berth holders

As an example of a coastal harbour, Br_1 attempted to show whether MAMPEC is influenced by the fact that the harbour has more guest berth holders than permanent ones. The critical difference was in the *removal* phase, because only the permanent berth holders treat their vessels locally on land. Therefore, for the *removal* phase modelling was performed once with the full number of boats and once with an assumed number of 400 permanent berth holders. Both models showed no differences for the low concentrated biocides, and for copper only very low differences in the concentrations, because the main emission of the biocidal active substances resulted from the *service life*. The emissions additionally resulting from *removal* are secondary to this.

Adjustment of the boat sizes

For boat lengths between 10 and 50 m an average underwater surface of 22.5 m² was assigned in the present MAMPEC scenario for marina. This is a rough assumption as the surveys from AP 2 clearly demonstrated that with boat lengths between 6 - 20 m the underwater surfaces varied between nearly 10 to over 80 m². Through the manual input of the boat length classes and the corresponding underwater surfaces, these could also be represented according to the survey in AP 2 in MAMPEC. In general, a more precise scaling should be adopted for modelling in marinas.

Documentation from maintenance & repair

For the calculations of the emissions from *maintenance & repair*, it is not obvious in MAMPEC which size of ship is used as a base. The entry here is only made by entering the amount of paint used, so that a sensible average amount of paint used must be selected for boats of different lengths.

AF release through washing on the slipway or on unprotected ground

When fouling or coatings from the boats are removed on land (*removal*), there is a difference between treatment with *high pressure washer* and grinding (*abrasion*). It is known from practice in Germany that boats are high-pressure washed in many harbours straight after landing on the slipway or on unprotected ground, as there are usually only wash down areas with collection and filter systems for a maximum of ten boats at a time, often even only for one boat. Grinding usually only takes place in winter storage sheds. The fractions to be calculated into MAMPEC (fraction water to soil) were adjusted according to these conditions in the sample harbours.

The latest Swedish surveys, however, depict a completely different picture: according to them, only a quarter of the emissions from boat coatings are released during use in water (*service life*). The larger proportion - in other words, three-quarters of the emissions released on land through inappropriate handling on-shore by washing off, grinding and applying - enter the harbour soil and from there the water (Eklund & Eklund 2014, Eklund et al. 2014). In Germany, there are no facts to confirm this at the moment. In MAMPEC, however, the weighting of the emissions *maintenance & repair* and *removal* is very low compared to *service life*, as shown in example Br_1.

4 Conclusion and Outlook

The nationwide census identified a total number of ca. 206,000 berths in 3,091 marinas throughout Germany. These numbers were determined using aerial photographs and additional sources such as marina guides, leisure boat maps, and harbour guides. This resulted in a considerably lower number than previously estimated. Freshwater areas with 146,000 berths make up 71 % of the number of leisure boats, while brackish waters reach approx. 26 % and the North Sea coast only accounts for 3 %. Regional agglomerations in the inland are the lower Rhineland area with 10,500 berths, the Mecklenburg lake area with 19,000 berths, the Bavarian alpine foothills with 23,000 berths, and the Berlin-Brandenburg area with 40,000 berths. Therefore, leisure boat activities in inland waters of Germany have an exceptional position and are a national peculiarity, which has to be taken into account when approving antifouling products. Typical freshwater marinas have about 40 berths and are smaller than the ones at the North Sea with 70 berths. Protective *safe* harbours are often present at the coast, whereas, 79 % of the inland marinas are more or less open to their adjoining water bodies.

Although the typical inland marinas are smaller than those at the North Sea coast, they are arranged like pearls on a string in many areas, so that these clusters can reach a total capacity of more than 1000 berths. If they are situated in waters with low or stagnating water exchange, AF biocidal active substances can accumulate also outside of the individual harbour areas in the neighbouring water section.

In the course of the screening campaign on all currently permitted antifouling active substances on the EU markets, water samples of 50 marinas from Flensburg to Lake Constance were analysed in summer 2013. The transformation products of some of the active substances were also analysed. For the active substances DCOIT, zineb and pyrithione, the concentrations were below the analytical limit of quantification, i.e. they were not currently measurable in the waters by the applied analytical methods used in this survey. Detection of transformation products of dichlofluanid, tolylfluanid and cybutryne demonstrated that antifouling biocides are also used in freshwater areas. For the active substance cybutryne (Irgarol), which degrades slowly in water, concentrations above the environmental quality standard

(EQS) 0.0025 µg/l were found in 35 of 50 marinas. This threshold is an annual average (AA-EQS) which should not be exceeded. At five sites, concentrations above the maximal acceptable concentration (MAC-EQS acc. EU Directive 2013/39/EU) of 0.016 µg/l were detected. These dissolved concentrations indicate risks for the aquatic environment. High concentrations could be demonstrated in brackish waters and especially in freshwater. The metals copper and zinc are not only released from antifouling products, but they also enter the aquatic environment due to many other applications. If concentration levels exceed an effect threshold concentration of about 8 µg/l - for both zinc and copper - a risk for the aquatic environment can appear. This exceeding was observed for copper at six and for zinc at nine of the sampling sites.

Comparing the predicted concentrations of the antifouling substances obtained from the model MAMPEC (incl. site-specific adaptions) with the analytical data gained from the survey, quite a good accordance was found for closed coastal harbours, for which the model was originally developed. Major differences between measured and predicted concentrations appeared at open moorings or at marinas without or with very limited embankment found at brackish or freshwater areas. Here, recurrent tidal flow patterns were missing and changing winds have a larger influence on the water currents. Furthermore, up to now no *standard parameters* are available for freshwater-specific input parameters. In this project, they had to be set as best guess or based on analytical data like the water composition. Therefore, the model MAMPEC in its present form does not meet the conditions of the majority of German freshwater marinas.

The tools like MAMPEC used for the estimation of the environmental concentrations of antifouling active substances in water bodies have to be improved and expanded. This study provides nationwide basic data for marinas for the first time, collected within the framework of a census stretching from inland to coast. The data are provided as a German contribution to support the EU risk assessment in the framework of the biocide directive. Furthermore, these results represent a reliable dataset for the specific adaptation of present scenarios for the risk assessment of antifouling active substances to national circumstances, and therefore provide for the high relevance of inland water bodies to the Federal Republic of Germany.

Although the total number of berths for antifouling-relevant sailing and motor boats is considerably lower than expected before, at regional and local level high densities of marinas and leisure boats are identified. Due to this, the released antifouling active substances may accumulate and negatively influence adjacent water bodies. Consequently, inland waters, which are of paramount importance for leisure boat activity in Germany, are with certainty exposed to these entries. Thus, also densely populated areas and clusters of marinas should be part of the risk assessment of antifouling active substances and products in the future.

The current results from the national antifouling active substance screening in 50 marinas revealed in some cases that the environmental quality standard for cybutryne (Irgarol) was clearly exceeded. These findings underline the necessity to enhance the effort to reduce the environmental impact of antifouling biocidal active substances. So far only the example of the Ratzeburger See shows the potential to run leisure boats without using biocidal antifoulants in freshwater. Freshwater areas, in which no fouling by incrusting organisms (zebra mussels or calcium encrusting algae) appear, are suitable for the use of biocide-free antifoulants. An exchange of experiences in cooperation with the leisure boat clubs from different areas can promote the use of practical and biocide-free antifouling processes.

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Appendix A Materials and Methods

A.1 Nationwide Census (AP 1)

A.1.1 General procedures for data collection

To optimize the method of data collection, test runs were performed to collect data and to test suitability of criteria and their plausibility. The set of features and their definition as well as the structure of the total data set were optimized and agreed with the customer.

For quality assurance, a manual of methods was written as a process instruction, which was mandatory for all co-workers (see Appendix C). Here, individual parameters were defined, the notation was finalised, and the mapping to the main catchment areas was performed. Furthermore, supra-regional data sources were cited, which were to be used (internet addresses, literature). The recorded data were listed in a two-dimensional table (Excel 2007, Microsoft) with a uniquely defined structure.

A.1.2 Research characteristics

For the survey, the following characteristics were recorded:

Location data

- Street, post code[1] , town
- E-mail address, internet address, telephone number, mobile number
- Name of the harbour[1]
- Name of the waters[1], water section[1], water type[1] (e.g. coast, estuary, river, canal, lake) harbour type[1], main stream
- Situation[1] (nearest city), Federal State[1]
- Geo referencing[1] (based on the geodetic reference system WGS84, degrees of latitude and longitude in the sexagesimal format)

Structure data

- Surface[1], length[1] and width[1], incl. identification for area recognition (harbour polygon)
- Width of harbour mouth[1]
- River width, maximum water depth, tidal range
- Salinity range (classes: freshwater <1 %, brackish water 1 – 18 %, saltwater >18 %)[1]
- Harbour infrastructure (slipways, crane, winter storage, wharf)[1]
- Dyke to the adjoining water body (open/ closed)[1]
- Number of berths from different source, stating the sources
- Maximum number of total berths (guest and permanent berths)[1]

Other

- Comments regarding peculiarities, special features
- Data situation and sources

A.1.3 Individual characteristics

A.1.3.1 Harbour locations and berths

Various data sources were used. The Wassertourismus Guide (WTG), Törn-planer (http://www.toern-planer.net/) and others were important tools to identify water sports clubs.

[1] Mandatory data

For the census of berths, various sources were used, including:

- Counts from aerial photographs using geo-data services via internet
- Figures published in the ADAC Marinaführer (marina guide) (2010)
- Internet pages of the yacht and boats clubs, the marina guide (http://www.marina-guide.de) and further regional sources for water sports and water tourism.

The different data sources are documented in the process instructions (see Appendix C).

If the information of the different sources varied greatly. Normally, the one was selected, which coincided best with the aerial counts or further information sources (e.g. personal information from the local harbour master).

Internet services, mapping the area throughout with aerial photography, like the portal GeoView of the Federal Agency for Cartography and Geodesy (BKG) or Google Earth (GE) were used to identify harbours, jetties and infrastructure as well as boats at private moorings. If the photo-graphs were taken in winter, showing large clouds, or were obviously outdated, additional seasonal material was researched as required.

The present berth counts are based on the aerial photographs, which were available within the course of the year 2012 on the internet, which, however, do not necessarily document the current state of 2012. This became apparent especially in the Lausitzer Seenland, where more and more marinas were built after flooding of the opencast brown coal mining areas, and by lack of current aerial photos.

If rowing boats, catamarans, dinghies, and others were identified - irrespective of water mooring or dry storage - they were excluded from the counting, because they are not antifouling treated.

In some cases smaller mooring sites, which were poorly documented and clustered tightly together, could not be assigned to the individual operator. This was the case for instance on the Steinhuder Meer, the Rur dam, the Scharfe Lanke and at Pichelsee in Berlin. In these cases, these jetties were locally addressed as a single unit and summarised under one name.

As a target set, 80 % of the marinas were to be surveyed. To limit the workload and by agreement with the customer, it was decided that marinas with a size of 10 or more berths have to be identified. At many lakes, there are numerous private landing stages with one or two berths along the shore. If they together amounted 10 berths or more, there were summed up and registered as unit.

Due to the systematic and detailed screening on coasts, main rivers, their tributaries, reservoirs and the larger lake regions as well as individual lakes, all the agglomeration areas for leisure boats as well as the less frequented areas of Germany have been registered by use of aerial photographs. In total, it is assumed that approx. 90 % of all berths in Germany have been registered.

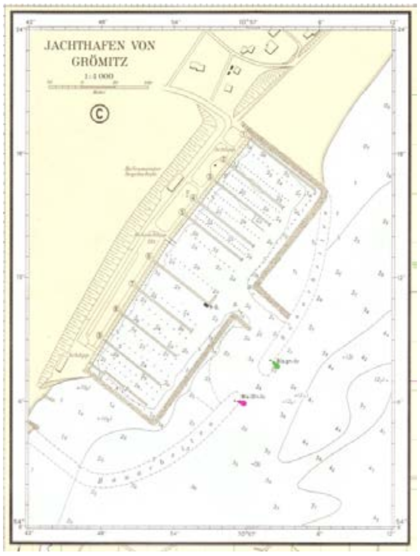
A.1.3.2 Extent of embankment of marinas

The extent of dyking of harbour basin has a large influence on the water exchange with the adjacent water body and therefore also on dilution processes of antifouling active substances inside the basin. Therefore, the degree of dyking was determined. A harbour was defined as *closed* if it was bordered on three sides by dyking or harbour facilities (cf. Appendix B). All other cases were defined as *open*. Due to very diverse structure of different harbours, this simplified definition turned out to be applicable even when used in teamwork.

A.1.3.3 Water depths in marinas

Figure A-1

Grömitz marina with detailed depth information



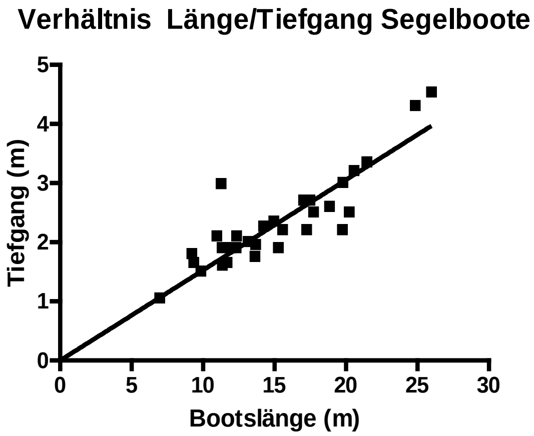
Source: Sportbootkarte BSH, Lübecker Bucht 1991

The water depths in the harbours, especially in the seawater areas, are well documented and are taken from harbour maps, nautical charts or other sources (Figure A-1).

For inland sites, information on water depth is often missing. In case it was possible to identify boats with certainty and their length could be measured clearly, the required water depth was estimated using the longest sailing boat. This linear regression was based on the evaluation of 30 typical sailing boats regarding length, width and draught (Figure A-2). The raw data were taken from well-known boat market places (www.boot24.com).

Figure A-2

Relation of boat length and draught of typical sailing boats offered on the market with lengths between 7 and 29 m



Bottom axis: Bootslänge = length of the hull. Left axis: Tiefgang = draught of the hull.
Source: www.boot24.com

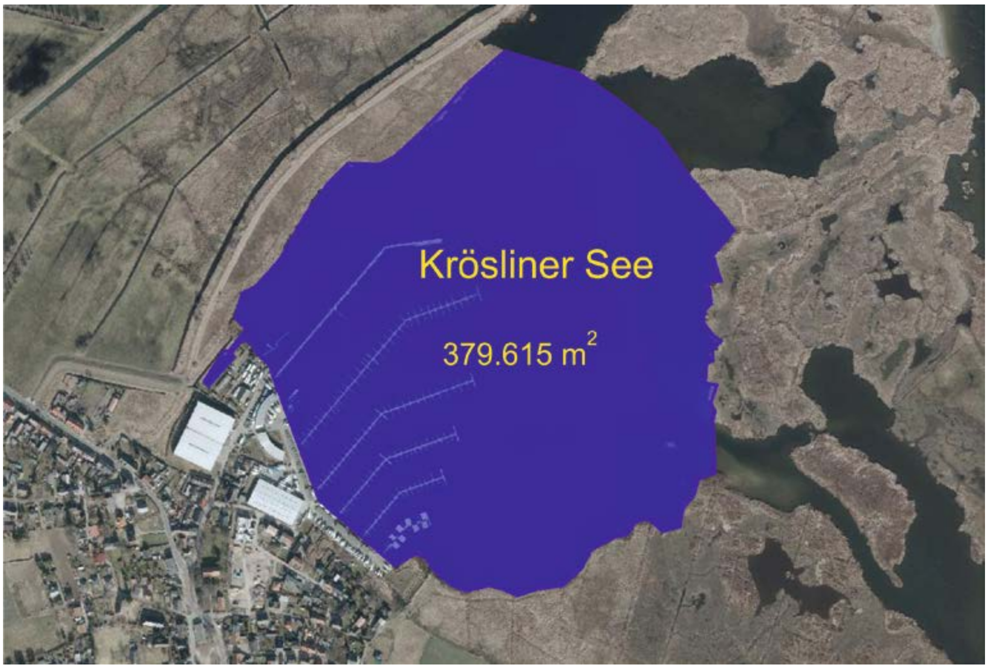
A.1.3.4 Size of marina area

The water surface was determined by measuring the area of the moorings plus one boat length distance in all directions, in closed harbours also to the borders.

For many of the moorings in smaller bays, e.g. in the lagoons (*bodden*) of the Baltic Sea it has to be discussed how to set the demarcation for these marinas. The example of the marina Kröslin (Figure A-3) shows that it makes sense to set the border around the entire bay, as due to the low water exchange rate it is likely that the entire water body is contaminated by the antifouling leaching into the water. If the border had been set around the moorings with one boat length distance, the water body would have been artificially separated, and thus an increased concentration of the AF biocides would have been calculated from the data entered into an exposure model. Consequently, the marina Kröslin has the largest water surface with nearly 380,000 m².

Figure A-3

Marina Kröslin, Peenestrom near Usedom



Source: © GeoBasis DE/BKG 2015; sg.geodatenzentrum.de/web_dop_viewer/dop_viewer_geoview.htm

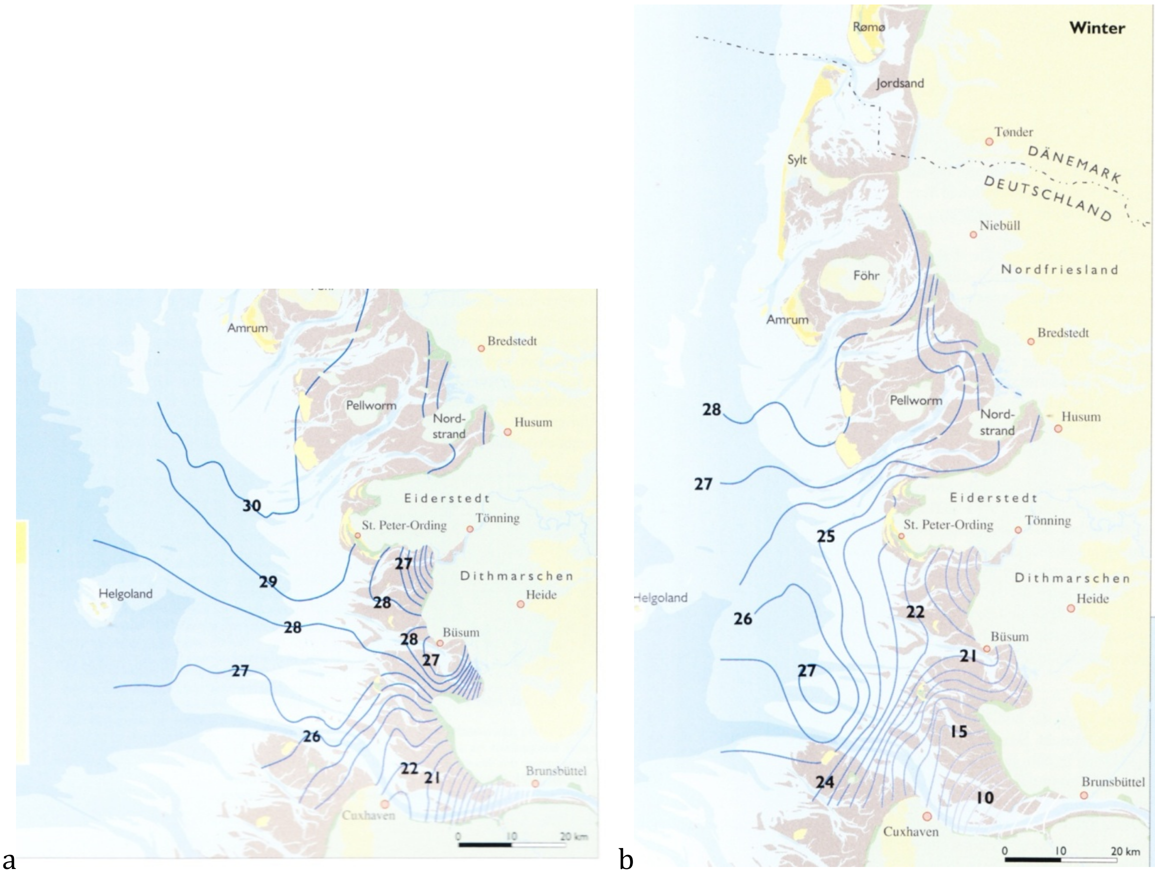
A.1.3.5 Classification of the study area according to salinity

The necessity to stop fouling on the hull is strongly dependent on the water body and on the location in fresh-, brackish or saltwater. While in freshwater there are no hard-shelled organisms, which fasten themselves onto the hulls using threads or sticky substances with the exception of zebra mussels, fouling in brackish water and saltwater mainly takes place by hard-shelled organisms such as barnacles, mussels, serpulids and softer branched algae, which firmly attach themselves onto the hull surface. Only in the highly calcareous lakes of the alpine foothills and in reservoirs incrustations can appear as chalk excretions caused by green algae (www.bewuchs-atlas.de).

