AR-1587

Merrimack Station
AR-1195

DRAFT

# 316(a) TECHNICAL GUIDANCE--THERMAL DISCHARGES

September 30, 1974

Water Planning Division
Office of Water and Hazardous Materials
Environmental Protection Agency

DRAFT

# TABLE OF CONTENTS

# ERRATA

## 316(a) DRAFT TECHNICAL GUIDANCE--THERMAL DISCHARGES

October 30, 1974

1. Delete subparagraph (d)(4)(D) from Chapter V (page 47) which reads:

   > "The information called for in subparagraph (c)(4)(D) above, except that such information may be limited to the area of the proposed discharge zone."

2. Chapter X, Community Studies, is amended as follows and included in its entirety.

# INTRODUCTION

## (a) Foreword.

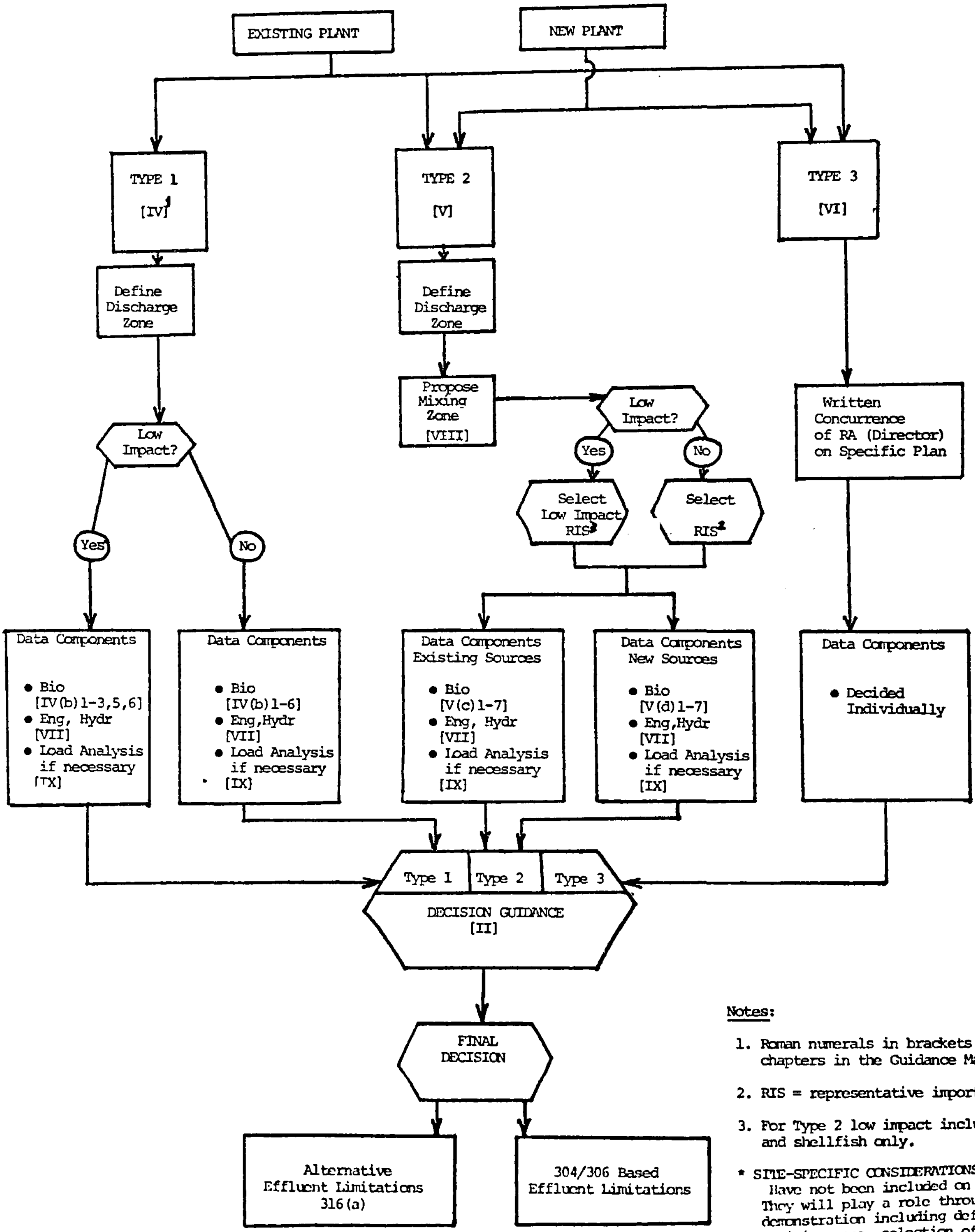
This guidance manual describes the information which should be developed and evaluated in connection with the possible modification, pursuant to section 316(a) of the Federal Water Pollution Control Act, as amended, 33 USC 1251, 1326(a), and 40 CFR Part 122, of any effluent limitation proposed for the control of the thermal component of any discharge otherwise subject to the provisions of section 301 or 306 of the Act. It is intended for use by EPA and State water quality agencies in establishing or reviewing proposed thermal effluent limitations, by owners or operators of point sources who may file applications under section 316(a) and by members of the public who may wish to participate in any 316(a) determination.

Three types of demonstration are defined--Absence of Prior Appreciable Harm (Type 1), Protection of Representative, Important Species (Type 2) and Biological, Engineering and Other Data (Type 3) (see 316(a) Information Flow Chart, below). Where preparation of a demonstration will require a significant period of time after application has been made for a permit to include alternative effluent limitations, a plan of study and demonstration should be established, with the advice and consultation of the Regional Administrator (or Director).[1] (See 40 CFR §122.5 (or §122.11).)

---

[1] Throughout these guidelines the phrase "Regional Administrator (or Director)" means the relevant permitting authority, unless the context requires otherwise.

# 316(a) INFORMATION FLOW CHART*



Notes:

1. Roman numerals in brackets refer to chapters in the Guidance Manual.
2. RIS = representative important species
3. For Type 2 low impact includes fish and shellfish only.

* SITE-SPECIFIC CONSIDERATIONS: Have not been included on the chart. They will play a role throughout any demonstration including definition of a mixing zone, selection of RIS, and changes, if any, in data components.

Each informational item identified in this guidance for the selected type(s) should be included in full in the demonstration unless the established plan provides otherwise.

(b) Legal Requirements.

Heat discharged into water is a pollutant. (Section 502(6), FWPC Act.) Point source dischargers of pollutants must achieve, not later than July 1, 1977, effluent limitations based on the best practicable control technology currently available ("BPCTCA") or any more stringent limitation required by certain State or Federal laws or regulations, including applicable water quality standards; and they must further achieve, not later than July 1, 1983, effluent limitations based on the best available technology economically achievable ("BATEA"). (Section 301.) The Administrator is required to publish regulations to define BPCTCA for classes and categories of point sources (section 304(b)) and establish Federal standards of performance for new sources within certain categories of sources. (Section 306.)

Effluent limitations guidelines under section 304(b) and new source standards of performance under section 306 include limitations on heat for those industries for which such limitations are appropriate. Effluent Limitations Guidelines and Standards, Steam Electric Power Generating Point Source Category (40 C.F.R. Part 423), include such limitations.

Effluent limitations proposed pursuant to section 301 or 306 for the thermal component of a discharge may be modified or waived if the owner or operator of the source is able to demonstrate that the effluent limitations proposed for the thermal component of the discharge are more stringent than necessary to protect the balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is made.[2] The basis for modification is a casebycase evaluation of the water quality impact of the individual discharge.

---

[2] Section 316(a) provides:

> "With respect to any point source otherwise subject to the provisions of section 301 or section 306 of this Act, whenever the owner or operator of any such source, after opportunity for public hearing, can demonstrate to the satisfaction of the Administrator (or, if appropriate, the State) that any effluent limitation proposed for the control of the thermal component of any discharge from such source will require effluent limitations more stringent than necessary to assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on the body of water into which the discharge is to be made, the Administrator (or, if appropriate, the State) may impose an effluent limitation under such sections for such plant, with respect to the thermal component of such discharge (taking into account the interaction of such thermal component with other pollutants), that will assure the protection and propagation of a balanced, indigenous population of shellfish, fish, and wildlife in and on that body of water."

Regulations describing requirements under section 316(a) should be consulted in connection with any 316(a) presentation. (See 40 C.F.R. Part 122.)

### (c) Applicant's Demonstration.

An applicant, after consultation with the Regional Administrator (for Director), may present evidence addressing any one or more appropriate demonstration types. All demonstrations should be completed within a time frame which will assure maximum progress towards compliance with the statutory deadlines of sections 301 and 306.

Each demonstration item set forth in Chapters IV-VI for the subject demonstration type will normally apply. The Regional Administrator (or Director) may authorize or request an applicant to modify, reduce, expand or eliminate any item as warranted by the circumstances of the particular case. The advance concurrence or nonconcurrence of the Regional Administrator (or Director) in a particular demonstration should help all parties identify a relevant showing. However, the statutory burden of proof for alternative effluent limitations is on the applicant. Therefore, any advance agreement should not be taken as reducing the applicant's responsibilities, nor should any disagreement be allowed to prejudice the conclusion.

Any alternative effluent limitation imposed pursuant to section 316(a) must assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife. Therefore, the applicant submitting evidence for a 316(a) evaluation should submit information on all modes of discharge that he may be contemplating. For example, if his information indicates that a closed system requirement is too stringent but does <u>not</u> justify the use of a simple once through discharge, then he should have sufficient evidence to justify some other mode of discharge (a diffuser or a "helper" cooling tower). This is imperative since time may not allow for another long-term 316(a) study (due to BPCTCA and BATEA deadlines). If this is the case and if there is not enough evidence to assure protection of the balanced, indigenous community in using another discharge cooling system, then there may be no other choice but to require a closed cycle cooling system.

Since by law the burden of proof in any 316(a) demonstration is on the applicant, effluent limitations proposed pursuant to sections 301 or 306 will not be modified if the weight of the evidence indicates that such limitations are not unnecessarily stringent. Neither will they be modified where the evidence is insufficient to allow the Regional Administrator (or Director) to determine whether they are unnecessarily stringent or not. Modification will be granted only where the applicant succeeds in making a demonstration which (1) affirmatively shows that the proposed limitations are more stringent than necessary and (2) is not outweighed by any evidence to the contrary.

(d) <u>Format of Demonstration</u>.

Each demonstration should include the following:

1. Pagination.
2. A table of contents.
3. Supportive reports, documents and raw data which are not from the open scientific literature.

4. Bibliographic citations to page number.

5. An interpretive, comprehensive narrative summary of the demonstration.

The summary should include a table of contents. Sources of data used in the summary should be cited to page number. The summary should include a clear discussion stating why the applicant's demonstration is sufficient to assure that the proposed discharge will assure the protection and propagation of a balanced, indigenous community.

(e) Application.

The following points may be helpful in the review and application of these guidelines.

I. How is the Manual to be used: Are its requirements binding?

A. The guidance should normally be followed for each demonstration. However, specific demonstration items can be changed to fit the circumstances of the particular case, with the advice and consultation of the Regional Administrator (or Director). The applicant is encouraged to develop its plan of study and demonstration promptly, in accordance with the law's time constraints. Of course, a demonstration plan cannot be binding on either the applicant or the Regional Administrator (or Director), in view of the possibility that developing information may suggest changes in the study; the potential for third party involvement or judicial review, and the law's mandate that the burden of proof under section 316(a) is on the applicant.

2. How should the right demonstration type be selected? Is there any screening procedure?

A. No formal screening mechanism can adequately predict the "right" demonstration type for each applicant. The applicant should select its proposed demonstration type or types through consideration of this guidance, the nature of its discharge (existing or new; low impact or other, etc.) and the availability or attainability of information. Consultation with the Regional Administrator (or Director) is also encouraged.

3. How comprehensive must a demonstration be in order to provide the required assurance of protection and propagation?

A. The study must provide reasonable assurance of protection and propagation of the indigenous community. Mathematical certainty regarding a dynamic biological situation is impossible to achieve, particularly where desirable information is not obtainable. Accordingly, the Regional Administrator (or Director) must make decisions on the basis of the best information reasonably attainable. At the same time, if he finds that the deficiencies in information are so critical as to preclude reasonable assurance, then alternative effluent limitations should be denied. It is expected in any case that after publication of this guidance potential applicants will conduct monitoring and data collection activities responsive to the applicable portions of this document. In that way, as initial permits come up for renewal, subsequent 316(a) judgments may be made with increasing levels of confidence, and new effluent limitations may be imposed as necessary (except as provided in section 316(c)).

4. Will there be enough time to prepare the demonstrations called for by the guidelines?

A. The statutory timetables are very tight, and the 316(a) statutory test may require preparation of rather extensive information in order to reach a reasonable conclusion. The time needed for individual demonstrations will vary according to the demonstration type being undertaken and the data which the applicant has already collected: No applicant should lack existing useful data on its own discharge or proposed discharge. Where a demonstration cannot be completed prior to the date for issuance of a permit, a permit may be issued for a term of up to five years which requires the source to achieve the initially proposed effluent limitations no later than the date specified by applicable law, regulations and standards, but the permittee may be afforded an opportunity to request a hearing after additional information has been developed. (See 40 C.F.R. §§122.10(b), 122.15(b).)

5. Shouldn't a showing of compliance or noncompliance with applicable water quality standards be conclusive?

A. The statutory test established by section 316(a) is distinct from the multiple statutory objectives of water quality standards. In addition, standards may fail to address site-specific issues, such as refined temperature limits to protect spawning areas or to reflect a community which has become adapted to natural local conditions. Therefore, compliance or noncompliance with standards alone is not a sufficient demonstration. The law indicates that standards should be modified where necessary to make them consistent with section 316(a) decisions. Where such modifications have taken place, or wherever the standards are fully consistent with the 1983 goals of the Act (see section 101(a)(2)), compliance or noncompliance with standards may be a persuasive factor in the 316(a) evaluation.

6. Can the outcome of a proposed demonstration be predicted, so that the applicant can commence any needed planning and construction?

A. Each demonstration involves a distinct case and a distinct water body situation. Firm decision rules would be arbitrary, and their application would fail to provide against excessive environmental risk or unnecessarily stringent outcomes. Instead of firm rules, therefore, the guidelines set forth for each demonstration type a series of factors the presence of which would tend to indicate that section 316(a) relief should not be granted. These non-binding guidelines should be useful to show the types of considerations which may be determinative.

7. Does completion of a satisfactory 316(a) demonstration respecting the thermal component of its discharge assure the applicant of relief from the requirements of sections 301 and 306?

A. No. All impacts of the plant must be analyzed and weighed. Section 316(a) requires consideration of the interaction of the thermal component of the discharge with other pollutants, such as chemicals or the thermal discharges of other sources. In addition to considerations under section 316(a), other possible harmful effects of the plant's operation and discharge must be prevented, including any excessive impact on water resources or harmful effects caused by the intake structure and/or entrainment. (See section 316(b) of the Act and 40 C.F.R. Parts 401, 402.) Guidance on entrainment will be forthcoming.

# II

# DECISION GUIDANCE

This chapter provides guidance for section 316(a) decisions by listing factors which suggest a failure to assure the protection and propagation of the balanced, indigenous community. These factors should be used solely as guidance, not as specific decision criteria for denial of alternative effluent limitations. The weight given to particular factors will differ regionally in accordance with emphasis on specific regional problems. Additional factors may also be considered.

NOTE: The factors set forth in this chapter relate solely to the thermal impact of the applicant's discharge. A permit may be issued only if the plant's operation and discharge will meet all applicable requirements of law, including restrictions on intake and entrainment effects and the chemical component of the discharge. Guidance on entrainment will be forthcoming.

1. Type I: Absence of Prior Appreciable Harm.

A failure to demonstrate the absence of prior appreciable harm may be suggested by any of the following:

(a) Evidence of damage to the balanced, indigenous community, or community components, resulting in such phenomena as those identified in the definition of appreciable harm. (See Chapter III, paragraph (10).)

(b) Absence of a convincing and otherwise satisfactory rationale where needed to explain any information submitted by the applicant. (See Chapter IV, paragraphs (b)(1)-(6).)

(c) Failure to provide sufficient information to form the basis for a determination.

(d) Any other evidence that the protection and propagation of the balanced, indigenous community is not being assured.

### 2. Type 2: Protection of Representative, Important Species.

A failure to demonstrate that the discharge (existing or proposed) is consistent with assurance of the protection and propagation of representative, important species may be suggested by any of the following:

(a) Any one or a combination of the factors listed for a Type I demonstration, paragraph (I), above, as those factors would apply to the existing or proposed discharge under consideration.

(b) Discharge zone receiving water temperatures outside the mixing zone in excess of the upper temperature limits for survival, growth and reproduction, as applicable, of any representative, important species occurring in the receiving water.

(c) Receiving water temperature within the mixing zone which fails to conform to minimum requirements for such area.

(d) Receiving water of such quality in the absence of the proposed thermal discharge that the addition or continuance of the discharge may select for excessive nuisance populations of phytoplankton, macroalgae, fouling or boring species, scavenger species or encrusting species.

(e) Insufficiency of information needed to select representative, important species; to verify the selection, or to evaluate the effects of the proposed discharge on the selected species. Sufficiency of information should be determined by the Regional Administrator (or Director) on the basis of the specific case, considering the significance of the species in question, the need for the information, its availability or attainability (including time for attaining) and the adequacy of the applicant's other information to allow appraisal of the overall impact of the discharge. If data crucial to the evaluation are not presented, the applicant's Type 2 application should be denied: Prior consultation with the Regional Administrator (or Director) as to informational needs should help avoid this result.

(f) Clear indications that the assurance of the protection and propagation of the selected representative, important species will not assure the protection and propagation of the balanced, indigenous community in and on the receiving water body segment.

3. Type 3: Biological, Engineering and Other Data.

A failure to demonstrate that the discharge (existing or proposed) is consistent with the assurance of the protection and propagation of the balanced, indigenous community by means of biological, engineering and other data is suggested by any of the following:

(a) Any one or a combination of such factors listed for a Type I or Type 2 demonstration as might be applicable. (Paragraphs (I) and (2), above.)

(b) Inadequacy or rebuttal of the applicant's additional data and information to demonstrate the assurance of the protection and propagation of a balanced, indigenous community.

To the extent feasible, the Regional Administrator (or Director) should define specific Demonstration Type 3 factors at the time the applicant's proposed specific plan of study and demonstration is prepared. (See Chapter I, subparagraph (e)(1).)

## III

## DEFINITIONS

Definitions and descriptions in this section pertain to a number of terms and concepts which are pivotal to the development and evaluation of 316(a) studies. These are developed for the general case to aid the Regional Administrator (or Director) in delineating a set of working definitions and concise end points requisite to a satisfactory demonstration for a given discharge.

(I) Balanced, Indigenous Community.

The regulation provides (40 C.F.R. §122.I(h)):

> The term "balanced, indigenous community" is synonymous with the term "balanced, indigenous population" in the Act and means a biotic community typically characterized by diversity, the capacity to sustain itself through cyclic seasonal changes, presence of necessary food chain species and non-domination of pollution tolerant species. Such a community may include historically non-native species introduced in connection with a program of wildlife management and species whose presence or abundance results from substantial, irreversible environmental modifications. Normally, however, such a community will not include species whose presence or abundance is attributable to the introduction of pollutants that will be eliminated by compliance by all sources with section 301(b)(2) of the Act, including alternative effluent limitations imposed pursuant to section 316(a).

A "community" in general is any:

> . . . assemblage of populations living in a prescribed area or physical habitat; it is an organized unit to the extent that it has characteristics additional to its individual and population components and functions as a unit through coupled metabolic transformations.
>
> Communities not only have a definite functional unity with characteristic trophic structures and patterns of energy flow but they also have compositional unity in that there is a certain probability that certain species will occur together.[1/]

All communities typically have characteristics including but not limited to:

(a) Diversity in its general sense (species richness, equitability and age structure);

(b) Biological processes, cycles, and periodicities such as regard productivity, reproduction, recruitment, short or long term succession, energy flow and nutrient turnover;

(c) Spatial characteristics, which may be ordered by the biota as well as the hydrography and geomorphology.

---

1. Odum, E.P., Fundamentals of Ecology (W. B. Saunders Co., Philadelphia, Pa. (1971)), p. 140.

A "balanced, indigenous" community means a desirable community consisting of fish, shellfish and wildlife plus the biota at other trophic levels which are necessary or desirable as a part of the food chain or otherwise ecologically important to the maintenance of the desirable community. In keeping with the objective of the Act, the community should be consistent with the restoration and maintenance of the biological integrity of the water. (See section 101(a).) However, it may also include species not historically native to the area which:

- Result from major modifications to the water body (such as hydroelectric dams) or to the contiguous land area (such as deforestation attributable to urban or agricultural development) which cannot reasonably be removed or altered.
- Result from management intent, such as deliberate introduction in connection with a wildlife management program.
- Are species or communities whose value is primarily scientific or aesthetic.

Thus, it is not necessary to show that the applicant's discharge is compatible with a community which may have existed in a pristine environment but which has not persisted.

Community imbalance may be evidenced by any one or more of the following:

- Blocking or reversing short or long term successional trends of community development.
- A flourishing of heat tolerant species and an ensuing replacement of other species characteristic of the indigenous community.
- Simplification of the community and the resulting loss of stability.

An imbalanced or nonindigenous community could also be characterized by excessive levels of:

- Species whose dominance results from the introduction of pollutants.
- Species introduced and maintained in residence as a result of habitat destruction by man's activities (for example, dredging).
- Species introduced by human activities (such as aquaculture) which colonize or establish themselves at the expense of endemic communities and which are beyond the limit of management intent. (See section 318, FWPC Act, and 40 C.F.R. Part 115.)

(2) Representative, Important Species.

The regulation provides (§122.1(g)):

> The term "representative, important species" means species which are representative, in terms of their biological requirements, of a balanced, indigenous community of shellfish, fish, and wildlife in the body of water into which the discharge is made.

Species should be representative of the community in the sense that a maintenance of water quality conditions assuring the natural completion of their life cycles will also assure the protection and propagation of the balanced, indigenous community. "Natural completion of life cycles" refers to species growth, development, reproduction, metabolism and behavior adequate to maintain the species within the community. Species can be important from a direct economic standpoint, as a food chain organism for an economic species, or broadly from the ecological aspect for normal community function and maintenance. For example, to maintain a desired fish species, temperatures must be limited not only to meet the thermal tolerance of the desired species itself but also to maintain species of relevant biotic categories necessary as part of the food web supporting the fish species.

(3) Biotic Categories.

Biotic categories include the following:

(i) Primary producers--autotrophic organisms that fix $CO_2$ into organic matter using radiant energy through photosynthesis. Aquatic examples include but are not limited to phytoplankton, periphyton, macrophytes, and macroalgae.

(ii) Macroinvertebrates--animals that are large enough to be seen by the unaided eye and can be retained by a U.S. Standard No. 30 sieve (28 meshes per inch, 0.595 mm openings). Aquatic examples include but are not limited to mollusks, insects, annelids, and crustaceans.

(iii) Fish--the common usage of this term.

(iv) Economically important species--plant and animal species of present or potential recreational or commercial value as objects of hunt or harvest.

(4) Principal Macrobenthic Species.

Principal macrobenthic species are those dominant macroinvertebrates and plants attached or resting on the bottom or living in bottom sediments. Examples include but are not limited to crustaceans, mollusks, polychaetes, and habitat forming species such as attached macroalgae, rooted macrophytes and coral.

(5) Nuisance Species.

Nuisance species are microbial, plant and animal species, most of which are pollution-tolerant, present in the indigenous community or recruitable from contiguous waters which, by virtue of the direct or indirect effects of the discharge, will be given sufficient advantage to appear in the zone of discharge in large numbers at the expense of other members of the indigenous community. The concept is intended to carry the connotation of "weeds" used in its agricultural sense and may refer to a species with otherwise desirable features. However, any species which indicates a hazard to ecological balance or human health and welfare that is not naturally a feature of the indigenous community must be defined as a nuisance species (e.g., large numbers of fecal streptococci or new blooms of coccoid or blue-green algae).

(6) Migrants.

Migrants are nonplanktonic organisms that are not permanent residents of the area but pass through the discharge zone and water contiguous to it. Examples include the upstream migration of spawning salmon and subsequent downstream run of the juvenile forms, or organisms that inhabit an area only at certain times for feeding or reproduction purposes.

(7) Threatened or Endangered Species.

A threatened or endangered species is any plant or animal that has been determined by the Secretary of Commerce or the Secretary of the Interior to be a threatened or endangered species pursuant to the Endangered Species Act of 1973, as amended.

(8) Discharge Zone.

The discharge zone is that portion of the receiving waters which falls within the delta 2°C. isotherm of the plume 30% or more of the time, as defined by data representing a period of at least a few months and preferably indicative of a complete annual cycle.

(9) Water Body Segment.

A water body segment is a portion of a basin the surface waters of which have common hydrologic characteristics (or flow regulation patterns); common natural physical, chemical, and biological processes, and which have common reactions to external stress, *e.g.*, discharge of pollutants. (See 40 C.F.R. §130.2(m).) Where they have been defined, the water body segments determined by the State Continuing Planning Process under section 303(e) of the Act will apply.

(10) Appreciable Harm.

Appreciable harm is damage to the balanced, indigenous community, or to community components which results in such phenomena as the following:

- Substantial increase in abundance or distribution of any nuisance species or heat tolerant community not representative of the highest community development achievable in receiving waters of comparable quality.
- Substantial decrease of formerly indigenous species, other than nuisance species.
- Changes in community structure to resemble a simpler successional stage than is natural for the locality and season in question.
- Unaesthetic appearance, odor or taste of the waters.
- Elimination of an established or potential economic or recreational use of the waters.
- Reduction of the successful completion of life cycles of indigenous species, including those of migratory species.
- Substantial reduction of community heterogeneity or trophic structure.

This definition describes harm which should be considered appreciable. It is not intended that every change in flora and fauna should be considered appreciable harm.

(11) Low Potential Impact.

An existing or proposed discharge may be determined to be a low potential impact discharge, on a case-by-case basis, in either of the following situations:

- The thermal plume comprises or would comprise a relatively small percentage of the shore to shore distance and cross-sectional area of the fresh water body segment or stream flow and is not in an area of high biological value.
- The discharge is an off-shore marine discharge which results or would result in a plume which does not or would not impact benthic or shoreline organisms, off-shore migratory paths, spawning areas of fishes or areas of upwelling.

Site-specific considerations which could influence the determination of low impact include the amount of thermal loading in the water body segment to which the discharge is to be made and lack of any important spawning areas in the discharge zone.

(12) The definitions of the following terms contained in the regulations shall be applicable to such terms as used in this guidance manual: "Effluent limitations," "alternative effluent limitations," "water quality standards," "section 316(a)," "pollutant," "discharge of a pollutant," "point source," "discharge" and "pollution."

## IV

## DEMONSTRATION TYPE I: ABSENCE OF PRIOR APPRECIABLE HARM (EXISTING SOURCES)

### (a) Introduction.

An existing source may present information pursuant to this chapter to demonstrate that the thermal component of its discharge has not caused appreciable harm to the balanced, indigenous community.

A Type I demonstration should include the information identified in this paragraph, unless written modifications are developed following consultation with the Regional Administrator (or Director). The demonstration may also include such additional information as the applicant may wish to be considered, provided that the additional information is accompanied by a rationale stating why such information indicates the absence of prior appreciable harm. Information to be submitted includes the following:[1]

- Water quality standards information. (Paragraph (b)(1).)
- Records of shutdowns. (Paragraph (b)(2).)
- Water quality related communications. (Paragraph (b)(3).)
- Species information. (Paragraph (b)(4).)
- Discussion of economic and recreational effects. (Paragraph (b)(5).)
- Other known reports on effects of the discharge. (Paragraph (b)(6).)

---

[1] Where field studies are carried out, sample replication should be adequate to determine the precision of the data generated and to conduct appropriate statistical tests.

- Engineering and hydrologic information. (Chapter VII.)
- Thermal load information, if needed. (Chapter IX.)

Information for a full Type I demonstration includes all of the above items. Wherever the applicant can show to the satisfaction of the Regional Administrator (or Director) that its discharge has a low potential impact on the receiving water body segment, the Regional Administrator (or Director) may provide in writing that the Type I demonstration may be limited by omitting the species information described in paragraph (b)(4).

In demonstrating that no appreciable harm has been caused, it is not necessary for the applicant to show that every species which would occur under optimal conditions is present, as long as it demonstrates that the community as a whole, and all major components thereof, are intact. At the same time, the applicant's demonstration should show the effects of its discharge on species in the entire water body segment: Demonstration of the absence of appreciable harm may not be wholly dependent on exempting a portion of the waters for a mixing zone.

The Type I demonstration is not available in either of the following cases:

- The applicant has not been discharging the heated effluent into the body of water for a sufficient period of time (generally at least 1 year) prior to its 316(a) application to allow evaluation of the effects of the discharge.

- The discharge has been made into waters which, during the period of the applicant's prior thermal discharge, were so despoiled as to preclude evaluation of the effects of the thermal discharge on species of shellfish, fish and wildlife.

(b) Applicant's Information.

Information to be submitted includes the following:

(1) Evidence of compliance with applicable water quality standards. The applicant should submit sufficient evidence for the Regional Administrator (or Director) to make a determination of compliance. If any of the evidence reveals non-compliance with water quality standards the applicant should submit a rationale stating why this evidence does not indicate prior appreciable harm to the balanced, indigenous community.

(2) Records of shutdowns and their effects on the aquatic biota. All shutdowns which resulted in the disruption (complete stoppage) of heated effluent flow during the last five years should be documented and some assessment of the known effects of each shutdown should be made by the applicant. If the applicant's records are incomplete or if he has no knowledge of harmful effects for a specific shutdown he should so note and should describe his monitoring efforts in connection with such shutdown. If any effects harmful to aquatic biota have resulted from shutdowns, the applicant should submit a rationale stating why these effects did not constitute appreciable harm to the balanced, indigenous community.