For the registration of the number of boats and the following estimation of the underwater surfaces coated with biocidal products, it was therefore particularly important to identify such large areas, which can be clearly distinguished under the aspect of fouling pressure and fouling problem. Thus, a clear distinction was made between freshwater, brackish water and saltwater sites (<1 %, 1 – 18 %, >18 %). The borders of these salinity zones vary seasonally and locally in the coastal areas. In Northern Germany, the transition between brackish and freshwater in the rivers is dependent on the inflow and outflow of saltwater and on the actual water discharge of the river. Thus, there are no fixed boundaries but rather there are transition zones. This study used the information supplied by the Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer (1998) and Bergemann (2005), however, for some areas the assignment was set by best guess.

Figure A-4

Salinity of the Schleswig-Holstein tidal mudflats. A: Summer, B: Winter



Source: Landesamt für den Nationalpark Schleswig-Holsteinisches Wattenmeer, 1998

The harbours at saltwater sites have a salt content of approx. 30 ‰ and are exclusively situated along the North Sea coast in Lower Saxony and Schleswig-Holstein (Figure 2-12), in the outer estuarial areas of the rivers Ems, Weser and Elbe, at the coats of East and North Frisian Islands including the Jade bay.

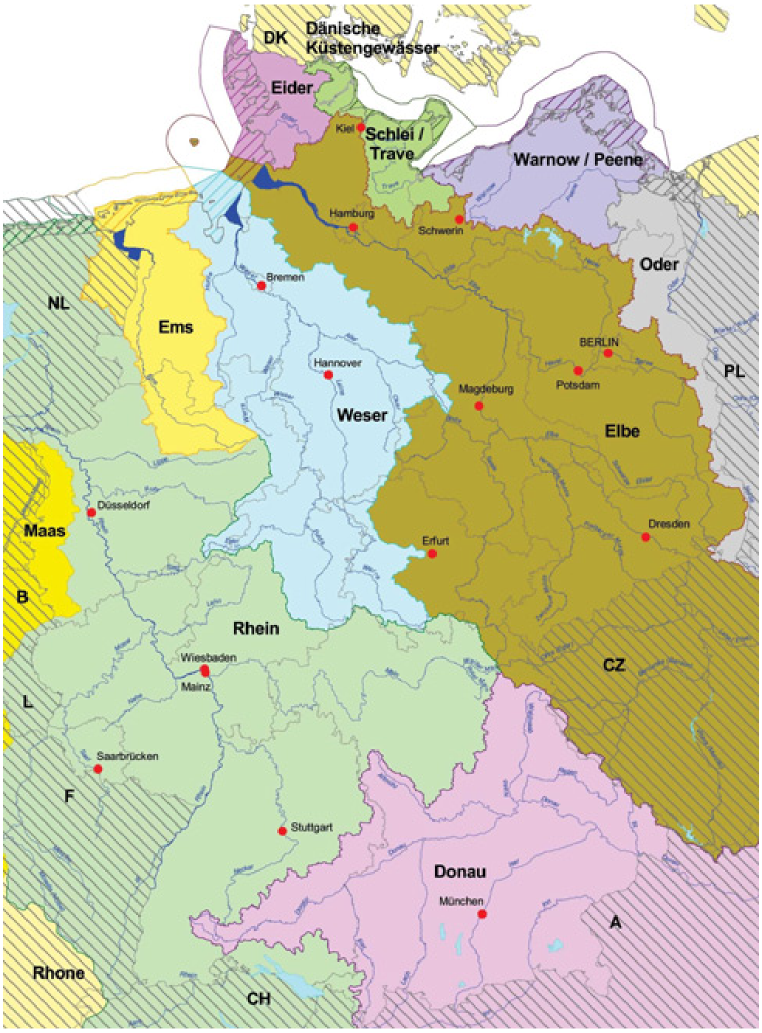
As Figure A-4 A and B show, the salinity fluctuates considerably on a seasonal basis at the North Sea coast and is strongly influenced by the current water discharges from the large rivers. Overall, a typical marine benthos community can be found along the German North Sea coast and in their harbours.

A.1.3.6 Classification of the study area according to river catchments

The allocation of harbours to the river catchment areas largely follows the EU Water Framework Directive (2000/60/EC) (Figure A-5). The only exception were the Mittelland Canal, the Rhine-Main-Danube Canal and the Kiel Canal, which were classified as individual units, as they overlay different river catchment areas. The North Sea islands and the coastal harbours distant from the rivers were also summarised as a separate unit.

Figure A-5

Catchment areas of main rivers in Germany according to Directive 2000/60/EC (Water Framework Directive)



Source: Umweltbundesamt, 2004, http://gis.uba.de/website/web/atlantis/karten/fge_wacd_ezg.htm; Map basis: Länderarbeitsgemeinschaft Wasser [LAWA], Federal Agency for Cartography and Geodesy [BKG].

A.1.4 Implementation of the berth census by different project members

Four contributors carried out the national berth survey in teamwork. A coordinator, who checked them in respect of format, content and completeness, pooled the obtained datasets.

To assess the error in berth counting by the individual employees, six different harbours were selected randomly to serve as standards. The counting was done simultaneously and independently by all contributors. Besides, these test counting based on aerial views, further sources had also to be covered and used to determine the currently available berths.

The results are shown in Table A-1 and depict the counts according to aerial photograph (AerCt) and the finally determined numbers of berths using additional sources (Final) for each contributor. In individual cases, the standard deviations vary by up to max. 15 % of the mean. For all six harbours, the mean standard deviation is about 5 - 6 % of the mean.

Table A-1

Comparison of boat counts of individual contributors

	Contr. 1		Contr. 2		Contr. 3		Contr. 4		Aerial count		Final count	
	AerCt	Final	AerCt	Final	AerCt	Final	AerCt	Final	Mean	SD	Mean	SD
Harbour 1	78	100	83	90	82	82	82	83	81.3	2.22	88.8	8.30
Harbour 2	92	92	101	101	94	97	98	100	96.3	4.03	97.5	4.04
Harbour 3	88	88	84	84	85	85	84	84	85.3	1.89	85.3	1.89
Harbour 4	160	160	169	169	165	169	170	170	166.0	4.55	167.0	4.69
Harbour 5	103	103	77	77	74	74	90	90	86.0	13.29	86.0	13.29
Harbour 6	67	67	68	68	68	68	65	68	67.0	1.41	67.0	0.50

AerCt: aerial view count, Final: final decision, Mean: arithmetical mean, SD: standard deviation

A.1.5 Statistical analysis

Parameters like berths per harbour, water surface area per harbour and water surface area per boat were tested in pairs for the saltwater, brackish and freshwater areas for significant differences using the Kolmogorov-Smirnov-test (KS-test) and the median (P50) using Mood's median test. Calculations were performed using OriginPro V 8.6 (OriginLab, USA).

A.2 Screening (AP 2)

A.2.1 Preload of antifouling in the harbours

To assess the preload of the harbours, which were foreseen for the sampling campaign, the federal state authorities were contacted for actual monitoring data. As biocide monitoring is not mandatory in Germany, the priority setting of the substances to be analysed is in the responsibility of the states, which seem to set the focus on actual problems. In general, it is apparent that biocides from antifoulants are monitored insufficient and on a very small scale compared to agricultural plant protectants (pesticides). For this survey, it was only possible to use background data from official surveys of the site Norderney.

A.2.2 Sampling methods

For the sampling campaign three teams, *Hamburg* and *Norderney* (both LimnoMar) and *Berlin* (UBA), were available. Due to the flooding period in May - June 2013, it was feared that several water parameters inside the marinas might be affected by the flooding and therefore may not reflect the *normal state* of the harbour and its surroundings (previous loading, loading from other sources). Therefore, the sampling in the areas affected by flooding was postponed to July - August 2013.

To get information on the actual flooding situation at selected harbour, further information was requested from federal state authorities. On the river Rhine at the water gauge Mainz, for instance, the flood notification stage 1 was no longer reached from the 11.06.13 (HLUG 2013), so that sampling in the neighbouring marinas could take place at the end of July.

LimnoMar has developed a harbour specification sheet for detailed recording of the harbour structures and for sampling, which was used to document all relevant parameters for the respective harbour and the sampling procedure (Appendix C).

The characteristics of infrastructure already registered in AP 1 (boats lift or slipways, wharfs and covered winter storage space) were compared with the actual situation and if necessary updated and noted on the harbour specification sheet. Based on these data, conclusions could be drawn whether or not additional input paths of paint residues with AF active substances that can be foreseen to enter the harbour water due to cleaning, repair or maintenance activities.

The water samples of the 50 harbour sites were analysed for the following parameters:

- Active substances from antifoulants and selected transformation products
- Further water quality parameter
- Seston (dry matter)

Besides the water samples from the marinas, 17 additional reference water samples close to the harbour were taken, to identify possible previous loads by other emission sources. Additional water quality parameter were not determined at these reference sites, as the focus was on the active substances.

The water samples were sent in parallel for analysis to the UBA and the institute Dr. Nowak. The UBA carried out the analyses of seston and further water quality parameter. Both laboratories analysed active antifouling ingredients.

A.2.2.1 Field methods

Water sampling was done in the centre of the marina.

Visibility depth and water depth were measured using a white Secchi disc (diameter 20 cm).

Electrical conductivity, water temperature and pH-value were measured at a water depth of 0.5 m using calibrated field probes (Multi 340i, Condi340, Multi 3430, pH197S, only pH, WTW, Weilheim, Germany). The conductivity data was temperature compensated (nLF-mode, 25° C). The salinity values (incl. temperature correction) are based on the conversions of the UNESCO Salinity Tables (UNESCO 1987). The 2-point calibration at pH 7 and 10 of the pH-meters was checked weekly.

Water sampling was carried out using 1 l Veral brown glass bottles at a water depth of 0.5 m using a handling rod. All glass bottles were flushed several times prior to taking the sample using local water.

The samples for antifouling active substances were filled into 1 l Veral brown glass bottles, which were closed with aluminium foil as a seal.

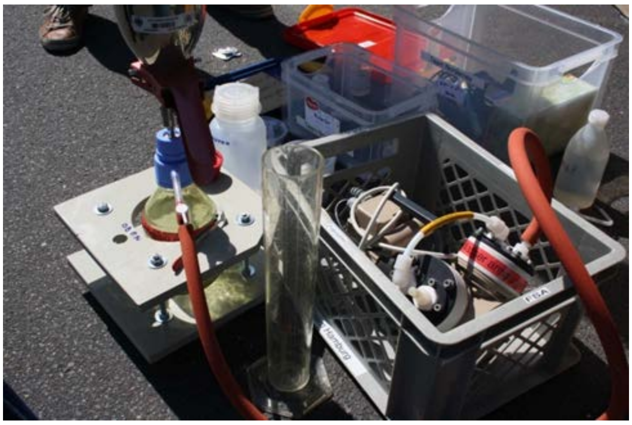
A 30 ml subsample was directly filled into a tightly closing polypropylene (PP) vessel for the analyses of total copper and zinc. For the metal contents of the filtered fraction, a 30 ml subsample was directly filtered into a similar vessel using disposable PP-syringes and a syringe filter (0.45 µm, Sartorius, Germany) on-site. The samples were acidified with nitric acid (65 %, Suprapur, Merck, Germany).

For the seston analyses and further water quality parameters, the samples were filled into 1 l PP wide-neck bottles. The seston samples were filtered on-site using a glass fibre filter (MN GF-5, Macherey-Nagel, Germany) (Figure A-6). Filters were stored air-dried until arrival at the lab.

The samples were transported in cool boxes (4 - 6° C) and sent to the laboratories by express courier service. The duration from sampling to arrival in the laboratory was on average between 3 - 5 days. Upon arrival, the samples were stored cool and dark at +4° C.

Figure A-6

Installation for filtration of the seston samples



Source: LimnoMar.

A.2.2.2 General laboratory methods

For seston analysis (dry matter), the glass fibre filters were dried for 12 h at 110 °C in a drying chamber and weighed afterwards.

To analyse the nutrients, major ion components and DOC, the water samples were filtered in the laboratory (0.45 µm, TNC, Schleicher & Schüll, Germany).

The nutrients silicate, o-phosphate, ammonium, nitrite and nitrate were photometrically determined using continuous flow analysis (San++; Skalar, Netherlands) (DIN-EN-ISO-11732, DIN-EN-ISO-13395, and DIN-EN-ISO-16264).

The major ion components calcium, magnesium, potassium, sodium, sulphate, chloride and bromide were analysed using ion chromatography, and the alkalinity was titrimetrically determined (TitrIC-System with 861 Compact ICs, column for cations: Metrosep C4-150, anions: Metrosep Supp 5-150 with CO2-Suppression, 855 Titrosampler; Metrohm, Switzerland) (DIN-EN-ISO-10304-1, DIN-EN-ISO-14911, DIN-EN-ISO-9963-1).

TOC and DOC were measured according to DIN-EN-1484 as non-purgeable organic carbon by catalytic combustion at 680 °C and IR-detection of the CO_2 using the TOC 5000A with ASI 5000A (Shimadzu, Japan).

A.2.2.3 Active substance specific laboratory methods

The biocidal active substances, their transformation products as well as the internal standards used for quality assurance are given in Table A-2. Additionally, the origin, purity grade and other identification characteristics are listed. Using the so-called ‘Method’ key in Table A-2 the corresponding applied analytical procedures are assigned and characterised in Table A-3.

The s-triazine cybutryne with M1 and terbutryn were analysed using GC-MS (Method 6), while all the other analytes, such as dichlofluanid with DMSA, tolylfluanid with DMST (both Method 1), Seanine 211 with NNOMA, NNOOA and NNOA (Methods 1, 4) were analysed using HPLC-MS/MS. As the polymer zineb degrades rapidly, only its transformation products ETU and EU were detected (Method 5). The organic fractions of copper and zinc pyrithione were determined as total-pyrithione, as was the transformation product PSA (Methods 2, 3).

Table A-2

Analytical characteristics of the AF active substances, degradation products and quality standards

Active substance	CAS	Status	Source	Purity [%]	Target / Transition	Method
Dichlofluanid, N-[dichloro (fluoro) methyl] sulfanyl-N-(dimethylsulfamoyl) aniline	1085-98-9	A	Dr.E	98.5	332.6 → 122.8 332.6 → 123.8	1
Tolylfluanid, N-[Dichloro (fluoro) methyl] sulfanyl-N-(dimethylsulfamoyl)-4-methyl-aniline	731-27-1	A	Dr.E	98.5	346.8 → 137.0 346.8 → 237.8	1
DMSA, N'-dimethyl-N-phenyl-sulphamide (breakdown product dichlofluanid)	4710-17-2	A	Dr.E	99.0	201.0 → 92.0 201.0 → 137.0	1
DMST, N,N-Dimethyl-N'-(4-methylphenyl)-sulfamide (break down product tolylfluanid)	66840-71-9	A	Dr.E	99.5	215.0 → 79.0 215.0 → 106.0	1
SeaNine 211, DCOIT, 4,5-dichloro-2-octyl-isothiazolone	64359-81-5	A	DOW	99	281.9 → 169.9 283.8 → 171.9	1
NNOA, N-(n-Octyl)-acetamide (breakdown product Seanine)	-/-	A	DOW	99.52	172.1 → 60.1 172.1 → 57.2	1
Atrazine-d5	1912-24-9	IS	Dr.E	98.5	221.0 → 179.0	1
Isoproturon-d6	34123-59-6	IS	Dr.E	97.5	213.0 → 78.0	1
Metolachlor-d6	51218-45-2	IS	Dr.E	97.7	290.0 → 258.0	1
Cu-pyrithione	14915-37-8	A	Cam	~95	316.0 → 141.9 316.0 → 188.9	2
Zn-pyrithione	13463-41-7	A	S-A	~95	-/-	2
Metolachlor-d6	51218-45-2	IS	Dr.E	97.7	290.0 → 258.0	2
PSA, 3-Pyridinesulfonic acid (break down product: Zn-, Cu-Pyrithione)	-/-	A.	S-A	97	158.0 → 80.0 158.0 → 94.0	3
13C8-Perfluorooctanoic acid	-/-	IS	WL	99	421.0 → 376.0	3
NNOOA, N-(n-Octyl) oxamide acid (breakdown product SeaNine)	-/-	A	DOW	99.96	200.0 → 127.8 200.0 → 171.7	4
NNOMA, N-, N-(n-Octyl) malonamic acid (breakdown product SeaNine)	-/-	A	DOW	96.5	214.0 → 169.7 214.0 → 58.0	4
Mecoprop-d6	7085-19-0	IS	Dr.E	98.0	216.0 → 144.0	4

Active substance	CAS	Status	Source	Purity [%]	Target / Transition	Method
ETU, Ethylene thiourea (breakdown product Zineb)	96-45-7	A	Dr.E	98.5	103.0 → 44.0 103.0 → 86	5
EU, Ethylene urea (breakdown product Zineb)	120-93-4	A	S-A	99.5	87.0 → 44.0 87.0 → 70.0	5
1-Propylene thiourea, 1,3-diazinane-4-thione	2122-19-2	IS	Dr.E	97.0	111.0 → 58.0 111.0 → 60.0	5
Irgarol, cybutryne	28159-98-0	A	S-A	98.4	253 m/z	6
M1 - GS26575 (breakdown product Irgarol)	-/-	A	Asca	≥ 95	198 m/z	6
Terbutryn	886-50-0	A	S-A	99.3	226 m/z	6
13C3-Propazine	-/-	IS	C.I.	99	217 m/z	6

Status: A: Analyte, IS: Internal quality standard, Source: Asca-Berlin (Germany), Cam.: Campro Scientific (Germany), C.I. Cambridge Isotopes (MA, USA), Dow: DOW (PA, USA), Dr.E.: Dr. Ehrenstorfer (Augsburg, Germany), S-A: Sigma-Aldrich (Germany), WL: Wellington Laboratories (Canada).

Table A-3

Method data for the analysis of AF active substances and breakdown products

Method No	SPE-sample enrichment	Reference procedures	Matrix type, equipment, separation columns	Separation medium HPLC / GC	Detection	LoQ [ng/L]
1	C18 HD cartridge[1], Online[3]	Acc. DIN EN ISO 11369-F12: 1997-11	LC-MS/MS, A, 1	A: 100 ml 0.1 % Ammonium acetate solution + 10 ml Acetonitrile + 390 ml LC-MS water; B: Methanol	ESI positive	10
2	- /-	Acc. DIN EN ISO 11369-F12: 1997-11	LC-MS/MS, A, 2	A: 100 ml 0.1 % Formic acid solution + 400 ml LC-MS water; B: Methanol, Separation: isocratic; 20 % 0.002 % Formic acid + 80 % Methanol	ESI positive	1000
3	- /-	DIN 38407-F35: 2010-10	LC-MS/MS[Aii]	A: 100 ml 0.1 % Formic acid solution + 400 ml LC-MS water; B: Methanol, Separation: isocratic; 5 % 0.002 % Formic acid + 95 % Acetonitrile	ESI negative	500
4	C18 HD cartridge[1], Gradient elution, A. & B.; Online[3]	DIN 38407-F35: 2010-10	LC-MS/MS[Ai]	A: 100 ml 0.1 % Formic acid solution + 10 ml LC-MS water; B: Methanol, Separation: isocratic; 5 % 0.002 % Formic ac-id + 95 % Acetonitrile	ESI negative	10

Method No	SPE-sample enrichment	Reference procedures	Matrix type, equipment, separation columns	Separation medium HPLC / GC	Detection	LoQ [ng/L]
5	- /-	Acc. DIN EN ISO 11369-F12: 1997-11	LC-MS/MS[Aii]	A: 100 ml 0.1 % Formic acid solution + 400 ml LC-MS water; B: Methanol, Separation: isocratic; 5 % 0.002 % Formic acid + 95 % Acetonitrile	ESI positive	1000
6	6 ml-ENV+-Column[2] manual	-/-	GC-MS[Biii]	Helium (pre-pressure 1.4 bar)	EI-SIM	[4]Irg.: 2 (1/5) [4]M1 : 3 (2/9) [4]Terb.: 2 (2/5)

Enrichment: 1: HyShere HD 7 µm (Spark Holland, Netherlands), 2: IST Biotage (Sweden)
Equipment: A: HPLC if necessary with 3) online-SPE Symbiosis Pico System (Spark Holland, Netherlands), MS 325 TripleQuad (Varian, USA), B: HP6890/5973 with Split-Splitless-Injector (Hewlett Packard, USA)
Separation columns: i: Pursuit 3 C18-A, 3 µm 50x2 mm (Varian, Agilent, USA), ii: Monochrome, 5 µm 100x2mm (Varian, Agilent USA), iii: Optima 17, i. D. 0.25 mm, 30 m (Macherey & Nagel, Germany)
LoQ: Limit of quantification, 4: LoQ was substance-specifically evaluated acc. to every analytical run listed as percentiles: P50 (P10/P90)

For the analysis of total copper and zinc, the unfiltered water samples were digested with nitric acid and hydrogen peroxide in a microwave (Multiwave 3000, Anton Paar, Austria; 210 °C, approximately. 20 bar) according to ISO 15587-2: 2002-03.

The copper and zinc concentrations were quantified using ICP-MS (XSeries 2, Thermo Scientific USA) and collision reaction cells in KED mode according to EN ISO 17294-2: 2005-02. The main isotopes ^{64}Zn, ^{66}Zn, ^{63}Cu and ^{65}Cu as well as the internal standards ^{103}Rh and ^{115}In were detected. Besides drift control (LLCCV), additional independent control samples were used to check the calibration (ICV) and the accuracy of the whole method ($QC_{Drinkingwater}$). The limits of quantification for Zn and Cu in freshwater were both 1 µg/l, increased by the required dilution of the saltwater matrix for brackish water to 2 µg/l and for seawater samples from the North Sea to 5 µg/l. The additional microwave digestion did not influence these limits.

For the determination of copper and zinc, the measurement uncertainty must be taken into consideration, so that the required dilution of the samples can lead to a deviation of <10 % in the freshwater samples and <25 % in the saltwater samples. This explains why in some saltwater and brackish water sites the concentrations of the filtered samples were higher than the concentrations of the unfiltered samples.

A.2.2.4 Determination of the underwater hull surface

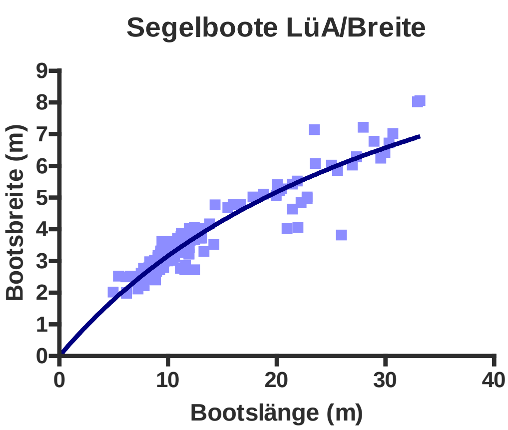
When visiting the 50 harbours, the focus was set on a detailed recording of the types of boats and on their sizes to calculate approximately their underwater hull surfaces. The outcome was used for the data input required to run the model MAMPEC (AP 3) to compare the predicted water concentration of active AF substances released by the underwater areas with the measured results from the screening.

The relationships of boat length, width and draught depicted in Figure A-7 to Figure A-10 are used for the calculation of the underwater surface area of the leisure boats present in the harbour. On-site, the length of the boats was estimated as the length overall (LoA).

We would like to thank the port operator of the marina Arnis situated at the Schlei fjord for compiling an anonymised list including length, width and draughts of all boats at berth. From this listing of 240 boats, 207 sailing vessels of lengths between 5 and 15 meters length could be identified, which were used for further evaluation. To get information on the size of larger boats, the homepage www.yachtall.com was used resulting in a total dataset of 250 boats. For calculating the underwater surface area of the different length classes, regression curves from the relations of length, width and draught were calculated. By use of these regressions, lengths (LoA) and their corresponding widths and draughts were calculated (Table A-4).

Figure A-7

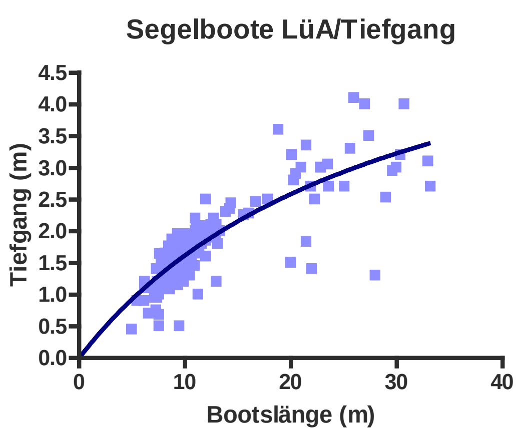
Relationship between boat length to width of 250 sailing boats with a LoA between 5 and 40 meters



Bottom axis: Bootslänge = length of hull. Left axis: Bootsbreite = width of hull.
Source: this study, LimnoMar.

Figure A-8

Relationship between boat length to draught of 250 sailing boats with a LoA between 5 and 40 meters



Bottom axis: Bootslänge = length of hull. Left axis: Tiefgang = draught of hull.
Source: this study, LimnoMar.

Table A-4

Sailing boats of different lengths with calculated averages of width and draught

LoA (m)	Width (m)	Draught (m)
5	1.8	0.9
6	2.1	1.1
7	2.3	1.2
8	2.6	1.4
9	2.9	1.5
10	3.2	1.6
12	3.6	1.9
12.5	3.7	2.4
14	4.1	2.1
16	4.5	2.3
17.5	4.8	2.4
18	4.8	2.4
20	5.2	2.6
25	5.9	2.9
30	6.5	3.2

The boat length at the waterline (LWL), which is shorter than the LoA, was calculated for sailing boats as between 8 and 15 m total length as LoA minus 1 m, and for boats over the length of 15 m in total as LoA minus 2 m. For boats under 8 m, the full length was assumed. When calculating the underwater surface for sailing boats, the following 'rule of thumb' was used:

$0.65 \times \text{lenght of waterline} \times (\text{width} + \text{draught})$

The underwater hull surfaces for the sailing boat lengths are given as size classes in Table A-5.

Table A-5

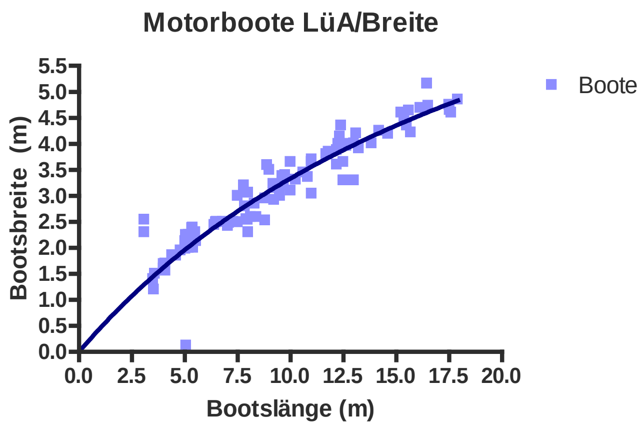
Calculated underwater surface (UWS) for different sailing boat lengths (LoA)

LoA (m)	UWS (m^2)
< 6	0.65 x 5 x (1.8 + 0.9) = 8.775
6 - 8	0.65 x 7 x (2.3 + 1.2) = 15.925
8 - 10	0.65 x 8 x (2.9 + 1.5) = 22.88
10 - 15	0.65 x 11.5 x (3.7 + 1.9) = 41.86
15 - 20	0.65 x 15.5 x (4.7 + 2.4) = 71.53

As there was no comparable data set available for motor boats, size data of 113 motor boats were gained from a German sales portal (www.bestboats24.com) with lengths between 2.5 and 20 meters (Figure A-9, Figure A-10, and Table A-6).

Figure A-9

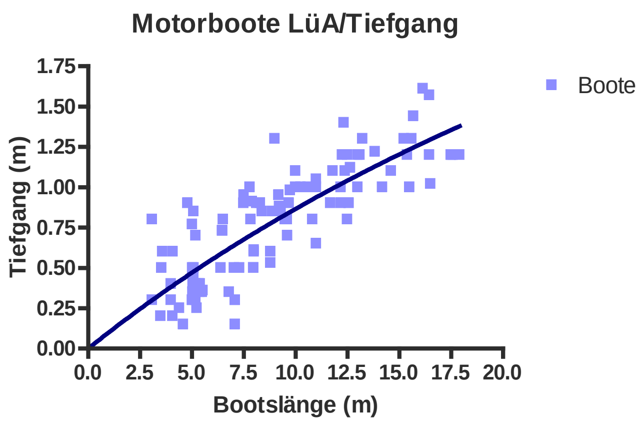
Relationship between boat length to width of 113 motor boats with between 2.5 and 18 meters LoA



Bottom axis: Bootslänge = length of hull. Left axis: Bootsbreite = width of hull.
Source: this study, LimnoMar.

Figure A-10

Relationship between boat length to draught of 113 motor boats with between 2.5 and 18 meters LoA



Bottom axis: Bootslänge = length of hull. Left axis: Bootsbreite = width of hull.
Source: this study, LimnoMar.

Table A-6

Motor boats of different lengths with calculated average of width and draught

LoA (m)	Width (m)	Draught (m)
5	1.9	0.5
6	2.3	0.6
7	2.6	0.6
8	2.9	0.7
9	3.1	0.8

LoA (m)	Width (m)	Draught (m)
10	3.4	0.9
12	3.8	1.0
12.5	3.9	1.0
14	4.2	1.2
16	4.5	1.3
17.5	4.8	1.4
18	4.8	1.4

For theoretical reasons, but also confirmed by the boat builder, the correction factor has to be larger for motor boats than for sailing boats, as the submerged surface of the hull of a motor boat is in general larger than that of a sailing boat. As opposed to sailing boats, there are many different types of V-shaped submerged parts of the hull. These were grouped and a correction factor of 0.85 was applied, as given by the paint manufacturer Hempel. For the conversion of the total length of a motor boat to the length of waterline, the factor 0.9 was selected, as the keel and bow overhang of motor boats are smaller than for sailing boats.

When calculating the underwater surface for motor boats, the following rule of thumb was used:

$$0.85 \times \text{lenght of waterline} \times 0.9 \times (\text{width} + \text{draught})$$

The calculated underwater surfaces for motor boats are given in Table A-7.

Table A-7

Calculated underwater surface (UWS) for different motor boat lengths

Motor boat lengths (m)	UWS (m^2)
< 6	0.85 x (5.5 x 0.9) x (2.1 + 0.55) = 11.15
6 - 8	0.85 x (7 x 0.9) x (2.6 + 0.63) = 17.3
8 - 10	0.85 x (9 x 0.9) x (3.15 + 0.8) = 27.19
10 - 15	0.85 x (12.5 x 0.9) x (3.93 + 1.1) = 48.10
15 - 20	0.85 x (17.5 x 0.9) x (4.7 + 1.4) = 81.66

A.3 Scenarios and modelling (AP 3)

A.3.1 General procedure

For modelling, version 2.5 of the program MAMPEC (Deltares, The Netherlands) was used.

A.3.1.1 Basic program settings

The general specification for data entry of the sample harbours in AP 3 was made based on the environmental prototype *estuarine harbour*, *marina* and *marina poorly flushed* in MAMPEC with the aim of creating a representation of the selected harbours as close to the reality as possible.

For input in the column *environment* in selected harbour scenarios, the main harbour data was entered based on the findings from AP 1 and AP 2. Some values were taken from the pre-set scenarios (*default value*). The sediment does not play any role here for the purpose of this study, therefore the default values were accepted, however, not used in the modelling. An overview is compiled in Table A-8.

In MAMPEC, calculations can be carried out for different active substances. In this project, the active substances copper, cybutryne, dichlofluanid and DCOIT were selected for modelling. The respective active substances were selected in the column *compound* with their default values and accepted without changes. Only for dichlofluanid, which decomposes very quickly in water, the hydrolytic decomposition was set to *zero* to allow comparison of the total amount of emitted dichlofluanid with the measured dichlofluanid and its transformation products DMSA.

In the column *emissions*, an emission rate is calculated for every biocide using the number of boats and sizes, leaching rates and application factor. The boat size classes were taken from AP 2 for the selected harbours, the underwater areas of sailing boats and motor boats were averaged. Exceptions were made if only one boat type in this particular size class was present, or if its presence was 10-times higher than the other one. The leaching rates of the active substances were taken from the set values from MAMPEC. The AF product manufacturers do not publish their market share in Germany and most other countries, so that the actual amounts used of the individual active substances are unknown (Hattum et al. 2006). Therefore, the *application factor* was selected based on the product shares on the German market, which does not necessarily reflect the market shares (LimnoMar 2013) (Table A-9). According to experience, it was assumed for all harbours that, during the application phase (*maintenance & repair*) no paint directly enters the surface water (*fraction to surface water* = 0).

Further emissions through working on the boats on land (*removal*) have been manually calculated using Tables 0.16 and 0.22 from the ESD PT21 (OECD 2004) and added to the emissions from *service life*. As suggested in MAMPEC, it was assumed that 10 % of the boats are treated professionally and the remaining 90 % are treated by the owners themselves. For this, it is necessary to state the concentration of the respective biocide in the products, which is only given as a range by the manufacturer. When setting the values for MAMPEC, it was recommended that the highest concentrations were always used in these cases. Based on the statements of the per cent weight of different AF products, the concentrations were set for the calculations of the model (Table A-10). In Germany, it is common practice to clean the hulls of leisure boats by use of high pressure washer. Commonly, the boats are not rubbed down directly after being taken out. It is assumed that later grinding in the winter storage does not lead to biocide introduction in the harbour water of the sampled harbours.

Table A-8

General definitions for data input for column *environment* in MAMPEC v2.5 for modelling of selected marinas from AP 2

Variable/ Parameter	Value	Source
Environmental conditions		
Tidal period (h)	12.41	Default value of OECD (2004)
Silt concentration (mg/l)	35	Default value of OECD (2004)
POC concentration (mg OC/l)	var.	TOC-DOC= POC from measurement AP 2
DOC concentration (mg/l)	var.	In situ measurement in AP 2
Chlorophyll (µg/l)	3	Default value of OECD (2004)
Salinity (psu)	var.	In situ measurement in AP 2
Temperature [°C]	var.	In situ measurement in AP 2
Latitude (degrees)	var.	Specific local geodata
pH	var.	In situ measurement in AP 2
Depth mixed sediment layer (m)	0.1	Default value of OECD (2004)
Sediment density (kg/m³)	1000	Default value of OECD (2004)

Variable/ Parameter	Value	Source
Degr. organic carbon in sediment (1/d)	0	Default value of OECD (2004)
Net sedimentation velocity (m/d)	0.2	Default value of OECD (2004)
Fraction organic carbon in sediment	var.	Default value of OECD (2004)
Layout		
Length x1(m)	x2≤x1≤1.5*x2	Default value of OECD (2004)
Length x2 (m)	var.	Value from AP 1
Width y1 (m)	var.	Value from AP 1
Width y2 (m)	0.5*y1≤y2≤y1	Default value of OECD (2004)
Depth (m)	var.	Value from AP 1
Mouth width x3 (m)	var.	Value from AP 1
Flow velocity (F) (m/s)	var.	Bibliography
Calculate exchange volume		
Tidal difference (m)	var.	Calendar of the tides 2013 (BSH)
Max. density difference tide (kg/m³)	0.1-0.4	Default value range of OECD (2004)
Non tidal daily water level change (m)	var.	Value from AP 1, AP 2
Fraction of time wind perpendicular	var.	www.windfinder.de
Average wind speed (m/s)	var.	www.windfinder.de
Flush (fl) (m³/s)	var.	Bibliography
Max. density difference flush	var.	Bibliography
Depth-MSL in harbour entrance h0 (m)	var.	Calculated from depth - height of submerged dam
Exchange area harbour mouth, below mean sea level (m²)	var.	Calculated from x3*Depth MSL
Height of submerged dam (m)	var.	Value from AP 1, AP 2
Width of submerged dam (m)	var.	Value from AP 1, AP 2

Table A-9

General definitions for data input for column *emission* in MAMPEC v2.5 for modelling of selected marinas from AP 2

Variable/ Parameter	Value	Source
Length class		
Class 1 (m)	0-6	Value from AP 2
Class 2 (m)	6-8	Value from AP 2
Class 3 (m)	8-10	Value from AP 2
Class 4 (m)	10-15	Value from AP 2
Class 5 (m)	15-20	Value from AP 2
Surface area		
Class 1 (m²)	9.96	Averages value from AP 2
Class 2 (m²)	16.61	Averages value from AP 2