(3) Copies of all water quality related communications (which indicate possible harmful effects) between the applicant and any regulatory agency other than EPA during the last five years. The applicant should submit copies of all such communications or show why he is unable to do so, except that in the case of State administration of the permit program, communications with the State need not be submitted but communications with EPA should be included. For each communication the applicant should also submit a rationale explaining why the concerns reflected in the communication did not reflect appreciable harm to the balanced, indigenous community.

(4)(A) A list, and an indication of the abundance, of threatened or endangered species and nuisance species, at any trophic level; principal macrobenthic species and species of fish, shellfish and wildlife, in:

(i) The discharge zone under existing conditions;

(ii) The water body segment just outside the discharge zone under existing conditions; and

(iii) The water body segment under theoretical conditions which would exist by including non-point source influences but excluding stress from point source discharges.

All threatened and endangered species should be except that no information should be requested that would require field sampling prohibited by the Endangered Species Act, 16 USC 1531 et. seq. The degree to which nuisance species, principal macrobenthic species and species of fish, shellfish and wildlife are to be listed should be determined by consultation between the applicant and the Regional Administrator (or Director).

Data should be provided for each of the following seasonal conditions: summer maximal temperature, fall transitional regime, winter minimal temperature, and spring transitional regime. The Regional Administrator (or Director) may request the applicant to conduct more thorough sampling where needed for his analysis of the particular case.

Information relating to the discharge zone should represent conditions throughout the zone (i.e., from the point of discharge to the 2°C. isotherm), unless the Regional Administrator (or Director) designates a particular portion of the discharge zone for study.

The estimation (iii) of the species which would be abundant under theoretical conditions should represent the applicant's best approximation based on historical data or the biota of appropriate (relatively unpolluted) nearby water bodies, *e.g.*, at upstream control stations. The basis and limits of comparability of such water bodies should be stated.

(B) Identification of the reproductive period (dates) and reproductive temperatures for each species of fish and shellfish listed.

(C) A map showing the location, within the discharge zone of reproductive and nursery areas, migratory routes, and principal macrobenthic forms.

(D) Where the Regional Administrator (or Director) has reason to believe there may be a specific disease or parasitism problem as a result of the thermal discharge, information on the incidence of disease and parasitism and on the condition of *fish* inhabiting the discharge zone and water body segment just outside the discharge zone. This information should include a comparison of affected *vs*. unaffected populations.

(E) The data called for in subparagraphs (A)-(C) above should be accompanied by a rationale stating why the information provided does not suggest prior appreciable harm to the balanced, indigenous community. This rationale should include a comparison of species and abundance lists and, where appropriate, estimates of areas impacted and levels of impact for locations of similar habitat within areas (i), (ii) and (iii), subparagraph (A) above, using a statistical method such as coefficient of similarity or analysis of variance. If such statistical methods are inappropriate, an appropriate method of comparison may be substituted and the rationale should include the reasons for the substitution.

(5) A description and discussion of the effect the heated effluent has had on economic and recreational uses of the balanced, indigenous community.

(6) All other known existing reports concerning the effects of the applicant's discharge on principal macrobenthic species; threatened or endangered species or species of shellfish, fish and wildlife. If any of these reports indicate effects harmful to any such species, the applicant should submit a rationale stating why these effects did not constitute appreciable harm to the balanced, indigenous community.

# V

# DEMONSTRATION TYPE 2: PROTECTION OF REPRESENTATIVE, IMPORTANT SPECIES

## (a) Introduction.

Any existing or new source may present information pursuant to this chapter to demonstrate that the thermal component of its discharge will assure the protection and propagation of representative, important species whose protection and propagation, if assured, will assure the protection and propagation of a balanced, indigenous community.

A Type 2 demonstration should include the information identified in this paragraph, unless the demonstration is changed following consultation with the Regional Administrator (or Director). The demonstration may also include such additional information as the applicant may wish to be considered, provided that the additional information is accompanied by a rationale stating why such information indicates assurance of the protection and propagation of the balanced, indigenous community. Information to be submitted includes the following:[1]

- Mixing zone information. (Paragraph (c)(1) or (d)(1); see also Chapter VIII and Appendix A.)
- Water quality standards information. (Paragraph (c)(2) or (d)(2).)
- Record of shutdowns. (Paragraph (c)(3) or (d)(3).)
- Biotic communities information. (Paragraph (c)(4) or (d)(4).)

---

[1] Where field studies are carried out, sample replication should be adequate to determine the precision of the data generated and to conduct appropriate statistical tests.

- Representative, important species information. (Paragraph (c)(5) or (d)(5); see also paragraph (b).)
- Discussion of economic and recreational effects. (Paragraph (c)(6) or (d)(6).)
- Other known reports on effects of the discharge. (Paragraph (c)(7) or (d)(7).)
- Engineering and hydrologic information. (Chapter VII.)
- Thermal load information, if needed. (Chapter IX.)

Information for a full Type 2 demonstration includes all of the above items. Wherever the applicant can show to the satisfaction of the Regional Administrator (or Director) that its discharge has or will have a low potential impact on the receiving water body segment, selection of representative, important species may be limited to fish and shellfish.

NOTE: The applicant should submit information on all modes of discharge under consideration. See Chapter I, paragraph (c).

(b) Selection of Representative, Important Species.

(1) General.

(A) The Regional Administrator (or Director) should select representative, important species pursuant to 40 CFR §122.9(b)(2) (or §122.15(b)(2)). Such species should consist of one or more species from each of the following biotic categories: macroinvertebrates, fish and economically important species; except that the Regional Administrator (or Director) may determine, based on the characteristics of the receiving water body segment, that species from one or more of these biotic categories need not be included. (See also paragraph (a), above.)

(B) In some cases those species most important in controlling community function are little understood and act in a subtle fashion, so that their role is only evident following environmental degradation. Until such species are identified, it remains prudent in selecting representative, important species in nondegraded environments to consider primarily community dominants. Dominant species include: (i) those with high biomass, and (ii) those of greatest numerical abundance, regardless of biomass. Included among these species would be many species important to energy and nutrient cycling, community structure, and habitat formation.

(C) Where species known to be temperature tolerant or capable of withstanding passage through the proposed discharge are selected as representative, important species (based on their community abundance, potential economic importance or other factors [*e.g.*, American oyster, blue crab, barnacle]), additional more thermally sensitive species in the same biotic category should generally be selected as well, in order better to reflect the thermal sensitivity of an entire biotic category.

(2) Species Selection Where Information is Adequate.

Where information pertinent to species selection is adequate, the Regional Administrator (or Director) should promptly select representative, important species. The applicant may suggest species for his consideration and may, as a part of its demonstration, challenge any selection. Species should be selected as follows:

(A) Applicable State water quality standards.

If the State's approved water quality standards designate particular species as requiring protection, these species should be designated, but alone may not be sufficient for purposes of a Type 2 demonstration.

(B) Consultation with Director and with Secretaries of Commerce and Interior.

In the case of species selection by the Regional Administrator, he must seek the advice and recommendation of the Director as to which species should be selected. The Regional Administrator must consider any timely advice and recommendations supplied by the Director and should include such recommendations unless he believes that substantial reasons exist for departure.

The Secretary of Commerce and the Secretary of the Interior, or their designees, and other appropriate persons (*e.g.*, university biologists with relevant expertise) should also be consulted and their timely recommendations should be considered. The Director should also consult with the agency exercising administration of the wildlife resources of the State.

(C) Threatened or endangered species.

Species selection should specifically consider any present threatened or endangered species, at whatever biotic category or trophic level, except that no information should be requested that would require field sampling prohibited by the Endangered Species Act, 16 USC 1531 *et*. *seq*.

(D) Thermally sensitive species.

The most thermally sensitive species (and species groups) in the local area should be identified and their importance should be given special consideration, since such species (or species groups) might be most readily eliminated from the community if effluent limitations allowed existing water temperatures to be altered. Consideration of the most sensitive species will best involve a total aquatic community viewpoint.

Thermal sensitivity data includes but is not limited to the data described in paragraph (c)(5)(A), below. Reduced tolerance to elevated temperature may also be predicted, for example, in species which experience natural population reduction during the summer. Species having the greatest northern range and least southward distribution may also possess reduced thermal tolerance.

(E) Economically important species.

Selection of economically important species should be based on a consideration of the benefits of assuring their protection.

(F) Far-field and indirect effects.

Consideration should include the entire water body segment. For example, an upstream cold water source should not be warmed to an extent that would adversely affect downstream biota. The impact of additive or synergistic effects of heat combined with other existing thermal or other pollutants in the receiving waters should also be considered.

(3) Species Selection Where Information is Inadequate.

Where the available information is not adequate to enable the Regional Administrator (or Director) to select appropriate representative, important species, he may request the applicant attempting to make a Type 2 demonstration to conduct such studies and furnish such evidence as may be necessary to enable such selection. Where species selection is based on information supplied by the applicant, the appropriateness of the species as representative and important is an aspect of the applicant's burden of proof.

The applicant's species selection studies or evidence should normally consist of:

(A) Early submittal of the species information described in paragraph (c)(4) or paragraph (d)(4), below, and the median tolerance limit information described in paragraph (c)(5) or (d)(5), below.

(B) Any available information regarding species identified by community studies, if (i) such community studies have been conducted at existing thermal discharge sites, (ii) the studied community included species also found at the applicant's proposed discharge site, and (iii) such studies have shown that any such species experienced appreciable harm as a result of the thermal component of the discharge. (See Chapter X.)

(C) Other information necessary or appropriate to enable the Regional Administrator (or Director) to address the considerations set forth in paragraph (b)(1), above.

(c) Applicant's Information--Existing Sources.

Information to be submitted by an existing source includes the following:

(1) Field data that the discharge conforms with an appropriate mixing zone and zone of passage. (See Chapter VIII.)

(2) Evidence of compliance with presently applicable water quality standards. The applicant should submit evidence sufficient to enable the Regional Administrator (or Director) to make a determination that water quality standards will be met. If any of the evidence reveals possible noncompliance with water quality standards, the applicant should submit a rationale stating why the expected deviations from water quality standards will not result in a failure to assure the protection and propagation of the selected species. (See Chapter VIII.)

(3) Records of shutdowns (resulting in complete stoppage of heated effluent flow) and their effects on the aquatic biota. All such shutdowns during the last five years should be documented and some assessment of the known effects of each such shutdown should be made by the applicant. If the applicant's records are incomplete or if he has no knowledge of harmful effects for a specific shutdown, he should so note and should describe his monitoring efforts in connection with such shutdown. If any effects harmful to aquatic biota have resulted from shutdowns, the applicant should submit a rationale stating why these effects did not interfere with the protection and propagation of the balanced, indigenous community. Projections of expected shutdowns and

their projected effects on the aquatic biota should also be made, and the applicant should also submit a rationale stating why the projected effects will not result in a failure to assure the protection and propagation of the balanced, indigenous community. For freshwater fish the nomograph in the Freshwater Thermal Criteria, Appendix B, should be consulted to determine the maximum allowable temperatures of plumes for various ambient temperatures. For non-fish and marine species appropriate information, as available, should be consulted.

(4)(A) A list and data documenting the abundance of each selected representative, important species; threatened or endangered species and nuisance species, at any trophic level; principal macrobenthic species; and other important species of fish, shellfish and wildlife, including all dominants (see paragraph (b)(1)(B), above) in:

(i) the discharge zone under existing conditions,

(ii) the water body segment just outside the discharge zone under existing conditions, and

(iii) the water body segment just outside the discharge zone under theoretical conditions which would exist when all point source dischargers of pollutants are in compliance with section 301(b) of the Act.

All representative, important species and threatened or endangered species should be listed, except that no information should be requested that would require field sampling prohibited by the Endangered Species Act, 16 USC 1531, *et. seq.* The degree to which nuisance species and other important species of shellfish, fish and wildlife are to be listed should be determined by consultation between the applicant and the Regional Administrator (or Director).

Data should be provided for each of the following seasonal conditions: summer maximal temperature, fall transitional regime, winter minimal temperature and spring transitional regime. The Regional Administrator (or Director) may request the applicant to conduct more thorough sampling where needed for his analysis of the particular case.

Information relating to the discharge zone should represent conditions throughout the zone (i.e., from the point of discharge to the 2°C. isotherm) unless the Regional Administrator (or Director) designates a particular portion of the discharge zone for study.

The estimation (iii) of the species which would be abundant under theoretical conditions should represent the applicant's best approximation based on historical data or on the biota of appropriate (relatively unpolluted) nearby water bodies (e.g., at upstream control stations). The basis and limits of comparability of such water bodies should be stated.

(B) A scale map showing the location within the proposed discharge zone of reproductive and nursery areas, migratory routes and principal macrobenthic species.

(C) The data called for in subparagraphs (A) and (B) above should be accompanied by a rationale stating why the information provided does not suggest a failure to assure the protection and propagation of a balanced, indigenous community. This rationale should include a comparison of species and abundance lists and, where appropriate, estimates of areas impacted and levels of impact for locations of similar habitat within areas (i), (ii) and (iii), subparagraph (A) above, using a statistical method such as coefficient of similarity or analysis of variance.

(5)(A) The 24-hour median tolerance limit of species of macroinvertebrates and fish which are dominant in the receiving water body segment. If such data are not available, the applicant should conduct adequately designed laboratory studies to determine such temperatures. Such studies should be conducted with summer populations or warm acclimated organisms and should employ accepted procedures for median tolerance tests for the particular species. Waters used for the tolerance tests should resemble actual receiving water quality anticipated during the period of the proposed discharge.

This information is for purposes of selecting and verifying the selection of representative, important species. It is useful primarily in predictive situations in the absence of reliable field data. The number of species which should be covered should be determined by consultation between the applicant and the Regional Administrator (or Director). Use of the 24-hour median tolerance limit is preferable for uniformity of comparisons; however, if median tolerance levels for some other time scale are the only data available, they may be used.

(B) The following life history thermal effects data for each representative, important species.

(i) Life History Thermal Effects Data.--For each species, the thermal criteria data identified in this subdivision should be provided,[1] except that:

- If such data are not available for selected representative, important species of macroinvertebrates, community studies of this group may be conducted at the request of the Regional Administrator (or Director) or at the applicant's option with the advice and consultation of the Regional Administrator (or Director). (See Chapter X.)
- An existing source sited on flowing waters may conduct *in situ* drift studies to demonstrate that plume temperatures will not be harmful to eggs, larvae and adults of representative, important macroinvertebrate species. These studies may substitute for appropriate components of life history thermal effects data.

Thermal effects data to be provided are the following:

- Short-term maximum temperature for survival (upper lethal temperature) of parent during reproduction. (Use acclimation temperature comparable to expected ambient temperature.)

---

[1] This list identifies general categories of data which relate to a wide range of species. In presenting thermal effects data, information categories should be tailored to the individual species being considered.

- Short-term maximum temperature for survival (upper lethal temperature) of appropriate life stage during the summer.
- Optimum temperature for growth of appropriate life stage (juveniles or adults).
- Minimum avoidance temperature (motile species).
- Maximum temperature at which normal incubation and larval development occurs.
- Normal reproductive dates (site specific) and temperatures (general) at which reproduction occurs.

The applicant's life history thermal effects data may be based on criteria and information published pursuant to section 304(a) of the Act; information set forth in Appendix A; adequately designed laboratory or field studies, or published studies on latitudinally comparable populations, as provided in subparagraph (E) below. Thermal effects data may be presented in tabular or narrative form, but in either case detailed explanations of assumptions made should accompany all data presented. All information should be footnoted as to source.

(ii) An evaluation of the effects of the proposed discharge on the representative, important species. The evaluation should be presented in tabular form as indicated on Sample Table A, below. One table should be submitted for each representative, important species. The evaluation should indicate the distribution and duration

## SAMPLE TABLE A

## EVALUATION OF THERMAL DATA

SPECIES: ______________________ (Common Name) ______________________ (Scientific Name)

| Biological Activity to be Protected[1] | Temperature | Data Source and Page | Area of Discharge Zone Exceeding Max. Temperature (Acres Covered and What Conditions, Including Time Period) | Activity Excluded From Discharge Zone by Heat | | Effects Outside Discharge Zone |
|---|---|---|---|---|---|---|
| | | | | % of Area Activity Excluded | % Time of Exclusion | |
| Max. for Survival of Parent[2] | | | | | | |
| Max. for Summer Survival | | | | | | |
| Optimum Growth | | | | | | |
| Minimum Avoidance | | | | | | |
| Max. for Development | | | | | | |
| Normal Reproduction Dates & Temperatures | | | | | | |

1. This table identifies activities which relate to a wide range of species. In presenting thermal evaluations, activity categories should be tailored to the individual species being considered. The table headings constitute summaries of the thermal effects data list set forth at subparagraph 5(b)(1), above.

2. Use acclimation temperature comparable to expected ambient temperature.

of potential exposure of the species (i) in the discharge zone and (ii) in the water body segment just outside the discharge zone during worst case and average conditions during each season.

(iii) A rationale stating why the information submitted pursuant to this subparagraph suggests that the heated discharge will not result in a failure to assure the protection and propagation of the selected species. Where data necessary to complete the life history thermal effects data are unavailable and community studies have not been substituted, the rationale should so note and indicate why obtaining the data is not feasible or not necessary to the analysis of the effects of the discharge or proposed discharge.

(C) When the Regional Administrator (or Director) believes it is appropriate, information on the chill requirements for gamete formation of selected species.

(D)(i) Except as provided in subparagraph (ii), below, the applicant's life history thermal effects data should consist of any applicable data contained in water quality criteria published by the Administrator pursuant to section 304(a) of the Act, when such data are published as final (rather than proposed) criteria. Life history thermal effects data compiled by EPA are provided in Appendix B and should be used where 304(a) criteria are not available or inapplicable.

(ii) Where 304(a) data or data provided by the Regional Administrator are not applicable or the applicant wishes to contest any of such data, the applicant may submit thermal tolerance data based on well-documented field deduction, adequately designed laboratory studies or published studies on latitudinally comparable populations. For information based on laboratory studies, a detailed description of methodology should be given or referenced. For information based on published studies, the complete bibliographic reference, including page number, should be given and the use of such other sources should be explained and justified. For information based on latitudinally comparable populations, the basis and limits of comparability should be stated.

(6) An assessment of the effect the heated effluent has had and an indication of the expected effects it will have on economic or recreational uses of the selected species.

(7) All other known existing reports concerning the effects of the proposed discharge on the aquatic biota. If any of these reports indicate a probability of effects harmful to aquatic biota, the applicant should submit a rationale stating why the proposed discharge will nonetheless assure the protection and propagation of the balanced, indigenous community.

(d) Applicant's Information--New Sources.

Information to be submitted by a new source includes the following:

(1) Data showing that the proposed discharge will conform with an appropriate mixing zone and zone of passage. (See Chapter VIII.)

(2) Evidence of compliance with presently applicable water quality standards. The applicant should submit evidence sufficient to enable the Regional Administrator (or Director) to make a determination that water quality standards will be met. If any of the evidence reveals possible noncompliance with water quality standards, the applicant should submit a rationale stating why the expected deviations from water quality standards would not result in a failure to assure the protection and propagation of the selected species. (See Chapter VIII.)

(3) Projections of expected shutdowns resulting in complete stoppage of heated effluent flow, and their projected effects on the aquatic biota. The applicant should submit a rationale stating why the projected effects will not result in a failure to assure the protection and propagation of a balanced, indigenous community. For freshwater fish the nomograph in the Freshwater Thermal Criteria, Appendix B, should be consulted to determine the maximum allowable temperatures of plumes for various ambient temperatures. For non-fish and marine species appropriate information, as available, should be consulted.

(4)(A) A list and an indication of the abundance of species as called for in subparagraph (c)(4)(A), above. These data should be supplied for:

(i) The proposed discharge zone under existing conditions

(ii) The water body segment just outside the proposed discharge zone under existing conditions.

(iii) The proposed discharge zone under projected conditions during discharge.

(iv) The water body segment just outside the proposed discharge zone under projected conditions during discharge.

(v) The water body segment just outside the proposed discharge zone under theoretical conditions which would exist when all point source discharges of pollutants are in compliance with section 301(b) of the Act.

(B) A map as called for in subparagraph (c)(4)(B), above.

(C) A rationale as called for in subparagraph (c)(4)(C), above. The rationale should state why the proposed discharge will assure the protection and propagation of a balanced, indigenous community. Where appropriate, the rationale should include estimates of areas which may be impacted and levels of impact which may be expected to occur.

(D) The information called for in subparagraph (c)(4)(D), above, except that such information may be limited to the area of the proposed discharge zone.

(5) Life history thermal effects data, evaluations and rationale as called for in subparagraphs (c)(5)(A) and (c)(5)(B) and, if appropriate, (c)(5)(C), above.

(6) An assessment of the effect the heated effluent is expected to have on economic or recreational uses of the selected species.

(7) All other known existing reports concerning possible effects of the proposed discharge on the aquatic biota. If any of these reports indicate a probability of effects harmful to aquatic biota, the applicant should submit a rationale stating why the proposed discharge will nonetheless assure the protection and propagation of the balanced, indigenous community.

# VI

# DEMONSTRATION TYPE 3: BIOLOGICAL, ENGINEERING AND OTHER DATA.

(a) Introduction.

Any existing or new source may present biological, engineering and other data to demonstrate that a proposed effluent limitation is more stringent than necessary to assure the protection and propagation of a balanced, indigenous community. The purpose of the Type 3 demonstration is to provide for the submittal of any information which the Regional Administrator (or Director) believes may be necessary or appropriate to facilitate evaluation of a particular discharge. It also provides for submittal of any additional information which the applicant may wish to be considered. Each Type 3 demonstration should consist of information and data appropriate to the case.

(b) Definition of Type 3 Demonstration; Written Concurrences.

Detailed definition of a generally applicable Type 3 demonstration is not possible, because of the range of potentially relevant information; the developing sophistication of information collection and evaluation techniques and knowledge, and the case-specific nature of the demonstration. Prior to undertaking any Type 3 demonstration, the applicant should consult with and obtain the advice of the Regional Administrator (or Director) regarding a proposed specific plan of study and demonstration. (See Chapter I, subparagraph (c).) Decision guidance may also be suggested. (See Chapter III, paragraph 3.)

In general, Types 1 and 2 represent baselines for the depth of analyses. While Type 3 information may be different in thrust and focus, proofs should be at least as comprehensive as in those types and should result in similar levels of assurance of biotic protection.

(c) Rationales.

Each item of information or data submitted as a part of a Type 3 demonstration should be accompanied by a rationale stating why it represents evidence that the proposed discharge will assure the protection and propagation of a balanced, indigenous community. The rationale should include an explanation as to why this demonstration approach was selected.

# VII

# ENGINEERING AND HYDROLOGIC DATA

## (a) Introduction.

This chapter describes the engineering and hydrologic information which should normally be included in any 316(a) demonstration. It also suggests formats for presentation of such information. The Regional Administrator (or Director) may request additional information or excuse the applicant from preparation of portions of this information as the situation warrants. The engineering and hydrologic information to be submitted should consist of all information reasonably necessary for the analysis. Where information listed in this chapter is not relevant to the particular case, it should be excused.

The engineering and hydrologic information and data supplied in support of a 316(a) demonstration should be accompanied by adequate descriptive material concerning its source. Data from scientific literature, field work, laboratory experiments, analytical modeling, infrared surveys and hydraulic modeling will all be acceptable, assuming adequate scientific justification for their use is presented.

## (b) Plant Operating Data.

(1) Cooling water flow. Complete Table B (indicate units).

(2) Submit a time-temperature profile graph indicating temperature on the ordinate and time on the abscissa. The graph should indicate status of water temperature from natural ambient through the

## TABLE B

## COOLING WATER CHARACTERISTICS[1/]

| % Unit Load | Unit Loading % Time | Intake Velocity* | Rate of Cooling Water Flow | Condenser $\Delta T$ | Discharge $\Delta T$** | Rate of Total Water Discharge |
|---|---|---|---|---|---|---|
| 40 | | | | | | |
| 50 | | | | | | |
| 60 | | | | | | |
| 70 | | | | | | |
| 80 | | | | | | |
| 90 | | | | | | |
| 100 | | | | | | |

---

1/ If seasonal variations occur, this should be so indicated.

*Intake velocity data should be provided at the point where the cooling water first enters the intake structure. Variations in intake velocity with changes in ambient conditions (*e.g.*, river flow, tidal height, water level) should be noted.

**Discharge $\Delta T$ = Discharge Temperature-Intake Temperature. (In many cases, condenser $\Delta T$ is equivalent to discharge $\Delta T$. However, for plants with supplemental cooling facilities, this is not the case.)

cooling system and discharge until its return to ambient. Worst case, anticipated average conditions, and ideal (e.g., minimum time/ temperature impact) conditions should be illustrated, preferably on the same graph.

(3) Submit a graph or table indicating the total heat rejected via the discharge as a function of time, including short-term (daily) and long-term (annual) fluctuations.

(4) For plants using fresh water, complete Table C, indicating units.

TABLE C

Water Use Table

| | Fresh Water Consumption | Receiving Water Evaporation* |
|---|---|---|
| Maximum Design | | |
| Monthly** | | |
| Average Annual | | |

*Increase in evaporation caused by the thermal discharge.
**If variable, please indicate degree of variations by percent or extremes. This may be illustrated graphically.

(c) Hydrologic Information.

(1) Flow: Provide the information called for in paragraph (i), (ii), (iii) or (iv), as applicable to the site:

(i) Rivers: flow -- monthly means and minima (7 day, 10 year low flows).

(ii) Estuaries: freshwater input, tidal flow volumes, net tidal flux -- monthly means and minima for each.

(iii) Reservoirs: flow through time, release schedules -- monthly means and minima.

(iv) Oceans: tidal heights and information on flushing characteristics.

(2) Currents: Provide the information called for in paragraph (i), (ii) or (iii), as applicable to the site:

(i) Rivers: maximum, minimum, and mean current speed, giving seasonal (or monthly) fluctuations.

(ii) Estuaries: tidal and seasonal changes in current speed and direction.

(iii) Large lakes and oceans: offshore prevailing currents; local tidal and seasonal changes in current speed and direction.

(3) Tabulate or illustrate monthly means and summer extremes in stratification characteristics and salinity variations in the vicinity of the intake and discharge. If intake and discharge conditions are identical, so state and provide only one tabulation or illustration.

(4) Tabulate or illustrate ambient temperature of the receiving waters, giving monthly means and extremes for the preceding 10 years as data availability permits. If comparable site waters are used, indicate the basis and limits of comparability.

(5) Indicate intake and receiving waters depth contours at 0.5 m. intervals. Provide other significant hydrological features (*e.g.*, thermal bar characteristics).

(d) Meteorological Data.

If energy-budget computations are included as part of the 316(a) demonstration, provide the following meteorological data for the plant site, giving both monthly means and seasonal extremes. Indicate units.

(1) Wet bulb air temperature.

(2) Dry bulb air temperature.

(3) Wind speed and direction.

(4) Long wave (atmospheric) radiation.

(5) Short wave (solar) radiation.

(6) Cloud cover.

(7) Evapotranspiration.

(e) Outfall Configuration and Operation.

Provide the following information on outfall configuration and operation, indicating units expressed.

(1) Length of discharge pipe or canal ____________________

(2) Area and dimensions of discharge port(s) ____________

(3) Number of discharge port(s) __________________________

(4) Spacing (on centers) of discharge ports _____________

(5) Depth (mean and extreme) _____________________________

(6) Angle of discharge as a function of:

A. horizontal axis ________________

B. vertical axis __________________

C. current direction(s) ___________

(7) Velocity of discharge:

A. maximum ____________________

B. most usual ____________________

(f) Thermal Plume Characteristics.

Provide the following information on thermal plume characteristics:

(1) Scale drawings accurately depicting the plume's configuration under various hydrological conditions. Drawings should provide isotherms in at least 2°C. increments and should indicate 3 spatial dimensions to the extent possible. Such drawings should be supplied for low and slack tides or low and average flows during each of the four seasons.

(2) Indicate by similar illustration the expected variation in plume isotherms under variable conditions of climate. A qualitative discussion of the effect of changes in relevant meteorological parameters may be provided if adequate information is available.

(3) Graph plume velocity vs. distance.

(i) along centerline

(ii) along bottom

(g) Chemical and Water Quality Data.

Section 316(a) specifies that the thermal component of the discharge must be evaluated ". . . taking into account the interaction of such thermal component with other pollutants. . . ." While data on such synergistic effects are limited, certain information will assist the Regional Administrator (or Director) in assessing potentially harmful interactions. The following information should be provided:

(1) The amount of chlorine used daily, monthly and annually, the frequency and duration of chlorination, and the maximum total chlorine residual at the point of discharge obtained during any chlorination cycle.

(2) A list of any other chemicals, additives, or other discharges which are contained in the cooling water discharge including the name, amount (including frequency and duration of application and the maximum concentration obtained prior to dilution), chemical composition and the reason for addition.

(3) The effect of the thermal discharge on the dissolved oxygen levels in the plume and in the receiving waters in increments of 0.5 mg/l.

# VIII

# MIXING ZONE GUIDELINES[1]

## (a) Introduction

### (1) General

The protection and propagation of a balanced, indigenous community in the receiving water body segment must be assured. Consistent with achieving this assurance, in many cases one or more areas of a segment may be designated as mixing zones. Within such zones, reduced water quality may be allowed, provided that the zones, individually and in combination with other point and nonpoint source influences on the segment, are so limited as not to preclude the statutory protection and propagation requirement.

The mixing zone to be employed should be the zone set forth in applicable water quality standards. Where the language of the standards is not sufficiently precise to identify the mixing zone with certainty, the Regional Administrator (or Director) should promptly identify the mixing zone called for by the standards. In the case of any new source, the Regional Administrator (or Director) should specifically identify an appropriate zone of passage at the outset of the demonstration.

If the applicant is seeking alternative effluent limitations which would be based on a mixing zone other than the mixing zone provided by the applicable water quality standards, the submittal should describe

---

1. See also Appendix A.

the location, size and shape of the desired zone and the water quality within the zone. This information should be accompanied by a rationale stating why the existence of such a zone will be consistent with the assurance of the protection and propagation of the balanced, indigenous community. The rationale should consider the mixing zone materials accompanying this guidance and should include an evaluation of the relationship of the recommended mixing zone with other discharges (present and potential, thermal and non-thermal) to the receiving water body segment. The rationale may also include such other information as the applicant may wish to present.