Variable/ Parameter	Value	Source
Class 3 (m^2)	25.03	Averages value from AP 2
Class 4 (m^2)	44.98	Averages value from AP 2
Class 5 (m^2)	76.59	Averages value from AP 2
Ships at berth (n)	var.	Value from AP 2
Ships moving (n)	0	Default value of OECD (2004)
Application factor for cybutryne	10	Product list LimnoMar (2013)
Application factor for DCOIT	10	Product list LimnoMar (2013)
Application factor for dichlofluanid	20	Product list LimnoMar (2013)
Application factor for copper	100	Product list LimnoMar (2013)
Leaching rate (at berth)		
Copper (µg/cm²/d)	50	Default value of OECD (2004)
Cybutryne / Dichlofluanid/ DCOIT (µg/cm²/d)	2.5	Default value of OECD (2004)
Leaching rate (moving):		
Copper (µg/cm²/d)	50	Default value of OECD (2004)
Cybutryne / Dichlofluanid/ DCOIT (µg/cm²/d)	2.5	Default value of OECD (2004)

Table A-10

General definitions for calculation of the emissions during the *removal* phase in MAMPEC v2.5 for modelling of selected marinas from AP 2

Variable/ Parameter	Value	Source
Professional removal leisure boats		
Removal period (d)	183	Default value of OECD (2004)
Number of boats treated per removal period	10 % of the total number of boats	Default value of OECD (2004)
Amount of paint applied per boat	4.5	International Farbenwerke: Anstrich-fibel
Fraction of the paint that is to be removed from the boat hull by HPW	0.2	Default value of OECD (2004)
Fraction of the paint that is to be removed from the boat hull by abrasion	0	Value from AP 2, observations
Concentration of active substance in the original paint	var.	Safety data sheets of AF products[1]
Fraction of a.i. remaining in exhausted paint removed by washing	0.05	Default value of OECD (2004)
Fraction of a.i. remaining in exhausted paint removed by abrasion	0.3	Default value of OECD (2004)
Fraction to surface water	Max. 1	Default value of OECD (2004)
Non-professional removal leisure boats		
Removal period (d)	91	Default value of OECD (2004)
Number of days for the treatment of one boat	1	Default value of OECD (2004)

Variable/ Parameter	Value	Source
Number of boats treated per removal period	45 %/90 % of the total number of boats[2]	
Amount of paint applied per boat	3/6[3]	In relation to the average boat length of
Fraction of the paint that is to be removed from the boat hull by HPW	0.2	Default value of OECD (2004)
Fraction of the paint that is to be removed from the boat hull by abrasion	0	Value from AP 2, observations
Concentration of active substance in the original paint	var.	Safety data sheets of AF products[1]
Fraction of a.i. remained in exhausted paint removed by washing	0.05	Default value of OECD (2004)
Fraction of a.i. remained in exhausted paint removed by abrasion	0.3	Default value of OECD (2004)
Fraction to surface water	max. 1	Default value of OECD (2004)
End calculation		
Elocalwater = (Vpaint + Nboat x Ndays + Ca.i. x (Fwashing x Fa.i.exh paint + Fabrasion x Fa.i.old paint) + Fwater) / Tremoval		

1: copper: 3200 g/l, cybutryne: 100 g/l, dichlofluanid: 25 g/l, DCOIT: 25 g/l, source: Safety data sheets (share by weight), 2: Assumption: 90 % of the boats are painted every other year, that is per year 45 % of the boats; in the North Sea 90 % of the boats are painted every year, 3: 3 l for one paint job per year, 6 l for 2 paint jobs every 2 years

A.3.2 Modelling and comparison with own measurements

A background concentration can be taken into consideration when modelling. In cases were reference samples are available for the sites from AP 2, these analytical results were used. For other sites, if available, background concentrations of monitoring surveys were utilised.

To create comparability of the active substance emissions from AP 2 and MAMPEC, it was necessary to not only take into account the parent substances but for dichlofluanid and cybutryne also the transformation products. The water analyses in AP 2 showed in addition to cybutryne also M1 and for dichlofluanid only the transformation product DMSA was above the limit of quantification. Therefore, the transformation products were calculated back to the parent active substances, taking into account the respective molecular weights.

For cybutryne, the recalculated value was added to the measured cybutryne value. This rough estimate is plausible, as it is reasonable to assume that the transformation products M1 and DMSA can only originate from cybutryne and dichlofluanid.

As MAMPEC calculates a rapid degradation rate in water as standard, but the dichlofluanid concentration was recalculated from the much more stable transformation product DMSA, the degradation rate in the program was reduced to allow a comparison of the model prediction by MAMPEC with the water concentrations of DMSA.

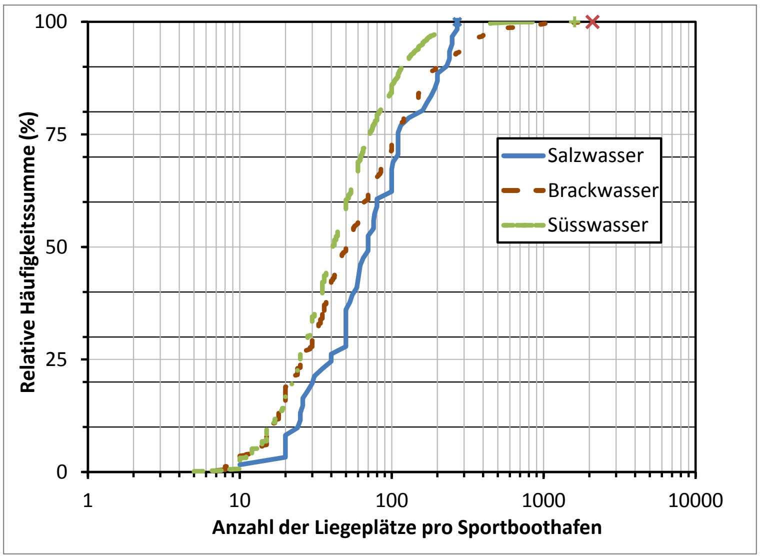
Appendix B Results

B.1 National census (AP 1)

B.1.1 Nationwide data

Figure B-1

Cumulative distribution function of the number of berths per marina in salt-, brackish and fresh-water



Source: this study, LimnoMar.

Table B-1

Statistical characteristics of the berths per marina in salt-, brackish and freshwater

Parameter	Salt	Brackish	Fresh	Salt+Brackish	Total
Min.	10	7	5	7	5
P10	25	16	16	17	16
P25	40	25	25	26	25
P50	70	50	40	52	43
P75	110	105	72	110	78
P90	230	200	118	200	132
Max	270	2,100	1,599	2,100	2,100
Mean	95	97	59	96	67
SD	73	156	65	150	90
N	61	-	2,470	621	3,091

Table B-2

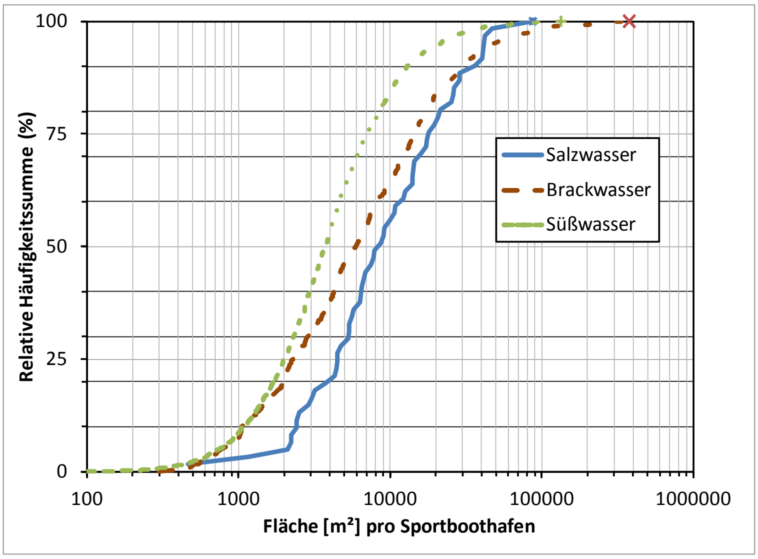
Test for statistically relevant differences in the distribution and median value of the moorings for each marina between the compartments salt-, brackish and freshwater

Areas	KS-test	Median-test
Salt - Brackish	xx	xxx
Salt - Fresh	xxx	xxx
Brackish - Fresh	xxx	xxx

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

Figure B-2

Cumulative distribution function of the water surface of marinas in salt-, brackish and freshwater



Source: this study, LimnoMar.

Table B-3

Statistical characteristics of the water bodies of marinas in salt-, brackish and freshwater

Parameter	Salt	Brackish	Fresh	Salt+Brackish	Total
Min.	465	297	98	297	98
P10	2,405	1,060	1,082	1,110	1,087
P25	4,502	2,295	1,996	2,461	2,068
P50	8,697	5,953	3,681	6,250	4,052
P75	17,883	14,562	7,025	14,607	8,268
P90	36,468	29,910	12,973	29,962	16,618
Max	87,072	379,615	133,468	379,615	379,615
Mean	14,367	14,234	6,478	14,247	8,039
SD	15,252	29,890	9,650	28,776	15,819
N	61	-	2,470	621	3091

Table B-4

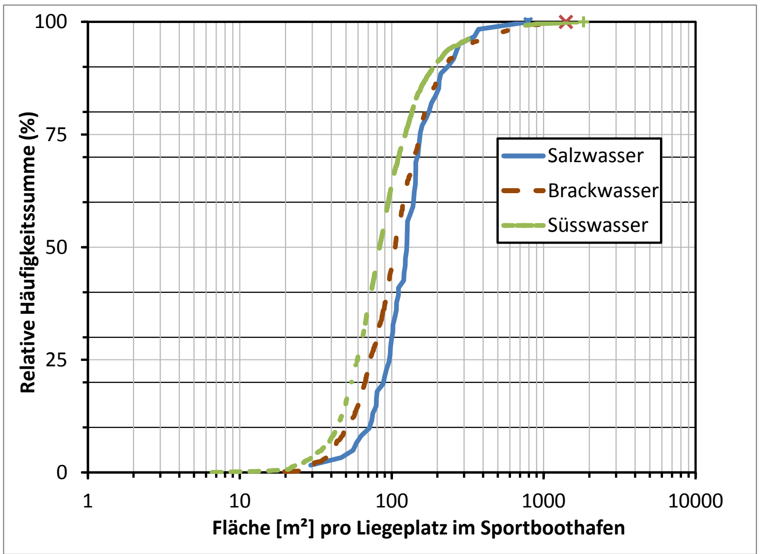
Test for statistically relevant differences in the distribution and median value of the water bodies for each marina between the compartments salt-, brackish and freshwater

Areas	KS-test	Median-test
Salt - Brackish	x	xxx
Salt - Fresh	xxx	xxx
Brackish - Fresh	xxx	xxx

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

Figure B-3

Cumulative distribution function of the water surface per berth in salt-, brackish and freshwater



Source: this study, LimnoMar.

Table B-5

Statistical characteristics of the water body [m^2] per berth in salt-, brackish and freshwater

Parameter	Salt	Brackish	Fresh	Salt+Brackish	Total
Min.	29.3	19.7	6.6	19.7	6.6
P10	73.8	49.6	43.6	50.3	44.8
P25	97.8	72.7	59.5	74.5	61.9
P50	125.8	105.6	83.2	106.9	88.0
P75	154.4	152.9	122.8	153.0	129.7
P90	235.6	223.7	187.2	223.8	198.2
Max	791.6	1,400.9	1,833.1	1,400.9	1,833.1
Mean	147.9	138.4	112.6	139.4	118.0
SD	107.1	138.2	122.8	135.4	125.9
N	61	.	2470	621	3091

Table B-6

Test for statistically significant differences in the distribution and median value of the water bodies for each marina between the compartments salt-, brackish and freshwater

Areas	KS-test	Median-test
Salt - Brackish	x	xxx
Salt - Fresh	xxx	xxx
Brackish - Fresh	xxx	xxx

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

B.1.2 Regionale Ergebnisse und Besonderheiten

B.1.2.1 Nordsee

An der Nordseeküste finden sich neben den Salzstandorten auch einige Brack- und sehr wenige Süßwasserstandorte. Zu den Brackwasserstandorten gehören die Häfen in Emden und Bremerhaven, die über die Zuflüsse der Ems bzw. der Weser auch Süßwasser beeinflusst sind und hinter einer Schleuse liegen. Gleiches gilt für Sielhäfen. Besonders in Ostfriesland gibt es viele Entwässerungskanäle, die mit einem Siel von der Nordsee abgeschlossen sind. Das seeseitig angeordnete Sieltor schließt automatisch bei auflaufendem Wasser durch den Wasserdruck und öffnet sich bei ablaufendem Wasser und steigendem Innendruck wieder. Wenn die Sielhäfen geschützt hinter dem Siel liegen, sind sie tideunabhängig und führen Brackwasser. Sielhäfen weisen durch den Oberflächenabfluss aus dem Hinterland immer Einflüsse durch die angrenzende Landwirtschaft auf. Durch den Tideeinfluß dringt Salzwasser in geringem Maß noch weiter die Weser hinauf bis nach Bremen-Vegesack (Hanslik et al. 1999). Genaue Grenzen zum Süßwasserbereich sind schwer zu ermitteln, da die Salzgehalte auch jahreszeitlichen Schwankungen unterliegen. Weitere Brackwasserstandorte finden sich im Elbästuar, werden aber in dieser Studie zur Elbe dazugerechnet. In der Summe ergeben sich daraus insgesamt 6470 Liegeplätze für die Nordsee (Table B-7). Darin sind die Standorte in den Flussästuaren (Emden - Ems, Bremerhaven - Weser) nicht berücksichtigt. Rechnet man diese mit ein, erhält man für die gesamte Nordseeregion 10.500 Liegeplätze (vgl. Figure 2-11).

Table B-7

Sportbootliegeplätze an der Nordsee (ohne Elbästuar)

Gebiet	Anzahl Häfen	Anzahl Liegeplätze
Ostfriesische Inseln	8	1402
Nordfriesische Inseln	13	1013
Ostfriesische Nordseeküste	27	2973
Nordfriesische Nordseeküste	27	1507
Gesamt	75	6470

B.1.2.2 Ostsee

Eine Besonderheit an der Ostsee bilden die Bodden. Die Darß-Zingster Boddengewässer erstrecken sich über 55 km von der Recknitzmündung bis zur Ostseeverbindung am Gellenstrom bei Barhöft. Der Grabow und der Barther Bodden werden zum sogenannten Ostteil zusammengefasst, der relativ stark mit der vorgelagerten Ostsee kommuniziert. Bodstedter und Saaler Bodden bilden den mehr durch Süßwasser geprägten Westteil, in dem der Wasseraustausch sehr beschränkt ist. Der Südteil des Saaler Boddens wird auch als Ribnitzer See bezeichnet. Der Süßwasserzufluss in die Bodden und Haffe hat diese Gewässer mit unterschiedlichen und zeitlich sehr variablen Salzgehaltsgradienten ausgestattet.

Die Salinität im Ostteil der Boddenkette schwankt zeitlich und räumlich in Abhängigkeit von den Intensitäten der Ein- und Ausstromprozesse. Im Allgemeinen liegen sie zwischen 8 und 15 %. Bei extremem Ostwasserzufluss oder nach starken Regenfällen können sie auch stärker variieren. Im inneren Teil der Boddenkette, insbesondere im Saaler Bodden und Ribnitzer See, liegt der Salzgehalt, verursacht durch einen eingeschränkten Austausch mit der Ostsee und Süßwasserzuflüsse (Recknitz, Körkwitzer und Saaler Bach) relativ stabil im oligohalinen Bereich <5 % (Schlungbaum et al. 1994).

B.1.2.3 Rhein mit Nebenflüssen

Der Niederrhein bis Bonn mit dem Nebenfluss Ruhr stellt mit ca. 10.650 Liegeplätzen ein intensiv frequentiertes Sportbootgebiet. Die abgehenden Kanäle sind hier nicht berücksichtigt. Auf den Flussläufen überwiegen Motorboote. Duisburg verfügt zwar über den größten Industriebinnenhafen, der größte Sportboothafen am Niederrhein ist aber Emmerich mit 420 Liegeplätzen. Die weiteren Häfen haben meist 50 - 120 Liegeplätze. Am Flusslauf der Ruhr sind nur vereinzelt Sportboothäfen zu finden. Entlang der Ruhr befinden sich auch einige Seen, die durch Aufstauung entstanden sind. Am Baldeneysee ist im Vergleich zum restlichen Ruhrlauf ein starkes Sportbootaufkommen zu verzeichnen. Dort sind nur Segelboote oder Elektroboote mit spezieller Genehmigung erlaubt. Insgesamt befinden sich in der Ruhr 30 Häfen (darunter auch Privat-Steganlagen ohne Vereinsadresse) und 1.342 Sportboote, davon am Baldeneysee 640 Liegeplätze. Ein größeres Segelaufkommen gibt es außerdem in verschiedenen Stauseen im Sauerland, die alle im Einzugsbereich der Ruhr liegen (Möhnesee: 946 LP, Sorpesee 438 LP, Biggesee 682 LP). In der Lippe wurden keine Sportboothäfen nachgewiesen.

Nahe dem Niederrhein, meist ohne Verbindung zum Rhein, befinden sich außerdem Baggerseen in ehemaligen Kiesgruben, auf denen Sportboote in kleinen Häfen beheimatet sind.

Auf dem Mittelrhein zwischen Bonn und Bingen und den Zuflüssen Mosel und Lahn sind kleinere Häfen mit weniger als 100 Liegeplätzen für Motorboote ansässig, der größte Hafen befindet sich in Neuwied mit 190 Liegeplätzen. Im Nebenfluss Lahn befinden sich neun Vereinssteganlagen.

In der Mosel ist mit 28 Häfen und Steganlagen und über 2.000 Liegeplätzen ein höheres Sportbootaufkommen zu verzeichnen, in der Saar sind nur 8 Häfen mit 442 Liegeplätzen zu finden. Insgesamt ergibt sich damit für den Bereich Mittelrhein eine Liegeplatzzahl von ca. 3.800.

An dem sehr viel längeren Abschnitt des Oberrheins zwischen Basel und Bingen gibt es auch eine entsprechend höhere Anzahl an Sportboothäfen, die sich bevorzugt in geschützten Seiten-und Altarmen oder geschlossenen Hafenbecken befinden. In der vorliegenden Recherche konnten 91 Häfen mit knapp 6.900 Sportbooten identifiziert werden. Der Neckar ist flussaufwärts bis Plochingen südlich von Stuttgart schiffbar. Bis dorthin sind auch Sportboothäfen mit Segel- und Motorbooten in meist offenen Steganlagen zu finden. Es konnten 30 ausschließlich kleine Häfen mit insgesamt 924 Liegeplätzen verzeichnet werden. Der Main ist flussaufwärts bis Bamberg schiffbar. Auf dem Fluss dominieren Motorboote. Es wurden 57 Häfen mit insgesamt 2.950 Sportbooten identifiziert. Hier überwiegen kleinere Häfen. Die Nebenflüsse des Mains werden nur von Kanus und Ruderbooten genutzt, man findet dort keine Sportboothäfen. Im Bereich Oberrhein befinden sich somit 10.807 Liegeplätze.

Am Hochrhein sind lediglich 6 offene Hafenanlagen mit zusammen 236 Liegeplätzen anzutreffen.

B.1.2.4 Ems und Nebengewässer

Für den Bereich Emsästuar konnten 852 Liegeplätze im Süßwasser gezählt werden. Es handelt sich um die Entwässerungskanäle, eine regionale Besonderheit in Ostfriesland, die in den Emder Hafen münden. Dort gibt es mit Ausnahme größerer Städte wie Leer oft keine Hafenanlagen, sondern die Boote liegen entlang der Kanäle an den Wassergrundstücken. Die Unterems mit ihrem Zufluss Leda ist weiterhin tidebeeinflusst. An den Zuflüssen entlang findet man kleinere sowohl offene als auch geschlossene Häfen mit meist unter 100 Liegeplätzen. Im weiteren Verlauf sind auf der Ems bis Rheine einige Sportboothäfen vertreten, sowie auf dem Bocholter und Münsteraner Aasee. Der Oberlauf der Ems wird im Gegensatz zum Dortmund-Ems-Kanal schifffahrtstechnisch wenig genutzt (vgl. Kapitel B.1.2.17). In der Unter- und Oberems zusammen wurden 1456 Liegeplätze erfasst.

B.1.2.5 Niedersächsische Seen

Die niedersächsischen Seen Steinhuder Meer und Dümmer liegen zwar im Einzugsbereich der Weser, sind aber aufgrund ihrer besonderen Stellung hinsichtlich des Segelsports separat erfasst worden (s.a. Hauptstrom: niedersächsische Seen).

Das Steinhuder Meer mit 29,1 km² und der Dümmer mit 13,5 km² sind die größten Binnenseen in Nordwestdeutschland. Sie sind in der letzten Kaltzeit entstanden und haben eine geringe Wassertiefe von durchschnittlich 1 - 1,5 m im Dümmer und 1 - 2,9 m im Steinhuder Meer. Der Dümmer wird von der Hunte durchflossen. Er wird jährlich mit hohen Nährstoffeinträgen aus der Moor-Mineralisierung und der intensiven Landwirtschaft, insbesondere durch den Maisanbau, belastet. In 2012 kam es zu massiven Blaualgenblüten, die ein Fischsterben nach sich zogen. Zahlreiche Regatten mussten abgesagt werden und für die Segelvereine am Dümmer stellt sich die Frage, ob in Zukunft Wassersport auf dem Dümmer noch möglich sein wird.

An beiden Seen stehen bestimmte Uferbereiche unter Naturschutz, andere Bereiche werden intensiv wassersportlich genutzt. Die Häfen auf dem Steinhuder Meer sind offen in den See ragende, meist bis 200 m lange Steganlagen, die sehr geballt an einigen Orten sind. An vielen Stellen konnte beobachtet werden, dass Boote nicht im Wasser liegen, sondern per Hebeeinrichtung hochgezogen wurden. Da Stege dicht an dicht liegen, waren die Stegbetreiber nicht eindeutig zuzuordnen. Die meisten Vereine haben auf ihren Internetseiten keine genauen Angaben zum Standort des Vereinsstegs und zur Anzahl der Liegeplätze. Laut Wikipedia sind auf dem See ca. 5000 Sport- und Segelboote zu finden. Mit unseren Recherchen konnten 3455 Sportboote identifiziert werden, wobei Tretboote und Ruderboote nicht berücksichtigt wurden.

Am Dümmer gibt es ca. 25 Segelvereine, die aber ebenfalls nicht alle per Luftbild zuzuordnen waren. Laut der zentralen Homepage für den Tourismus am Dümmer gibt es an diesem See mehr als 2.000 Segelboote (www.duemmer.de). In der vorliegenden Recherche konnten 1.700 Sportboote identifiziert werden.

B.1.2.6 Weser und Nebengewässer

Im Bereich Unterweser gibt es auf dem auch noch tidebeeinflussten Zufluss Lesum einen regen Sportbootbetrieb. Die offenen Steganlagen der Häfen sind dort perlschnurartig flussaufwärts angeordnet. In Bremen ist der Hasenbürener Yachthafen mit 560 Liegeplätzen der größte Hafen. Für den Bereich Unterweser wurden insgesamt 4.069 Liegeplätze erfasst. In Mittel- und Oberweser finden sich überwiegend kleine Vereine mit unter 80 Liegeplätzen. Lediglich die in Bremen ansässigen Vereine der Mittelweser verfügen über große Hafenanlagen, in denen überwiegend Segelboote liegen. Auf der Weser flussaufwärts findet man fast ausschließlich Motorboote vor. Für die Mittelweser wurden ca. 2.300 Liegeplätze gezählt, für die Oberweser 870 Liegeplätze.

In der Fulda, die dem Hauptstrom der Oberweser angegliedert ist, befindet sich in dem aufgestauten Edersee ein hohes Bootsaufkommen mit 1.931 gezählten Liegeplätzen.

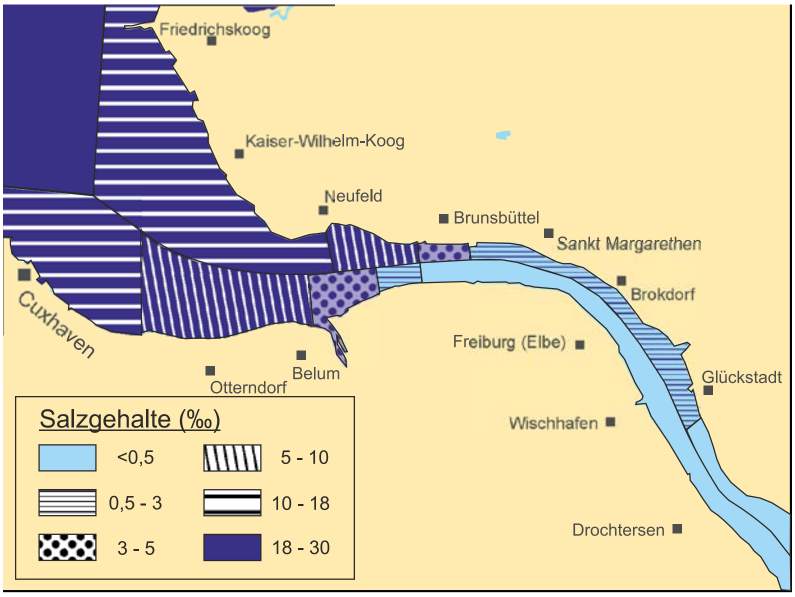
B.1.2.7 Elbe und Hamburg

Hamburg mit dem Elbästuar ist mit seinen vielen, aber hauptsächlich kleinen Häfen und Steganlagen und insgesamt ca. 10.250 Liegeplätzen als eines der Ballungsgebiete zu bezeichnen.

Wie aus Figure B-4 hervorgeht, war in den neunziger Jahren die Unterelbe von Geesthacht bis Hamburg und am südlichen Ufer bis Brunsbüttel von Süßwasser durchströmt, der Abschnitt von Glückstadt bis Brunsbüttel war durch Brackwasser charakterisiert und das Salzwasser konnte von der Elbmündung bis zur Ostemündung vordringen. Inzwischen hat sich durch die Vertiefung der Elbe der Brackwasserbereich bis Wedel vorgeschoben, und der Salzwasserbereich reicht inzwischen bis nach Brunsbüttel (www.portal-tideelbe.de). Hierdurch haben sich die Bewuchsbedingungen stark verändert und der Bewuchsdruck eindeutig in Richtung hartschaliger Organismen wie z.B. der Brackwasserseepocke flussaufwärts erhöht.

Figure B-4

Salz-, Brack- und Süßwasserzonen in der Unterelbe und Elbästuar in den 90er Jahren



Quelle: ARGE ELBE, 1992, vereinfacht; Kartengrundlage: Geodatenbasis DLM1000 © BKG 2013

Trotz des regen Schiffsverkehrs auf der Unterelbe ist das Gebiet insbesondere für Segler ein sehr beliebtes Revier und wird stark befahren (Figure B-5). Es gibt Schätzungen, wonach bis zu 25.000 Segler, davon 15.000 allein aus Hamburg, auf der Unterelbe ihrem Sport nachgehen, von denen 90 % als Fahrtensegler eingestuft werden (Schmidt, 2005). Hinzu kommen ca. 2.000 Motorbootbesitzer.

Figure B-5

Das Unterelbe-/Elbästuar-Gebiet von Hamburg bis Cuxhaven

Quelle: Geodatenbasis DLM1000 © BKG 2013

Elbästuar und Unterelbe unterliegen von Cuxhaven bis Geesthacht dem Tidenwechsel. Das Gebiet stellt durch Wind, Tide und Flussstrom ein überaus anspruchsvolles Revier dar. Bis zu 3 m Höhenunterschied liegen zwischen Hoch- und Niedrigwasser. Neben der Fahrwasserrinne mit bis zu 14 m Tiefe existieren an den Ufern flache Wattzonen und Sande, die den Sportboothäfen vorgelagert sind. Rund um und in Hamburg liegen zahlreiche kleinere Sportboothäfen, wobei besonders im Hafengebiet von Hamburg-Harburg an unzähligen Stegen Traditionsschiffe von klassischen Jollen bis zu großen Teeklippern unablässig restauriert werden (Fritsch, 2012). Wie die Erhebung zeigt, liegen auch hier zahlreiche Kielyachten, und von Harburg bis Finkenwerder finden sich ebenfalls zahlreiche Yachtwerften. Im Zentrum von Hamburg ist der City-Hafen errichtet worden, der vor allem von Gastliegern für Boote bis 50 m Länge besucht wird. Westlich von Hamburg liegen Häfen in Finkenwerder, der Jollenhafen Mühlenberg und der Yachthafen Wedel, der zugleich der größte Sportboothafen Deutschlands mit aktuell 2.100 Liegeplätzen ist. Des Weiteren sind drei Sportboothäfen in Stade zu erwähnen, die an den Sommerwochenenden von Fahrtenseglern (Gastlieger) stark frequentiert werden. In Glückstadt und elbabwärts bis nach Stade befinden sich weitere kleine Yachthäfen, welche vor allem an den Mündungen der Nebenflüsse wie der Stör, Oste und Medem konzentriert sind. In Brunsbüttel an der Mündung des Ostseekanals ist trotz des starken Verkehrs mit über 55.000 Schiffsbewegungen im Jahr ein großer Yachthafen errichtet worden. In Otterndorf zweigt der Elbe-Weser-Schifffahrtsweg (auch Hadelner Kanal genannt) von der Medem ab und mündet bei Bremerhaven in die Weser. In Cuxhaven befindet sich ein Yachthafen, der neben den Inhabern fester Liegeplätze vor allem Gastliegern aus allen Nordseeanrainerstaaten als Zwischenstation dient und in den Sommermonaten hohe Bootsdichten aufweist.

Der Mittel- und Oberlauf der Elbe ist kein typisches Segelrevier. Im Oberlauf konnten nur 12 kleine Häfen ausgemacht werden, einige davon auch Mischhäfen, mit insgesamt 319 Bootsliegeplätzen. Es handelt sich hauptsächlich um Motorboote. In der Mittelelbe ist eine ähnliche Struktur vorhanden: Kleine Häfen in sowohl offenen als auch geschlossenen Anlagen, oft zusammen mit Schiffen als Mischhafen, wobei Motorboote überwiegen. Die Dichte der Häfen nimmt mit der Nähe zu Hamburg zu, in denen sich zusammen für die Mittelelbe 2.470 Liegeplätze erkennen lassen. In den der Mittelelbe nahegelegenen Seen, wie Goitzschesee und Muldestausee und der Mulde selbst wird vor allem Segelsport betrieben. In verschiedenen Sportboothäfen liegen insgesamt 522 Segel- und Motorboote, die diese kleinen Reviere befahren.

Die Saale als Nebenfluss der Elbe wird ebenfalls wassersportlich genutzt. Es gibt einige kleine Vereine mit je 10 - 40 Liegeplätzen. Insgesamt konnten über 600 Liegeplätze festgestellt werden. Die Talsperren Hohenwarte I und Bleiloch im Oberlauf der Saale werden als Segelrevier genutzt (Wassersport erlaubt, aber Verbrennungsmotoren verboten), ebenso Förmitztalsperre und Talsperre Pöhl (Nebenfluss der Weißen Elster), in der die Boote zum größten Teil an Land liegen. Die vielen weiteren Talsperren im Vogtland und im Thüringer Wald sind frei von Sportbooten.

Als weitere Besonderheit ist die neu entstehende Seenlandschaft zwischen Saale und Mulde zu nennen. Nahe dem bestehenden Goitzschesee nördlich von Leipzig wurden ehemalige Braunkohletagebaue geflutet und ließen neue Seen entstehen. Auch südlich von Leipzig sind neue Seen entstanden. Diese Seen erfahren zurzeit eine intensive Entwicklung, auf dem Cospudener See ist z.B. eine Marina mit 215 Liegeplätzen errichtet worden. Weitere Steganlagen sind am Hainer See entstanden, die bisher auf den verfügbaren Luftbildern noch nicht abgebildet waren.

Weitere Nebenflüsse der Mittelelbe wie Havel und Elde sind separat erfasst worden (Hauptströme: Havel, Mecklenburger Seenplatte).

B.1.2.8 Seen in Schleswig-Holstein

Im Zentrum dieses Hauptstromgebiets liegt die Holsteinische Schweiz mit dem Plöner See, Dieksee und Kellersee, im Norden schließen sich Westernsee und Wittensee an sowie Großer Segeberger und Ratzeburger See im Süden neben weiteren kleinen Seen. Einige der Seen in Schleswig-Holstein, wie z.B. der größte Teil des Schaalsees, werden nicht für den Wassersport genutzt, er gehört zum Biosphärenreservat der Wakenitz. Auf dem Ratzeburger See ist als Besonderheit in Deutschland der Sportbootverkehr erlaubt, aber der Einsatz von biozidhaltigen Antifoulingbeschichtungen ist durch die Wakenitz-Verordnung untersagt (GVO-Schleswig-Holstein, 2000).

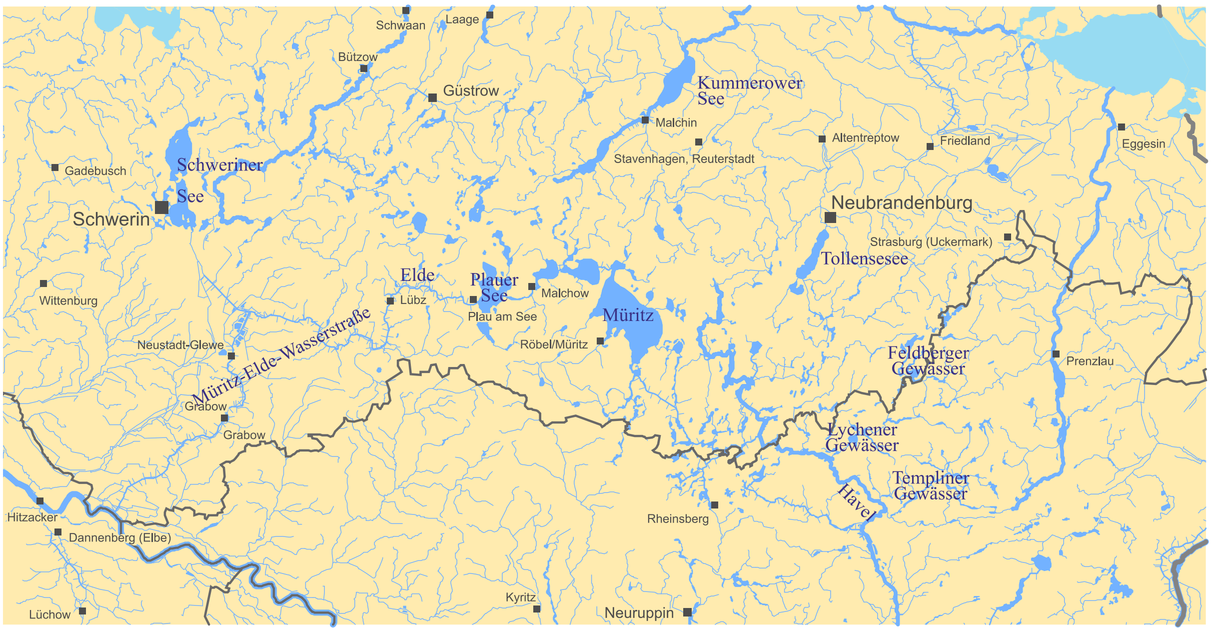
Bei den überwiegend offenen Hafenanlagen handelt es sich immer um kleinere Vereine und Steganlagen mit maximal 110, oft aber auch nur 20 - 50 Liegeplätzen. Insgesamt konnten 2.911 Sportboot-Liegeplätze identifiziert werden.

B.1.2.9 Mecklenburger Seenplatte

Die Mecklenburger Seenplatte ist ein großflächiges Seengebiet, das durch zahlreiche Flussläufe und Kanäle vernetzt ist. Auch wenn der Nordostteil der Seen nicht Richtung Elbe, sondern über Warnow und Peene zur Ostsee entwässert, ist das gesamte Gebiet als Hauptstrom *Mecklenburger Seenplatte* für AP 1 unter dem Aspekt der regionalen Verteilung der Sportbootliegeplätze zusammengefasst (Figure B-6). Eine andere Auswertung nach Flusseinzugsgebieten findet sich in Kapitel 2.1.2.

Figure B-6

Mecklenburg-Vorpommersche Seenplatte mit angrenzenden Gewässern



Quelle: Geodatenbasis DLM1000 © BKG 2013

In Westmecklenburg liegt der Schweriner See, nach der Müritz der zweitgrößte See in Norddeutschland. Er entwässert über Stör und Störkanal in die Elde (Elde-Müritz-Wasserstraße) und weiter in die Elbe. Die Häfen sind oft sehr geschützt angelegt, vom eigentlichen See etwas abgetrennt und als geschlossene Häfen gebaut. Am Schweriner See einschließlich der kleineren Nebenseen konnten 3.209 Boote gezählt werden.

Die Elde-Müritz-Wasserstraße verbindet weiter den Schweriner See mit dem Plauer See, der seine Fortsetzung im Fleesensee, Kölpinsee und der Müritz hat, zusammengefasst als das Mecklenburger Großseenland. Dort konzentrieren sich die Hafenanlagen auf die wenigen Städte wie Plau am See, Malchow, Röbel und Waren, denn weite Teile der Ufer unterliegen dem Naturschutz. Die Bootsschuppenbereiche sind oft durch quer vorgelagerte Stege oder kleine Dämme vor Schwell geschützt. Dieses Gebiet umfasst 6.920 Sportboote.

Östlich der Müritz schließen sich das Neustrelitzer Kleinseengebiet entlang der Müritz-Havel-Wasserstraße und Oberen Havel-Wasserstraße bis zur Feldberger Seenlandschaft an, im Nordosten der Tollensesee und die Mecklenburgische Schweiz, die bis Neubrandenburg reicht. Die Seen sind durch viele verschlungene Buchten gekennzeichnet, einige Seen sind für Sportboote nicht zugänglich.

In diesem Gebiet finden sich neben Hafen- oder Steganlagen auch Bootshausreihen. Es gibt außerdem auch Bootshäuser als Wochenendhäuser, in denen oberhalb eine Ferienwohnung eingerichtet ist und unterhalb das Boot im Wasser liegt (Figure B-7).

Im Gebiet der Müritz-Havel-Wasserstraße gibt es ca. 2000 Bootsliegeplätze und im Gebiet der Oberen Havel-Wasserstraße ca. 2700 Bootsliegeplätze. In der Feldberger Seenlandschaft befinden sich ca. 250 Liegeplätze.