Any mixing zone must be limited to a temporal and spatial (area, volume, configuration and location) distribution which will assure the protection and propagation of a balanced, indigenous community of shellfish, fish and wildlife in and on the receiving water body. If the applicant's submittal involves review of the mixing zone, the Regional Administrator (or Director) should:

- Consider the principles set forth in this chapter and Appendix A, as appropriate.[1]
- Consider applicable water quality standards.[2]

---

[1] Guidelines for mixing zones in fresh water are set forth in paragraph (b) of this chapter; guidelines for marine mixing zones are included at paragraph (c). Appendix A contains additional materials which may be considered in connection with fresh water mixing zones. The guidelines may be supplemented with information on mixing zones contained in the report of the National Academy of Sciences, "Water Quality Criteria" (1973).

[2] The statutory rule of section 316(a) that effluent limitations should "assure the protection and propagation of a balanced, indigenous population" requires maintenance of receiving water body characteristics which will assure that protection and propagation, notwithstanding any possible departure from otherwise applicable water quality standards, including their mixing zone provisions.

- In the case of a determination by the Regional Administrator, consult with the Director.
- In the case of interstate or international waters, consult with the responsible water quality management agencies of such other jurisdictions.
- Consider of any pertinent information submitted by the applicant or however obtained.

(2) Definition.

A mixing zone is an area contiguous to a discharge where receiving water quality does not meet the requirements otherwise applicable to the receiving water. Description and delineation of mixing zones pose difficult regulatory problems. It is obvious that any time an effluent is added having lesser quality than the receiving water, there will be a zone of mixing. The definition as used here is that receiving water area where exceptions to otherwise applicable water quality standards are granted. It is important to recognize that by this definition the effluent or plume may be identifiable at distances or in places outside the defined mixing zone. This definition should not be confused with engineering usages, often employed in designing outfalls, and that refer to the area before complete mixing occurs. The mixing zone is a place to mix and not a place to treat effluents.

### (3) General Principles.

There are several principles that are applicable to most mixing zones and provide the basis upon which to establish conditions for them. A most important principle is that since by their definition mixing zones provide for exceptions to otherwise applicable water quality standards and damage may occur, the permissible size of the mixing zone is dependent on the acceptable amount of damage. For obvious regulatory reasons, as well as biological ones, the size and shape of the mixing zone should be specified so that both the discharger and the regulatory agency know its bounds. A mixing zone should be determined taking into consideration unique physical and biological features of the receiving water, but there are principles about the size and shape that can aid in decision making.

### (4) Physical Size.

For physical reasons, the size of the mixing zone may need to be larger for very large discharges than for very small ones. The permissible size depends in part on the size of the receiving water; the larger the body of water, the larger the mixing zone may be without exceeding a given portion of the total receiving water. The acceptable size for a mixing zone depends also on the number of mixing zones on a body of water. The greater the number, the smaller each must be in order to keep the area devoted to mixing zones sufficiently small. In this connection, future growth of industry and population must be considered

(5) Quality Within Zones.

There are upper limits to the permissible degree of degradation within mixing zones. All mixing zones should be free of:

(i) Materials that will settle to form objectionable deposits.

(ii) Floating debris, oil, scum, and other matter.

(iii) Substances producing objectionable color, odor, taste, or turbidity.

(iv) Substances and conditions or combinations thereof in concentrations which produce nuisance aquatic life.

The conditions that may exist in the mixing zone should be determined for each site but general principles can guide. There should be no conditions permitted that are rapidly lethal to locally important and desirable aquatic life. Therefore, rapid mixing is desirable. Many planktonic organisms are such weak swimmers that they must drift through the mixing zone and and will be exposed to its conditions for the period of time required to drift through and in lakes or reservoirs this may be an extended period. Therefore, toxicity or adverse conditions should be such that these organisms can survive without undue damage or stress while they are passing through. There are concentrations of some pollutants that attract animals but are also lethal or clearly adverse. Such pollutants that attract aquatic life are more troublesome than those pollutants that are avoided. For example, crowding together in a heated plume enhances disease susceptibility and transmission. Concentrations exceeding the 96-hour $LC_{50}$ should not be permitted.

### (6) Fresh Water/Marine Water Distinction.

For purposes of this chapter, water may be delineated as fresh water or marine water on the basis of salinity or tide. Marine waters include all oceanic waters and those under the influence of the ocean. Specifically, they include waters of the coastal region and those extending into bays, estuaries, river mouths, and other lowlands to that point at which either (a) the salinity falls below 0.5 parts per thousand, or (b) a predictable tide no longer persists. All waters above this point should be considered fresh water. At boundary locations, the Regional Administrator (or Director) may indicate, based on the hydrological and biological features of the site, whether the mixing zone, if any, should be evaluated on the basis of fresh water or marine water principles.

## (b) Fresh Water Mixing Zones.

### (1) Summary.

The following discussion is a tool to aid decision-making when mixing zones are established. It cannot replace knowledge of local areas or common sense, but it can assist in identifying key elements upon which to base decisions.

The basic components are:

(i) Delineation of the most valuable areas and consideration of biological values.

(ii) Selection of a level of protection for each area and determination of the portion of the area to be allocated to all mixing zones.

(iii) Limitation of the permissible conditions of quality in the mixing zones.

(iv) Allocation to present and future dischargers.

NOTE: This paragraph discusses general principles regarding fresh water mixing zones. A proposed optional system for establishing fresh water mixing zones based on receiving waters' biological value is set forth at Appendix A.

(2) Biological Considerations.

From a biological standpoint, the location of the mixing zone is important. It is generally true that an offshore discharge has a lesser potential for adverse effect than a comparable onshore discharge into shallow water. Shallow water in lakes, reservoirs, and rivers is generally more biologically valuable and productive. There are several reasons and some of them are critical during site selection.

Food production is greater in the shallow water zone because light penetration is sufficiently deep to support growth of periphyton, attached algae, and rooted vegetation; nutrients from runoff are commonly more plentiful; terrestrial food organisms are more plentiful; there is a greater variety of substrates (sand, sediment, and rubble as contrasted to mostly fine sediment in deeper water) that provide habitat for many kinds of food organisms; and oxygen concentrations are more favorable because wave action and diffusion processes transport oxygen to the bottom.

The density and variety of fish are greater in shallow water because most fish spawn in shallow areas and their progeny utilize these areas as nursery grounds; prior to spawning migrations into tributary streams, numerous fish species concentrate in shallow waters until conditions are optimal for spawning runs; cover provides more protection from larger predators; the more diverse substrates support a greater variety of species in larger numbers than in the more uniform habitat of deep waters; and, in rivers and streams, many fish species migrate through the shallow shore zones. Shallow, protected bays and coves on large lakes and reservoirs are often the most biologically important, probably for the above reasons, but also because wind and wave action are reduced and the bottom is more stable.

Mixing zones in shallow water affect a greater benthic area as the result of limited dilution volume and natural turbulence resulting in top to bottom mixing. In some instances, however, the very shallow water (less than a few meters) can be less productive due to an unstable substrate of shifting sand and sediment caused by wave action by wind or shipping activities.

The location of mixing zones should consider migratory routes of important species, and they should not be positioned so as to form a block to such movements. If less than one-half the width of a stream or river is used, then discharges on opposite sides will not constitute a block. In this connection, future dischargers must also be considered. Thus it is good practice to limit single mixing zones to one-third or one-quarter of the width of a stream or river.

Recreational uses, such as water contact sports and sport fishing, are concentrated in the shore zone also. This zone is important to the aesthetic appeal of water bodies, as well.

(3) Positioning.

The positioning of mixing zones relative to each other is important. Special concern is needed where mixing zones contain different components (such as heat and copper) and may be adjacent or overlap. Overlapping or superimposed mixing zones are acceptable if there is not an additive effect and the toxicity limits given below are met. In this way, less area is used for a given number of dischargers but regulatory problems may be made more difficult.

(4) Shape.

The shape of mixing zones is important because the boundaries must be easily located for compliance purposes. Actual plumes are not fixed in either size or shape and therefore cannot be used as boundaries. The prudent approach is to adopt a simple configuration that is easy to locate in the body of water and yet avoids excessive impingement on important areas. A circle with a specified radius is preferable. Other shapes could be used, depending upon unusual site requirements. "Shore-hugging" plumes should be avoided.

An accepted fact is that the plume will not conform exactly to arbitrary configurations but within some portion of that configuration mixing to quality as good as receiving water standards must occur. It is true that water currents may cause the plume to bend different directions on different days, but the intent is to require that the plume quality be as good as receiving water standards by the time the boundary is reached. It is obvious then that the practice of calling the plume a mixing zone is prohibited. Indeed, some sites may require diffusers or other devices to meet the requirements. For future discharges, these limitations may force site selection considerations and if so--everyone will gain.

### (c) Marine Water Mixing Zones.

### (1) Introduction.

General recommendations are presented to aid in defining mixing zones for heated water discharge into estuarine and coastal waters. New sites should be selected to permit effective employment of a near bottom diffuser discharge. This is recommended to optimize the dissipation of heat by vertical diffusion through the water column and minimize the surface area impacted by excessive temperature. Considerations of location, configuration and maximum size are outlined for single mixing zones. In summary, specific recommendations for marine mixing zones include:

(A) Location at sites with good flushing characteristics and a bottom community of minimal ecological importance.

(B) Siting which will not result in thermal addition to the intertidal zone.

(C) Discharge at depth sufficient to permit good subsurface dilution of the heated effluent without excessive impact to the bottom nor excessive loss of cross-sectional water column area for pelagic and planktonic life.

(D) Maximum width of the mixing zone at slack water not exceeding ten percent of the shore-to-shore distance of a waterway nor of the cross-sectional area of a waterway.

Final delineation of a mixing zone must take into consideration other mixing zones as well as pertinent socio-economic factors, which are highly site specific. These guidelines must be supplemented by careful consideration of such factors. Two cases in point are (a) local water quality conditions and (b) mixing zones, thermal or non-thermal and existing or potential. Factors such as these can greatly influence permissible size and location of a new thermal mixing zone. However, guidelines to weight these factors have not yet been developed for the marine environment.

(2) Location Guidelines.

(A) Mixing zones should not impinge over five percent of the time on shallow shoreline waters subject to appreciable natural summer atmospheric heating which normally experience wide tidal or diurnal fluctuations in temperature. Maintenance of normal temperature fluctuations, both in amplitude and frequency, is imperative for protection of the indigenous shallow water and intertidal community. Shallow water is defined for this purpose as the extreme low water line minus three feet for sites having a maximum shoreline current in excess of 0.5 knots; or as extreme low water minus six feet at sites having less shoreline current.

(B) Sites having good flushing characteristics are preferable.

(C) Sites having a dense, well-developed bottom community are not desirable.

(D) Open coastal waters are more preferable for mixing zones than the estuary due to the latter's dominant role as a plankton dependent nursery ground.

(E) Sites bordered by a narrow intertidal zone are preferable; sites bordered by wide intertidal flats or marshes are undesirable due to the potential adverse influence of a heated discharge on these shallow, highly productive habitats.

(3) Size and Configuration Guidelines.

(A) The slack water maximum dimension of any mixing zone should not exceed ten percent of the respective shore-to-shore dimension of a waterway, nor occupy over ten percent of its cross-sectional area. A 90 percent zone of passage should be maintained for the passive flow of planktonic algae, zooplankton and developmental stages of invertebrates and fishes and for the active passage of highly motile forms such as fishes and crustacea.

(B) The cross-sectional area devoted to a mixing zone should be minimized. Biologically, loss of surface area can be as important as volume consideration in the marine environment. At well-selected new sites, near-bottom diffuser discharge should be at a depth which would not only meet receiving water criteria at the surface but which also results in a mixing zone without excessive horizontal dimensions.

(4) Multiple Mixing Zone Considerations.

The maximum number of mixing zones that are ecologically permissible, existing or potential, in a single estuary or adjacent open coastal strand is dependent on variations in hydrography, geography and local thermal and biotic characteristics. Thus, the question can only be resolved on a case-by-case basis, and analysis of the total thermal load on the segment may be appropriate. (See Chapter IX.) The characteristics enumerated in paragraph (2) regarding preferable mixing zone location also pertain to the question of multiple mixing zones. Where site conditions are highly favorable, multiple mixing zones may be considered. A potentially preferable site could be a coastal strand which does not receive estuarine waters. Long-shore migration of fishes, the nature of the bottom community and other factors would have to be taken into consideration as well. In contrast, within small estuaries, multiple power plant siting may be precluded entirely by the increased adverse impact on planktonic life caused by cooling water pumping of an additional plant or by other thermal or non-thermal mixing zones, existing or proposed.

# IX

# THERMAL LOAD ANALYSES

## Introduction

For 316(a) evaluations, the major emphasis is on developing information to support a determination as to the assurance of the protection and propagation of the balanced indigenous community (Chapters IV-VII) and the determination of an allowable mixing zone based on biological considerations (Chapter VIII). While the "mixing zone" approach may constitute the primary means of evaluating thermal discharges in specific cases, at times an additional calculation of the total thermal load on the receiving water body segment is needed. Such a calculation should be made whenever there is indication that the effect of one or more thermal discharges discharging during critical hydrological (low flow), meteorological or biological conditions may cause critical temperature conditions in the segment.

Basically the approach in thermal load analyses is to measure total heat contribution from all discharges entering a water body, determining the volume and/or surface area of the receiving water under consideration, and compare the possible physical changes in the receiving water with pertinent water quality standards and criteria (temperature, temperature change, BTU's, etc.) or other temperature requirements determined as a part of the 316(a) process. The need for total thermal load calculation should be especially considered in the case of new sources to be located near existing facilities or the reservation of thermal load allocations to future discharges to certain receiving waters.

The following outline addresses several points to consider:

I. When is the load analysis required?

A. When there are occurring or suspected violations to water quality standards and/or criteria relating to temperature (including standards which are in existence and any changes to them which have been proposed by the State or which the Regional Administrator has requested the State to adopt) during critical conditions (low flow, adverse meteorology, intense local biological activity [*e.g.*, spawning season], peak output of plant, etc.); or

B. When there are several thermal discharges in close proximity or where future growth plans indicate the installation of several new facilities (power plants, steel mills, etc.); or

C. Where thermally loaded waters are specifically identified under Section 303(d)(l)(B) and (D) of P.L. 92-500.

II. When is the load analysis sufficient?

A. When the analysis has identified the probable compliance with or violations of water quality standards and criteria relating to temperature (whether such standards are in existence, proposed by the State or requested of the State by the Regional Administrator) for daily variations of plant operation or receiving water conditions, various seasons, extremes of low flow and weather, etc.; and

B. When the analysis provides sufficient detail regarding the control strategy(ies) which are needed (i.e., the rate of heat rejection limits [*e.g.*, in BTU/hr.] allocated to each discharger under consideration); and

C. If models are used for the analysis, when the accuracy of these models is firmly established. Therefore, specific accuracy levels for the model being used in a particular case should be reported by the applicant (temperature, heat load, etc.).

III. Information to be obtained by the applicant.

A. See Chapter VII "Engineering & Hydrologic Information."

B. If the applicant is the only significant thermal discharger on the receiving stream where violations are suspected, he will bear the burden of supplying data for the entire study (both near and far field).

C. If there are several dischargers within the study area, each discharger is responsible for data collection in his immediate area.

1. All dischargers in the study area should collect data useful for the specific model being used.

2. The Regional Administrator or State Director may be responsible for requesting data collection by dischargers other than the applicant, for organizing all data and for conducting the overall load allocation study. Exceptions include:

a. If one facility is discharging nearly all the heat, it should carry the burden of the study.

b. Joint studies by major heat dischargers should be conducted.

IV. Information to be supplied by the Regional Administrator or State Permit Program Director.

A. Applicable water quality standards and/or criteria relating to temperature, including standards which are in existence and any changes to them which have been proposed by the State or which the Regional Administrator has requested the State to adopt.

B. Where there are multiple dischargers, it may be necessary for the Regional Administrator (or Director) to conduct the overall load analysis (far field).

V. Procedures.

Thermal load analyses require the use of acceptable analytical methods and techniques. Several methods are illustrated in the technical literature and range from those using very simplified techniques of low level accuracy to others which incorporate complex computer programs. Therefore, prior to commencing its analysis the applicant should submit information on the methodology to be employed; provide justification for its selection and use, and obtain the written concurrence of the Regional Administrator (or Director) in the proposed methodology.

# X

## Community Studies

### (a) Introduction

This chapter identifies community studies which may be appropriate in any 316(a) demonstration. In particular, the applicant may submit results of such studies as a substitute for certain information items of a Type 2 demonstration (see Chapter IV, paragraphs (c)(5)(B) and (d)(5), above) or as a supplement to any demonstration; or the Regional Administrator (or Director) may request such studies as a supplemental information item.

For purposes of Section 316(a), community studies for the groups, primary producers, zooplankton, and macroinvertebrates, are appropriate. These studies focus on parameters which are indicative of an array of species within a biotic category. They seek, therefore to relate the effects of a discharge or proposed discharge to the community of organisms of a given biotic category, rather than to individual species in that category.

Studies described herein are neither exhaustive nor all-inclusive. The Regional Administrator (or Director) may expand or delete listed informational items as site-specific conditions may warrant. For greater detail the following references may be consulted:

(1) Biological field and laboratory methods for measuring the quality of surface waters and effluents, C. I. Weber (ed.). National Environmental Research Center, Office of Research and Development, U. S. EPA, Cincinnati, Ohio (1973).

(2) American Nuclear Society Standards 18.4: Guidelines for aquatic ecological surveys for nuclear power plants (near completion).

(b) Data Collection

(1) General. The informational items described below are some of the possible community studies which can be undertaken. Collection of data during all four seasons is preferable; however, the Regional Administrator (or Director) may determine that less information is adequate for a particular study. The taxonomic level to which organisms are identified depends on needs, experience, and available resources. This level should be determined and kept constant in each major group for the whole study. For existing plants samples should be collected within the discharge zone, just outside the discharge zone, and at a comparison site upstream of the plant, if appropriate, or in a nearby similar waterway unaffected by thermal discharge. Where baseline data exist, comparison may instead be based on conditions at the discharge site (within and just outside the discharge zone) before and after the beginning of plant operation. Comparisions should be based on samples taken from similar habitats and bases and limits of comparability should be stated. For new plants samples should be collected from the proposed discharge zone. Comparisions will necessarily be predictive in nature. These will be discussed in greater detail below (see paragraph (c)(2)). Where field studies are carried out, sample replication should be adequate to

determine the precision of the data generated and to conduct appropriate statistical tests.

For some of the parameters enumerated below, when taken alone, it is difficult to interpret whether a community is imbalanced and under stress, or not. Yet, when taken as an aggregate, they may prove useful in evaluating the degree of similarity between a community receiving a thermal discharge and the community at a comparable site which is not receiving heat.

(2) Primary producers

- (A) Phytoplankton
  - (i) quantitative measure of taxonomic composition
  - (ii) species diversity (including equitability)
  - (iii) total cell counts
  - (iv) standing crop biomass (mg/l)
  - (v) chlorophyll content
  - (vi) productivity
- (B) Periphyton
  - (i) quantitative measure of taxonomic composition
  - (ii) standing crop biomass
  - (iii) chlorophyll content
  - (iv) productivity

(C) Macrophyton and macroalgae

(i) quantitative measure of taxonomic composition

(ii) standing crop biomass

(iii) chlorophyll content

(iv) productivity

(3) Zooplankton

(A) quantitative measure of taxonomic composition

(B) species diversity (including equitability)

(C) standing crop biomass

(4) Macroinvertebrates

(A) quantitative measure of taxonomic composition

(B) species diversity (including equitability)

(C) standing crop biomass

(D) benthic community respiration

(5) Fouling or boring communities. For marine waters studies of fouling or boring communities may be conducted by maintaining panels at several stations distributed throughout the discharge zone, just outside the discharge zone and at a comparison site or through before and after comparisons at the discharge site (see paragraph (b)(1), above). Sets of panels should be suspended horizontally to collect benthic components as well as being placed vertically. The resulting fouling or boring communities may indicate consequences of thermal addition for the indigenous community. Such consequences may include

competitive exclusion due to the flourishing of heat-tolerant and nuisance species, failure of larval settlement of certain species, and economic loss due to fouling or boring.

(c) Data Evaluation.

The data called for in paragraph (b) above, should in each case, be accompanied by a rationale stating how the information presented suggests the assurance of the protection and propagation of a balanced indigenous community.

(1) For existing sources the rationale should include a comparison of affected vs. unaffected communities using standard statistical analysis. It should be noted that a statistically significant difference in any community parameter does not necessarily indicate detriment and also that lack of such a difference does not insure protection; scientific judgment should prevail since no hard and fast decision rule is available given the present state of the art. Where a potentially adverse statistically significant difference between an affected and unaffected area is found (e.g., a large decrease in either the total number of species present or the diversity index, the applicant should present an estimation of the physical area covered by this difference and an explanation why this difference does not suggest a failure to assure the protection and propagation of a balanced, indigenous community.

(2) For new sources, comparisons will necessarily be predictive. In such cases the data called for in paragraph (b) should serve as a baseline to the predictive comparisons described below. Because these methods are predictive and therefore less precise analytical tools, any assumptions which are made should be clearly defined. Predictive comparisons include:

(A) Predictive modeling of biological response to a thermal discharge, using a specific ecological model developed for that purpose. Verification should be carried out using data from a comparable existing source, making the assumptions necessary to do so. Bases and limits of comparability and their effects upon modeling results should be explained.

(B) Extrapolation of future community effects using community data from a well studied existing thermal discharge which is comparable to the proposed discharge. Features of comparability include similar geomorphology, substrate type, environmental regime, hydrography, water quality, latitude and discharge size and design, or existence of a highly similar biological community. It is recognized that a comparable site may not exist in a majority of cases.

For predictive modeling, the rationale should include a discussion of the validity of the model, including the verification procedure, and a showing of long-term (*e.g.*, one or more years) system stability. For extrapolation from other communities, the rationale should include a discussion of the comparability of the studied site and the proposed discharge site, and should also include an explanation why the existing discharge is consistent with the protection and propagation of a balanced, indigenous community.

For predictive modeling, the rationale should include a discussion of the validity of the model, including the verification procedure, and a showing of long-term (*e.g.*, one or more years) system stability. For extrapolation from the comparability of the studied site and the proposed discharge site, and should also include an explanation why the existing discharge is consistent with the protection and propagation of a balanced, indigenous community.

# APPENDIX A

## Biological Value System for Establishing Mixing Zones

This appendix sets forth a proposed system for establishing fresh water mixing zones based on allocation of the biological value of the receiving waters. Use of the system is optimal

### (a) Delineation of Biotic Zones.

The total area allocated to mixing zones can be more easily and accurately allocated than can areas for individual ones. This is so because the error, if any, is distributed proportionately to each mixing zone and the decision considers the potential combined effects of all discharges. This must be done by competent staff but only needs to be decided once.

The mixing zone discussion in Chapter VIII identifies certain biotic zones (*e.g.*, shore zone) that are more important than others and are related to water depth. Depth than can be used as a convenient tool to delineate the various zones.

The light intensity at which oxygen production in photosynthesis and oxygen consumption by respiration of the plants concerned are equal, is known as the compensation point, and the depth at which the compensation point occurs is called the compensation depth. This depth will vary, of course, in any segment and is dependent upon season, time of day, cloudiness of the sky, condition of the water (turbidity), and other factors. An approximate determination of the compensation depth as the means of differentiating the shallow and deep water zones is simpler than conducting a thorough biological characterization.. If such a characterization, based on the various biological populations, is available in adequate detail, it should be used but if not, the following can be substituted.

In general, the compensation depth is that depth at which light intensity is about 1 per cent of full sunlight intensity. This depth should be determined using photometric techniques and measurements should be obtained with a frequency capable of establishing the average condition. As an alternative, Secchi disk readings represent the zone of light penetration down to about 5 per cent of the solar radiation reaching the surface and a depth 3 - 4 times the Secchi disk depth is a good approximation of the compensation depth. Either technique should suffice and there are usually more data available on Secchi disk readings than photometric measurements.

The use of light penetration to distinguish the shallow and deep water zones should be an acceptable means of delineating the more productive and biologically shallow water zone and the deeper, less critical (and, therefore, less sensitive) zones. Stratified water in which, during summer months, trout and salmon are restricted, by natural temperature, to the deeper, hypolimnetic waters, cannot be differentiated as readily since the deeper, cooler water is critical to the continued presence of these valued species. Once the compensation depth has been determined, a depth contour is used to calculate the surface area of each zone.

(b) Biological Value.

Since some biotic zones are more important than others, mixing zones should be located in the less important ones or in those that are larger in area. A relative biological value for the various zones is needed in order to allocate portions of each zone for mixing.

To be sure, this biological valuation cannot be strictly objective but must utilize professional, expert opinion of biologists familiar with the local situation. Highly valued trout waters in two-story lakes or areas inhabited by endangered species can be given an infinite value and no mixing zones allowed in those areas. Biological value can be based on the species diversity of the zones and the value made proportional to the ratio of species diversity in various zones. Current-swept mid-channels of large rivers or deep waters, devoid of D.O. in large lakes, both can be given low value. Where data are inadequate, it may be possible to use only two values--a value of two for one zone known to be more important than the second zone. A value of ten for a "highly" important zone could be given instead of a value of two as in the preceeding situation.

Occasions will arise when there is not a competent data base upon which to establish biological value. In such cases, one may assume the biological value to be the same for both areas. (i.e., the value of a unit area is inversely proportional to the total area in each zone).

Assignment of total biological value is important because it defines upper limits on the amount of each biotic zone that may be used for mixing. This assignment offers dischargers a chance to select better sites for installation and allows the Regional Administrator (or Director) to encourage dischargers to locate in the areas least likely to be damaged.

The biological value "weighs" the various zones, thus allowing the same percent of the value of each (but not area) to be used for mixing. without stressing one zone more than another.

(c) Level of Protection (Degree of Risk).

What percent of total biological value, then, should be used? Conditions necessary for all life history processes may not be provided in mixing zones. When an excessively large percent of a segment is made up of mixing zones, the population of some species will decline and an unpredictable chain of events may ensue. Furthermore, estimates of an acceptable percent of an aquatic environment that can be allocated to mixing zones must be conservative, since predictive capabilities are uncertain.

Determination of the amount of a segment's biological value to be allocated to mixing zones is based on a variety of criteria, including type of water body, water velocity, depth, the number and type of habitats, migration patterns, and the nature of the local food chain. Level of productivity, water temperature, ability of tributary waters to provide recruitment, human value (aesthetic, commercial and sport fishing, recreational), endangered species, and other criteria must all be considered.

It is acknowledged that any estimate of the amount of area assigned to mixing zones, that will not have an unacceptable effect on a water segment, must be based on expert opinion. However, it is apparent that there are varying degrees of protection desired or required for different water bodies or in different words, the acceptable risk differs with location. Consequently, degrees of protection are recommended: Maximum level of protection for unique or fragile environments; low level of protection for the less valuable environment or an environment most capable of withstanding insults; and a moderate level of protection intermediate between the two. The per cent of biological value to be consigned to mixing zones could be one per cent for maximum protection and ten percent for a low level of protection with specific values from one to ten being selected for intermediate protection.

### (d) Allocation Alternatives.

(1) The final step is not a biological one, but an administrative process of allocation to present and to future dischargers. This decision cannot be universal. However, there are several considerations that should be given attention when making this decision. Available projections on future municipal-industrial growth can be evaluated to estimate the potential future need for mixing zones. The planned plant closures due to obsolescence, etc. should be known. Also, some classes of industry are utilizing production or waste treatment technology based on more efficient use of surface waters (e.g., closed-cycle cooling, water reclamation and re-use).

Basically, the determination of specific mixing zone sizes is a process of allocation of which there are several options:

(A) All mixing zones the same size.

Advantages--simple, direct and easy to calculate.

Disadvantages--large volume discharges would require a much greater level of treatment than would small volume discharges. Allows small volume dischargers to discharge relatively large quantities of persistent pollutants.

(B) Each discharger in a general class of discharges (paper mills, metal finishing, municipal waste, power plant) is given the same size mixing zone, but different classes are given different sizes.

Advantages--simple and direct, could better allow for general differences in volume of discharge, could take into account general persistence or toxicity of different classes of discharges.

Disadvantages--there is a rather large variation in discharge volumes in any given class. Penalizes large plants and favors small ones.

(C) Mixing zone directly proportional to the volume of the the discharge (e.g., for each unit volume the mixing zone would be a unit area).

Advantages--calculation simplified, superficially fair to all dischargers.

Disadvantages--encourages dilution pumping to obtain a larger zone.

(D) Mixing zone proportional to some monotonic increasing function of the discharge volume, that has a finite upper bound.

Advantages--in contrast to "(C)" would discourage dilution pumping and would not unduly favor large volume discharges.

(E) Mixing zone apportionment based on toxic units that consider toxicity and volume of waste.

This approach has as a basis the actual cause for concern--hazard to aquatic life. Its chief disadvantage lies in the probable frequent need for toxicity tests before decisions can be made.

(2) Example.

To illustrate how these suggestions might be employed to establish mixing zone sizes and placement, consider the following general example.

Assume that on the basis of the foregoing considerations a water segment has been divided into m zone types, with known areas ($A_1$, $A_2$, ··· $Am$) and correspondingly assigned relative biological values ($BV_1$, $BV_2$, ··· $BVm$). Also, assume that there are presently n dischargers on the segment with relative flow rates of ($Q_1$, $Q_2$, ···, $Qn$). From this information, we must establish a policy for mixing zones for the present and any future dischargers on this segment.

Several decisions of critical importance must be made before we may proceed. The level of protection $1\% \leq p \leq 10\%$ and the fraction of biological value $0 < \theta \leq 1$ alloted to present dischargers must be chosen. Also, an allocation scheme to divide the deemed expendable biological value among dischargers must be decided.