Im Süden der Müritz liegt das Rheinsberger Seenland, das nach Süden über den Rhin in die Havel entwässert. Neben den kleinen Steganlagen gibt es dort ein neu angelegtes Hafendorf mit insgesamt 330 Liegeplätzen. Das Gebiet umfasst insgesamt 1.321 Liegeplätze.

Die Seenplatte findet aber auch in Brandenburg ihre Fortsetzung mit der Uckermark und den Ruppiner Gewässern. In den Ruppiner Gewässern befinden sich ca. 1000 und in der Uckermark nur ca. 200 Liegeplätze.

Figure B-7

Bootsschuppen, teilweise mit Ferienwohnungen

Quelle: LimnoMar.

Darüber hinaus werden in der gesamten Mecklenburger Seenplatte viele Anleger ausschließlich von Kanus und Ruderbooten genutzt, die in dieser Zählung nicht berücksichtigt wurden. Ebenfalls wurden Einzelliegeplätze und einzelne kleine Bootshäuser nicht miterfasst. In der Summe jedoch stellen sie eine nicht zu vernachlässigende Größe dar.

Die Gesamtzahl an erfassten Bootsliegeplätzen für diese Studie liegt für die Mecklenburger Seenplatte bei ca. 18.850 Liegeplätzen.

Aufgrund ihrer relativ hohen Anzahl sind Bootsschuppen als eine regionale Besonderheit für die Mecklenburger Seenplatte auszuweisen. Diese im Wasser gebauten Schuppen sind oftmals sehr alt und stehen zumindest teilweise unter Denkmalschutz. Laut Internetquellen wie www.bootshausmarkt.de verfügen einige Bootsschuppen über Hebeeinrichtungen. Nach mündlicher Auskunft vor Ort ist aus wirtschaftlichen Gründen anzunehmen, dass diese Bootschuppen i.d.R. sowohl als Sommer- wie auch als Winterliegeplatz genutzt und die Boote im Winter oberhalb des Wassers im Schuppen fixiert werden. Aufgrund des beschränkten Platzes - auch in der Höhe - wird erwartet, dass es sich eher um kleinere, relativ leichte und nicht zu hohe Boote handelt, die hier untergestellt werden. Die Spanne der Bootstypen reicht nach mündlicher Auskunft vom Angelkahn, über Motorboot bis zum Segelboot mit leicht legbarem Mast. Inwieweit ein Antifouling-Einsatz bei diesen Booten erfolgt, bleibt offen.

Einen Belegungsgrad mit Sportbooten in diesen Bootsschuppen abzuschätzen, ist anhand der Luftbilder nicht möglich. Jedoch ist aufgrund der großen Nachfrage ein Leerstand eher unwahrscheinlich. Da Bootsschuppen z.B. an einigen Uferbereichen der Müritz oder am Plauer See in großer Zahl vorkommen (Figure B-8), wurde eine Schätzung vorgenommen. In der Regel wurde eine Bootsbreite von 3 m kalkuliert und diese auf die Länge der Bootsschuppen übertragen. Für eine große Bootsschuppenanlage bei Waren an der Müritz (www.angelsportverein-kamerun.de) wurde eine Belegung von 200 Booten angenommen.

Figure B-8

Bootsschuppen an der Müritz

Quelle: LimnoMar.

B.1.2.10 Berliner Gewässer

Figure B-9

Berliner Gewässer, Märkische Gewässer und untere Havel mit Übergängen zu Elbe und Oder

Quelle: Geodatenbasis DLM1000 © BKG 2013

Berlin und Umgebung bildet mit den vielen zusammenhängenden Seen ein großes Ballungsgebiet innerhalb der deutschen Sportschifffahrt (Figure B-9). Für die Erfassung des Bootsbestands in Berlin wurde als Begrenzung im Norden, Osten und Süden der Berliner Ring festgelegt, im Westen endet der Bereich in etwa entlang der Autobahn 115 bis zur Spreemündung und der Mündung des Teltowkanals in die Havel. Die untere Havel ist als eigenes Hauptstromgebiet erfasst worden (vgl. Kapitel B.1.2.11). Einige Seen in der Havel gehören aber auch zu Berlin, so dass eine Bootsliegeplatzzahl für Berlin je nach Umfang des Gebietes sehr schwanken kann. Nach unseren Recherchen umfasst das beschriebene Gebiet 10.550 Bootsliegeplätze.

Schiffbare Flüsse wie Havel, Spree, Dahme durchziehen mit einer Gesamtlänge von 88,6 km Berlin (Fiedler et al. 2003). Die Oder ist durch den Oder-Havel-Kanal, den Oder-Spree-Kanal, Havel und Elbe-Havel-Kanal mit der Elbe vernetzt. Mit der Wiedervereinigung wurden wassertouristisch ganz neue Möglichkeiten geschaffen und mit dem Neubau der Schleuse Spandau wurde ab 2002 die Nord-Süd-Durchfahrt der Havel wieder freigegeben (Fiedler et al. 2003). Der Wassersporttourismus erfährt zurzeit eine enorme Entwicklung. Es wurden Hafenkonzepte für verschiedene innerstädtische Standorte entwickelt und umgesetzt wie z.B. am Hafen Tempelhof. Es gibt Planungen, Marinas in neu angelegten Wohngebieten wie z.B. Oberschöneweide anzulegen sowie Planungen für Schaffung und Ausbau von Gastliegeplätzen im Stadtgebiet. Die Verbesserung der dortigen Ver- und Entsorgungssituation ist ebenfalls geplant.

Im Berliner Gebiet konzentrieren sich sehr viele Hafenanlagen entlang der Dahme und am westlichen Ufer des Zeuthener und Langer Sees, *Die Bänke*, Dämeritzsee, Flakensee, Kalksee, Müggelspree und Spree. Der Müggelsee weist trotz seiner Größe eher wenige Hafenanlagen auf. In der Regel sind die Häfen offen angelegt, es handelt sich meist um ältere, etablierte Vereinsanlagen. Auf der innerstädtischen Spree sind nur wenige Häfen und Steganlagen ansässig. Stattdessen gibt es viele Fahrgastschiffe und öffentliche Sportbootliegeplätze, an denen Gastlieger für 24 Stunden festmachen dürfen (Fiedler et al. 2003). Sie sind nur mit erfasst worden, wenn sie in den digitalen Aufnahmen als Steganlage zu erkennen waren.

B.1.2.11 Havel und Nebengewässer

Der Havel kommt aus Sicht der Sportschifffahrt eine große Bedeutung zu. Neben der abwechslungsreichen Naturlandschaft entlang der Oberen Havel-Wasserstraße der Mecklenburger Seenplatte durchfließt die mittlere und untere Havel mehr städtisch geprägte Gebiete. Über Havel und Havel-Kanäle sind Elbe und Oder verbunden, und es wird ein großer Teil der Mecklenburger Seenplatte über die Havel entwässert (Figure B-10). Die vielen Seen in Berlin, Potsdam und Brandenburg, durch die die untere Havel fließt, haben einen hohen Erholungswert für die Städter. Dementsprechend sind sehr viele Häfen und Vereine in diesem beliebten Segelrevier beheimatet. Die Häfen sind in der Regel offen gestaltet und die einzelnen Vereine meist eher kleiner. Sie liegen aber in geschützten Buchten und entlang der Havel oft dicht gedrängt beieinander, so dass sie lokal große Liegeplatzbestände erreichen. Die größten Bootaufkommen wurden u.a. an Scharfe Lanke, Stössensee und Großem Wannsee ermittelt. Die Gebiete dieses Havelabschnitts mit den kleinen Havel-Kanälen umfassen ca. 23.000 Liegeplätze. In dem separat erfassten Oder-Havel-Kanal mit den zufließenden Seen auf nördlicher Seite befinden sich 2.285 Liegeplätze.

Figure B-10

Havel und Nebengewässer

Quelle: Geodatenbasis DLM1000 © BKG 2013

B.1.2.12 Märkische Gewässer

Das Hauptstromgebiet Märkische Gewässer umfasst ein natürliches Seengebiet südöstlich von Berlin. Dazu gehören die Flüsse Spree und Dahme und der Oder-Spree-Kanal sowie die Talsperre Spremberg, die von der Spree durchflossen wird. Im Norden grenzt das Gebiet an die Berliner Gewässer an. Als Grenze ist für diese Erfassung die Stadtautobahn Berliner Ring gewählt worden, also die Dahme-Wasserstraße nördlich des Krimnicksees bzw. des Ortes Königs-Wusterhausen.

Die Märkischen Gewässer, die vielfach über Kanäle oder Dahme und Spree mit einander verbunden sind, bilden mit den vielen Seen ein ideales Segelrevier. Größter See in diesem Gebiet ist der Schwielochsee (von der Spree durchflossen), gefolgt vom Scharmützelsee (Abfluss über Wendisch Rietz in Dahme). Auf den größeren Seen wird Segel- und Motorsport betrieben, von den kleineren Seen werden viele nicht wassersportlich genutzt. Es finden sich viele kleine Vereine mit offenen Steganlagen. Besonders im Schweriner und Teupitzer See sowie im Krüpelsee und Krimnicksee fallen die vielen kleinen Stege am Ufer auf. Der Uferbereich ist offen, fast alle Grundstücke am Ufer haben auch Zugang zum Wasser und verfügen über einen privaten Steg, an dem auch oft ein Boot liegt (Ruder-, Motor- oder Segelboot). Viele der Seen beherbergen ausschließlich Ruderbootsanlagen und andere Seen werden auch gar nicht wassersportlich genutzt.

Insgesamt handelt es sich fast ausschließlich um offene Hafen- und Steganlagen, die meist unter 100, in einigen Fällen auch zwischen 120 - 160 Liegeplätze vorhalten. Für das gesamte Gebiet konnten 6.521 Sportboote gezählt werden.

B.1.2.13 Lausitzer Seenland

Das Lausitzer Seenland ist ein künstlich angelegtes Seengebiet in der Lausitz. Viele stillgelegte Braunkohlentagebaue des Lausitzer Braunkohlereviers wurden und werden geflutet, so dass dadurch Deutschlands viertgrößtes Seengebiet entstehen wird. Einige der Seen haben ihren Endwasserstand bereits erreicht, andere werden erst in einigen Jahren vollständig geflutet sein (geplant bis 2018). Das Seenland liegt in der Lausitz zwischen Calau in Brandenburg und Görlitz in Sachsen und ist unterteilt in 6 nördliche Seen in Brandenburg, 18 mittlere Seen, von denen 9 mit schiffbaren Kanälen verbunden sind und 11 südliche Seen in Sachsen, zu denen der Bärwalder See zählt.

Geplant ist, die Seenlandschaft zu einer überregional bedeutsamen Wasserlandschaft mit sportlich attraktivem Charakter zu entwickeln. Zu diesem Zweck sind umfangreiche Investitionen in die Infrastruktur getätigt worden bzw. sind noch geplant: Herstellen von Badestränden, Yachthäfen (Marinas), Stützpunkte für Wasser- und Jetski, Camping, Gastronomie usw. Die ersten Projekte befinden sich in der Realisierung. Derzeit werden am Geierswalder See eine Wasserskianlage, ein Sportboothafen und eine Marina mit schwimmenden Häusern gebaut. Eine Besonderheit wird der Wasserflugplatz am nördlichen Ufer des Sedlitzer Sees sein.

Am Bärwalder See, der nach seiner Fertigstellung der flächenmäßig größte See Sachsens ist, wurde 2008 ein Sportboothafen am südlichen Seeufer eröffnet. Weitere Marinas sind am West- und Nordostufer bereits vorhanden.

Bei der Erfassung der Sportboote lagen leider keine aktuellen Luftbilder vor, so dass die Anzahl der erfassten Boote nicht den inzwischen angestiegenen Bestand wiedergibt. Es konnten an den Talsperren Bautzen, Quitzdorfer See, Geierswalder See und Senftenberger See (die beiden letztgenannten gehören zu der miteinander verbundenen Seenkette), Knappensee und Bärwalder See (beide im südlichen Bereich) insgesamt 18 offene Hafenstandorte mit Sportbooten ausgemacht werden. In der Summe wurden deshalb nur 648 Liegeplätze gezählt, deren Anzahl inzwischen sicher höher liegt.

B.1.2.14 Donau mit Nebenflüssen

Während die Donau für die Berufsschifffahrt erst ab Kelheim mit dem Zufluss des Main-Donau-Kanals schiffbar ist, finden sich Sportboothäfen bis hinauf nach Donauwörth. Wie auf den anderen süddeutschen Flüssen handelt es sich mit wenigen Ausnahmen um kleine Häfen mit unter 60 Liegeplätzen. Auf den meisten Nebenflüssen rechts und links der Donau sind keine Sportboothäfen ansässig, nur auf dem Lech im Mandichosee befinden sich Segelboote. Die Voralpenseen als großes Segelrevier sind separat erfasst. Die Flüsse, die diese Seen durchfließen und entwässern, münden alle in die Donau. Von Donauwörth bis Untergriesbach nahe der österreichischen Grenze befinden sich 28 Häfen mit 1.200 Liegeplätzen.

B.1.2.15 Bodensee

Der Bodensee gehört mit einer Fläche von 536 Quadratkilometern und einer maximalen Tiefe von 254 Metern zu den größten Seen Mitteleuropas. Nachdem in zahlreichen Publikationen seit 1990 die Zahl der registrierten Wasserfahrzeuge für den Bodensee insgesamt mit ca. 57.000 Einheiten angegeben wurden (IBN, 2011), führte die Internationalen Gewässerschutzkommission für den Bodensee (IGKB 2011) im Jahr 2010 eine sehr genaue Studie zur Erfassung des Bootsbestandes durch, nach der die Zahlen mit gut 24.000 deutlich niedriger liegen. Die Diskrepanz zu älteren Studien erklärt sich aus der Registrierungspflicht aller Wasserfahrzeuge. Diese Einträge bleiben 3 Jahre gültig und werden nicht gelöscht, da sie jederzeit wieder aktiviert werden können. Hierdurch wurden wahrscheinlich viele Fahrzeuge in der Statistik weiter geführt, die nicht mehr am Bodensee ihren Liegeplatz hatten.

Für den Bodensee liegt eine Erhebung vor, aus der hervorgeht, dass 53 % der Eigner ihr Boot weniger als 30 Tage im Jahr nutzen. Bei ca. 55 % der Eigner wurde das Boot im Durchschnitt zu 12 Tagen zusätzlich von weiteren Personen benutzt. Geht man von einer Sportbootsaison von 6 Monaten aus, bedeutet dies, dass die Boote in 17 % der zur Verfügung stehenden Zeit genutzt werden und 83 % der Zeit im Hafen ungenutzt liegen (Heinbach & Klee, 2006).

Table B-8

Liegeplätze und Hafeninfrastrukturanlagen am Bodensee

Anlagen	Baden-Württemberg	Bayern	Vorarlberg	St. Gallen	Thurgau
Häfen / Wasserliegeplätze	8.506	584	4.043	1.637	3.150
Stege / Wasserliegeplätze	1.178	586	65	27	789
LP-Bojenfelder	1.362	75	0	20	828
LP-Einzelbojen	22	10	0	0	215
LP-Sonstige	578	0	155	22	315
Su. Wasserliegeplätze	**1.1646**	**1.255**	**4.263**	**1.706**	**5.297**
Su. Trockenliegeplätze	3.527	232	252	357	2.040
Krananlagen	23	3	3	4	10
Slipanlagen	94	20	16	10	19
Waschplätze	10	3	1	4	9

LP: Liegeplätze; Su: Summe

Ergebnisse der aktuellen Erhebung des IGKB (2011) aus dem Jahr 2010 sind für Bundesländer und Kantone in Table B-8 zusammengestellt. Lage und Größe der Hafenliegeplätze und Bojenfelder sowie der Hafeninfrastrukturanlagen (Kran, Slip etc.) sind zusätzlich als Karten im Internet unter dem Stichwort *Schifffahrtsanlagen* veröffentlicht (IGKB 2011). Die Zahlen für den deutschen Bereich sind in Table B-9 zusammengefasst und dem gesamten Liegeplatzbestand am See gegenübergestellt. Aus diesen geht hervor, dass sich ca. die Hälfte aller Wasserfahrzeuge am Bodensee in Häfen, an Steganlagen oder in Bojenfeldern im Bereich des deutschen Ufers befindet. Die Gesamtzahl der Liegeplätze im deutschen Bereich entspricht mit 12.901 ungefähr der vorliegenden Erfassung und den Daten, die von Wassersportverbänden wie z.B. dem Bodensee-Segler-Verband in eigener Regie erhoben wurden (BSVB, 2010). In der vorliegenden Recherche wurden auf dem Bodensee in deutschem Gebiet 78 Häfen mit insgesamt 12.630 Liegeplätzen ermittelt. Viele Häfen besitzen z.T. ausschließlich, manche auch zusätzlich zu den Stegen feste Bojenfelder in Ufernähe, an denen etwa 30 - 70, in manchen Fällen auch über 100 Liegeplätze ganzjährig zur Verfügung stehen. Insgesamt liegen nach diesen Zählungen etwa 1.800 Boote in Bojenfeldern, nach Angaben der internationalen Gewässerschutzkommission sind es 1.437 Boote.

Wie aus der Aufstellung in Table B-9 ebenfalls zu entnehmen ist, befindet sich neben den Hafenliegeplätzen (70.5 %) ein erheblicher Teil der Boote an Stegen und in Bojenfeldern (11,1 %), wie sie am Beispiel des Bojenfeldes Iznang in Figure B-11 erkennbar ist. Die Bojenfelder waren Gegenstand intensiver Diskussionen im Hinblick auf ihre negativen Auswirkungen auf die Unterwasserflora durch schwoiende Ankerketten (Wessels et al. 2001; Ostendorp et al. 2006). Neben einer Reduktion der Bojenfelder zugunsten von Hafenanlagen wurden daraufhin vor allem technische Verbesserungen der Ankervorrichtungen vorgeschlagen. Dennoch ist auf Luftbildern immer noch eindeutig zu erkennen, dass es zu Veränderungen der Benthosgemeinschaft kommt (Figure B-12).