Given these factors, we proceed as follows:

(A) The total biological value of the segment is calculated by taking the sum of the biological value for each zone so that

$$BV = BV_1 + BV_2 + \cdots + BVm$$

(B) The total amount of biological value deemed expendable for present and future mixing zones is calculated to be

$$pBV$$

(C) The amount of biological value allocated to present dischargers is thus

$$\theta pBV$$

(D) The fraction of this to be allocated to an individual discharger is to be made proportional to some as yet unspecified function $f(Q)$ of a discharger's flow rate. Thus, if we define

$$Sn = f(Q_1) + f(Q_2) + \cdots + f(Qn)$$

the amount of biological value to be given to a discharger with flow rate $Qk$ is

$$U_k = \frac{\theta pBV}{Sn} f(Qk)$$

(E) The only task remaining in order to explicitly define $U_k$ is to give $f(Q)$ a specific form.

The choice of $f(Q)$ is dependent upon the goals desired in a segment and thus is not unique, but should as a minimum be monotonically increasing and have a finite upper bound. One such function that meets these criteria is

$$f(Qk) = \frac{Qk}{Qk + \overline{Q}\,(W-1)}$$

where $\overline{Q} = (Q_1 + Q_2 + \cdots + Qn)/n$ is the average flow rate and $1 \leq W \leq \infty$ is the ratio of the biological value that would be allocated to a theoretical discharger with an infinite flow rate to that allocated to a discharger with flow rate $\overline{Q}$. The larger W is, the more biological value is alloted to large dischargers. If $W=1$, then all dischargers would receive the same number of biological units independent of their flow rates. If $W=\infty$, then each discharger would receive an amount that is in the same proportion as the flow rate. (See figure 2)

A compromise between these two extremes would be to linearly interpolate to find a half-way point. Since one value is infinite, the interpolation would have to be done on a reciprical scale, thus interpolating half way between the reciprocals we have, that

$$1/1 = 1, \quad 1/\infty = 0 \quad \text{halfway is} \quad 1/2 = 1/W \quad \text{or } W = 2.$$

Using $W=2$, our function $f(Qk)$ has the simple form

$$f(Qk) = \frac{Qk}{Qk + \overline{Q}}$$

and the allocation formula in this instance may be expressed as

$$U_k = \frac{\theta pBVQk}{Sn(Qk + \overline{Q})}$$

(F) Once $U_k$ is specified, it is up to the individual discharger to choose his own mixing zone as he sees fit, subject only to the constraints that it is circular in form and contains no more than his allocated number of biological units. In order to protect the very shallow shore areas and give the discharger incentive to discharge into deeper water, any land in the discharger's chosen circle can be given the same biological value as the water zone in his circle with greatest biological value.

If the mixing zone circle is contained totally in one type of zone, then the radius $r_{jk}$ of a circle in the $j^{th}$ zone allocated to a discharger of flow rate $Q_k$ is

$$r_{jk} = \sqrt{\frac{U_k A_j}{\pi BV_j}}$$

If a mixing zone is in more than one zone type, the radius of the circle must be obtained by trial and error, where a radius is specified and the number of biological units in the circle is computed to be:

$$\frac{A_{1k}BV_1}{A_1} + \frac{A_{2k}BV_2}{A_2} + \cdots + \frac{A_{mk}BV_m}{A_m}$$

where $A_{jk}$ is the area of the circle in the $j^{th}$ zone given to the $k^{th}$ discharger. The radius is then adjusted until the computed biological units are equal to the allotted number of biological units.

Present dischargers are free to obtain a mixing zone according to this formula and future dischargers can be issued permits on the same basis, until the total number of allocated biological units are exhausted.

In addition, it should be noted that by using this procedure, it is possible to utilize a proportion $pBV/BV_j$ of the area of the $j^{th}$ zone type for mixing zones. Thus, an upper bound for each type zone might also be established that would limit the total area that could be taken for any one type of zone by not issuing any permits in that type of zone, once this upper limit was met.

As a guide to following these concepts, consider the following concrete numerical example.

A segment, shown in Figure 1, is divided into two zones on the basis of a compensation point which occurs at a 10-meter depth. The areas ($A_1$, $A_2$, $m = 2$) and corresponding relative biological values ($BV_1$, $BV_2$) of each zone are specified and the total biological value computed as indicated in Figure 1. We shall also assume that we have three ($n=3$) dischargers on the segment with relative flow rates shown in Table 1. Choosing ($p = .02$, $o = .5$, $W = 2$) we obtain the allocation formula

$$U_k = \frac{.02182\, Q_k}{Q_k + 3}$$

and the allocation of biological units also indicated in Table 1.

If an individual with relative flow rate of 9 was to have his circle entirely in the first zone, his radius would be

$$r = \sqrt{\frac{(.02182)9\ (35)}{(9+3)\ (\pi)(2)}} = .3019$$

or an individual with relative flow rate of .5 units, all in zone 2, would have a radius of size

$$r = \sqrt{\frac{(.02182)(.5)(25)}{(.5+3)\ (1)}} = .2792$$

## Conclusion

In essence, the approach in these guidelines focuses on the need to consider the collective effects of all discharges to the segment or large portion of the segment. The guidelines identify critical overall considerations and suggest decisional alternatives. They discuss allocation of the total acceptable mixing zone area among present and future discharges.

The Regional Administrator (or Director) can employ the decision-making process of these guidelines and still use available local expertise and common sense. Thus, the determinations will be visibly rational and consistent among discharges; at the same time each decision will be tailored to the local situation.

Table 1.

$p = .02, \theta = .5, W = 2$

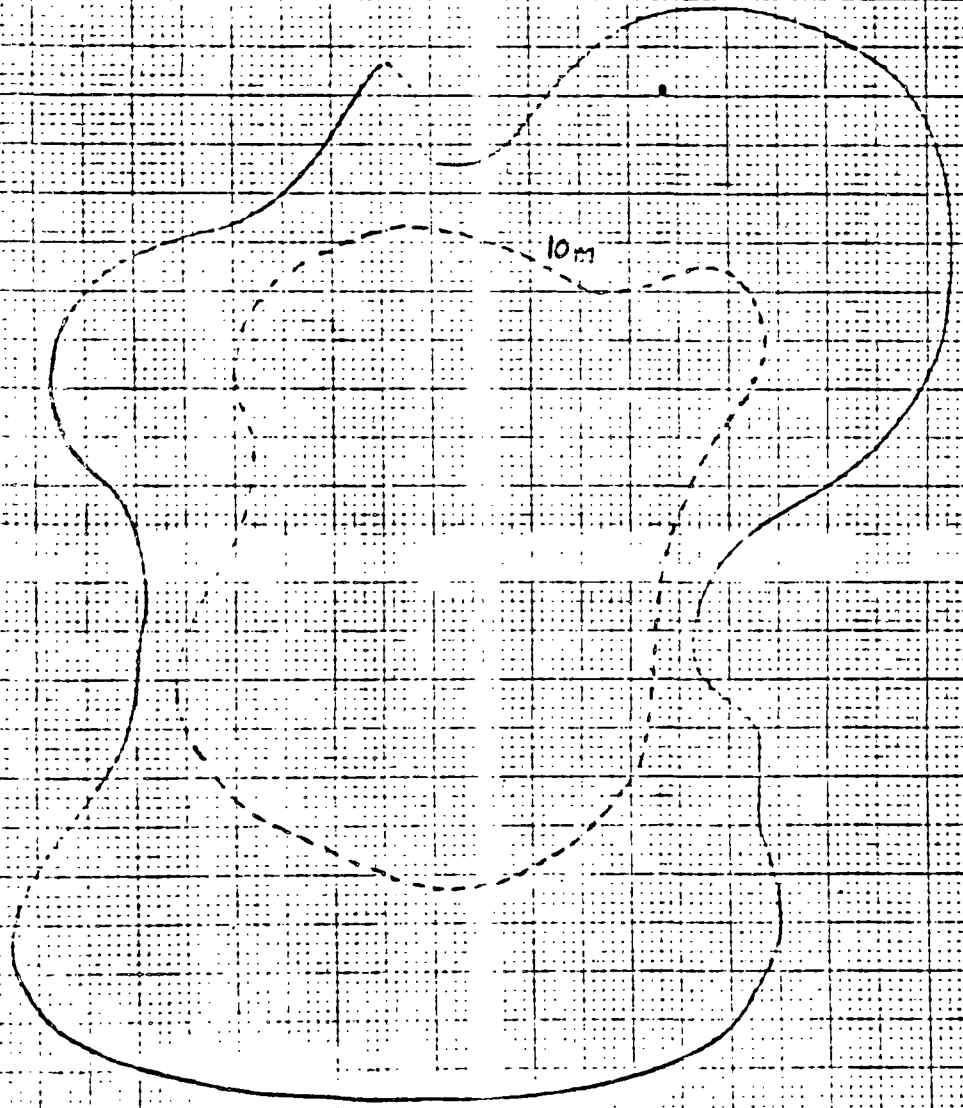
### Numerical Example

| $k$ | $Qk$ | $f'(Qk) = \frac{Qk}{Qk+3}$ | $Uk = \frac{(.5X.02X3)f(Qk)}{1.375} = .02182f(Qk)$ |
|---|---|---|---|
| 1 | 1 | .25 | .00545 |
| 2 | 3 | .50 | .01091 |
| 3 | 5 | .625 | .01364 |
| $\Sigma$ | 9 | 1.375 | .03 |

$\bar{Q} = (1 + 3 + 5)/3 = 3$

$Sn = .25 + .5 + .625 = 1.375$

FIGURE 1 - BASIC DATA FOR HYPOTHETICAL BIOLOGICAL AND NUMERICAL EXAMPLE



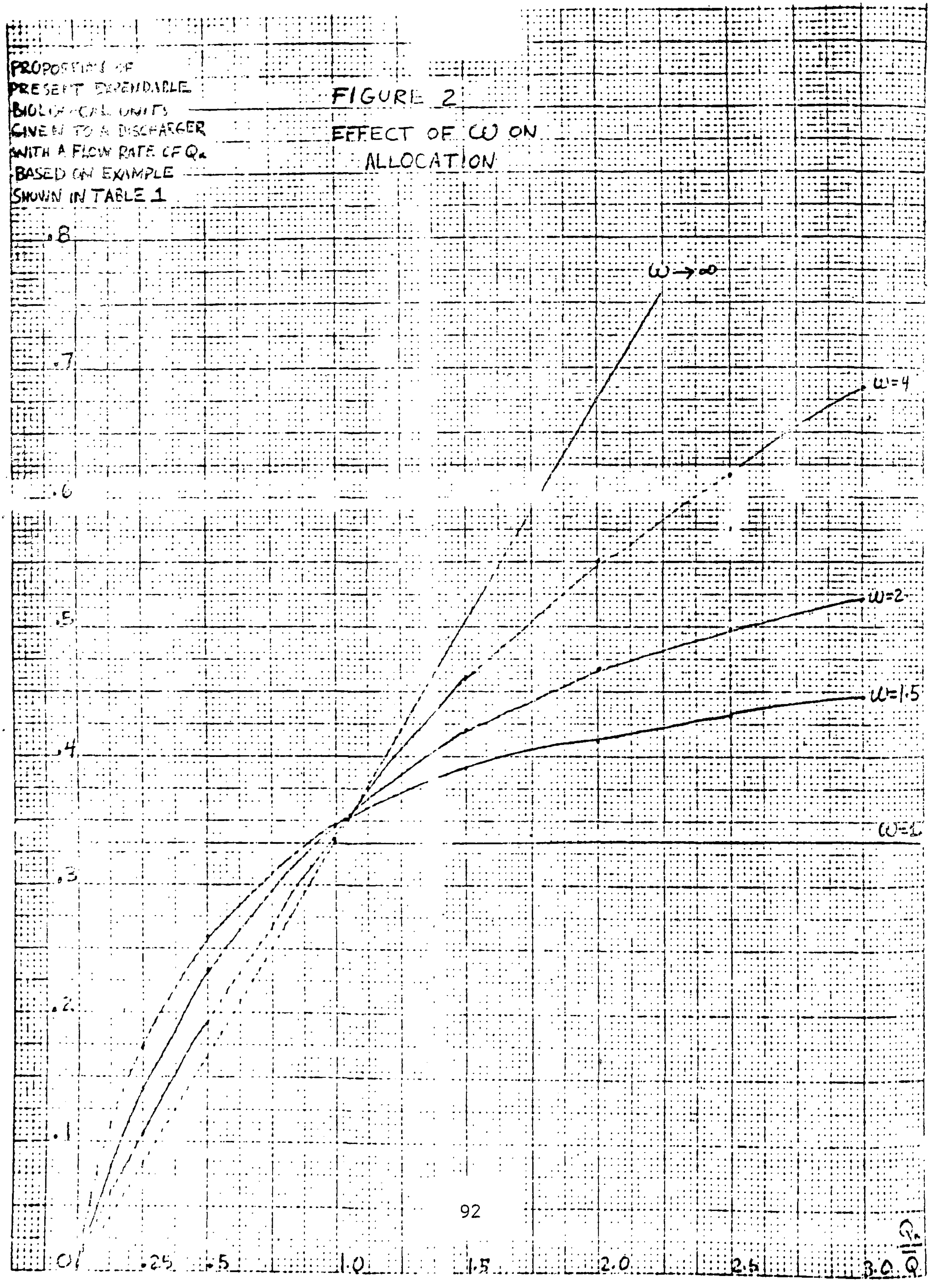
ZONE 1 $\leq$ 10m $A_1 = 35$ $BV_1 = 2$

ZONE 2 $>$ 10m $A_2 = 25$ $BV_2 = 1$

$$A = A_1 + A_2 = 60$$
$$BV = BV_1 + BV_2 = 3$$

FIGURE 2

EFFECT OF ω ON ALLOCATION



# APPENDIX B

## I

## FRESH WATER TEMPERATURE CRITERIA

Acceptable temperature limits in fresh water during any time of the year are:

a. A maximum weekly average temperature that:

1. In receiving waters during the warmer months (approximately April through October in the North and March through November in the South) is one-third of the range between the optimum temperature for growth and the ultimate upper incipient lethal temperature for the most sensitive important species (or appropriate life stage) that is normally found at the location at that time (see Table 1).

2. In the heated plume during the cooler months (approximately mid-October to mid-April in the North and December to February in the South) corresponds to the appropriate ambient temperature in the nomograph in Figure 1. This should protect against most fish mortality when the temperature to which the fish are exposed in the plume rapidly drops to the ambient temperature. In some areas this limit may also be applicable in the summer.

3. During reproduction seasons (generally April-June and September-October in the North and March-May and October-November in the South) meets specific site requirements for successful maturation, migration, spawning, egg incubation, fry rearing, and other reproductive functions of important species as presented in part in Table 2.

or 4. At a specific site is found necessary to preserve normal species diversity or prevent undesirable growth of nuisance organisms.

and b. maximum temperatures for short-term exposures at any season as developed using the resistance time equation:

$$\log(\text{time in min.}) = a + b\,(\text{Temp. in } ^\circ\text{C})$$

where a and b respectively are intercept and slope, which are characteristics of each acclimation temperature for each species (see later detailed discussion). During the spawning season this limitation, which was designed to prevent juvenile and adult fish mortality, would not be adequately protective of reproduction. Consequently, this limitation will be superseded by short-term maximum temperatures based on maximum successful spawning and egg incubation temperatures.

Local requirements for reproduction should supersede all other requirements when they are applicable. Detailed ecological analysis of both natural and man-modified aquatic environments is necessary to ascertain when these requirements should apply.

Available data on temperature requirements for growth and reproduction, lethal limits for various acclimation temperature levels, and various temperature-related characteristics of many of the more important freshwater fish species are included in Appendix A.

## Rationale (Temperature):

Living organisms do not respond to the quantity of heat but instead, to degrees of temperature or to temperature changes caused by transfer of heat. Organisms have upper and lower thermal tolerance limits, optimum temperatures for growth, preferred temperatures in thermal gradients, and temperature limitations for migration, spawning and egg incubation. Temperature also affects the physical environment of the aquatic medium (e.g., viscosity, degree of ice cover, and oxygen capacity); therefore, the composition of aquatic communities depends largely on temperature characteristics of the environment.

Because temperature changes may affect the composition of an aquatic community, an induced change in the thermal characteristics of an ecosystem may be detrimental. On the other hand, altered thermal characteristics may be beneficial, as evidenced in some of the newer fish hatchery practices and at other aquacultural facilities. The general difficulty in developing suitable criteria for temperature (which would limit the addition of heat) is to determine the deviation from "natural" temperature a particular body of water can experience without adversely affecting its desired biota. Whatever requirements are suggested, natural diurnal and seasonal cycles must be retained, annual spring and fall changes in temperature must be gradual, and large unnatural day-to-day fluctuations should be avoided. In view of the many variables, it seems obvious that no single temperature rise limitation can be applied uniformly to continental or large regional areas; the requirements must be closely related to each body of water and to its particular community of organisms, especially the important species found in it. These should include invertebrates, plankton, or other plant and animal life that may be of importance to food chains or otherwise interact with species of direct interest to man. Since thermal requirements of various species differ, the social choice of the species to be protected allows for different "levels of protection" among water bodies. Although such decisions clearly transcend the scientific judgments needed in establishing thermal criteria for protecting selected species, biologists can aid in making these decisions. Some measures useful in assigning levels of "importance" to species are: (1) high yield or desirability to commercial or sport fisheries, (2) large biomass in the existing ecosystem (if desirable), (3) important links in food chains of other species judged important for other reasons, and (4) "endangered" or unique status. If it is desirable to attempt strict preservation of an existing ecosystem, then the most sensitive species or life stage may dictate the criteria selected.

Criteria for making recommendations for water temperature to protect desirable aquatic life cannot be simply a maximum allowed change from natural temperatures. This is principally because a change of even one degree from an ambient temperature has varying significance for an organism, depending upon where the ambient level lies within the tolerance range. In addition, historic temperature records or, alternatively, the existing ambient temperature prior to any thermal alterations by man are not always reliable indicators of desirable conditions for aquatic populations. Multiple developments of water resources also change water temperatures both upward (e.g., upstream power plants or shallow reservoirs) and downward (e.g., deepwater releases for large reservoirs) so that ambient and natural temperatures at a given point can best be defined only on a statistical basis. Criteria for temperature should consider both the multiple thermal requirements of aquatic species and requirements for balanced communities. The number of distinct requirements and the necessary values for each require periodic reexamination as knowledge of thermal effects on aquatic species and communities increases. Currently definable requirements include:

- Maximum sustained temperatures that are consistent with maintaining desirable levels of productivity (growth minus mortality);
- Maximum levels of thermal acclimation that will permit return to ambient winter temperatures should artificial sources of heat cease;
- Temperature limitations for survival of brief exposures to temperature extremes, both upper and lower;
- Restricted temperature ranges for various stages of reproduction, including (for fish) gonad growth and gamete maturation, spawning migration, release of gametes, development of the embryo and larva, commencement of

independent feeding (and other activities) by juveniles; and temperatures required for metamorphosis, emergence, and other activities of lower forms;

- Thermal limits for diverse compositions of species of aquatic communities, particularly where reduction in diversity creates nuisance growths of certain organisms, or where important food sources or chains are altered;
- Thermal requirements of downstream aquatic life where upstream warming of cold water sources will adversely affect downstream temperature requirements.

Thermal criteria must also be formulated with knowledge of how man alters temperatures, the hydrodynamics of the changes, and how the biota can reasonably be expected to interact with the thermal regimes produced. It is not sufficient, for example, to define only the thermal criteria for sustained production of a species in open waters, because large numbers of organisms may also be exposed to thermal changes by being pumped through the condensers and mixing zone of a power plant. Design engineers need particularly to know the biological limitations to their design options in such instances. Considerations such as impingement of fish upon intake screens, mechanical or chemical damage to zooplankton in condensers, or effects of altered current patterns on bottom fauna in a discharge area may reveal non-thermal impacts of cooling processes that may outweigh temperature effects. The environmental situations of aquatic organisms (e.g., where they are, when they are there, in what numbers) must also be understood. Thermal criteria for migratory species should be applied to a certain area only when the species is actually there. Although thermal effects of power stations are currently of greater interest, other less dramatic causes of temperature change including deforestation, stream channelization, and impoundment of flowing water must be recognized.

Available data for temperature requirements for growth and reproduction, lethal limits for various acclimation temperature levels, and various temperature-related characteristics of many of the more desirable freshwater fish species are included in the Appendix. General temperature criteria for these species are summarized in Tables 1 and 2.

## Terminology Defined

Some basic thermal response of aquatic organisms will be referred to repeatedly and are defined and reviewed briefly here. Effects of heat on organisms and aquatic communities have been reviewed periodically (e.g., 1, 2, 3, 4, 5, 6). Some effects have been analyzed in the context of thermal modification by power plants (7, 8, 9, 10, 11). Bibliographic information is available in various publications (12, 13, 14, 15, 16, 17).

The thermal tolerance range is adjusted upward by acclimation to warmer water and downward by cooler water, although there is a limit to such accommodation. The lower end of the range usually is at zero degrees centigrade (32° F) for species in temperate latitudes (somewhat less for saline waters), while the upper end terminates in an "ultimate incipient lethal temperature" (18). This ultimate threshold temperature represents the "breaking point" between the highest temperatures to which an animal can be acclimated and the lowest of the temperatures that will kill the warm-acclimated organism.

At the temperatur above and below the upper and lower incipient lethal temperatures, survival depends not only on the absolute temperature but also on the duration of exposure, with mortality occurring more rapidly the further the temperature departs from the threshold.

Because the equations based on research on thermal tolerance predict 50 percent mortality, a safety factor is needed to assure no mortality. Several studies have indicated that a two degree centigrade (3.6° F) reduction of an upper lethal temperature results in no mortalities within an equivalent exposure duration (19, 20). The validity of a two degree safety factor was strengthened by the results of Coutant (21), which showed that for median mortality at a given high temperature, for about 15 to 20 percent of the exposure time there was induced selective predation on thermally shocked salmon and trout. This also amounted to reduction of the effective stress temperature by about two degrees centigrade. Unpublished data from subsequent predation experiments showed that this reduction of about two degrees centigrade also applied to the incipient lethal temperature. The level at which there is no increased vulnerability to predation is the best estimate of no-stress exposure that is currently available.

## Maximum Weekly Average Temperature for Growth

Occupancy of habitats by most aquatic organisms often is limited within the thermal tolerance range to temperatures somewhat below the ultimate upper incipient lethal temperature. This is the result of poor physiological performance at near lethal temperatures (e.g., growth, metabolic scope for activities, appetite, food conversion efficiency), interspecies competition, disease, predation, and other subtle ecological factors. This complex limitation is evidenced by restricted southern and altitudinal distributions of many species. On the other hand, optimum temperatures (such as those producing fastest growth rates) are not generally necessary at all times to maintain thriving populations and are often exceeded in nature during summer months. Moderate temperature fluctuations can generally be tolerated as long as a summer maximum upper limit is not exceeded for long periods.

A true temperature limit for exposures long enough to reflect metabolic acclimation and optimum ecological performance must lie somewhere between the physiological optimum and the ultimate upper incipient lethal temperature.

Examination of literature on physiological optima (swimming, metabolic rate, temperature preference, growth, natural distribution, and tolerance) of several species has yielded an apparently sound theoretical basis for estimating an upper temperature limit for long-term exposure. The most sensitive function for which data are available appears to be growth rate.

A temperature that is one-third of the range between the optimum temperature for growth and the ultimate incipient lethal temperature can be calculated by the formula:

$$\begin{array}{l}\text{Optimum} \\ \text{temp} \\ \text{for growth}\end{array} + \frac{\text{Ultimate incipient lethal temp} - \text{optimum temp for growth}}{3}$$

This formula offers a practical method for obtaining allowable limits, while retaining as its scientific basis the requirements of preserving adequate rates of growth. This formula was used to calculate the summer growth (on a monthly basis) criteria in Table 1.

The criterion for a specific location would be determined by the most sensitive life stage or the sensitive important species likely to be present in that location at that time. Since many fishes have restricted habitats (e.g., specific depth zones) at many life stages, the thermal criterion must be applied to the proper zone. There is field evidence that fish avoid localized areas of unfavorably warm water. This has been demonstrated both in lakes where coldwater fish normally evacuate warm shallows in summer and at power station heated plumes. In most large bodies of water there are both vertical and horizontal thermal gradients that mobile organisms can follow to avoid unfavorable high (or low) temperatures. The summer maxima must apply to restricted local habitats such as lake hypolimnia or thermoclines, that provide important summer sanctuary areas for coldwater species. Any avoidance of a warm area within the normal seasonal habitat of the species will mean that less area of the water body is available to support the population and that production may be reduced. Such reduction should not interfere with biological communities or populations of important species to a degree which is damaging to the ecosystem or other beneficial uses. Non-mobile organisms that must remain in the warm zone will probably be the limiting organisms for that location. Any upper limiting temperature criteria must be applied carefully with understanding of the population dynamics of the species in question in order to establish both local and regional requirements.

## Maximum Weekly Average Temperature for Winter

Although artificially produced temperature elevations during winter months may actually bring the temperature closer to optimum or preferred temperature for important species, and therefore attract fish, metabolic acclimation to these higher levels can preclude safe return of the organism to ambient temperatures should the artificial heating suddenly cease or the organism be driven from the heated area. The lower limit of the range of thermal tolerance of important species must, therefore, be maintained at the normal seasonal ambient temperatures throughout cold seasons. This can be accomplished by limitations on temperature elevations in such areas as discharge canals and mixing zones where organisms may reside, or by insuring that maximum temperatures occur only in areas not accessible to important aquatic life for lengths of time sufficient to allow metabolic acclimation. Such inaccessible areas would include the high-velocity zones of diffusers or screened discharge channels. This reduction of maximum temperatures would not preclude use of slightly warmed areas as sites for intense winter fisheries.

This consideration may be important in some regions at times other than in winter. The Great Lakes, for example, are susceptible to rapid changes in elevation of the thermocline in summer which may induce rapid decreases in shoreline temperatures (upwelling). Fish acclimated to exceptionally high temperatures in discharge canals may be killed or severely stressed without changes in power plant operations.

Some numerical values for acclimation temperatures and lower limits of tolerance ranges (lower incipient lethal temperatures) for several species are given in Appendix A. Lower winter temperature is necessary for some species such as yellow perch for egg maturation and lake whitefish for egg incubation.

Figure 1 is a nomograph that demonstrates the relationship between the maximum weekly average temperature acceptable in heated plumes and different ambient temperatures. The nomograph was calculated using lower incipient lethal temperature data that would, after applying the 2° C safety factor, ensure protection against partial lethality for most fish species for which there are data (22). At an acclimation (heated plume) temperature of 10° C (50° F) or less, warm water fishes can tolerate a drop in temperature to any lower ambient temperature. Conversely (see Fig. 1), whenever the ambient temperature is less than 2.5° C (37° F), the heated plume may be as warm as 10° C (50° F). However, trout and salmon cannot withstand comparable temperature declines and the nomograph should be used down to an ambient temperature of 0° C (32° F). At this temperature a maximum plume temperature of 5° C (41° F) is permissible.

The maximum weekly average temperatures during the winter months are applicable to the heated plume rather than the receiving water since the principal concern for most fish at that time is to protect against excessive rapid decline in temperature. At the time that the earliest spawning should occur, the appropriate maximum weekly average temperature for the receiving water must be applied again. If species similar to yellow perch or lake whitefish are to be protected, a maximum weekly average temperature in the receiving water during the winters should be necessary as well as the limitation in the plumes.

Short-term Exposure to Extreme Temperature

To protect aquatic life and yet allow other uses of the water, it is essential to know the lengths of time organisms can survive extreme temperatures (i.e., temperatures that exceed the 7-day incipient lethal temperature). The length of time that 50 percent of a population will survive temperature above the incipient lethal temperature can be calculated from a regression equation of experimental data as follows:

$$\log \text{(time in min.)} = a + b \text{ (Temp. in °C)}$$

where a and b are intercept and slope, respectively, which are characteristics of each acclimation temperature for each species (22). In some cases the time-temperature relationship is more complex than the semilogarithmic model given above. This equation, however, is the most applicable, and is generally accepted by the scientific community (5). Caution is recommended in extrapolating beyond the data limits of the original research. Thermal resistance may be diminished by the simultaneous presence of toxicants or other debilitating factors. The most accurate predictability can be derived from data collected using water from the site under evaluation.

It is clear that adequate data are available for only a small percentage of aquatic species, and additional research is necessary. Thermal resistance information should be obtained locally for critical areas to account for simultaneous presence of toxicants or other debilitating factors, a consideration not reflected in the Appendix data.

The resistance time equation discussed earlier was used to calculate tolerance limits for many species of fish for several time intervals up to 10,000 minutes. The results of these calculations revealed a uniform relationship between these species that would permit establishing maximum acceptable temperatures for spring, summer, and fall that would protect fish against lethal conditions when subjected to occasional temperature levels exceeding the maximum weekly average temperature during these seasons. These limits, applicable to the receiving water, are summarized in Table 1 and are based on the 24-hour median tolerance limit, minus the 2° C (3.6° F) safety factor discussed earlier using the maximum weekly average temperature as the acclimation temperature.

Since these temperatures exceed those permitting satisfactory, albeit sub-optimal growth, unnatural excursions above the maximum weekly average temperature to the maximum temperature should be permitted only in extreme instances and then only for short time periods.

A procedure has been developed and discussed for the evaluation of specific thermal discharge sites using a rearrangement of the resistance-time equation (22). This useful procedure allows the summation of specific effects on aquatic organisms during passage through condensors, discharge canals and heated plumes.

During the spawning season short-term maxima determined using the resistance time equation will protect the spawning population from lethal temperatures. However, spawning and egg incubation temperature requirements are more restrictive (lower) and these biological processes would not be protected by those maxima. The upper temperature limits for successful spawning and egg incubation for a given fish species are essentially the same and these limits are the recommended short-term maxima during the spawning season (Table 2).