Table B-9

Schifffahrtsanlagen am deutschen Seeufer des Bodensees (Baden-Württemberg und Bayern) und die Gesamtzahlen für das deutsche, österreichische und Schweizer Ufer

Anlagen	Deutsches Ufer	Gesamt
Häfen / Wasserliegeplätze	9.090	17.920
Stege / Wasserliegeplätze	1.746	2.645
Bojenfelder	1.437	2.285
Einzelbojen	32	247
Sonstige	578	1.070
Summe Wasserliegeplätze	12.901	24.167
Summe Trockenliegeplätze	3.759	6.408
Krananlagen	26	43
Slipanlagen	114	159
Waschplätze	13	27

Quelle: IGKB, 2011, umgerechnet

Figure B-11

Bojenfeld und Hafen Iznang, Zeller See, Bodensee

Quelle: © GeoBasis DE/BKG 2015; sg.geodatenzentrum.de/web_dop_viewer/dop_viewer_geoview.htm; 20.01.2012

Figure B-12

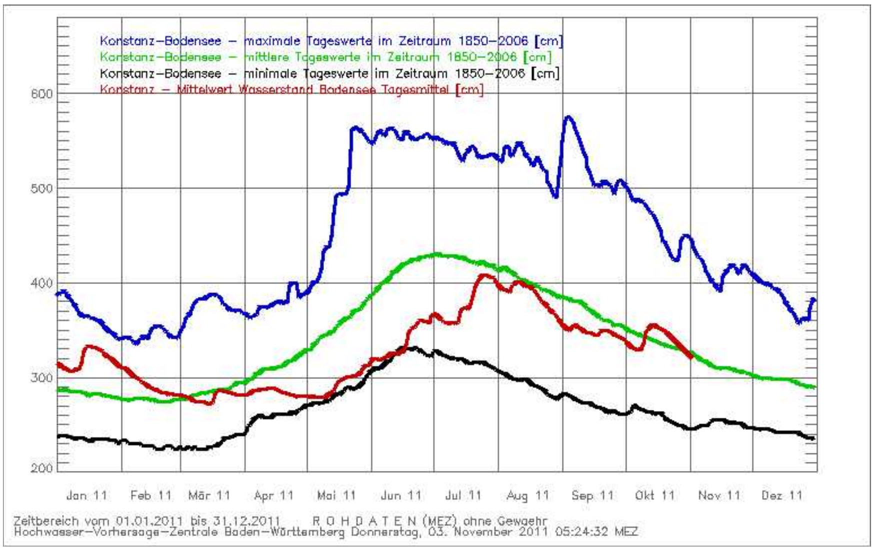
Bojenfeld Allensbach mit deutlich sichtbaren Veränderungen der Benthosgemeinschaft

Quelle: © GeoBasis DE/BKG 2015; sg.geodatenzentrum.de/web_dop_viewer/dop_viewer_geoview.htm; 20.01.2012

Der Bodensee gehört zu den wenigen nichtregulierten Seen in Deutschland und weist daher im Jahresverlauf erhebliche Wasserstandschwankungen auf (Hochwasser-Vorhersage-Zentrale Baden-Württemberg 2011). In Figure B-13 ist erkennbar, dass der Wasserstand des Bodensees im Zeitraum zwischen 1850 und 2006 maximale Pegelschwankungen von 2 m und mittlere Schwankungen von 1,40 m aufwies (Zintz et al. 2009). Da diese Schwankungen auch die Hafenbecken betreffen, können die aktuellen Wassertiefen der Häfen täglich abgerufen werden (www.tiefgang-bodensee.ch).

Figure B-13

Wasserstandschwankungen im Bodensee



Quelle: Hochwasser-Vorhersage-Zentrale Baden-Württemberg, 2011

B.1.2.16 Weitere Voralpenseen

Table B-10

Anzahl der Sportbootliegeplätze in den Voralpenseen

See	Liegeplätze
Starnberger See	2317
Chiemsee	2773
Ammersee	1745
Brombachsee	1018
Wörthsee	907
Forggensee	569
Tegernsee	392
Altmühlsee	335
Pilsensee	172
Simssee	64
Walchensee	55
Großer Alpsee	46

Die Seen im Voralpenbereich entwässern über verschiedene Flüsse in die Donau. Einige Seen dienen dem Hochwasserschutz und der Wasserregulierung in Bayern und weisen schwankende Wasserstände mit bis zu 3 m Unterschied während des Jahresverlaufs auf. Auf den in Table B-10 aufgeführten Seen wird Wassersport betrieben, allerdings mit unterschiedlicher Intensität. In einigen sind Motorboote verboten (z.B. Pilsensee). Auf vielen anderen, meist kleinen Seen sind nur Ruderboote zu finden bzw. wird kein Wassersport betrieben.

In den bayrischen Voralpenseen ergeben sich zusammen 10.393 Liegeplätze, verteilt auf 126 Häfen. Die Seen mit dem höchsten Sportbootaufkommen sind der Chiemsee, Starnberger See und Ammersee (Table B-10). Vielen gemeinsam ist, dass neben den Häfen und Bojenfeldern oft auch die ans Ufer grenzenden Grundstücke über kleine Privatstege im Wasser verfügen, die ganz unterschiedlich belegt sind.

Der Chiemsee ist mit einer Fläche von 79,9 km² der größte See in Bayern und nach dem Bodensee und der Müritz der drittgrößte See in Deutschland. Der größte Zufluss des Sees ist die Tiroler Achen, der einzige Abfluss die Alz. Die Zuflüsse Tiroler Achen und Prien spülen Sand und Geröll in den See, so dass er langsam verlandet. Der Wasserstand kann im Jahresverlauf um bis zu 3 m schwanken (www.nid.bayern.de). Der Chiemsee ist ein intensiv genutztes Wassersportrevier mit insgesamt 2.773 Liegeplätzen in Häfen und Bojenfeldern.

Der Starnberger See (früher Würmsee) ist der fünftgrößte See Deutschlands, auf Grund seiner großen Durchschnittstiefe jedoch der zweitwasserreichste. Der See verfügt über keine nennenswerten Hauptzuflüsse und speist sich lediglich aus mehreren, eher kleineren oberflächigen Fließgewässern und wenigen unterirdischen Quellen. Wegen der wenigen Zuflüsse dauert es rund 21 Jahre, bis der See sein Wasser einmal komplett austauscht, und er weist nur geringfügige Wasserstandschwankungen von ca. 1 m auf. Der langsame Wasseraustausch des derzeit mesotrophen Sees macht ihn besonders anfällig für Belastungen. Am See befinden sich neben den Häfen und Vereinen zugehörigen Bojenfeldern zahlreiche kleinere, private Bojenfelder, Einzelboote an Bojen und zahlreiche private Stege mit Booten. Insgesamt befinden sich am Starnberger See 2.317 Liegeplätze und Ankerbojen.

Der Ammersee ist nach dem Chiemsee und dem Starnberger See der drittgrößte See in Bayern. Der See hat eine Fläche von rund 47 Quadratkilometern und eine maximale Tiefe von etwa 80 Metern. Sein

Hauptzufluss ist durch die aus den Kalkalpen kommende Ammer bestimmt. Bei besonderen Wetterbedingungen, etwa wenn die Schneeschmelze mit anhaltend starkem Dauerregen einhergeht, können die Abflüsse stark ansteigen und von Schwebstoffen getrübt sein. Am Ende einer lang dauernden Trockenperiode sinkt die Abflussspende der Ammer bisweilen auf unter 3 m^3/s. Die Amper dient als Abfluss für den Ammersee und mündet in die Isar. Die Schwankungen des Wasserstandes können im Jahresverlauf bis zu 3 m betragen. Am Ammersee gibt es mehrere landgestützte offene Steganlagen, welche zu Vereinen gehören. Die überwiegende Mehrheit der Boote liegt aber in Bojenfeldern, die rund um den See verteilt sind. Die Vergabe der Liegeplätze in diesen Bojenfeldern wird zentral von der Seeverwaltung in Inning am Ammersee geregelt. Insgesamt konnten auf dem Ammersee 1.745 Bootsliegeplätze gezählt werden.

B.1.2.17 Kanäle

Zu den wichtigsten Kanälen in Deutschland, die viel frequentierte Flüsse verbinden und als Bundeswasserstraßen eingestuft sind, zählen u.a. Mittellandkanal (MLK), Dortmund-Ems-Kanal (DEK), Main-Donau-Kanal (MDK) und Nord-Ostsee-Kanal (NOK) (Figure B-14). Letzterer ist nach Anzahl der Schiffe die meistbefahrene künstliche Wasserstraße weltweit (www.wsv.de), weil dadurch der Weg in die Ostsee nicht über die Nordspitze Dänemarks erfolgen muss. Am Kanal selbst sind keine Sportboothäfen angesiedelt, sondern in den alten Flussläufen und Seen mit Anbindung an den Kanal (z.B. Rendsburg). Insgesamt konnten 7 Häfen mit 466 Liegeplätzen ausfindig gemacht werden. Am Mittellandkanal, dem längsten Kanal, konnten 1.098 Liegeplätze in 21 Häfen erfasst werden. Die Häfen sind als teils geschlossene, teils zum Kanal offene Hafenbecken angelegt. Es überwiegen Motorboote. Darüber hinaus gibt es entlang des Kanals viele Liegestellen für Sportboote. Der Mittellandkanal wird von vielen Sportbooten auch als Verbindungsstrecke vom Dortmund-Ems-Kanal zur Elbe und weiter zur Ostsee sowie über Magdeburg und Havel-Oder-Wasserstraße (HOW) nach Berlin und weiter Richtung Märkische Seen oder Mecklenburger Seenplatte genutzt. Nach Fenzl (1992) wird die Schleuse Anderten (Hannover) jährlich von über 2.000 Sportbooten durchfahren. Durch den steigenden Wassertourismus von Berlin-Brandenburg liegt die Zahl heute wahrscheinlich höher.

Figure B-14

Ausgewählte Kanäle und Hauptwasserstraßen in Deutschland

Kanäle und Kanalabschnitte von Wasserstraßen sind rot gekennzeichnet. Abkürzungen werden im Text erläutert.
Quelle: Geodatenbasis DLM1000 © BKG 2013

Am Dortmund-Ems-Kanal (DEK) und Datteln-Hamm-Kanal (DHK) finden sich 14 Hafenanlagen, die überwiegend von Motoryachtclubs betrieben werden. In Wesel-Datteln-Kanal (WDK) und Rhein-Herne-Kanal (RHK) (beide Hauptstrom Rheinseitenkanal) befinden sich zusammen 10 kleine Häfen mit 15 - 100 Liegeplätzen, die insgesamt knapp 500 Liegeplätze stellen.

Die vielen kleineren Kanäle sind nicht separat erfasst worden, sondern in den jeweiligen Gebieten beschrieben.

B.1.2.18 Talsperren

In Deutschland befinden sich 133 Talsperren (www.talsperren.net), von denen 60 Talsperren zur Trinkwassergewinnung genutzt werden. Um zu klären, ob insbesondere auf den Trinkwassertalsperren Sportbootverkehr sowie der Einsatz von Antifoulingbeschichtungen erlaubt ist, wurde Kontakt mit der Arbeitsgemeinschaft Trinkwassertalsperren e.V. (ATT) aufgenommen. Innerhalb der Arbeitsgemeinschaft befasst sich der Arbeitskreis Talsperrenbewirtschaftung u.a. mit folgenden Fragestellungen, welche auch die Frage des Sportbootverkehrs einschließen:

- Eintragswege von stofflichen Belastungen
- Beschaffenheit und Güteüberwachung von Zuflüssen und Talsperren
- Integrale Bewirtschaftung und Lösung von Konflikten aus konkurrierenden Nutzungen
- Umsetzung der europäischen Wasserrahmenrichtlinie

Nach mündlicher Auskunft von Herrn Döhmen (ATT) kann davon ausgegangen werden, dass auf 90 % der deutschen Trinkwassertalsperren keinerlei Bootsverkehr erlaubt ist.

Völlig anders sieht die Situation auf einigen Talsperren wie Möhnesee (946 LP, Hauptstrom: Ruhr), Rurtalsperre (2127 LP, Hauptstrom: Maas/Rur), Edertalsperre (1931 LP, Hauptstrom: Fulda) und dem Brombachsee (1018 LP, Hauptstrom: Voralpenseen) aus, die sehr beliebte und stark frequentierte Sportbootreviere sind.

B.2 Screening (AP 2)

B.2.1 Analysis results of other chemical parameters

Table B-11

Statistical characteristics for dry matter content in [mg DM/l] in marinas in fresh-, brackish and saltwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	8.8	2.6	0.1	2.6	0.1
P10	11.8	3.2	0.8	3.3	1.1
P25	16.4	4.1	1.8	6.1	3.3
P50	18.4	8.1	5.7	15.7	6.7
P75	22.6	24.1	9.9	23.7	14.6
P90	66.6	47.0	15.0	71.5	23.0
Max	96.0	275.5	38.5	275.5	275.5
Mean	32.4	37.7	7.2	36.0	16.4
SD	35.9	80.0	7.4	68.0	40.4
N	5	11	34	16	50

Table B-12

Test on statistical differences among the distributions of the dry matter content in marinas between the compartments salt-, brackish and freshwater

Areas	KS-test
Salt - Brackish	-
Salt - Fresh	xx
Brackish - Fresh	-

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

Table B-13

Statistical characteristics for dissolved organic carbon in [DOC/l] in marinas in fresh-, brackish and saltwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	1.7	2.1	0.4	1.7	0.4
P10	2.1	2.1	1.4	2.1	1.6
P25	2.6	2.5	2.3	2.5	2.3
P50	2.7	3.0	4.0	2.9	3.7
P75	6.7	4.7	4.9	5.1	4.9
P90	10.7	5.2	5.8	8.0	6.8
Max	13.4	9.3	38.2	13.4	38.2
Mean	5.4	3.9	4.7	4.4	4.6
SD	4.9	2.1	6.2	3.1	5.4
N	5	11	34	16	50

Table B-14

Test on statistical differences among the distributions of the DOC-content in marinas between the compartments salt-, brackish and freshwater

Areas	KS-test
Salt - Brackish	-
Salt - Fresh	-
Brackish - Fresh	-

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

Table B-15

Statistical characteristics data for total organic carbon in [TOC/l] in marinas in fresh-, brackish and saltwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	2.7	2.1	1.1	2.1	1.1
P10	3.1	2.2	1.4	2.3	1.7
P25	3.8	2.7	3.1	3.0	3.0
P50	5.0	5.7	4.7	5.7	4.8
P75	7.9	6.8	5.7	7.3	6.0
P90	11.2	8.5	10.5	11.0	12.4
Max	13.4	27.8	36.3	27.8	36.3
Mean	6.6	7.0	5.9	6.9	6.2
SD	4.3	7.2	6.6	6.3	6.5
N	5	11	34	16	50

Table B-16

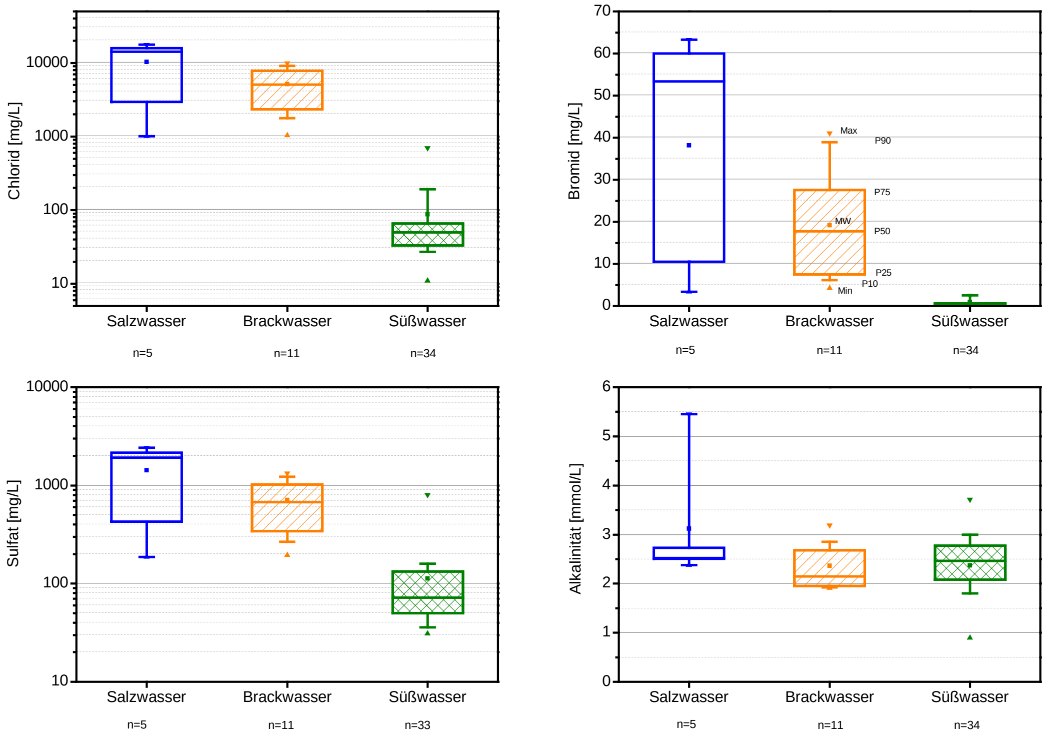
Test on statistical differences among the distributions of the TOC-content in marinas between the areas of salt-, brackish and freshwater

Areas	KS-test
Salt - Brackish	-
Salt - Fresh	-
Brackish - Fresh	-

Significance level: x: 0.05, xx: 0.01, xxx: 0.001; KS-test: Kolmogorov-Smirnov-Test

Figure B-15

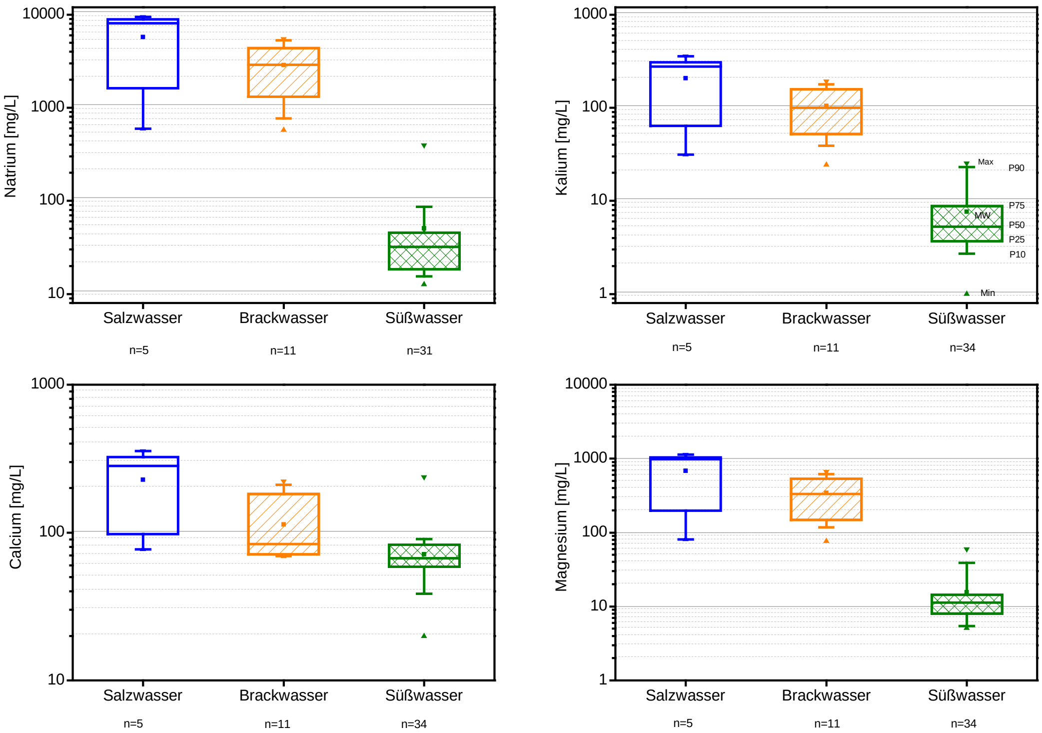
Statistical characteristics for chloride, sulphate, bromide in [mg/l] and alkalinity in [mmol/l] marinas in fresh-, brackish and saltwater