## Reproduction and Development

The sequence of events relating to gonad development, spawning migration, release of gametes, development of the egg and embryo, and commencement of independent feeding represents one of the most complex phenomena in nature, both for fish (23) and invertebrates (6). These events are generally the most thermally sensitive of all life stages. The erratic sequence of failures and successes of different year classes of lake fish attests to the unreliability of natural conditions for providing optimum reproduction each year.

Uniform elevations of temperature by a few degrees during the spawning period, while maintaining short-term temperature cycles and seasonal thermal patterns, appear to have little overall effect on the reproductive cycle of resident aquatic species, other than to advance the timing for spring spawners or delay it for fall spawners. Such shifts are often seen in nature, although no quantitative measurements of reproductive success have been made in this connection. For example, thriving populations of many fishes occur in diverse streams of the Tennessee Valley in which the date of spawning may vary in a given year by 22 to 65 days. Examination of the literature shows that shifts in spawning dates by nearly one month are common in natural waters throughout the U. S. Populations of some species at the southern limits of their distribution are exceptions - the lake whitefish (Coregonus clupeaformis) in Lake Erie that require a prolonged, cold incubation period (24) and species such as yellow perch (Perca flavescens) that require a long chill period for egg maturation prior to spawning (25).

Highly mobile species that depend upon temperature synchrony among widely different regions or environments for various phases of the reproductive or rearing cycle (e.g., anadromous salmonids or aquatic insects) could be faced with dangers of dis-synchrony if one area is warmed, but another is not. Poor long-term success of one year class of Fraser River (British Columbia) sockeye salmon (Oncorhynchus nerka) was attributed to early (and highly successful) fry production and emigration during an abnormally warm summer followed by unsuccessful, premature feeding activity in the cold and still unproductive estuary (26).

## Changes in Structure of Aquatic Communities

Significant change in temperature or in thermal patterns over a period of time may cause some change in the composition of aquatic communities (i.e., the species represented and the numbers of individuals in each species). Allowing temperature changes to significantly alter the community structure in natural waters may be detrimental, even though species of direct importance to man are not eliminated.

Alteration of aquatic communities by the addition of heat may occasionally result in growths of nuisance organisms provided that other environmental conditions essential to such growths (e.g., nutrients) exist.

Data on temperature limits or thermal distributions in which nuisance growths will be produced are not presently available due in part to the complex interactions with other growth stimulants. There is not sufficient evidence to say that any temperature increase will necessarily result in increased nuisance organisms. Careful evaluation of local conditions is required for any reasonable prediction of effect.

## EXAMPLE

The nuances of developing freshwater aquatic life criteria for temperature can best be understood by an example (Table 3). Tables 1 and 2 and Figure 1 and the Appendix are the principal sources for the criteria. The following additional information about the specific environment to which the criteria will apply is needed.

1. Species to be protected by the criteria. (In this example, they are bluegill, largemouth bass, and white crappie).

2. Local spawning seasons for these species. (Bluegill - May to July; white crappie - April to June; largemouth bass - May to July).

3. Normal seasonal rise in temperature during the spawning season. (Since spawning may occur over a period of a few months and only a single

maximum weekly average temperature for optimal spawning is given for a species (Table 2), one would use that optimal temperature for the middle month of the spawning season. In a normal season the criterion for the first month of a three-month spawning season should be below the maximum weekly average temperature for spawning for the species to be protected, and the last month should be above this temperature. Such a pattern should simulate the natural seasonal rise .

4. Normal ambient winter temperature. (In this case it is 5° C (41° F) in December and January and 10° C (50° F) in November, February, and March. These will be used to determine permissible plume temperatures in the winter (Figure 1).)

5. The principal growing season for these species. (In this example it is July through September. Criteria in Table 1 will be used).

6. Any local extenuating circumstances. (If certain non-fish species or food organisms are especially sensitive and thermal requirement data are available, these data should be used as well as the criteria considered for the fish species).

In some instances there will be insufficient data to determine each necessary criterion for each species (Table 3). One must make estimates based on any available data and by extrapolation from data for species for which there are adequate data. For instance, if the above example had included the white bass for which only the maximum weekly average temperature for spawning is given, one would of necessity have to estimate that its summer growth criterion would approximate that for the white crappie which has a similar spawning requirement.

The choice of desirable fish species is very critical. Since in this example the white crappie is the most temperature sensitive of the three species, the maximum weekly average temperature for summer growth is based on the white crappie. Consequently, the criteria would result in lower than optimal conditions for the bluegill and largemouth bass. An alternate approach would be to develop criteria for the single most important species even if the most sensitive is not well protected. The choice is a socioeconomic one.

## REFERENCES

1. Bullock, T. H. 1955. Compensation for temperature in the metabolism and activity of poikilotherms. Biol. Rev. (Cambridge) 30:311-342.

2. Brett, J. R. 1956. Some principles in the thermal requirements of fishes. Quart. Rev. Biol. 31:75-87.

3. Fry, F.E.J. 1947. Effects of the environment on animal activity. Univ. of Toronto Stud. Biol. Ser. No. 55 Publ. Ont. Fish. Res. Lab. No. 68:1-62.

4. Fry, F.E.J. 1964. Animals in aquatic environments: fishes temperature effects Chapter 44. Handbook of Physiology, Section 4: Adaptation to the Environment. Amer. Physiol. Soc., Washington, D. C.

5. Fry, F.E.J. 1967. Responses of vertebrate poikilotherms to temperature (review). In: Thermobiology, A. H. Rose, ed. (Academic Press, New York), pp. 375-409.

6. Kinne, O. 1970. Temperature--animals--invertebrates, in marine ecology, O. Kinne, ed. (John Wiley & Sons, New York), vol. 1, pp. 406-514.

7. Parker, F. L. and P. A. Krenkel, eds. 1969. Engineering aspects of thermal pollution. (Vanderbilt University Press, Nashville, Tennessee), 351.

8. Krenkel, P. A. and F. L. Parker, eds. 1969. Biological aspects of thermal pollution. (Vanderbilt University Press, Nashville, Tennessee), 407 p.

9. Cairns, J., Jr. 1968. We're in hot water. Scientist and Citizen 10:187-198.

10. Clark, J. R. 1969. Thermal pollution and aquatic life. Sci. Amer. 220:18-27.

11. Coutant, C. C. 1970. Biological aspects of thermal pollution. I. Entrainment and discharge canal effects. CRC Critical Rev. Environ. Contr. 1:341-381.

12. Kennedy, V. S. and J. A. Mihursky. 1967. Bibliography on the effects of temperature in the aquatic environment (Contribution 326) (University of Maryland, Natural Resources Institute, College Park). 89 p.

13. Raney, E. C. and B. W. Menzel. 1969. Heated effluents and effects on aquatic life with emphasis on fishes: a bibliography, 38th ed. (U. S. Department of the Interior, Water Resources Information Center, Washington, D. C.) 469 p.

14. Coutant, C. C. 1968. Thermal pollution--biological effects: a review of the literature of 1967. J. Water Pollut. Contr. Fed. 40:1047-1052.

15. Coutant, C. C. 1969. Thermal pollution--biological effects: a review of the literature of 1968. J. Water Pollut. Contr. Fed. 41:1036-1053.

16. Coutant, C. C. 1970. Thermal pollution--biological effects: a review of the literature of 1969. J. Water Pollut. Contr. Fed. 42:1025-1057.

17. Coutant, C. C. 1971. Thermal pollution--biological effects. Literature review. J. Water Pollut. Contr. Fed. 43:1292-1334.

18. Fry, F. E. J., J. S. Hart, and K. F. Walker. 1946. Lethal temperature relations for a sample of young speckled trout, _Salvelinus fontinalis_. University of Toronto biology series no. 54. The University of Toronto Press. Toronto. pp. 9-35.

19. Fry, F. E. J., J. R. Brett, and G. H. Clawson. 1942. Lethal limits of temperature for young goldfish. Rev. Can. Biol. 1:50-56.

20. Black, E. C. 1953. Upper lethal temperatures of some British Columbia freshwater fishes. J. Fish. Res. Board Can. 10:196-210.

21. Coutant, C. C. 1970. Thermal resistance of adult coho (_Oncorhynchus kisutch_) and jack chinook (_O. tshawytscha_) salmon, and the adult steelhead trout (_Salmo gairdnerii_) from the Columbia River. [SEC BNWL-1508], Battelle Northwest, Richland, Washington. 24 p.

22. Water Quality Criteria of 1972. NAS Report - In press.

23. Brett, J. R. 1970. Temperature--animals--fishes. _In_: Marine Ecology. O. Kinne, ed. John Wiley & Sons, New York. Vol. 1. pp 515-560.

24. Lawler, G. H. 1965. Fluctuations in the success of year-classes of white-fish populations with special reference to Lake Erie. J. Fish. Res. Board Can. 22:1197-1227.

25. Jones, B. R., K. E. F. Hokanson, and J. H. McCormick. 1974. Winter temperature requirements of yellow perch, Perca flavescens (Mitchill). Manuscript. National Water Quality Laboratory, Duluth, Minnesota.

26. Vernon, E. H. 1958. An examination of factors affecting the abundance of pink salmon in the Fraser River. Progress report no. 5. International Pacific Salmon Fisheries Commission. New Westminster, British Columbia.

## TABLE 1

### Maximum Weekly Average Temperatures for Growth and Short-Term Maxima for Survival for Juveniles and Adults During the Summer (Centigrade and Fahrenheit)[a]

| Species | Growth | Maxima[a] |
|---|---|---|
| Atlantic Salmon | 20 (68) | 23 (73) |
| Bigmouth Buffalo | - | - |
| Black Crappie | 27 (81) | - |
| Bluegill | 29 (84) | 32 (90) |
| Brook Trout | 19 (66) | 23 (73) |
| Carp | - | - |
| Channel Catfish | 32 (90) | 36 (97) |
| Coho Salmon | 18 (64) | 24 (75) |
| Emerald Shiner | 30 (86) | 31 (88) |
| Freshwater Drum | - | - |
| Lake Herring (Cisco) | 17 (63)[b] | 25 (77) |
| Largemouth Bass | 32 (90) | 34 (93) |
| Northern Pike | 28 (82) | 30 (86) |
| Rainbow Trout | 19 (66) | 24 (75) |
| Sauger | 25 (77) | - |
| Smallmouth Bass | 29 (84) | - |
| Smallmouth Buffalo | - | - |
| Sockeye Salmon | 18 (64) | 22 (72) |
| Striped Bass | - | - |
| Threadfin Shad | - | - |
| White Bass | - | - |
| White Crappie | 27 (81) | - |
| White Sucker | 28 (82)[b] | - |
| Yellow Perch | 22 (72) | 29 (84) |

[a] Based on 24-hour median lethal limit minus 2° C (3.6° F) and acclimation at the maximum weekly average temperature for summer growth.

[b] Based all or in part on data for larvae.

## TABLE 2

Maximum Weekly Average Temperature for Spawning and Short-term Maxima for Embryo Survival During the Spawning Season (Centigrade and Fahrenheit).

| Species | Spawning | Maximum |
|---|---|---|
| Atlantic Salmon | 5 (41) | 7 (45) |
| Bigmouth Buffalo | 17 (63) | 27 (81) |
| Black Crappie | - | - |
| Bluegill | 25 (77) | 34 (93) |
| Brook Trout | 9 (48) | 13 (55) |
| Carp | 21 (70) | 26 (79) |
| Channel Catfish | 27 (81) | 29 (84) |
| Coho Salmon | 10 (50) | 13 (55) |
| Emerald Shiner | 23 (73) | 27 (81) |
| Freshwater Drum | 21 (70) | 26 (79) |
| Lake Herring (Cisco) | 3 (37) | 8 (46) |
| Largemouth Bass | 21 (70) | 27 (81) |
| Northern Pike | 12 (54) | 19 (66) |
| Rainbow Trout | 9 (48) | 13 (55) |
| Sauger | 10 (50) | 21 (70) |
| Smallmouth Bass | 17 (63) | 25 (77) |
| Smallmouth Buffalo | 17 (63) | 21 (70) |
| Sockeye Salmon | 10 (50) | 13 (55) |
| Striped Bass | 18 (64) | 24 (75) |
| Threadfin Shad | 18 (64) | 34 (93) |
| White Bass | 19 (66) | 24 (75) |
| White Crappie | 18 (64) | 23 (73) |
| White Sucker | 10 (50) | 21 (70) |
| Yellow Perch | 12 (54) | 20 (68) |

## TABLE 3

### Criteria Developed for Example[a] (Centigrade and Fahrenheit)

| Month | Maximum Weekly Average Temperature | | Decision Basis |
|---|---|---|---|
| | Receiving Water | Heated Plume | |
| JAN | -[a] | 15 (59) | Protection against temperature drop |
| FEB | -[a] | 25 (77) | Protection against temperature drop |
| MAR | -[a] | 25 (77) | Protection against temperature drop |
| APR | 18 (64) | - | White crappie spawning |
| MAY | 21 (70) | - | Largemouth bass spawning |
| JUN | 25 (77) | - | Bluegill spawning and white crappie growth |
| JUL | 27 (80) | - | White crappie growth |
| AUG | 27 (80) | - | White crappie growth |
| SEP | 27 (80) | - | White crappie growth |
| OCT | 21 (70) | - | Normal gradual seasonal decline |
| NOV | -[a] | 25 (77) | Protection against temperature drop |
| DEC | -[a] | 15 (59) | Protection against temperature drop |

| | Short-Term Maximum | Decision Basis |
|---|---|---|
| JAN | - | |
| FEB | - | |
| MAR | - | |
| APR | 26 (79) | Bluegill[b] survival (estimated) |
| MAY | 29 (84) | Bluegill[b] survival (estimated) |
| JUN | 32 (90) | Bluegill[b] survival |
| JUL | 32 (90) | Bluegill[b] survival |
| AUG | 32 (90) | Bluegill[b] survival |
| SEP | 32 (90) | Bluegill[b] survival |
| OCT | 29 (84) | Bluegill[b] survival (estimated) |
| NOV | - | |
| DEC | - | |

[a] If a species had required a winter chill period for gamete maturation or egg incubation, receiving water criteria would also be required.

[b] No data available for the slightly more sensitive white crappie.

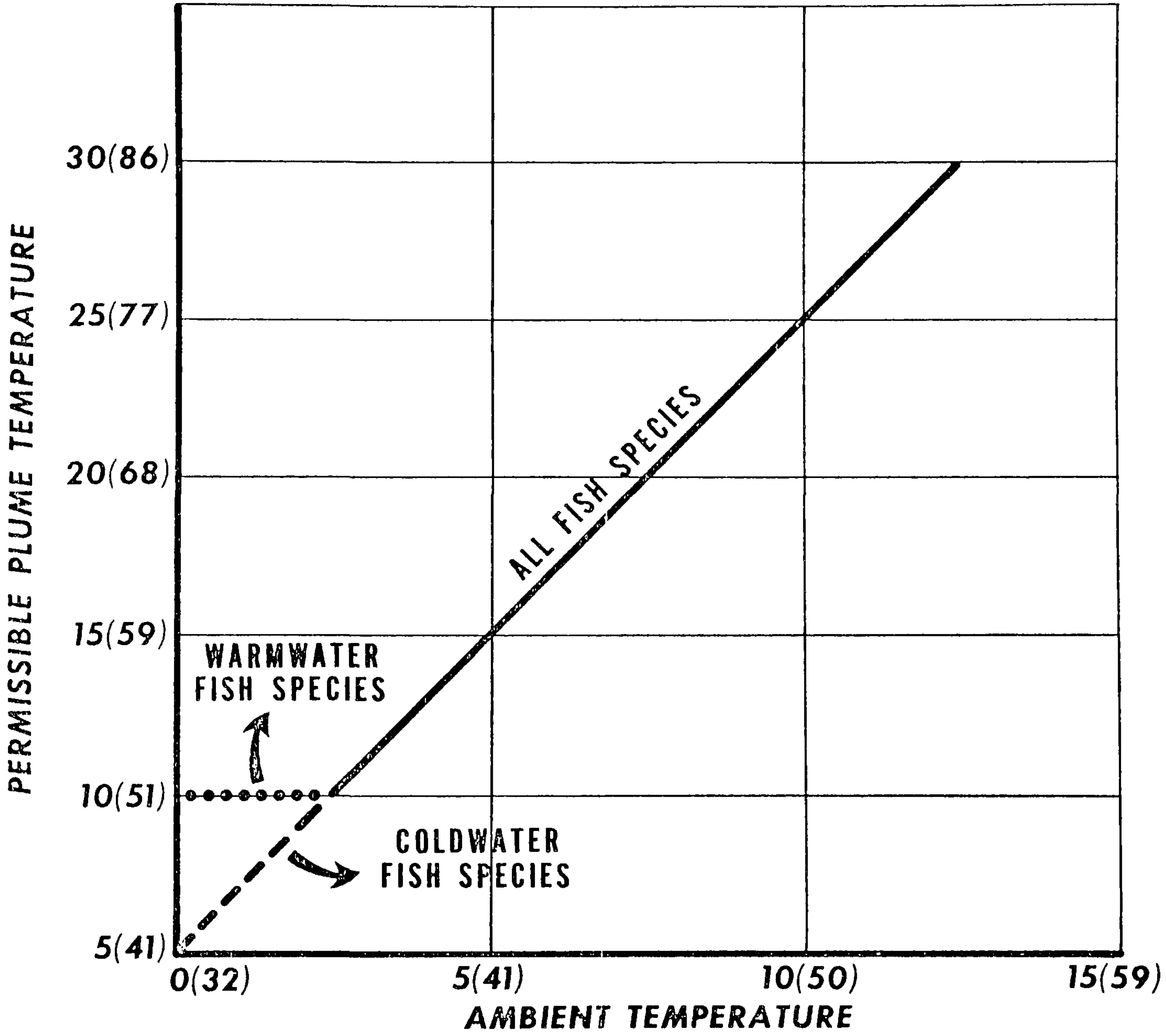


FIGURE 1. NOMOGRAPH TO DETERMINE THE MAXIMUM WEEKLY AVERAGE TEMPERATURE OF PLUMES FOR VARIOUS AMBIENT TEMPERATURES, °C (°F).

# FISH TEMPERATURE DATA SHEET

Species: Atlantic salmon *Salmo salar*

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 5 | | 22* | | 1 |
| | 6 | 22 | | | 1 |
| | 10 | | 23* | | 1 |
| | 20 | | 23 * | | 1 |
| | 27.5 | | 27.5 | | 10 |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

*30 days after hatch

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | | 16-18 | | 4 |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | adults 23 or less, smolt 10 or less | | | 7 |
| Spawning | | 5-6(9) | Oct-Dec(8) | 8,9 |
| Incubation and hatch | | 0.5-7 | | 3 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | 4 | 14(2) | | | 2 |
| | Summer | | 17(5) | 14-16(6) | 5,6 |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Atlantic salmon

## References

1. Bishai, H. M. 1960. Upper lethal temperatures for larval salmonids. Jou. Du Conseil 25(2):129-133.

2. Fisher, Kenneth C. and P. F. Elson. 1950. The selected temperature of Atlantic Salmon and Speckled Trout and the effect of temperature on the response to an electrical stimulus. Physiol. Zoology 23:27-34.

3. Dexter, R. 1967. Atlantic salmon culture. U.S. BSFW (mimeographed). In: DeCola, J.N. 1970. Water Quality Requirements for Atlantic Salmon. U. S. Dept. of the Interior, Federal Water Quality Administration Report CWT 10-16.

4. Markus, H. C. 1960. Hatchery reared atlantic salmon smolts in ten months. Prog. Fish. Cult. 24:3.

5. Javoid, M. Y. and J. M. Anderson. 1967. Thermal acclimation and temperature selection in Atlantic Salmon, Salmo salar and rainbow trout, S. gairdneri. J. Fish. Res. Bd. Canada 24(7).

6. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15:607-624.

7. Meister, A. 1970. Atlantic Salmon Commission, Univ. of Maine (personal communication). In: DeCola, J.M. 1970. Water Quality Requirements for Atlantic Salmon. USDI, Fed. Water Qual. Admin. Report CWT 10-16.

8. Carlander, K. D. 1969. Handbook of Freshwater Fishery Biology. Vol. 1. Iowa State Univ. Press, Ames, Iowa.

9. DeCola, J. N. 1970. Water quality requirements for atlantic salmon. U.S.D.I. Fed. Water Qual. Admin. Report CWT 10-16.

10. Garside, E. T. 1973. Ultimate upper lethal temperature of Atlantic Salmon Salmo salar L. Can. J. Zool. 51:898-900.

# FISH TEMPERATURE DATA SHEET

Species: Bigmouth buffalo, Ictiobus cyprinellus

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | | | | |
| [range[2]] | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 17 | 14-27 | Apr-June | 1,2,3,4,6 |
| Incubation and hatch | | 14-17 | | 2,5,6 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Summer | | | 31-34* | 7 |
| | | | | *Ictiobus sp.<br>field | |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Bigmouth buffalo

## References

1. Johnson, R. P. 1963. Studies on the life history and ecology of the bigmouth buffalo, *Ictiobus cyprinellus* (Valenciennes). J. Fish. Res. Bd. Canada 20:1397-1429.

2. Eddy, S. and T. Surber. 1947. Northern fishes. Univ. of Minn. Press.

3. Walburg, C. H. and W. R. Nelson. 1966. Carp, river carpsucker, smallmouth buffalo and bigmouth buffalo in Lewis and Clark Lake, Missouri River. Bur. Sport Fish. and Wildl. Research Report 69.

4. Harlan, J. R. and E. B. Speaker. 1956. Iowa Fish and Fishing State Conservation Commission.

5. Walker, M. C. and P. T. Frank. 1952. The propagation of buffalo. Prog. Fish. Cult. 14:129-130.

6. Swingle, H. S. 1955. Experiments on commercial fish production in ponds. Proc. S. E. Assoc. Game and Fish Commission for 1954, pp. 69-74.

7. Gammon, J. R. 1973. The effects of thermal inputs on the population of fish and macroinvertebrates in the Wabash River. Tech. Rept. No. 32. Purdue Univ. Water Resources Research Center.

# FISH TEMPERATURE DATA SHEET

Species: Black crappie, Pomoxis nigromaculatus

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | 29 | | 33* | | 2 |
| | | | | | |
| | | | *Ultimate incipient level | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1/] | larvae | juvenile | adult | data source |
|---|---|---|---|---|
| Optimum and | | 22-25 | | 2 |
| [range[2/]] | | (11-30)* | | 2 |
| | | | | |
| | | *limits of zero growth | | |

| III. Reproduction: | optimum | range | month(s) | data source |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 14-18 (4)* | Mar(4)-July(3) | 3,4 |
| Incubation and hatch | | *begin spawning | | |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | data source |
|---|---|---|---|---|---|
| | Summer | 18-20(5) | | 24-34(1) | 1,5 |
| | | | | | |
| | | | | | |

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

## Black crappie

## References

1. Neill, W. H., J. J. Magnuson and G. G. Chipman. 1972. Behavioral thermoregulation by fishes - new experimental approach. Science 176 (4042:1443)

2. Hokanson, K.E.F. and C. F. Kleiner. 1973. Effects of constant and diel fluctuations in temperature on growth and survival of black crappie. Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

3. Breder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. Nat. History Press.

4. Goodson, L. F. 1966. Crappie. In: Inland Fisheries Management. A. Calhoun, Ed., Calif. Dept. Fish and Game.

5. Faber, D. J. 1967. Limnetic larval fish in northern Wisconsin lakes. Jour. Fish. Res. Bd. Canada. 24:927-937.

# FISH TEMPERATURE DATA SHEET

Species: Bluegill, *Lepomis macrochirus*

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source3/ |
|---|---|---|---|---|---|
| Upper | 15(2), 12(8) | | 27(8) | 31 (2) | 2,8 |
| | 20 | | | 32 | 2 |
| | 25(2), 26(8 | | 36(8) | 33 (2) | 2,8 |
| | 30 | | | 34 | 2 |
| | 33 | | 37 | | 8 |
| Lower | 15(2), 12(8) | | 3 (8) | 3 (2) | 2,8 |
| | 20 | | | 5 | 2 |
| | 25(2), 26(8) | | 10 (8) | 7 (2) | 2,8 |
| | 30 | | | 11 | 2 |
| | 33 | | 15 | | 8 |

| II. Growth:1/ | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | | | 24-27(3) | 3 |
| [range2/] | | | (16(1)-30(4)) | 1,4 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 25(5) | 19(5)-32(6) | Apr-Aug.<br>(1) | 1,5,6 |
| Incubation and hatch | 22-24 | 22-34 | | 8 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | 32 | | 9 |
| | | | | | |
| | | | | | |

---

1/ As reported or net growth (growth in wt. minus wt. of mortality).

2/ As reported or to 50% of optimum if data permit.

3/ List sources on back of page in numerical sequence.

# Bluegill sunfish

## References

1. Emig, J. W. 1966. Bluegill sunfish. In: Inland Fisheries Mgt. A. Calhoun ed., Calif. Dept. Fish and Game.

2. Hart, J. S. 1952. Geographical variations of some physiological and morphological characters in certain freshwater fish. Univ. Toronto biology series No. 60.

3. Anderson, R. O. 1959. The influence of season and temperature on growth of the bluegill (Lepomis macrochirus). Ph.D. Thesis, Univ. Mich.

4. Maloney, John E. 1949. A study of the relationship of food consumption of the bluegill, Lepomis macrochirus) Rafinesque, to temperature, M.S. Thesis, Univ. of Minn. 43 pp.

5. Snow, H., A. Ensign and John Klingbiel. 1966. The bluegill, its life history, ecology and management. Wis. Cons. Dept. Publ. No. 230.

6. Clugston, J. P. 1966. Centrarchid spawning in the Florida Everglades Quart. Jour. Fla. Acad. Sci., 29:137-143.

8. Banner, A. and J. A. Van Arman. 1972. Thermal effects on eggs, larvae and juvenile of bluegill sunfish. Report, EPA Contract No. 14-12-913.

9. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada. 15:607-624.

# FISH TEMPERATURE DATA SHEET

Species: Brook trout *Salvelinus fontinalis*

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | 3 | | 23 | | 3 |
| | 11 | | 25 | | 3 |
| | 12 | 20*,25** | | | 2 |
| | 15 | | 25 | | 3 |
| | 20 | | 25 | | 3 |
| | 25 | | 25 | | 3 |
| Lower | | | | | |

*Newly hatched
**Swimup

| II. Growth:[1/] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | 12-15(2) | | 16(1) | 1,2 |
| [range[2/]] | (7-18)(2) | | (10-19)(1) | 1,2 |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | <9 | -12 | Sept.-Nov. | 1 |
| Incubation and hatch | 6 | -13 | | 1 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | 14-19* | | 4 |

*age not given

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

Brook trout

## References

1. Hokanson, K.E.F., J. H. McCormick, B. R. Jones, and J. H. Tucker. 1973. Thermal requirements for maturation, spawning, and embryo survival of the brook trout, Salvelinus fontinalis (Mitchill). J. Fish. Res. Bd. Canada, 30(7):975-984.

2. McCormick, J. H., K.E.F. Hokanson, and B. R. Jones. 1972. Effects of temperature on growth and survival of young brook trout, Salvelinus fontinalis. J. Fish. Res. Bd. Canada. 29:1107-1112.

3. Fry, F.E.J., J. S. Hart, and K.F. Walker. 1946. Lethal temperature relations for a sample of young speckled trout, Salvelinus fontinalis. Univ. Toronto Studies, Biol. Ser. 54, Publ. Ontario Fish Res. Lab. 66:1-35.

4. Carlander, K. D. 1969. Handbook of freshwater fishery biology, Vol. 1, 3rd Ed. The Iowa State Univ. Press, Ames, Iowa.

# FISH TEMPERATURE DATA SHEET

Species: Carp, *Cyprinus carpio*

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 20 | | 31-34* | | 3 |
| | 26 | | 36* | | 3 |
| | | | | | |
| | | | | | |
| | | | *24 hr. $TL_{50}$ | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | | | | |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 19-23(2) | 16(4)-26(: | Mar-Aug(5 | 2,4,5 |
| Incubation and hatch | | 17-22 (7) | | 7 |
| | Abnormal larvae after 35° shock of embryo | | | 1 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | 25-35(6) | | 31-32(6) | | 6 |
| | Summer | | | 33-35 | 8 |
| | 10 | | 17 | | 6 |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Carp

### References

1. Frank, M. L. 1973. Relative sensitivity of different stages of carp to thermal shock. Thermal Ecology Symposium, May 3-5, 1973, Augusta, Ga.

2. Swee, U. B. and H. R. McCrimmon. 1966. Reproductive biology of the carp, _Cyprinus carpio L._, in Lake St. Lawrence, Ontario. Trans. Amer. Fish. Soc. 95:372-380.

3. Black, E. C. 1953. Upper lethal temperatures of some British Columbia freshwater fishes. J. Fish. Res. Bd. Can. 10:196-210.

4. Sigler, W. F. 1958. The ecology and use of carp in Utah. Utah Agric. Exp Sta., Bull. 405.

5. Carlander, K. 1969. Handbook of Freshwater Fishery Biology, Vol. 1, Iowa State Univ. Press. p. 105.

6. Pitt, T. K., E. T. Garside, and R. L. Hepburn. 1956. Temperature selection of the carp (_Cyprinus carpio_ Linn.). Can. Jour. Zool. 34:555-557.

7. Burns, J. W. 1966. Carp. In: Inland Fisheries Management. A. Calhoun, ed., Calif. Div. Game and Fish.

8. Gammon, J. R. 1973. The effect of thermal inputs on the population of fish and macroinvertebrates in the Wabash River. Tech. Rept. No. 32, Purdue Univ. Water Resources Res. Center.

# FISH TEMPERATURE DATA SHEET

Species: Channel catfish, Ictalurus punctatus

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 15 | 31(3)* | | 30(2) | 2,3 |
| | 25 | | 35(1) | 33(2) | 1,2 |
| | 30 | | 37 | | 1 |
| | 35 | | 38 | | 1 |
| | | *No acclimation temperature give | | | |
| Lower | 15 | | | 0 | 2 |
| | 20 | | | 0 | 2 |
| | 25 | | | 0 | 2 |
| | | | | | |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | 29-30(3) | 28-30(10) | | 3,10 |
| [range[2]] | (27-31)(3) | (22-34)(4) | | 3,4 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 27(5) | 21-29(5) | Apr-July(6 | 5,6 |
| Incubation and hatch | 22(8) | 18(7)-29(5) | | 5,7,8 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Summer | | | 30-32* | 9 |
| | | | | | |
| | | | | | |
| | | | | *field | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Channel catfish

## References

1. Allen, K. O. and K. Strawn. 1968. Heat tolerance of channel catfish, Ictalurus punctatus. Proc. Conf. of S. E. Assoc. of Game and Fish Comm. 1967.

2. Hart, J. S. 1952. Geographical variations of some physiological and morphological characters in certain freshwater fish. Univ. Toronto Biological Series No. 60.

3. West, B. W. 1966. Growth, food conversion, food consumption and survival at various temperatures of the channel catfish, Ictalurus punctatus (Rafinesque). Master's Thesis, Univ. Ark.

4. Andrew, J. W. and R. R. Stickney. 1972. Interaction of feeding rate and environmental temperature of growth, food conversions and body composition of channel catfish. Trans. Amer. Fish. Soc., 101:94-97.

5. Clemens, H. P. and K. F. Sneed. 1957. The spawning behavior of the channel catfish, Ictalurus punctatus. USFWS, Special Sci. Rept. Fish No. 219.

6. Brown, L. 1942. Propagation of the spotted channel catfish, Ictalurus lacustris punctatus. Kan. Acad. Sci. Trans., 45:311-314.

7. McClellan, W. G. 1954. A study of southern spotted channel catfish, Ictalurus punctatus (Rafinesque). M. S. Thesis, N. Texas St. College. Cited in: Carlander, K. D., 1969. Handbook of Freshwater Fishery Biology. Vol. 1, Iowa State Univ. Press, Ames, Iowa.

8. Hubbs, C. L. and E. R. Allen. 1944. Fishes of Silver Springs, Florida. Proc. Fla. Acad. Sci., Vol. 6, 1943-44.

9. Gammon, J. R. 1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River. Tech Rept. 32, Purdue Univ. Water Resources Res. Center.

10. Andrews, J. W., L. H. Knight, and Takeshi Murai. 1972. Temperature requirements for high density rearing of channel catfish from fingerling to market size. Prog. Fish. Cult. 34:240-241.

# FISH TEMPERATURE DATA SHEET

Species: Cisco (Lake herring), Coregonus artedii

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | 2(3), 3(2) | 20(2) | 20(3) | 20(4,6)* | 2,3,4,6 |
| | 5(3), <10(5) | | 22(3) | <24(5) | 3,5 |
| | >13 | | 26 | | 3 |
| | 20 | | 26 | | 3 |
| | 25 | | 26 | | 3 |
| | | | | *accl. temp. unknown | |
| Lower | 2 | | 3 | | 3 |
| | 5 | | .5 | | 3 |
| | 10 | | 3 | | 3 |
| | 20 | | 5 | | 3 |
| | 25 | | 10 | | 3 |

| II. Growth:[1/] | larvae | juvenile | adult | data source |
|---|---|---|---|---|
| Optimum and | 16 | | | 2 |
| [range[2/]] | (13-18) | | | 2 |

| III. Reproduction: | optimum | range | month(s) | data source |
|---|---|---|---|---|
| Migration | To spawning grounds at ≈ 5 | | | 7 |
| Spawning | 3 | 1-5 | Nov-Dec | 7,8,9 |
| Incubation and hatch | 6(1) | 2-8(1) | Apr-May<br>(8-9) | 1,8,9 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | data source |
|---|---|---|---|---|---|
| | | | | 13 | 6 |

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

# Cisco

## References

1. Colby, P. J. and L. T. Brooks. 1970. Survival and development of the herring (Coregonus artedii) eggs at various incubation temperatures. In: Biology of Coregonids, C. C. Lindsay and C. S. Woods, ed., Univ. Manitoba. pp. 417-428.

2. McCormick, J. H., B. R. Jones and R. F. Syrett. 1971. Temperature requirements for growth and survival of larval ciscos (Coregonus artedii). J. Fish. Res. Bd. Canada 28:924-927.

3. Edsall, T. A. and P. J. Colby. 1970. Temperature tolerance of young-of-the-year Cisco, Coregonus artedii. Trans. Amer. Fish. Soc. 99:526-531.

4. Frey, D. G. 1955. Distributional ecology of the Cisco (Coregonus artedii). Investigations of Indiana Lakes and Streams. 4:177-228.

5. Colby, P. J. and L. T. Brooke. 1969. Cisco (Coregonus artedii) mortalities in a Southern Michigan lake, July 1968. Limnology & Oceanog. 14:958-960.

6. Dryer, W. R. and J. Beil. 1964. Life history of lake herring in Lake Superior. U. S. Fish. Bull. 63:493-530.

7. Cahn, A. R. 1927. An ecological study of southern Wisconsin fishes, the brook silversides (Labidesthes sicculus) and the cisco (Leucichthys artedii, LeSueur). Ill. Biol. Monogr. 11:1-151.

8. Carlander, K. D. 1969. Handbook of Freshwater Fishery Biology. Vol. 1, Iowa State Univ. Press, Ames, Iowa.

9. McCormick, J. H. 1973. Personal observations.

# FISH TEMPERATURE DATA SHEET

Species: Coho salmon, *Oncorhynchus kisutch*

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 5 | | 23 | | 1 |
| | 10 | | 24 | 21* (3) | 1,3 |
| | 15 | | 24 | | 1 |
| | 20 | | 25 | | 1 |
| | 23 | | 25 | | 1 |
| | | | | *Accl. temp | unknown |
| Lower | 5 | | 0.2 | | 1 |
| | 10 | | 2 | | 1 |
| | 15 | | 3 | | 1 |
| | 20 | | 5 | | 1 |
| | 23 | | 6 | | 1 |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | | 15* | | 2 |
| [range[2]] | | (5-17) | | 6 |
| | | | | |
| | | | | |
| | | *unlimited food | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | 7-16 (5) | | 5 |
| Spawning | | 7-13 (3) | Fall | 3 |
| Incubation and hatch | | | | |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Winter | | | 13 | 4 |
| | | | | | |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Coho salmon

## References

1. Brett, J. R. 1952. Temperature tolerance in young pacific salmon, genus Oncorhynchus. J. Fis. Res. Bd. Can. 9:265-323.

2. Great Lakes Research Laboratory, 1973. Growth of Lake trout in the laboratory Progress in Sport Fishery Research. 1971. USDI, Fish and Wildlife Service, Bureau of Sport Fisheries and Wildlife.

3. Anonymous. 1971. Columbia River thermal effects study. Vol. 1, Environmental Protection Agency.

4. Edsall, T. 1970. Personal communication to J. H. McCormick, National Water Quality Laboratory, Duluth, Minnesota.

5. Burrows, R. E. 1963. Water temperature requirements for maximum productivity of salmon. Proceedings of the 12th Pacific N. W. Symposium on Water Poll. Res.

6. Averett, R. C. 1968. Influence of temperature on energy and material utilization by juvenile coho salmon. Ph.D. Thesis, Oregon State Univ.

# FISH TEMPERATURE DATA SHEET

Species: Emerald Shiner, Notropis atherinoides

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| | 5 | | 22-23 | | 1 |
| Upper | 10 | | 27 | | 1 |
| | 15 | | 29 | | 1 |
| | 20 | | 31 | | 1 |
| | 25 | | 31 | | 1 |
| Lower | | | | | |
| | | | | | |
| | 15 | | 2 | | 1 |
| | 20 | | 5 | | 1 |

| II. Growth:[1/] | larvae | juvenile | adult | data source |
|---|---|---|---|---|
| Optimum and | | 29 | | 2 |
| [range[2/]] | | (24-31) | | 2 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | data source |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 20(3)-27(6) | May-Aug(1)<br>(5) | 1,3,5,6 |
| Incubation and hatch | | | | |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | data source |
|---|---|---|---|---|---|
| | Summer | | 25* | | 3 |
| | Winter | | 27* | | 4 |
| | | | | | |

*unknown age

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

## Emerald shiner

## References

1. Carlander, R. D. 1969. Handbook of freshwater fishery biology. Vol. 1, Iowa State Univ. Press, Ames, Iowa.

2. McCormick, J. H. and C. F. Kleiner. 1970. Effects of temperature on growth and survival of young-of-the-year emerald shiners (*Notropis atherinoides*) Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

3. Campbell, J. S. and H. R. Mac Crimmon. 1970. Biology of the emerald shiner *Notropis atherinoides* Rafinesque in Lake Simcoe, Canada. J. Fish. Biol. 2(3):259-273.

4. Wapora, Inc. for the Ohio Electric Utilities Inst. 1971. The effect of temperature on aquatic life in the Ohio River. Final Report.

5. Flittner, G. A. 1964. Morphometry and life history of the emerald shiner, *Notropis atherinoides* Rafinesque. Ph.D. Thesis, Univ. of Mich.

6. Gray, J. W., 1942. Studies on *Notropis atherinoides athernoides* Rafinesque in the Bass Islands Region of Lake Erie. Master's Thesis, Ohio State Univ.

## FISH TEMPERATURE DATA SHEET

Species: Freshwater drum, *Aplodinotus grunniens*

I. Lethal threshold:

| | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

II. Growth:[1/]

| | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2/]] | | | | |
| | | | | |
| | | | | |
| | | | | |

III. Reproduction:

| | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 21 | 19-24 | May-June | 1,2,3,5,6 |
| Incubation and hatch | | 22-26 | | 1,4,6 |

IV. Preferred:

| acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|
| Summer | | | 29-31* | 7 |
| | | | | |
| | | | | |

*Field

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

## Freshwater drum

## References

1. Wrenn, B. B. 1969. Life history aspects of smallmouth buffalo and freshwater drum in Wheeler Reservoir, Alabama. Proc. 22nd Ann. Conf. S. E. Assoc. Game and Fish Comm., 1968. p. 479-495.

2. Butler, R. L. and L. L. Smith, Jr. 1950. The age and rate of growth of the sheepshead, *Aplodinotus grunniens* Rafinesque, in the upper Mississippi River navigation pools. Trans. Amer. Fish. Soc. 79:43-54.

3. Daiber, F. C. 1953. Notes on the spawning population of the freshwater drum, *Aplodinotus grunniens* (Rafinesque) in western Lake Erie. Amer. Mid. Nat. 50:159-171.

4. Davis, C. D. 1959. A planktonic fish egg from freshwater. Limn. Ocean 4:352-355.

5. Edsall, T. A. 1967. Biology of the freshwater drum in Western Lake Erie. Ohio Jour. Sci. 67:321-340.

6. Swedberg, D. V. and C. H. Walburg. 1970. Spawning and early life history of the freshwater drum in Lewis and Clark Lake, Missouri River. Trans. Am. Fish. Soc. 99:560-571.

7. Gammon, J. R. 1973. The effect of thermal inputs on the populations of fish and macroinvertebrates in the Wabash River. Tech. Rept. 32. Purdue Univ. Water Resources Research Center.

# FISH TEMPERATURE DATA SHEET

Species: Largemouth bass, Micropterus salmoides

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | 20 | | 33 | | 1 |
| | 25 | | 35 | | 1 |
| | 30 | | 36 | | 1 |
| | 35 | | 36 | | 1 |
| Lower | 20 | | 5 | | 1 |
| | 25 | | 7 | | 1 |
| | 30 | | 11 | | 1 |
| | | | | | |

| II. Growth:[1/] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | 27 | 30(8) | | 2,8 |
| [range[2/]] | (20-30) | 23-31(8) | | 2,8 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 21(4) | 16-27(4) | Apr-June(3)<br>Nov-May(4) | 3,4 |
| Incubation and hatch | 20(5) | 13(6)-26(9) | | 5,6,9 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | 30-32* | | 7 |
| | | | | | |
| | | | | | |

*season not given

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

# Largemouth bass

## References

1. Hart, J. S. 1952. Geographic variations of some physiological and morphological characters in certain freshwater fish. Univ. Toronto Biological Series No. 60.

2. Strawn, Kirk. 1961. Growth of largemouth bass fry at various temperatures. Trans. Amer. Fish. Soc., 90:334-335.

3. Kramer, R. H. and L. L. Smith, Jr. 1962. Formation of year class in largemouth bass. Trans. Amer. Fish. Soc., 91:29-41.

4. Clugston, J. P. 1966. Centrarchid spawning in the Florida Everglades. Quart. Jour. Fla. Acad. of Sci., 29:137-143.

5. Badenhuizen, T. 1969. Effect of incubation temperature on mortality of embryos of largemouth bass Micropterus salmoides Lacepede. Master's Thesis, Cornell University.

6. Kelley, J. W. 1968. Effects of incubation temperature on survival of largemouth bass eggs. Prog. Fish. Cult. 30:159-163.

7. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15:607-624.

8. Lee, R. A. 1969. Bioenergetics of feeding and growth of largemouth bass in aquaria and ponds. MS Thesis, Oregon State University.

9. Carr, M. H. 1942. The breeding habits, embryology and larval development of the largemouth black bass in Florida. Proc. New Eng. Zool. Club, 20:43-77.

## FISH TEMPERATURE DATA SHEET

Species: Northern pike, Esox lucius

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 18 | 25,28* | | | 2 |
| | 25 | | 32 | | 1 |
| | 27 | | 33 | | 1 |
| | 30 | | 33** | | 1 |
| Lower | | | | | |
| | 18 | 3* | | | 2 |

*At hatch and free swimming, respectively
**Ultimate incipient level

*At hatch and free swimming

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | 21 | 26 | | 2 |
| [range[2]] | (18-26) | | | 2 |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 4(4)-19(3) | Feb-June (5) | 3,4,5 |
| Incubation and hatch | 12 | 7-19 | | 2 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | 24,26* | | 6 |

*Grass pickrel and musky, respec

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Northern pike

### References

1. Scott, D. P. 1964. Thermal resistance of pike (*Esox lucius L.*) muskellunge (*E. masquinongy*, Mitchell) and their $F_1$ hybrid. J. Fish. Res. Bd. Canada 21:1043-1049.

2. Hokanson, K.E.F., J. H. McCormick and B. R. Jones. 1973. Temperature requirements for embryos and larvae of the northern pike, *Esox lucius* (Linnaeus). Trans. Amer. Fish. Soc. 102:89-100.

3. Fabricus, E. and K. J. Gustafson. 1958. Some new observations on the spawning behavior of the pike, *Esox lucius* L. Rep. Inst. Freshwater Res., Drottningholm 39:23-54.

4. Threinen, C. W., C. Wistrom, B. Apelgren and H. Show. 1966. The northern pike, its life history, ecology, and management. Wis. Con. Dept. Publ. No. 235, Madison.

5. Toner, E. D. and G. H. Lawler. 1969. Synopsis of biological data on the pike *Esox lucius* (Linnaeus 1758). Food and Ag. Org. Fisheries synopsis No. 30, Rev. 1.

6. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15:607-624.

## FISH TEMPERATURE DATA SHEET

Species: Rainbow trout, Salmo gairdneri

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 18 | | 27 | | 1 |
| | 19 | | | 21 | 2 |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | | 17-19 | | 5 |
| [range[2]] | (3(8) - ) | | | 8 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 5-13(6) | Nov-Feb(7)<br>Feb-June(7) | 6,7 |
| Incubation and hatch | 5-7(9) | 5-13(4) | | 4,9 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Not given | | 14 | | 3 |
| | | | | | |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Rainbow trout

## References

1. Alabaster, J.S. and R. L. Welcomme. 1962. Effect of concentration of dissolved oxygen on survival of trout and roach in lethal temperatures. Nature, Lond. 194(4823), 107-.

2. Coutant, C. C. 1970. Thermal stress of adult coho (Oncorhynchus kisutch) and jack chinook (O. tshawytscha) salmon, and the adult steelhead trout (Salmo gairdnerii) from the Columbia River. AEC BNWL 1508.

3. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada, 15:607-624.

4. McAfee, W. R. 1966. Rainbow trout. In: Inland Fisheries Management. A. Calhoun, (ed.), Calif. Dept. Fish & Game, pp.192-215.

5. Hokanson, K.E.F. and C. F. Kleiner. 1973. Unpublished data, National Water Quality Laboratory, Duluth. Minnesota.

6. Rayner, H. J. 1942. The spawning migration of rainbow trout at Skaneateles Lake, New York. Trans. Amer. Fish. Soc. 71:180-83. In: Carlander, K. D. 1969. Handbook of Freshwater Fishery Biology, Vol. 1.

7. Carlander, K. D. 1969. Handbook of Freshwater Fishery Biology. Vol. 1, The Iowa State Univ. Press, Ames, Iowa.

8. Wojno, T. 1972. The effect of starvation and various doses of fodder on the changes of body weight and chemical composition and the survival rate in rainbow trout fry (Salmo gairdneri, Richardson) during the winter. Roczniki Nauk Rolniczych Series H - Fisheries 94, 125. In: Thermal effects. A review of the 1973 literature, C. C. Coutant and H. A. Pfuderer.

9. Timoshina, L. A. 1972. Embryonic development of the rainbow trout (Salmo gairdneri irideus, Gibb.) at different temperatures. Jour. Icthyol. (USSR), 12, 425. In: Thermal effects, a review of the 1973 literature, C. C. Coutant and H. A. Pfuderer.

## FISH TEMPERATURE DATA SHEET

Species: Sauger, Stizostedion canadense

I. Lethal threshold:

| | acclimation temperature | larvae | juvenile | adult | data source3/ |
|---|---|---|---|---|---|
| Upper | 9-21 | 75-92%* | | | 5 |
| | 12 | | 27 | | 5 |
| | 18 | | 29 | | 5 |
| | 22 | | 30 | | 5 |
| | 26 | *survival | 31 | | 5 |
| Lower | 6 | 0%* | | | 5 |
| | | | | | |
| | | | | | |

*survival

II. Growth:1/

| | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range2/] | | 22 | | 5 |
| | | | | |
| | | | | |
| | | | | |

III. Reproduction:

| | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 10(4) | 6(1)-14(3) | Apr-May(3,1) | 1,3,4 |
| Incubation and hatch | 12-15* | 10-16* | | 5 |

*Max. egg survival *>50% survival

IV. Preferred:

| | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | 19* | 2 |
| | Summer | | | 27-29 | 6 |
| | | | | | |

*field

---

1/ As reported or net growth (growth in wt. minus wt. of mortality).

2/ As reported or to 50% of optimum if data permit.

3/ List sources on back of page in numerical sequence.

## Sauger

## References

1. Nelson, W. R. 1968. Reproduction and early life history of sauger, Stizostedion canadense, in Lewis and Clark Lake. Trans. Amer. Fish. Soc. 97:167-174.

2. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada. 15:607-624.

3. Hall, G. E. 1972. Personal communication, TVA.

4. Hassler, W. W. 1956. The influence of certain environmental factors on the growth of Norris Reservoir sauger Stizostedion canadense canadense (Smith). Proceedings of Southeastern Assoc. of Game and Fish Commissioners Meeting, 1955. p. 111-119.

5. Smith, L. L. 1973. The effect of temperature on the early life history stages of the Sauger, Stizostedion canadense (Smith). Preliminary data, EPA Grant.

6. Gammon, J. R. 1973. The effect of thermal input on the populations of fish and macroinvertebrates in the Wabash River. Tech. Rept. 32, Purdue Univ. Water Resources Res. Center.

## FISH TEMPERATURE DATA SHEET

Species: Smallmouth bass, micropterus dolomieui

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | | 33* (9) | 35(3) | | 9, 3 |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | 15(3) | 4(9)* | 2(3) | | 3,9 |
| | 18 | | 4 | | 3 |
| | 22 | | 7 | | 3 |
| | 26 | | 10 | | 3 |

*acclimation not given

*acclimation temperature not given

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | 28-29(2) | 26(3) | | 2,3 |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 17-18(5) | 13(8)-21(7) | May-July(8) | 5,7,8 |
| Incubation and hatch | | | | |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Summer | | | 21-27 | 6 |
| | Winter | | | >8*(1)-28(4) | 1,4 |
| | | | | | |

*Life stage unknown

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

Smallmouth bass

## References

1. Munther, G. L. 1968. Movement and distribution of smallmouth bass in the Middle Snake River. Master's Thesis, Univ. Idaho.

2. Peek, F. W. 1965. Growth studies of laboratory and wild population samples of smallmouth bass. Master's Thesis, Univ. Arkansas.

3. Horning, W. B. and R. E. Pearson. 1973. Temperature requirements for juvenile smallmouth bass (Micropterus dolomieui): growth and lower lethal temperatures. J. Fish. Res. Bd. Canada (in press).

4. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada. 15:607-624.

5. Breder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. Natural History Press.

6. Emig, J. W. 1966. Smallmouth bass. In: Inland Fisheries Mgt., A. Calhoun, ed; Calif. Dept. Fish and Game.

7. Hubbs, C. L. and R. M. Baily. 1938. The smallmouth bass. Cranbrook Inst. Sci. Bull. 10.

8. Surber, E. W. 1943. Observations on the natural and artifical propagation of the smallmouth black bass, Micropterus dolomieui. Trans. Amer. Fish. Soc. 72:233-245.

9. Larimore, R. W. and M. J. Duever. 1968. Effects of temperature acclimation on the swimming ability of smallmouth bass fry. Trans. Amer. Fish. Soc. 97:175-184.

# FISH TEMPERATURE DATA SHEET

Species: Smallmouth buffalo, Ictiobus bubalus

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | | | | |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 17(1,3) | 14(1)-21(1,2) | Mar-Jun (3) | 1,2,3 |
| Incubation and hatch | | 14(1)-21(2) | | 1,2 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | 31-34* | 4 |
| | | | | | |
| | | | | | |

*Ictiobus sp. field

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## Smallmouth buffalo

## References

1. Wrenn, W. B. 1969. Life history aspects of smallmouth buffalo and freshwater drum in Wheeler Reservoir, Alabama. Proc. 22nd Ann. Conf. S. E. Assoc. Game & Fish Comm., 1968. pp. 479-495.

2. Walburg, C. H. and W. R. Nelson. 1966. Carp, river carpsucker, smallmouth buffalo and bigmouth buffalo in Lewis and Clark Lake, Missouri River. Bur. Sport Fish. and Wildl. Res. Rep. 69.

3. Walker, M. C. and P. T. Frank. 1952. The propagation of buffalo. Prog. Fish. Cult. 14:129-130.

4. Gammon, J. R. 1973. The effect of thermal input on the populations of fish and macroinvertebrates in the Wabash River. Tech. Rept. 32, Purdue Univ. Water Resources Research Center.

# FISH TEMPERATURE DATA SHEET

Species: Sockeye salmon, *Oncorhynchus nerka*[a]

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | 5 | | 22 | | 1 |
| | 10 | | 23 | | 1 |
| | 15 | | 24 | | 1 |
| | 20 | | 25 | | 1 |
| Lower | 5 | | 0 | | 1 |
| | 10 | | 3 | | 1 |
| | 15 | | 4 | | 1 |
| | 20 | | 5 | | 1 |
| | 23 | | 7 | | 1 |

| II. Growth:[1] | larvae | juvenile | adult | data source |
|---|---|---|---|---|
| Optimum and | 15(6) | 15(2)* | | 2,6 |
| [range[2]] | | 10-15 | | 5 |
| | | | | |
| | | | | |

*Max. with excess food

| III. Reproduction: | optimum | range | month(s) | data source |
|---|---|---|---|---|
| Migration | | 7-16 | | 5 |
| Spawning | | 7-13 | Fall | 7 |
| Incubation and hatch | | 6-13 | | 4 |

| IV Preferred: | acclimation temperature | larvae | juvenile | adult | data source |
|---|---|---|---|---|---|
| | | | | | |
| | Summer | | 15 | | 3 |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

[a] Data for sea-run Sockeye, not Kokanee

## Sockeye Salmon

## References

1. Brett, J. R. 1952. Temperature tolerance in young pacific salmon, genus, Oncorhynchus. J. Fis. Res. Bd. Can. 9:265-323.
2. Griffiths, J. S. and D. F. Alderdice. 1972. Effects of acclimation and accute temperature experience on the swimming speed of juvenile coho salmon. J. Fish. Res. Bd. Can. 29:251-264.
3. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Can. 15:607-624.
4. Combs, B. D. and R. E. Burrows. 1957. Threshold temperatures for the normal development of chinook salmon eggs. Prog. Fish. Cult. 19:3-6.
5. Burrows, R. E. 1963. Water temperature requirements for maximum productivity of salmon. Proceedings of the 12th Pacific N. W. Symposium on Water Poll. Res.
6. Shelbourn, J. E. 1973. Effect of temperature and feeding regime on the specific growth rate of sockeye salmon fry (Oncorhynchus nerka) with a consideration of size effect. Jour. Fish. Res. Bd. Can. 30, 1191 No. 8
7. Anonymous. 1971. Columbia River thermal effects study. Vol. 1, Environmental Protection Agency.

# FISH TEMPERATURE DATA SHEET

Species: Striped bass, Morone saxatilis

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

| II. Growth:[1/] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2/]] | | | | |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 17-19 | 13-22 | Apr-July | 1,2,3,4,5 |
| Incubation and hatch | | 16-24 | | 1 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | | |
| | | | | | |
| | | | | | |

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

## Striped bass

## References

1. Shannon, E. H. 1970. Effect of temperature changes upon developing striped bass eggs and fry. Proc. 23rd Conf. S. E. Assoc. Game and Fish Comm. October 19-22, 1969, pp. 265-274.

2. Goodson, L. F., Jr. 1966. Landlocked striped bass. In: Inland Fisheries Mgmt, A. Calhoun, ed., Calif. Dept. Fish & Game.

3. Talbot, G. B. 1966. Estuarine environmental requirements and limiting factors for striped bass. In: "A Symposium on Estuarine Fisheries," Amer. Fish. Soc. Special Publ. No. 3, pp. 37-49.

4. Pearson, J. C. 1938. The life history of the striped bass or rockfish. Bull. of the Bureau of Fisheries 48 (28):825-851.

5. Raney, E. C. 1952. The life history of the striped bass. Bull. Bingham Oceanogr. Coll. 14:5-97.

# FISH TEMPERATURE DATA SHEET

Species: Threadfin shad Dorosoma petenense

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3/] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |
| Lower | | | | | |
| | | | 9* | | 1 |
| | | | | | |
| | | | | | |

*lowest permitting some survival

| II. Growth:[1/] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2/]] | | | | |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 14-21(3,4) | Apr-Aug (4) | 3,4 |
| Incubation and hatch | | 23(5)-34(7)<br>17-27(6) | | 5,6,7 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | >19 | 2 |
| | | | | | |
| | | | | | |

---

[1/] As reported or net growth (growth in wt. minus wt. of mortality).

[2/] As reported or to 50% of optimum if data permit.

[3/] List sources on back of page in numerical sequence.

# Threadfin shad

## References

1. Strawn, K. 1963. Resistance of threadfin shad to low temperatures. Proc. 17th Ann. Conf. Southeastern Assoc. of Game and Fish Comm. pp. 290-293.

2. Adair, W. D. and D. J. DeMont. 1970. Effects of thermal pollution upon Lake Norman fishes. N. Carolina Wildlife Res. Comm., Div. Inland Fisheries. Summary Report, Fed. Aid Fish Restoration Project F-19-2. 14 p.

3. Maxwell, R. and A. R. Essbach. 1971. Eggs of threadfin shad successfully transported and hatched after spawning on excelsior mats. Prog. Fish. Cult. 33:140.

4. Carlander, K. D. 1969. Handbook of freshwater fishery biology. The Iowa State Univ. Press, Ames, Iowa.

5. Shelton, W. L. 1964. The threadfin shad, *Dorosoma petenense* (Gunther): Oogenesis, seasonal ovarian changes and observations on life history. Master's Thesis, Oklahoma State Univ. 49 p.

6. Breder, C. M. and D. E. Rosen. 1969. Modes of reproduction in fishes, Natural History Press.

7. Hubbs, C. and C. Bryan. 1974. Maximum incubation temperature of the threadfin shad, *Dorosoma petenense*. Trans. Amer. Fish Soc. 103:369-371.

# FISH TEMPERATURE DATA SHEET

Species: White bass Morone chrysops

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | | | | | |
| Lower | | | | | |
| | 17 | 14* | | | 3 |

*% mortality not given

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | | 23-24* | | 4 |

*good growth in S.D. reservoir

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | | 14-24 (north) | Apr-Jul(North) | 1 |
| | | 12- (Tenn.) | Mar-May(Tenn) | 1 |
| Incubation and hatch | 16-17 | | | 2 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Summer | | | 28-30* | 5 |

*Field

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

# FISH TEMPERATURE DATA SHEET

Species: White crappie, Pomoxis annularis

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source[3] |
|---|---|---|---|---|---|
| Upper | | | | | |
| | | | | | |
| | | | | | |
| | | | 33* | | 5 |
| Lower | | | | | |
| | | | | | |
| | | | | | |
| | | | | | |

*Ultimate incipient level

| II. Growth:[1] | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and [range[2]] | | 25 | | 5 |
| | | | | |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 16-20(6) | 14-23(6)<br>18-20(4)* | Mar(4)-<br>July(3) | 3,4,6 |
| Incubation and hatch | | | | |

*begin spawning

Hatch in 24-27-1/2 hrs. at 21-23 — 2

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | 28-29 | 1 |
| | | | | | |
| | | | | | |

---

[1] As reported or net growth (growth in wt. minus wt. of mortality).

[2] As reported or to 50% of optimum if data permit.

[3] List sources on back of page in numerical sequence.

## White crappie

## References

1. Gammon, J. R. 1973. The effect of thermal input on the populations of fish and macroinvertebrates in the Wabash River. Tech.Rept. 32, Purdue Univ. Water Resources Research Center.

2. Breder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. Nat. History Press.

3. Morgan, G. D. 1954. The life history of the white crappie (Pomoxis annularis) of Buckeye Lake, Ohio. J. Sci. Lab. Denison Univ., Granville, Ohio. 43:113-144.