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

Figure B-16

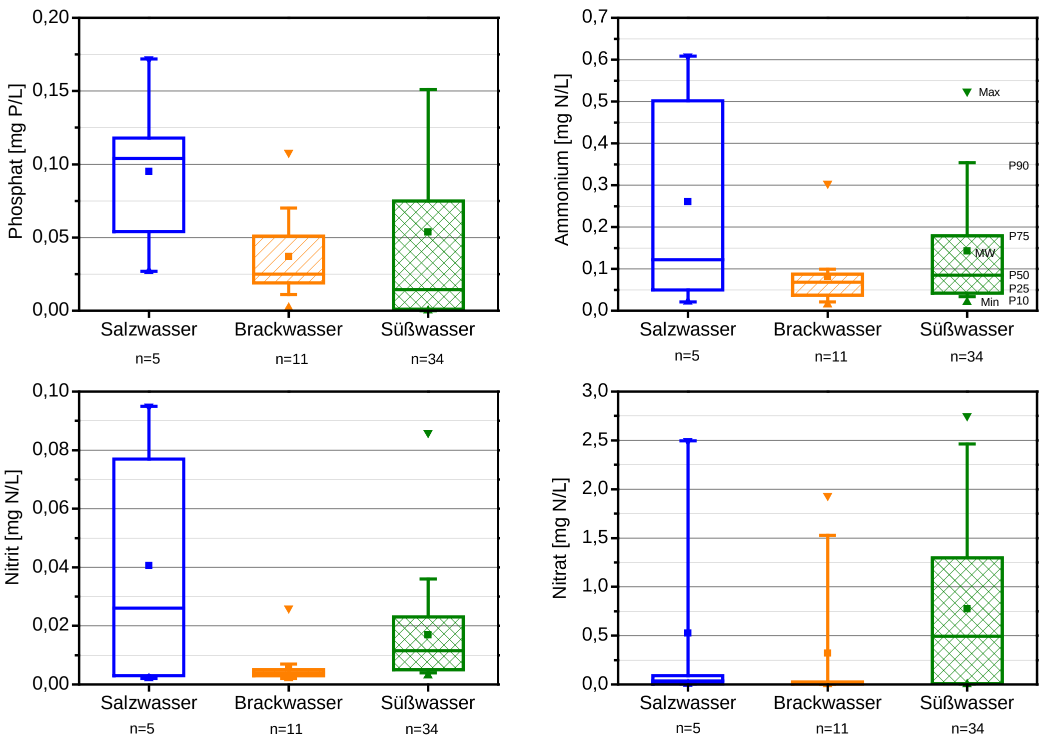
Statistical characteristics for sodium, potassium, calcium and magnesium in [mg/l] in marinas in fresh-, brackish and saltwater



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

Figure B-17

Statistical characteristics for phosphate, ammonia, nitrite and nitrate in [mg/l] in marinas in fresh-, brackish and saltwater



Bottom axis: Salzwasser = salt water, Brackwasser = brackish water, Süßwasser = freshwater. Box-Whisker-Plot: Min: minimum, Max: Maximum, P10, P25, P50, P75, P90: percentiles, MW: arithmetic mean.
Source: this study, LimnoMar.

B.2.2 Analysis results of active substances from antifoulants and selected transformation products

Table B-17

Statistical parameters of the copper content in the filtered fraction [µg Cu/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	1.0	1.0	1.0	1.0	1.0
P10	3.4	1.1	1.0	1.0	1.0
P25	7.0	2.0	2.0	2.0	2.0
P50	7.0	5.0	4.0	5.0	4.0
P75	7.0	6.3	5.8	7.0	6.0
P90	11.2	8.8	8.5	11.0	9.0
Max	14.0	20.0	20.0	20.0	20.0
Mean	7.2	5.6	4.7	6.1	5.0
SD	4.6	5.2	3.8	4.9	4.1
N ≥ BG	5	12	46	17	63
N < BG	2	1	1	3	4

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-18

Statistical parameters of the zinc content in the filtered fraction [µg Zn/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	1.0	2.0	1.0	1.0	1.0
P10	1.6	4.0	2.0	2.0	2.0
P25	4.0	5.0	3.0	4.8	3.0
P50	6.0	6.0	4.0	6.0	4.0
P75	10.5	10.0	5.0	10.0	6.0
P90	16.6	15.6	7.0	17.8	10.0
Max	25.0	27.0	16.0	27.0	27.0
Mean	8.7	8.5	4.0	8.6	5.5
SD	8.1	6.8	2.7	7.0	5.0
N ≥ BG	7	13	41	20	61
N < BG	0	0	6	0	6

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-19

Statistical parameters of DMSA contents [µg/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	0.017	0.011	0.010	0.011	0.010
P10	0.018	0.012	0.011	0.012	0.011
P25	0.021	0.017	0.013	0.017	0.014
P50	0.024	0.021	0.019	0.021	0.020
P75	0.028	0.033	0.032	0.033	0.032
P90	0.030	0.068	0.098	0.059	0.083
Max	0.031	0.105	0.280	0.105	0.280
Mean	0.024	0.035	0.043	0.033	0.040
SD	0.010	0.030	0.062	0.028	0.054
N ≥ BG	2	9	29	11	40
N < BG	5	4	18	9	27

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-20

Statistical parameters of DMST contents [µg/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	0.012	0.015	0.005	0.012	0.005
P10	0.013	0.017	0.012	0.015	0.012
P25	0.015	0.019	0.013	0.018	0.014
P50	0.021	0.035	0.017	0.025	0.021
P75	0.026	0.040	0.030	0.035	0.033
P90	0.027	0.070	0.050	0.044	0.050
Max	0.028	0.110	0.100	0.110	0.110
Mean	0.020	0.040	0.027	0.033	0.029
SD	0.008	0.033	0.024	0.028	0.025
N ≥ BG	4	7	17	11	28
N < BG	3	6	30	9	39

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-21

Statistical parameters of cybutryne contents [µg/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	0.003	0.002	0.001	0.002	0.001
P10	0.003	0.003	0.002	0.003	0.002
P25	0.004	0.003	0.004	0.004	0.004
P50	0.004	0.005	0.005	0.004	0.005
P75	0.006	0.009	0.010	0.008	0.009
P90	0.006	0.026	0.015	0.019	0.016
Max	0.006	0.029	0.110	0.029	0.110
Mean	0.005	0.010	0.011	0.008	0.010
SD	0.001	0.010	0.020	0.008	0.017
N ≥ BG	5	10	34	15	49
N < BG	2	3	13	5	18

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-22

Statistical parameters of M1 contents [µg/l] in 50 marinas[1] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	0.004	0.002	0.002	0.002	0.002
P10	0.004	0.002	0.003	0.002	0.002
P25	0.004	0.002	0.005	0.002	0.002
P50	0.005	0.002	0.008	0.002	0.005
P75	0.005	0.003	0.011	0.004	0.008
P90	0.005	0.004	0.020	0.005	0.014
Max	0.005	0.005	0.071	0.005	0.071
Mean	0.005	0.003	0.012	0.003	0.009
SD	0.001	0.001	0.017	0.001	0.014
N ≥ BG	2	7	15	9	24
N < BG	5	6	32	11	43

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

Table B-23

Statistical parameters of the sum from cybutryne and M1[1] [µg/l] in 50 marinas[2] from salt-, brackish and freshwater

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	0.003	0.002	0.001	0.002	0.001
P10	0.004	0.005	0.003	0.004	0.003
P25	0.004	0.006	0.004	0.005	0.004
P50	0.005	0.008	0.007	0.006	0.006
P75	0.006	0.011	0.016	0.010	0.015
P90	0.008	0.029	0.029	0.020	0.029
Max	0.011	0.032	0.194	0.032	0.194
Mean	0.006	0.012	0.017	0.009	0.015
SD	0.003	0.010	0.034	0.009	0.029
N ≥ BG	6	10	34	16	50
N < BG	1	3	13	4	17

1: corrected for the molecular weight of cybutryne.
2: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters.

Table B-24

Statistical parameters of terbutryn contents [µg/l] in 50 marinas[1] from salt-, brackish and fresh-water

Parameter	Salt	Brack	Fresh	Salt+Brack	Total
Min.	-/-	0.002	0.002	0.002	0.002
P10	-/-	0.002	0.003	0.002	0.003
P25	-/-	0.002	0.004	0.002	0.003
P50	0.009	0.002	0.007	0.003	0.006
P75	-/-	0.003	0.010	0.005	0.009
P90	-/-	0.003	0.013	0.007	0.012
Max	-/-	0.003	0.023	0.009	0.023
Mean	0.009	0.002	0.007	0.004	0.007
SD	-/-	0.001	0.005	0.003	0.005
N ≥ BG	1	3	28	4	32
N < BG	6	10	19	16	35

1: plus 17 samples outside the harbours close to shore as reference and from the middle of the waters

B.3 Scenarios and modelling (AP 3)

Table B-25

Harbour Sa_1 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l][1]	-	-	-	1	1
Calculated emission [g/d]	20.63	20.63	41.26	4126	4126
Manual calculated emission [g/d]	0.250	0.999	0.250	31.965	31.965
Total emission [g/d]	**20.88**	**21.63**	**41.51**	**4158**	**4158**
Maximum concentration [µg/l]	0.018	0.064	0.0615	13.3	6.50
95% concentration [µg/l]	0.018	0.062	0.060	12.9	6.29
Average concentration [µg/l]	0.009	0.046	0.038	9.88	4.82
Median concentration [µg/l]	**0.008**	**0.048**	**0.037**	**10.1**	**4.93**
Minimum concentration [µg/l]	0.002	0.010	0.008	2.95	1.44
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.012**	**0.036**	**-/- (<5)[2] (unfiltered)**	**7 (<5)[2] (filtered)**

Water exchange 329,570 m³/ tide; 241% of the total volume
1: Source: NLWKN 2012. 2: Data in brackets: Repeat measurement in 2014

Table B-26

Harbour Sa_2 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l][1]	-	0.002	-	7	7
Calculated emission [g/d]	9.0606	9.0606	18.1211	1812.11	1812.11
Manual calculated emission [g/d]	0.2052	0.8356	0.2089	26.74	26.74
Total emission [g/d]	**9.266**	**9.896**	**18.33**	**1839**	**1839**
Maximum concentration [µg/l]	0.023	0.066	0.0735	18.9	9.21
95% concentration [µg/l]	0.023	0.066	0.0735	18.9	9.21
Average concentration [µg/l]	0.010	0.039	0.0357	13.8	6.74
Median concentration [µg/l]	**0.008**	**0.039**	**0.0357**	**13.8**	**6.74**
Minimum concentration [µg/l]	0.002	0.011	0.0077	8.62	4.20
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.005**	**0.019**	**-/- (6)[2] (unfiltered)**	**1 (4)[2] (filtered)**

Water exchange 84,110 m³/ tide; 205% of the total volume.
1: Source: Reference sample Br_2 from AP 2. 2: Data in brackets: Repeat measurement in 2014

Table B-27

Harbour Br_1 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l]	-	-	-	-	-
Calculated emission [g/d]	54.51	54.51	109.01	10,901.33	10,901.33
Manual calculated emission [g/d]	0.560	2.242	0.560	71.736	71.736
Total emission [g/d]	**55.07**	**56.75**	**109.57**	**10,973**	**10,973**
Maximum concentration [µg/l]	0.0341	0.455	0.131	81.1	39.5
95% concentration [µg/l]	0.0341	0.452	0.131	80.6	39.3
Average concentration [µg/l]	0.0082	0.342	0.0473	60.2	29.3
Median concentration [µg/l]	**0.0031**	**0.343**	**0.0328**	**60.2**	**29.4**
Minimum concentration [µg/l]	0.0002	0.113	0.0055	19.7	9.60
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.031**	**0.1201**	**-/- (7)[1] (unfiltered)**	**20 (10)[1] (filtered)**

Water exchange 116,790 m³/ tide; 35.3% of the total volume.
1: Data in brackets: Repeat measurement in 2014.

Table B-28

Harbour Br_2 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l][1]	-	0.002	-	5	5
Calculated emission [g/d]	97.263	97.263	194.527	19,452.76	19,452.76
Manual calculated emission [g/d]	2.901	11.604	2.901	371.34	371.34
Total emission [g/d]	**100.17**	**108.87**	**197.43**	**19,824**	**19,824**
Maximum concentration [µg/l]	0.0135	0.152	0.050	31.2	15.2
95% concentration [µg/l]	0.0135	0.147	0.050	30.4	14.9
Average concentration [µg/l]	0.0043	0.116	0.0235	25.0	12.2
Median concentration [µg/l]	**0.0026**	**0.118**	**0.0195**	**25.3**	**12.4**
Minimum concentration [µg/l]	0.0003	0.032	0.0038	10.3	5.01
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.005**	**0.023**	**-/- (5)[2] (unfiltered)**	**4 (4)[2] (filtered)**

Water exchange 841,710 m³/ tide; 71.8% of the total volume.
1: Source: Reference sample Br_2 from AP 2. 2: ( ): Repeat measurement in 2014

Table B-29

Harbour Br_3 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l]	-	-	-	-	-
Calculated emission [g/d]	18.23	18.23	36.46	3646.34	3646.34
Manual calculated emission [g/d]	0.5591	2.23658	0.5591	71.5708	71.5708
Total emission [g/d]	**18.79**	**20.47**	**37.02**	**3718**	**3718**
Maximum concentration [µg/l]	0.0814	0.495	0.300	85.2	41.5
95% concentration [µg/l]	0.0814	0.495	0.300	85.2	41.5
Average concentration [µg/l]	0.0224	0.275	0.116	46.8	22.8
Median concentration [µg/l]	**0.0113**	**0.275**	**0.090**	**46.5**	**22.7**
Minimum concentration [µg/l]	0.0010	0.056	0.013	9.48	4.62
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.010**	**0.068**	**-/- (8)[1] (unfiltered)**	**4 (3)[1] (filtered)**

Water exchange 21,467 m³/ tide; 32.6% of the total volume.
1: Data in brackets: Repeat measurement in 2014.

Table B-30

Harbour Br_4 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l]	-	-	-	-	-
Calculated emission [g/d]	3.68	3.68	7.36	736.19	736.19
Manual calculated emission [g/d]	0.2340	0.9362	0.2340	29.9581	29.9581
Total emission [g/d]	**3.91**	**4.62**	**7.60**	**766.14**	**766.14**
Maximum concentration [µg/l]	0.0111	0.194	0.045	32.0	15.6
95% concentration [µg/l]	0.0111	0.194	0.045	32.0	15.6
Average concentration [µg/l]	0.0018	0.106	0.011	17.4	8.50
Median concentration [µg/l]	**0.0002**	**0.105**	**0.0038**	**17.3**	**8.43**
Minimum concentration [µg/l]	0.000002	0.0201	0.0002	3.29	1.60
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.021**	**0.024**	**-/- (7)[1] (unfiltered)**	**9 (8)[1] (filtered)**

Water exchange 11,615 m³/ tide; 7.9% of the total volume.
1: Data in brackets: Repeat measurement in 2014

Table B-31

Harbour Sü_1 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l][1]	-	-	-	2	2
Calculated emission [g/d]	69.24	69.24	138.48	13,847.87	13,847.87
Manual calculated emission [g/d]	2.1659	8.6637	2.1659	277.239	277.239
Total emission [g/d]	**71.41**	**77.90**	**140.65**	**14,125**	**14,125**
Maximum concentration [µg/l]	0.0099	0.181	0.040	35	17.1
95% concentration [µg/l]	0.0099	0.181	0.040	35	17.1
Average concentration [µg/l]	0.0018	0.124	0.011	24.4	11.9
Median concentration [µg/l]	**0.0003**	**0.124**	**0.005**	**24.4**	**11.9**
Minimum concentration [µg/l]	0.000009	0.0591	0.0006	11.7	5.71
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.029**	**0.036**	**-/- (unfiltered)**	**11 (filtered)**

Water exchange 61,267 m³/ 12.4 h; 3.03% of the total volume.
1: Source: Reference sample Sü_1 from AP 2.

Table B-32

Harbour Sü_2 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l]	-	-	-	-	-
Calculated emission [g/d]	6.89	6.89	13.78	1377.75	1377.75
Manual calculated emission [g/d]	0.2167	0.8669	0.2167	27.7422	27.7422
Total emission [g/d]	**7.11**	**7.76**	**13.99**	**1405**	**1405**
Maximum concentration [µg/l]	0.0474	0.945	0.201	168	81.9
95% concentration [µg/l]	0.0474	0.945	0.201	168	81.9
Average concentration [µg/l]	0.0070	0.508	0.041	89.9	43.8
Median concentration [µg/l]	**0.0004**	**0.501**	**0.011**	**88.5**	**43.2**
Minimum concentration [µg/l]	0.000002	0.0910	0.0004	16.0	7.81
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.167**	**0.189**	**-/- (unfiltered)**	**14 (filtered)**

Water exchange 3778 m³/ 12.4 h; 7.85% of the total volume

Table B-33

Harbour Sü_3 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l]	-	-	-	-	-
Calculated emission [g/d]	26.61	26.61	53.23	5322.68	5322.68
Manual calculated emission [g/d]	1.0726	4.2902	1.0726	137.2875	137.2875
Total emission [g/d]	**27.69**	**30.90**	**54.30**	**5460**	**5460**
Maximum concentration [µg/l]	0.0078	0.296	0.032	53.8	26.3
95% concentration [µg/l]	0.0078	0.290	0.032	52.6	25.7
Average concentration [µg/l]	0.0014	0.240	0.008	43.7	21.3
Median concentration [µg/l]	**0.0002**	**0.243**	**0.003**	**44.2**	**21.6**
Minimum concentration [µg/l]	0.000003	0.0902	0.0003	16.5	8.04
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.019**	**0.029**	**-/- (unfiltered)**	**4 (filtered)**

Water exchange 132,760 m³/ 12.4 h; 14.8% of the total volume.

Table B-34

Harbour Sü_4 – emission rates [g/d] and water concentrations [µg/l] of DCOIT, cybutryne, dichlofluanid and copper during modelling with MAMPEC and from the measurement in AP 2

	DCOIT	Cybutryne	Dichlofluanid	Total Cu	Dissolved Cu
Background concentration [µg/l][1]		0.006	0.007	6	6
Calculated emission [g/d]	26.04	26.04	52.09	5208.92	5208.92
Manual calculated emission [g/d]	1.3243	5.2973	1.3243	169.51	169.51
Total emission [g/d]	**27.37**	**31.34**	**53.41**	**5378**	**5378**
Maximum concentration [µg/l]	0.0364	1.71	0.171	264	129
95% concentration [µg/l]	0.0364	1.71	0.171	264	129
Average concentration [µg/l]	0.00435	0.916	0.025	139	67.8
Median concentration [µg/l]	**0.000002**	**0.889**	**0.001**	**133**	**64.8**
Minimum concentration [µg/l]	3.02E-9	0.196	0.0002	32.4	15.8
Measurement AP 2 [µg/l] (active substance + if applicable transformation products)	**< 0.01**	**0.0108**	**0.0326**	**-/- (unfiltered)**	**13 (filtered)**

Water exchange 7609.1 m^3/ 12.4 h; 2.16 % of the total volume.
1: Source: Reference sample Bootscenter Keser from AP 2

Appendix C Raw data

C.1 AP 1

Dataset containing nationwide census of berths and marinas in Germany

C.2 AP 2

Dataset containing analytical screening at 50 marinas

C.3 AP 3

Dataset on request