4. Goodson, Lee F. 1966. Crappie. In: Inland Fisheries Management A. Calhoun, Ed., Calif. Dept. Fish & Game.

5. Kleiner, C. F. and K. E. F. Hokanson. 1973. Effects of constant temperature on growth and mortality rates of juvenile white crappie, Pomoxis annularis Rafinesque. Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

6. Siefert, R. E. 1968. Reproductive behavior, incubation and mortality of eggs and post larval food selection in the White crappie. Trans. Amer. Fish. Soc. 97:252-259.

# FISH TEMPERATURE DATA SHEET

Species: White sucker Catostomus commersoni

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source 3/ |
|---|---|---|---|---|---|
| | 5 | | 26(2) | | 2 |
| Upper | 10 | 28 (1)* | 28(2) | | 1,2 |
| | 15 | 31 (1) | 29(2) | | 1,2 |
| | 20(2), 21(1) | 30 (1) | 29(2) | | 1,2 |
| | 25 | | 29 | | 2 |
| | 25-26 | | 31 | | 3 |
| | | *7-day TL50 for swimup | | | |
| Lower | | | | | |
| | 20 | | 2-3 | | 2 |
| | 21 | 6* | | | 1 |
| | 25 | | 6 | | 1 |
| | | *7-day TL50 for swimup | | | |

| II. Growth: 1/ | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | 27 | | | 1 |
| [range 2/] | (24-27) | | | 1 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | ∿ 10(5) | ∿ 4-18(5,6) | Mar-June (2) | 2,5,6 |
| Incubation and hatch | 15 | 8-21 | | 1 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | | | | 19-21 | 4 |
| | | | | | |
| | | | | | |

---

1/ As reported or net growth (growth in wt. minus wt. of mortality).

2/ As reported or to 50% of optimum if data permit.

3/ List sources on back of page in numerical sequence.

## White sucker

## References

1. McCormick, J. H., B. R. Jones, and K.E.F. Hokanson. 1972. Effects of temperature on incubation success and early growth and survival of the white sucker, Catostomus commersoni (Lacepede). Unpublished data, National Water Quality Laboratory, Duluth, Minnesota.

2. Carlander, K. D. 1969. Handbook of freshwater fishery biology. Vol. 1, 3rd Ed., The Iowa State Univ. Press., Ames, Iowa.

3. Brett, J. R. 1944. Some lethal temperature relations of Algonquin Park fishes. Publ. Ont. Fish. Res. Lab., 63:1-49.

4. Horak, D. L. and H. A. Tanner. 1964. The use of vertical gill nets in studying fish depth distribution. Horsetooth Reservoir, Colorado. Trans. Amer. Fish. Soc., 93:137-45.

5. Webster, D. A. 1941. The life history of some Connecticut fishes. Conn. Geol. and Nat. Hist. Survey Bull. No. 63. A Connecticut fishery survey, Section III, pp. 122-227.

6. Raney, E. C. 1943. Unusual spawning habitat for the common white sucker Catostomus c. commersonii Copeia. 4:256.

FISH TEMPERATURE DATA SHEET

Species: Yellow perch Perca flavescens

| I. Lethal threshold: | acclimation temperature | larvae | juvenile | adult | data source 3/ |
|---|---|---|---|---|---|
| Upper | 5 | | | 21 | 1 |
| | 11(1), 10(4) | 10(4)* | | 25(1) | 1,4 |
| | 15(1), 19(4) | 19(4)* | | 28(1) | 1,4 |
| | 25 | | | 30* | 1 |
| | 25 | *swim-up | | 32** | 1 |
| Lower | | | | *winter<br>**summer | |
| | | | | | |
| | 25 | | 4 | | 1 |
| | | | | | |

| II. Growth: 1/ | larvae | juvenile | adult | |
|---|---|---|---|---|
| Optimum and | | | | |
| [range 2/] | | | 13(6)-20(7) | 6,7 |
| | | | | |
| | | | | |

| III. Reproduction: | optimum | range | month(s) | |
|---|---|---|---|---|
| Migration | | | | |
| Spawning | 12(3) | 7(5)-15(3) | Mar-June (3) | 3,5 |
| Incubation and hatch | 10 up 1°/day to 20 | 7-20 | | 4 |

| IV. Preferred: | acclimation temperature | larvae | juvenile | adult | |
|---|---|---|---|---|---|
| | Winter | | 22(8) | 21(2) | 8,2 |
| | Summer | | 24 | | 2 |
| | 24 | | 20-23 | 18-20 | 9 |

---

1/ As reported or net growth (growth in wt. minus wt. of mortality).

2/ As reported or to 50% of optimum if data permit.

3/ List sources on back of page in numerical sequence.

## Yellow perch

## References

1. Hart, J. S. 1947. Lethal temperature relations of certain fish in the Toronto region. Trans. Roy. Soc. Can., Sec. 5 41:57-71.

2. Ferguson, R. G. 1958. The preferred temperature of fish and their midsummer distribution in temperate lakes and streams. J. Fish. Res. Bd. Canada 15:607-624.

3. Jones, B. R., K. E. F. Hokanson and J. H. McCormick. 1973. Winter temperature requirements of yellow perch. Unpublished data. National Water Quality Laboratory, Duluth, Minnesota.

4. Hokanson, K.E.F. and C. F. Kleiner. 1973. The effect of constant and rising temperature on survival and development rates of embryonic and larval yellow perch, Perca flavescens (Mitchill). Submitted for publication at International Symposium in the early life history of fish, Oban, Scotland, 1973.

5. Breeder, C. M. and D. E. Rosen. 1966. Modes of reproduction in fishes. Natural History Press.

6. Coble, D. W. 1966. Dependence of total annual growth in yellow perch on temperature. J. Fish. Res. Bd. Canada. 23:15-20.

7. Weatherley. 1963. Thermal stress and interrenal tissue in the perch, Perca fluviatilus (Linnaeus). Proc. Zool. Soc., London, Vol. 141:527-555.

8. Mildrim, J. W. and J. J. Gift. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthological Associates Bulletin 7, 301 Forest Drive, Ithaca, N.Y.

9. McCauley, R. W. and L. A. A. Read. 1973. Temperature selections by juvenile and adult yellow perch (Perca flavescens) acclimated to 24 C. J. Fish. Res. Bd. Canada. 30:1253-1255.

## II

## MARINE TEMPERATURE CRITERIA

The philosophy underlying criteria for marine and estuarine cooling water is that volumes shall be minimized to reduce plant passage of planktonic organisms. Accordingly, there shall be no dilution pumping.

a. The maximum acceptable increase in surface temperatures is 2.2°C (4°F) during fall, winter, and spring.

b. The maximum acceptable increase in surface temperatures is 1.1°C (2°F) during the summer (defined as July-September north of Long Island and the northern extremity of California; June-September south of those points).

c. Alteration of characteristic daily temperature cycles in either frequency or amplitude is unacceptable.

d. Exceeding the following summer maxima is unacceptable:

| | Maximum | True Daily Mean* |
|---|---|---|
| Tropical Regions (South of Cape Canaveral and Tampa Bay, Florida, Puerto Rico, Pacific tropical islands) | 32.2°C (90°F) | 30°C (86°F) |
| Cape Hatteras, N.C. to Cape Canaveral, Florida | 32.2°C (90°F) | 29.4°C (85°F) |
| Long Island (south shore) to Cape Hatteras, N.C. | 30°C (86°F) | 27.8°C (82°F) |

*True Daily Mean = the daily average of 24 hourly temperature readings. Data presently are not sufficient to prescribe general upper limits for other regions of the country. Nonetheless, development of ceilings on a case-by-case basis using best available data is recommended.

e. Rapid temperature decreases associated with plant shutdown are unacceptable when ambient water temperature is less than 15°C (59°F).

### RATIONALE

The preceding criteria summarize temperature conditions necessary to protect marine ecosystems and represent constraints which can be met by using submerged discharge. Volume of the vertical diffusion zone in which temperature criteria do not apply is intended to be minimized by siting on relatively deep and well flushed waters. Near-bottom diffuser discharge should be at a depth which would not only meet summer receiving water criteria at the surface (i.e. a delta 2°F rise) but which also results in a mixing zone without excessive horizontal dimensions. Biologically, loss of surface area is as important as volume considerations in the marine environment. As shallow portions of estuaries are highly productive and represent important nursery areas, shallow water discharge is not recommended.

An instantaneously measured ambient temperature is to serve as the baseline for permissible elevations. Baseline thermal conditions shall be measured at a site in which there is no unnatural thermal addition from any source, which is in reasonable proximity to the power plant, and which has similar hydrography to that of the receiving waters at the discharge point. Measurements shall be made 6 inches below the surface.

Estuarine and coastal communities normally experience diurnal and tidal temperature variations. Laboratory studies have demonstrated that thermal tolerance is enhanced when animals are maintained under a diurnally fluctuating temperature regime rather than at constant temperature (Costlow, 1971). In addition, a daily cyclic regime is protective as it serves to reduce the duration of single exposures of supraoptimal temperatures. This has been observed in the intertidal blue mussel (Mytilus edulis) (Pearce, 1969; Gonzalez, 1972). A mussel bed can tolerate brief exposure to summer low tide temperatures of 29-30°C if it is flooded intermittently by cooler tidal water. In the laboratory, constant exposure to 30°C caused mussel death in 9-12 hours, while 6-hour cyclic exposures from 30 to 25°C were tolerated for over 40 days.

It is also necessary to maintain the natural annual temperature cycle. This should approximate the historical thermal regime under which local biota evolved and indigenous communities developed. Regular thermal events, such as the diurnal cycle and irregular phenomena including atmospheric frontal passages, are examples of components of this historical regime. These natural heterogeneous temperature patterns must be maintained. A permissible incremental rise over ambient conditions is presently the best approach to define ecologically safe thermal elevations for the marine community.

During late fall, winter, and spring, natural temperature conditions are usually well below critical upper thermal limits for most life functions. More subtle effects of artificial heat on the biota, particularly from a total system standpoint, are not well documented for these seasons. Some marine species, including winter flounder and cod, require periods of cold water temperatures for maintenance of physiological condition, development, reproduction, and survival and growth of eggs and larvae (Rogers, in press; Johansen & Krogh, 1914). The recommended constraint of 2.2°C (4°F) elevation over ambient represents an increase of approximately 50 percent of the range of diurnal fluctuation in temperature commonly observed in well-mixed estuarine waters. The permissible elevation should meet environmental requirements of cold water species. It falls well within the tolerance range of most motile marine organisms passing through a thermal discontinuity Also protected are benthic or intertidal species confronted with thermal pulses resulting from tidal circulation of warm water.

During summer, natural thermal maxima can occur in magnitude sufficient to cause heat death or emigration by motile forms. This is particularly common in the tropics and warm temperate zones (Vaughan, 1918; Glynn, 1968; Chin, 1961). Natural thermal kills also occur in more northern waters, <u>e.g</u>. a winter flounder kill in Moriches Bay, Long Island, N.Y. (Nichols, 1918). Temperature incremental ceilings are applicable during the period of maximum natural heating when further thermal addition could be deleterious. These increments may be lower than prevailing water temperatures in some coastal embayments for certain periods, yet these are nonetheless times of thermal stress for the marine system. Some organisms continue to populate waters having a warmer daily regime, but thermally sensitive species are absent. Addition of heat from artificial sources at such sites during periods of maximum heating is not appropriate. For these regions of the country where data presently are not sufficient to prescribe general upper thermal limits, development of ceilings on a case-by-case basis is recommended.

Boundaries for regional ceilings are demarcated by biogeographic provinces. Species composition of the marine system, and most important, responses to elevated temperature, are generally similar within a region. Boundaries of a biotic province are characterized by significant thermal discontinuities. Boundary areas are maintained during summer or winter due to combined forces of current, wind, and coastal geomorphology. On the east coast, Cape Canaveral, Fla., Cape Hatteras, N.C., and Cape Cod, Mass., represent these boundaries. On the west coast, Pt. Conception in southern California marks the limit of warm and cold temperate zones.

Recommended thermal criteria are based on scientific evaluation of best available data. Selected representative data are tabulated below for an array of ecologically diverse marine organisms, grouped by biotic region. Data largely document limitations of thermal addition during summer. Unless otherwise noted, cited studies deal only with summer or warm-acclimated organisms. Results of sublethal effects studies are cited also. Twenty-four hour TLm (median tolerance limit) data have been adjusted by subtracting 2.2°C to estimate the upper thermal protection limit for the life history stage in question (Mihursky, 1969). Recognized biological variables such as recent environmental history, nutritional state, size, sex, and age are considered for all thermal effects investigations. Likewise, contrasting methods of study are considered.

Normally, thermal effects data derived in one biotic region should not be applied to another. Latitudinally separated populations of widely distributed species may exhibit significant generic variability and usually have experienced different recent environmental histories. The manner in which data relate seasonally to a local temperature regime is illustrated by the Cold Temperate Zone (southern portion) superimposed on the 20-year mean temperature curve of the Pawtuxet River at Solomons, Md. (Figure 1). It should be recognized that mean temperature curves show only the thermal norm, and not short-term extremes which are ecologically the more significant.

Boreal Zone, Atlantic Coast: This region extends from Cape Cod, Mass., to the Gulf of Maine. Insufficient data are available for setting regional temperature limits. Upper limits should be determined on a case-by-case basis using best available data for the site and its environs.

In the boreal region, maintenance of a general temperature regime resembling natural conditions is particularly important during winter months. Some boreal species require periods of uninterrupted low water temperatures to fulfill environmental requirements for successful maturation of sexual products, spawning, and subsequent egg and larval survival. Winter flounder (Pseudopleuronectes americanus) have an upper limit for spawning of 5.5°C (Bigelow and Schroeder, 1953). Spawning occurs during the winter.

Ten °C is the upper thermal limit for Atlantic salmon (Salmo salar) smolt migration to the sea, which normally occurs in June. Twelve °C inhibits maturation of sex products (DeCola, 1970). Development of winter flounder (Pseudopleuronectes americanus) eggs to hatching is reduced 50% at 13°C (Rogers, in press). Blood worm (Glycera americana) spawning is induced when temperatures reach 13°C (Creaser, 1973). Fifteen °C is the upper limit for spawning Atlantic herring (Clupea harangus) (Hela and Laevastu, 1962), and of an amphipod, Psammonx nobilis, (Scott, unpublished). In Atlantic herring, there is above normal incidence of a protozoan disease at 15°C (Sinderman, 1965); and at 16°C, there is a prevalence of erythrocyte degeneration (Sherburne, 1973). Field mortality of yellowtail flounder larvae (Limanda ferruginea) was observed at 17.8°C (Colton, 1959). The protection limit for yearling Atlantic herring (48-hr TLm - 2.2°C) is 19.0°C (Brawn, 1960). At 21°C, embryonic development ceases in the amphipod, Gammarus deuben (Steele and Steele, 1969). Above 21.1°C, spores are killed and growth is reduced in the macroalga, Chondrus crispus, which is commerically harvested as Irish moss (Prince & Kingsbury, 1973).

Cold Temperate Zone, Atlantic Coast: Temperature ceilings are particularly critical in the southern portion of this region (south shore of Long Island to Cape Hatteras, N.C.) where enclosed sounds and large coastal-plain bays and rivers are prevalent. Maximum temperatures should not exceed 30°C (86°F). The true daily mean should not exceed 27.8°C (82°F). Were 30°C to persist for over 4 to 6 hours, appreciable stress or direct mortality would occur among juvenile winter flounder, striped mullet larvae, Atlantic silversides eggs, larvae, and adults; adult northern puffer, adult blue mussel, and adult soft shell clam (*Mya arenaria*). Specific critical temperatures for these species are detailed in Figure 1. Adult protection limit (TLm - 2.2°C) is 28.8°C for sand shrimp (*Crangon septemspinosa*) and 30.8°C for opossum shrimp (*Neomysis americanus*). Both are important food organisms for fish (Mihursky & Kennedy, 1967). Respiration rate is depressed above 30°C in the mole crab (*Emerita talpoida*) (Edwards & Irving, 1943). At 31.5°C, there is 67% mortality in coot clam (*Mulinia lateralis*) when exposed for 6 hours (Kennedy, et al, 1974).

A limit of 27.8°C approximates the upper limit for larval growth of the coot clam (27.5°C; Calabrese, 1969) and the upper tolerance limit for soft shell clam adults (28.0°C; Pfitzenmeyer, unpublished). Between 28 and 30°C juvenile amphipods (*Corophium insidiosum*) leave their tubes and thereby lose natural protection from predation (Gonzelez, 1972). Such elevated temperatures may also have subtle sublethal effects, such as reducing feeding and growth. In the quahaug (*Mercenaria mercenaria*), growth is optimum at 20°C (Ansell, 1968). Growth is inhibited above 24°C in a rock weed (*Ascophyllum nodosum*) (Southland & Hill, 1970). Prolonged locomotion is markedly reduced at 22°C in the rock crab, *Cancer borealis*; at 28°C in *C. irroratus* (Jeffries, 1967). An oyster pathogen (*Dermocystidium marinum*) proliferates readily only above 25°C (Andrews, 1965).

High temperature will usually elicit avoidance response in fishes. Avoidance is triggered at 29°C in Atlantic menhaden (*Brevoortia tyrannus*), and at 26.5°C in sea trout (*Cynoscion regalis*) (Meldrin & Gift, 1971). Breakdown of the avoidance response in striped bass occurs at 30°C (Gift & Westman, 1971). Maximum reported temperature for capture of spotted hake (*Urophycis regis*) is 24.8°C in Chesapeaka Bay (Barans, 1972).

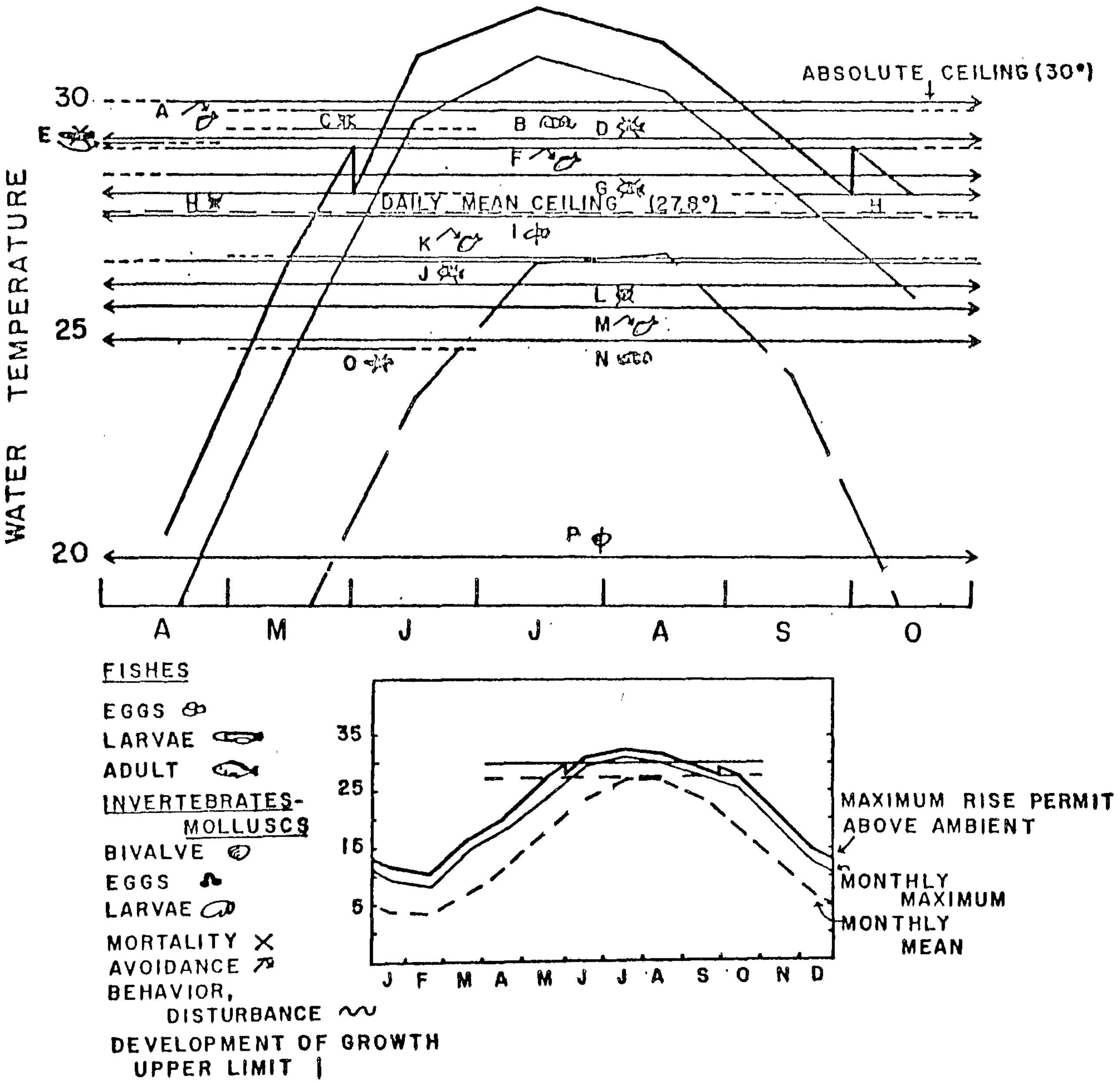


Figure 1. THERMAL EFFECTS ON MARINE SPECIES

## TABLE 1. SELECTED THERMAL REQUIREMENTS & LIMITING TEMPERATURE DATA

Atlantic Cold Temperate Biotic Province (Southern Portion):
South of Long Island, N.Y. to Cape Hatteras, N.C.

| Figure Designation | Temperature °C | °F | Effect | Species | Seasonal Occurrence | Reference |
|---|---|---|---|---|---|---|
| A | 30 | 86.0 | Avoidance response breakdown (CTM) | *Morone saxatilis*<br>(striped bass) | April-November | Gift & Westman, 1971 |
| B | 29.8 | 85.6 | Behavior-reduced feeding and behavior altered | *Pomatomus saltatrix*<br>(bluefish) | May-October | Olla, 1971 |
| C | 29.4 | 84.9 | Survival-eggs (50% optimal survival) | *Menidia menidia*<br>(Atlantic silverside) | May-June | Everich & Neves (unpublished) |
| D | 29.1 | 84.3 | Survival-larvae (TLm) | *Mugil cephalus*<br>(striped mullet) | January-April (coastal waters) | Cortenay & Roberts, 1973 |
| E | 29.0 | 84.2 | Survival-adult protection limit (TLm - 2.2°C) | *Sphaeroides maculatus*<br>(Northern puffer) | January-December | Hoff & Westman, 1966 |
| F | 29.0 | 84.2 | Avoidance response | *Brevoortia tyrannus*<br>(Atlantic menhaden) | April-October | Meldrim & Gift, 1971 |
| G | 29.2 | 82.7 | Survival-adult protection limit (TLm - 2.2°C) | *Menidia menidia*<br>(Atlantic silverside) | April-November | Hoff & Westman, 1966 |
| H | 28.0 | 82.4 | Survival-adult limit | *Mya arenaria*<br>(soft shell clam) | January-December | Pfitzenmeyer (unpublished) |
| I | 27.5 | 81.5 | Development-upper limit larval development | *Mulinia lateralis*<br>(coot clam) | March-October | Calabrese, 1969 |
| J | 26.9 | 80.4 | Survival-juvenile protection limit (TLm - 2.2°C) | *Pseudopleuronectes americanus*<br>(winter flounder) | April-December | Hoff & Westman, 1966 |
| K | 26.5 | 79.7 | Avoidance response | *Cynoscian regalis*<br>(sea trout) | May-October | Gift & Westman, 1971 |
| L | 26.0 | 78.8 | Survival-adult | *Mytilus edulis*<br>(blue mussel) | January-December | Gonzalez, 1973 |
| M | 25.5 | 77.9 | Avoidance response | *Leiostomus xanthrus*<br>(spot) | January-December | Gift & Westman, 1971 |
| N | 24.8 | 76.7 | Occurrence-maximum temperature for occurrence in Chesapeake Bay | *Urophycis reguis*<br>(spotted hake) | January-December | Barans, 1972 |
| O | 24.6 | 76.2 | Survival-larvae (TLm) | *Menidia menidia*<br>(Atlantic silverside) | May-June | Everich & Neves (unpublished) |
| P | 20 | 68.0 | Growth-optimum | *Mercenaria mercenaria*<br>(Northern quahaug) | January-December | Ansell, 1968 |

North of Long Island, a 1.1°C rise above summer ambient provides reasonable protection. For example, maximum short-term temperatures in Narragansett Bay, Rhode Island, usually would not exceed 23.4°C in August (judging from 15-year mean temperature data for Fox Island). Larval Atlantic silversides, juvenile winter flounder, and blue mussel should be protected by that thermal limitation. Thermal protection limit (TLm - 2.2°C) for juvenile winter flounder (Pseudopleuronectes americanus) is 26.9°C (Gift & Westman, 1966). Everich and Neves (unpublished) found that exposure to 24.6°C for 15 days caused 50% mortality of Atlantic silverside larvae (Menidia menidia). Repeated exposures to 25°C would stress the blue mussel (Mytilus edulis), causing cessation of feeding (Gonzalez, 1972) and arrest of embryonic development and larval growth (Hrs-Brenko, unpublished). Diurnal summer maxima exceeding 22°C can alter normal metabolic rates in embryonic tautog (Tautoga onitis) (Laurence, 1973) and cause feeding problems for adult winter flounder (Olla, 1969) and the sand-collar snail (Polinices duplicata) (Hanks, 1953).

Optimum for summer development of the rock crab larva (Cancer irroratus) is 20°C; at 25°C, mortality precludes completion of larval development. Optimum for the northern crab (C. borealis) is 15°C, with development blocked at 20°C (Sastry, unpublished). Between 15 and 20°C, activity of the amphipod (Gammarus oceanicus) is much reduced (Halcrow & Boyd, 1967). Initiation of spawning is often cued by temperature. Blue mussel spawning occurs when spring temperatures reach 12°C (Engle & Loosonoff, 1944). A minimum of 10°C is required for their embryonic development (Hrs-Brenko & Calabrese, 1969) and spawning occurs at 15°C. Migration occurs among striped bass, blue fish and Atlantic silversides (Hennekey, unpublished) at 15°C. Peak spawning runs of American shad (Alosa sapidissima) into rivers occurs at 19.5°C (15 year average, Connecticut River); downstream migration of juveniles occurs as temperature falls below 15.5°C (Leggett & Whitney, 1972). Menhaden migrate at 10°C (Bigelow & Schroeder, 1953); striped bass (Morone saxitallis) migrate into or leave rivers at 6 to 7.5°C (Merrimim, 1941). In the fall and winter, fishes congregate in discharge plumes which exceed these temperatures. These fishes exhibit increased incidence of disease and a general loss of physiological condition (Mihursky, et al, 1970).

*Warm Temperate Zone, Atlantic and Gulf Coasts*: This region extends from Cape Hatteras, N.C., to Cape Canaveral, Fla., and on the Gulf Coast from Tampa, Fla., to Mexico. A maximum of 32.2°C is the recommended ceiling. Exposures to temperatures above this level would adversely effect portions of the biota. The upper incipient lethal temperature for two dominant estuarine fishes, mullet and pinfish, is 33°C (Ceck, unpublished). At 33°C, bay anchovy (*Anchoa mitchilli*) embryonic development is reduced to 50% of optimum (Rebel, 1973). The upper tolerance limit for coot clam embryos (*Mulinia lateralis*) and for embryos and larvae of American oyster and quahaug is 32.5°C (Anon, 1969). The upper limit for growth of juvenile white shrimp (*Panaeus setiferus*) is 32.5°C (Zein-Eldin & Griffith, 1969). A decline in field abundance of brown shrimp (*P. aztecus*) at temperatures above 30°C was reported by Chin (1961).

Protection limits (50% of optimal survival) of two sardines (*Harengula jaquana* and *H. pensacolae*) for development of the yolk sac larval stage are 31.4°C and 32.2°C, respectively (Rebel, 1973; Sakensa, et al, 1972). The critical thermal maximum (CTM) is exceeded for striped bass at 30°C (Gift & Westman, 1971). Larval pinfish (*Lagodon rhompoides*), and spot (*Leistomus xanthurus*) have CTM's of 31.0°C and 31.1°C, respectively (Hoss, Hettler & Coston, 1973). Protection limit (TLm - 2.2°C) for young-of-the-year Atlantic menhaden is 30.8°C (Lewis & Hettler, 1968). Upper limit for adult growth of the quahaug (*Mercenaria mercenaria*) is 31°C (Ansell, 1968).

Mean temperatures exceeding 29°C would result in mortality of striped mullet (*Mugil cephalus*) eggs. Their 96-hr TLm is 26.4°C (Courtenay & Roberts, 1973). Egg and yolk sac larval survival of sea bream (*Archosargus rhomboidalis*) is reduced to 50% of optimal at 29.1°C. For yellowfin menhaden (*Brevoortia smithi*), exposure to 29.8°C reduced survival of egg and yolk sac larvae to 50% of optimal (Rebel, 1973). Sublethal but potentially damaging ecological effects could occur at levels well below 29°C. For example, the upper limit for optimal growth of post larval brown shrimp (Penaeus aztecus) is 27.5°C (Zein-Eldrin & Aldrich, 1965); in the American oyster (Crassostrea virginica) it is 25°C (Collier, 1954). Developing embryos and fry of striped bass cannot tolerate 26.7°C in fresh water (Shannon, 1969). This report may also apply to fry in waters at the head of estuaries. This species spawns in early spring. Elevation of winter temperatures above 20°C in St. Johns River, Florida, could interfere with upstream migration of American shad (Alosa sapidissima) (Leggett & Whitney, 1972).

Tropical Regions: Ceilings for tropical regions such as south Florida (Cape Canaveral and Tampa southward), Puerto Rico, and tropical-zone Pacific Islands are an instantaneous maximum 90°F (32.3°C) and a true daily mean not exceeding 86°F (30°C). A review by Zieman and Wood (in press) suggests that the thermal optimum is 26-28°C (79-82°F) for tropical marine systems, with chronic exposure to temperatures between 28 and 30°C causing heat stress. Death of the biota is readily discernible between 30°C and 32°C (86-89°F). Mayer (1914) recognized that nearshore tropical marine biota normally lives at temperatures only a few degrees below their upper lethal limit. A study of elevated temperature effects on the benthic community in Biscayne Bay, Florida, resulted in the following data (Roessler, 1971):

| Phylum | Temperature for High Species Diversity (°C) | Temperature for 50% Species Exclusion (°C) |
|---|---|---|
| Molluscs | 26.7 | 31.4 |
| Echinoderms | 27.2 | 31.8 |
| Coelenterates | 25.9 | 29.5 |
| Porifera | 24.0 | 31.2 |

Other thermal data for tropical biota include a 25.4-27.8°C optimum for fouling community larval settlement (Roessler, 1971); 25°C optimum for larval development of Polyonyx gibbesi, a commensal crab (Gore, 1968); 27°C for growth and gonad development in sea urchins (Lytechinus variegatus) and for growth in a snail (Cantharus tinctus) (Albertson, 1973); 27 to 28°C optimum for larval development of pink shrimp (Penaeus duorarum) (Thorhaug, et al, 1971); and 30°C optimum for turtle grass (Thalassia testidinum) productivity (Zieman, 1970). Kuthalingham (1959) studied thermal tolerance of newly hatched larvae of ten tropical marine fishes in the laboratory. When held at a series of constant temperatures for 12 hours, immediately following hatch, optimal survival for all species fell between 28-30°C, but their tolerance limit ranged from 30-32°C.

Thermal stress of the fouling community is seen in 50% reduced settlement rate at 28°C (Roessler, 1971). Fifty percent reduction in gonadal volume of the sea urchin (Lytechinus varigatus) occurs at 29.9°C (Thorhaug, et al, 1971 b). These workers also report irreversible plasmyolysis of the macroalga (Valonia ventricosa) at 29.9°C and of V. macrophysa at temperatures above 29.7°C. Survival of developing embryos to the yolk sac larval stage reduced to 50% of optimal at 29.1°C among sea bream (Archosargus rhomboidalis). At 29.8°C, yellowfin menhaden (Brevoortia smithi); and at 31.4°C scaled sardines (Harengula jaquana) suffer similar mortalities during early development (Rebel, 1973). Temperatures in excess of 31-33°C can interfere with embryonic development in six species of mangrove-associated nematodes, even though adults can tolerate 2 to 7°C additional heat (Hopper, et al, 1973). Upper limit for larval (naupliar) metamorphosis in pink shrimp (Penaeus duorarum) is 31.5°C (Thorhaug, et al, 1971 b). Upper lethal temperatures include 31.5°C for five species of Valonia (Thorhaug, 1970); death in 3-8 hours for five Hawaiian corals at 31-32°C (Edmondson, 1928; Jokiel & Coles, 1974); a 32°C TLm (95 hr) for the sea squirt (Ascidia nigra) and sea urchin (Lytechinus varigatis) (Chesher, 1971). Average daily temperatures near 31°C for three to ten days results in decreased growth in seagrass, Thallassia testudinium and red macroalgae, Laurencia poitei. Between 32 and 33°C, health and abundance of these species declines markedly (Thorhaug, 1971, 1973). Replacement of seagrass is slow, especially if rhizomes are damaged due to excessive consumption of stroed starch during heat stress (Zieman, 1973). Recovery of Thallassia beds may take decades (Zieman & Wood, in press).

Pacific Coast: Fewer thermal effects studies have been conducted on West Coast species. However, the concept of seasonal restrictions for temperature elevations above ambient are well supported in several East Coast provinces and is deemed applicable to the West Coast as a general biological principle. Data are not sufficient to develop specific regional ceilings. These must be determined on a case-by-case basis until specific principles emerge.

The Pacific Coast consists of two distinct biogeographical regions. The cold temperate province ranges north from Pt. Conception, California; the warm temperate region from Pt. Conception south. Published data on thermal effects are summarized by biotic province. These should provide a general guideline to prevent possible adverse effects on indigenous species by excessive thermal discharge.

*Pacific Cold Temperate Zone*: Some winter and spring spawning temperature ranges include 3-6°C for Pacific herring (*Clupea pullasi*) (McCauley & Hancock, 1971); 7-8°C for English sole (*Parophrys vetulus*) (Alderdice & Forester, 1968); 13°C for May and June spawning of razor clams (*Siliqua patula*) (McCauley & Hancock, 1971) and 12-14°C for native little neck clams (*Protothaca staminea*) (Schink & Woelke, 1973). Optimal growth occurs at 10°C in the small filamentous red algae (*Antithamnion* spp) (West, 1968), and 12-16°C is optimal for growth and reproduction of various red and brown algae, including kelp (*Macrocystis pyrifera*) (Druehl & Hisiao, 1969). Twelve to 16°C favors sea grasses, *Zostera marina* and *Plyllospadix scouleri* (McRoy, 1970). Spawning migration of striped bass (*Morone saxitilis*) occurs at 15-18°C (Albrecht, 1964); in American shad (*Alosa sapidissima*), spawning runs occur at 16.0-19.5°C (Leggett & Whitney, 1972). At Vancouver Island, B.C., distribution of a kelp (*Laminaria gzaenlandica*) is temperature influenced. (The long stipe form is not found above 13°C; the short stipe form does not occur above 17°C. In the laboratory, elevation of temperature to 13°C produces abnormal sporophytes (Druehl, 1967).) Dungeness crab (*Cancer magister*) larval development is optimal at 10 and 13.9°C, survival is reduced at 17.8°C, with no survival to megalops at 21.7°C (Reed, 1969). Upper thermal limit for razor clam embryonic and larval development is 17°C (McCauley & Hancock, 1971). Upper growth limit for small filamentous red algae (e.g. *Antithamnion* spp) is 18°C (West, 1968). King salmon migration into San Juaquin River may be delayed by estuarine temperatures in excess of 17.8°C (Dunham, 1968).

The sea grass (*Phyllospadix scouleri*) begins to die off at 20°C (McRoy, 1970), and the pea pod borer (*Botula fulcata*) ceases to develop

(Fox & Corcoran, 1957). Twenty °C is also the upper limit for embryonic and larval development of the summer-spawning horse clam (*Tresus nuttalli*) and native little neck clam (*Protothaca staminea*) (Schink & Woelke, 1973). Upper incipient lethal temperature for the mysid shrimp (*Neomysis intermedia*) is 21.7°C (Hair, 1971). This value is collaborated by reports of a drop in field populations of this important fish food organism above 22.2°C in the San Joaquin estuary (Heubach, 1969). Twenty-two °C is the upper tolerance limit for embryological development of the wooly sculpin (*Clinocttus analis*) (Hubbs, 1956). A four hour exposure to 23°C results in significant mortality of the adult razor clam (*Siliquo patula*) (Woelke, 1971) and the sockeye salmon (*Oncorhynchus nerka*) (Brett & Alderdice, 1958). Striped bass (*Morone saxatilis*) are believed stressed at temperatures above 23.9°C (Dunham, 1968). Sexual maturation in a gobiid fish (*Gillicthys mirabilis*) is blocked at high temperatures. Gonadal regression begins at 22°C in females; at 24°C in males. Gonadal recrudescence will not occur at 24°C or above, regardless of photoperiod (DeVlaming, 1972). The 36 hour TLm for red abalone adults is 23°C when acclimated to 15°C; for the embryos, 26°C, when exposed for 30 hours (Ebert, 1974). Sea urchin (*Strongylocentrotus purpuratus*) upper tolerance limit is 23.5°C for adults (Gonor, 1968); 25°C is lethal to embryos and renders adults limp and unresponsive after 4 hours (Farmanfarmaian and Giese, 1963).

*Pacific Warm Temperate Zone*: The thermal threshold for spawning in Pacific sardine (*Sardinops caerulea*) is 13°C (Marr, 1962). Reports of temperature optima for spawning include 15°C in a ctenophore (*Pleurobranchia bachei*) (Hirota, 1973); 16°C in the spring spawning wooly sculpin (*Clinocottus analis*) (Graham, 1970); 17.5°C for northern anchovy (*Engraulis mordax*); 19°C for opaleye fish (*Girella nigricans*) (Norris, 1963). Larval survival is best at 16-18°C in white abalone (*Haliotis sorenseni*) (Leighton, 1972).

Limiting effects of temperature include scarcity of the kelp isopod in the beds above 17.8°C (Jones, 1971). Upper limit for growth in *P. bachei* is 17°C; 20°C is the upper tolerance limit for the adult ctenophore (Hirota, 1973). Twenty °C also causes limited survival in recently settled juvenile white abalone (Leighton, 1972). Limiting effects for wooly sculpin include the upper limit of optimal growth at 21°C; at 22°C, a 50% reduction in successful development of eggs; at 24°C, the upper limit for embryonic development is reached (Hubbs, 1966). Sea urchins (*Strongylocentrotus* sp.) are weakened or killed at 24-25°C (Leighton, 1971). At 25°C, partial osmoregulatory failure occurs in staghorn sculpin (*Leptocottus armatus*) at 37.6'o/oo (Morris, 1960). A maximum temperature of occurrence of 25°C is reported for top smelt (*Atherinops affinis*) by Doudoroff (1945) and northern anchovy (*Engraulis mordax* (Baxter, 1967). For topsmelt, the upper limit at which larvae hatch is 26.8°C (Hubbs, 1965).

Natural summer temperatures are stressful to beds of giant kelp, *Macrocystis pyrifera*, in southern California. This precludes any thermal discharge in the vicinity of these beds. Deterioration of surface blades is evident from late June onward, due in part to reduced photosynthesis (Clendenning, 1971). Several weeks' exposure to 18.9°C is harmful to the beds (Jones, 1971), while temperatures over 20°C results in pronounced loss of kelp (North, 1964). Brandt (1923) reported some 60% reduction of kelp harvest when the average temperature was 20.65°C and that a bacterial disease, black rot, thrives on kelp at 18-20°C. One day exposure to 22°C is quite harmful to cultured gametophytes of giant kelp (North, 1972).

## REFERENCES CITED

Albertson, H.D. 1973. A comparison of the upper lethal temperatures of animals of fifty common species from Biscayne Bay. M.S. Thesis, Univ. Miami, Coral Gables, Fla.

Albrecht, A.B. 1964. Some observations on factors associated with survival of striped bass eggs and larvae. Calif. Fish and Game 50 (1): 100-113.

Alderdice, D.F. and C.R. Forrester. 1968. Some effects of salinity and temperature on early development and survival of the English sole (*Parophrys vetulus*). J. Fish. Res. Bd. Canada 27 (3): 495-521.

Andrews, J.D. 1965. Infection experiments in nature with *Dermocystidium marinum* in Chesapeake Bay. Chesapeake Sci. 6 (1): 60-67.

Anom. 1969. Quarterly thermal addition report to Florida Power Corporation for July, August, September, 1969. Marine Research Laboratory, Florida Dept. Natural Resources, St. Petersburg, Fla.

Ansell, A.D. 1968. The rate of growth of the hard clam, *Mercenaria mercenaria* (L), throughout the geographical range. J. Cons. perm. int. Explor. Mer 31 (3): 364-409.

Barans, C.A. 1972. Spotted hake, *Urophycis regius*, of the York River and lower Chesapeake Bay. Chesapeake Sci. 13 (1): 59-68.

Baxter, J.L. 1967. Summary of biological information on the northern anchovy, *Engraulis mordax* Girard. *In*: Symposium on anchovies, genus *Engraulis*, Lake Arrowhead, Calif. Nov. 23-24, 1964. Calif. Coop. Oceanic Fish. Invest. Rep. 11: 110-116.

Bigelow, H.B. and W.C. Schroeder. 1953. Fishes of the Gulf of Maine. U.S. Fish and Wildlife Serv. Fish. Bull. 74, Vol, 53: 577 p.

Brandt, R.P. 1923. Potash from kelp: early development and growth of the giant kelp, *Macrocystis pyrifera*. U.S. Dept. Agr., Dept. Bull. 1191, 40 p.

Brawn, V.M. 1960. Temperature tolerance of unacclimated herring (*Clupea harengus* L.). J. Fish. Res. Bd. Canada 17 (5): 721-723.

Brenko, M. and A. Calabrese. 1969. The combined effects of salinity and temperature on larvae of the mussel, Mytilus edulis. Mar. Biol. 4 (3): 224-226.

Brett, J.R. and Alderdice. 1958. Unpublished data, p. 526-527, Cited in Brett, J.R. 1970. Temperature, animals, fishes. In: Kinne [ed] Marine ecology - a comprehensive treatise on life in oceans and coastal waters. Vol. 1, environmental factors. Wiley-Interscience, London, 681 p.

Calabrese, A. 1969. Individual and combined effects of salinity and temperature on embryos and larvae of the coot clam, Mulinia lateralis (say). Biol. Bull. 137 (3): 417-428.

Chesher, R.H. 1971. Biological impact of a large-scale desalination plant at Key West. EPA Water Poll. Control Res. Ser. 18080 GBX. EPA Office of Research and Monitoring, Washington, D.C.

Chin, E. 1961. A trawl study of an estuarine nursery area in Galveston Bay with particular reference to penaeid shrimp. Ph.D. Dissertation, Univ. Washington, 113 p.

Clendenning, K.A. 1971. Photosynthesis and general development in Macrocystis, p. 171-263. In: W.J. North [ed] The biology of giant kelp beds (Macrocystis) in California. Beihefte Zur Nova Hedwigia. J. Crämmer, Lehre, Germany.

Collier, A. 1954. A study of the response of oysters to temperature, and some long range ecological interpretations. Nat. Shellfish Assoc. Annual 1953 Meeting, p. 13-31.

Colton, J.B., Jr. 1959. A field observation of mortality of marine fish larvae due to warming. Limn. and Oceanog. 4: 219-221.

Costlow, J.D., Jr. and C.G. Bookhout. 1971. The effect of cyclic temperatures on larval development in the mud crab, Rhithropanopeus harrisii, p. 211-220. In: D.J. Crisp [ed] Fourth European Mar. Biol. Symp., Cambridge Univ. Press, London.

Courtenay, W.R., Jr. and M.H. Roberts, Jr. 1973. Environmental effects on toxaphene toxicity to selected fishes and crustaceans. EPA Ecol. Res. Ser. EPA R3-73-035, EPA Office of Research and Monitoring, Washington, D.C.

Creaser, E.P., Jr. 1973. Reproduction of the blood worm (Glycera dibranchiata) in the Sheepscot estuary, Maine. J. Fish. Res. Bd. Canada 30 (2): 161-166.

DeCola, J.N. 1970. Water quality requirements for Atlantic salmon. U.S. Dept. of the Interior, Federal Water Quality Administration, Northeast Region, New England Basins Office, Needham Heights, Massachusetts. 42 p., Appendices, Mimeo.

DeVlaming, V.L. 1972. The effects of temperature and photoperiod on reproductive cycling in the estuarine gobiid fish, Gillichthys mirabilis. Fishery Bull. 70 (4): 1137-1152.

Doudoroff, P. 1945. The resistance and acclimatization of marine fishes to temperature changes. II. Experiments with Fundulus and Atherinops. Scripps Inst. of Oceanography, Series No. 253, p. 194-206.

Druehl, L.D. 1967. Distribution of two species of Laminaria as related to some environmental factors. J. Phycology 3 (2): 103-108.

Dunham, L.R. 1968. Recommendations on thermal objectives for water quality control policies on the interstate waters of California. Water Projects Branch Report No. 7. Calif. Dept. Fish and Game, 155 p.

Ebert, E.E. 1974. Unpublished data. Pacific Gas and Electric Co. Cooperative Research Agreement 6S-1047. Calif. Dept. Fish and Game Marine Culture Laboratory, Monterey, Calif.

Edmonson, C.H. 1928. Ecology of a Hawaiian coral reef. B.P. Bishop Mus. Bull. 45, 100 p.

Edwards, G.A. and L. Irving. 1943. The influence of temperature and season upon the oxygen consumption of the sand crab, Emerita talpoida Say. J. Cell Physiol. 21: 169-181.

Engle, J.B. and V.L. Loosanoff. 1944. On season of attachment of larvae of Mytilus edulis. Ecol. 25: 433-440.

Farmanfarmaian, A. and A.C. Giese. 1963. Thermal tolerance and acclimation in the Western Purple Sea urchin, Strongylocentrotus purpuratus. Physiol. Zool. 36: 237-243.

Fox, D.L. and E.F. Corcoran. 1957. Thermal and osmotic countermeasures against some typical marine fouling organisms. Corrosion 14: 31-32.

Gift, J.J. and J.R. Westman. 1971. Responses of some estuarine fishes to increasing thermal gradients. Dept. Environ. Sci., Rutgers Univ., New Brunswick, N.J., 154 p Mimeo.

Glynn, P.W. 1968. Mass mortalities of echinoids and other reef flat organisms coincident with midday, low water exposures in Puerto Rico. Mar. Biol. 1 (3): 226-243.

Gonor, J.J. 1968. Temperature relations of central Oregon marine intertidal invertebrates: A prepublication technical report to the Office of Naval Research Dept. of Oceanography, Oregon State Univ. Reference 68-38.

Gore, R.H. 1968. The larval development of the commensal crab, *Polyonx gibbesi*. Haig, 1956 (Crustacea: Decapoda). Biol. Bull. 135 (1): 111-129.

Graham, J.B. 1970. Temperature sensitivity of two species of intertidal fishes. Copeia 1970 (1): 49-56.

Hair, J.R. 1971. Upper lethal temperature and thermal shock tolerances of the opossum shrimp, *Neomysis awatschensis*, from the Sacramento-San Joaquin Estuary, California. Calif. Fish and Game 57 (1): 17-27.

Hanks, J. 1953. Comparative studies on the feeding habits of *Polinices heros* and *Polinices duplicata* relative to temperature and salinity. Fourth Ann. Conf. on Clam Res., U.S. Fish and Wildlife Serv., Boothbay Harbor, Me., p. 88-95.

Hela, I. and T. Laevastu. 1962. Fisheries hydrography. Fishing News Ltd., London.

Heubach, W. 1969. *Neomysis awatschensis* in the Sacramento-San Joaquin River Estuary. Limnol. and Oceanog. 14 (4): 533-546.

Hirota, J. 1973. Quantitative natural history of *Pleurobrachia bachei* A. Agassiz in La Jolla Bight. Ph.D. Thesis, Univ. Calif., San Diego.

Hopper, B.E., J.W. Fell, and R.C. Cafalu. 1973. Effect of temperature on life cycles of nematodes associated with the mangrove (Rhizophora mangle) detrital system. Mar. Biol. 23: 293-296.

Hoss, D.E., W.F. Hettler, and L.C. Coston. 1973. Effects of thermal shock on larval estuarine fish -- Ecological implications with respect to entrainment in power plant cooling systems. Symp. on Early Life History of Fish, Proc. Oban, Scotland, 1973. In press.

Hubbs, C. 1965. Developmental temperature tolerance and rates of four southern California fishes, Fundulus parvipinnis, Atherinops affinis, Leuresthes tenuis, and Hypsoblennius sp. Calif. Fish Game 51 (2): 113-122.

Hubbs, C. 1966. Fertilization, initiation of cleavage, and developmental temperature tolerance of the cottid fish, Clinocottus analis. Copeia 1966 (1): 29-42.

Jeffries, H.P. 1967. Saturation of estuarine zooplankton by congeneric associates. In: G.H. Lauff [ed] Estuaries. American Association for the Advance of Science, Publ. No. 83, Washington.

Johansen, A.C. and A. Krogh. 1914. The influence of temperature and certain other factors upon the rates of development of the eggs of fishes. Publs. Circonst. Cons. Perm. Int. Explor. Mer. 68: 1-44.

Jokiel, P.L. and S.L. Coles. 1974. Effects of heated effluent on hermatypic corals at Kahe Point, Oahu. Pacific Sci., in press.

Jones, L.G. 1971. Studies on selected small herbivorous invertebrates inhabiting Macrocystis canopies and holdfasts in southern California kelp beds, p. 343-367. In: W.J. North [ed] The Biology of Giant Kelp Beds (Macrocystis) in California. Beihefte zur Nova Hedwigia, Heft 32. J. Cramer, Lehre, Germany.

Kennedy, V.S., W.H. Roosenberg, H.H. Zion, and M. Castagna. 1974. Temperature-time relationships for survival of embryos and larvae of Mulinia lateralis (Mollusca: Bivalvia). Mar. Biol. 24: 137-145.

Kuthalingam, M.D.K. 1959. Temperature tolerance of the larvae of ten species of marine fishes. Current Sci. 2: 75-76.

Laurence, G.C. 1973. Influence of temperature on energy utilization of embryonic and postlarval tautog, *Tautoga onitis*. J. Fish. Res. Bd. Can. 30 (3): 435-442.

Leggett, W.C. and R.R. Whitney. 1972. Water temperature and the migrations of American shad. Fish. Bull. 70 (3): 659-670.

Leighton, D.L. 1971. Grazing activities of benthic invertebrates in southern California kelp beds, p. 421-453. *In*: W.J. North [ed] The biology of giant kelp beds (*Macrocystis*) in California. Beihefte zur Nova Hedwigia, Heft 32. J. Cramer, Lehre, Germany.

Leighton, D.L. 1972. Laboratory observations on the early growth of the abalone, *Haliotis sorenseni*, and the effect of temperature on larval development and settling success. Fish. Bull. 70 (2): 373-381.

Lewis, R.M. and W.F. Hettler, Jr. 1968. Effect of temperature and salinity on the survival of young Atlantic menhaden, *Brevoortia tyrannus*. Amer. Fish. Soc. Trans. 97 (4): 344-349.

Marr, J.C. 1962. The causes of major variations in the catch of the Pacific sardine, *Sardinops caerulea* (Girard). Proc. World Scientific Meeting on the Biology of Sardines and Related Species, FAO, Rome. 3: 667-791.

Mayer, A.G. 1914. The effects of temperature upon tropical marine animals. Papers Mar. Biol. Lab. Tortugas, Carnegie Inst. Wash. 6 (1): 3-24.

McCauley, J.E. and D.R. Hancock. 1971. Biology of selected northwest species or species groups, p. 246-303. *In*: Oregon State Univ. Oceanography of the Nearshore Coastal-Waters of the Pacific Northwest Relating to Possible Pollution. Vol. 1. EPA Water Pollution Control Research Series 1607 EOK. EPA. Water Quality Office, Washington, D.C.

McRoy, C.P. 1970. The biology of eel grass in Alaska. Ph.D. Thesis Univ. Alaska, p. 156.

Meldrin, J.W. and J.J. Gift. 1971. Temperature preference, avoidance and shock experiments with estuarine fishes. Ichthyological Associates, Ithaca, N.Y., Bull. 7.

Merriman, D. 1941. Studies on the striped bass (Roccus saxatilis) of the Atlantic coast. U.S. Fish & Wildlife Serv., Fish. Bull. 50, Vol. 35, p. 77.

Mihursky, J.A. 1969. Patuxent thermal studies. Natural Res. Inst. Spec. Rept. 1, Univ. Md., p. 20.

Mihursky, J.A. and V.S. Kennedy. 1967. Water temperature criteria to protect aquatic life, p. 20-32. In: E.L. Cooper [ed] Special Publ. 4, Am. Fish. Soc. Trans. 96 (1) Supplement.

Mihursky, J.A., A.J. McErlean, and V.S. Kennedy. 1970. Thermal pollution, aquaculture and pathobiology in aquatic systems. J. Wildlife Diseases 6: 347-355.

Morris, W. 1960. Temperature, salinity, and southern limits of three species of Pacific cottid fishes. Limn. and Oceanog. 5 (2): 175-179.

Nichols, J.T. 1918. An abnormal winter flounder and others. Copeia No. 55: 37-39.

Norris, K.S. 1963. The functions of temperature in the ecology of the percoid fish, Girella nigricans (Ayres). Ecol. Monogr. 33: 23-62.

North, W.J. 1964. Experimental transplantation of the giant kelp, Macrocystis pyrifers, p. 248-255. In: DeVirville and Feldmann [eds] IVth Int. Seaweed Symp. (Biarritz, 1961). Pergamon, New York.

North, W.J. 1972. Kelp habitat improvement project. W.M. Keck Lab. of Environ. Health Engr., Cal. Inst. Tech., Annual Report, 1 July, 1971 - 30 June, 1972, p. 200.

Olla, B.L., R. Wicklund, and S. Wilk. 1969. Behavior of winter flounder in a natural habitat. Amer. Fish. Soc. Trans. 98: 717-720.

Pearce, J.B. 1969. Thermal addition and the benthos, Cape Cod Canal. Ches. Sci. 10 (3,4): 227-233.

Prince, J.S. and J.M. Kingsbury. 1973. The ecology of Chondrus crispus at Plymouth, Massachusetts. III. Effect of elevated temperature on growth and survival. Biol. Bull. 145: 580-588.

Rebel, T.P. 1973. Effects of temperature on survival of eggs and yolk sac larvae of four species of marine fishes from south Florida. M.S. Thesis, Unv. Miami, Coral Gables, Florida, p. 53.

Reed, P.H. 1969. Culture methods and effects of temperature and salinity on survival and growth of Dungeness crab (Cancer magister) larvae in the laboratory. J. Fish. Res. Bd. Can. 26: 389-397.

Roessler, M.A. 1971. Studies of the effects of thermal pollution in Biscayne Bay, Florida. A report to the Environmental Protection Agency, Univ. of Miami, 211 p.

Rogers, C.A. 1974. Effects of temperature and salinity on the survival of winter flounder embryos. Fish. Bull., In press.

Saksena, V.P., C. Steinmetz, Jr., and E.D. Houde. 1972. Effects of temperature on growth and survival of laboratory-reared larvae of the scaled sardine, Harengula pensacolae. Goode and Bean. Amer. Fish. Soc. Trans. 4: 691-695.

Schink, T.D. and C.E. Woelke. 1973. Development of an in situ marine bioassay with clams. EPA Water Pollution Control Research Series 18050 DOJ. EPA, Office Research and Monitoring, Washington, D.C.

Shannon, E.H. 1969. Effect of temperature changes upon developing striped bass eggs and fry. Proc. Twenty-Third Annual Conf. S.E. Assoc. Game and Fish Comm., p. 265-274.

Sherburne, S.W. 1973. Erythrocyte degeneration in Atlantic herring, Clupea harengus L. Fish. Bull. 71 (1): 125-134.

Sinderman, C.J. 1966. Diseases of marine fishes. Adv. Mar. Biol. 4: 1-89.

South, G.R. and R.D. Hill. 1970. Studies on marine algae of Newfoundland. I. Occurrence and distribution of free living Ascophyllum nodosum in Newfoundland. Can. J. Bot. 48: 1697-1701.

Steele, D.H. and V.J. Steele. 1969. The biology of Gammarus (Crustacea: Amphipoda) in the northwestern Atlantic. I. Gammarus duebeni Lillj. Can J. Zool. 47 (2): 235-244.

Thorhaug, A. 1970. Temperature limits of five species of Valonia. J. Phycol. 6: 27.

Thorhaug, A. 1971. Grasses and macroalgae, p. X1-63. In: R.G. Bader and M.A. Roessler [eds] An ecological study of South Biscayne Bay and Card Sound. Progress Rept. to USAEC and Fla. Power and Light Co. (Univ. of Miami, Coral Gables, Fla.).

Thorhaug, A. 1973. Grasses and macroalgae laboratory temperature studies. Annual Report (1972-1973) to the USAEC and Fla. Power and Light (Univ. Miami, Coral Gables, Fla.), 92 p.

Thorhaug, A., T. Devany, and B. Murphy. 1971 a. Refining shrimp culture methods: The effect of temperature on early stages of the commercial pink shrimp. Gulf and Caribbean Fish. Inst., Proc. Twenty-third Annual Session, p. 125-132.

Thorhaug, A., H.B. Moore, and H. Albertson. 1971 b. Laboratory thermal tolerances, p. XI-31. In: R.G. Bader and M.A. Roessler [eds] An ecological study of South Biscayne Bay and Card Sound. Progress Rept. to USAEC and Fla. Power and Light Co. (Univ. Miami, Coral Gables, Fla.).

Vaughan, T.W. 1918. The temperature of the Florida coral-reef tract. Publs. Carnegie Inst. Wash. 213: 319-339.

West, J.A. 1968. Morphology and reproduction of the red algae, Ocrochaetium pectinatum, in culture. J. Phycol. 4: 88-89.

Woelke, C.E. 1971. Some relationships between temperature and Pacific northwest shellfish. Western Assoc. State Game and Fish Comm., Proc. Fifty-first Ann. Conf.

Zieman, J.C. and E.J.F. Wood, in press. Effects of thermal pollution on a tropical-type estuary. In: E.J.F. Wood and R. Johannes [eds] Pollution of the Tropical Marine Environment. Elserier, N.Y.

Zieman, J.C., Jr. 1970. The effects of a thermal effluent stress on the sea grasses and macroalgae in the vicinity of Turkey Point, Biscayne Bay, Florida. Ph.D. Dissertation, Unv. Miami, Coral Gables, Fla., 129 p.

Zein-Eldin, J.P. and D.V. Aldrich. 1965. Growth and survival of postlarval *Penaeus aztecus* under controlled conditions of temperature and salinity. Biol. Bull. 129: 199-216.

Zein-Eldin, J.P. and G.W. Griffith. 1969. An appraisal of the effects of salinity and temperature on growth and survival of postlarval penaeids. FAO Fish. Rep. 57 Vol. 3: 1015-1026.

## REFERENCES CITED
## ADDENDA

Druehl, L.D. and S.I.C. Hsiao. 1969. Axenic culture of Laminariales in defined media. Phycologia 8 (1): 47-49.

Gonzalez, J.G. 1972. Seasonal variation in the responses of estuarine populations to heated water in the vicinity of a steam generating plant. Ph.D. Dissertation, Univ. Rhode Island, 142 p.

row, K. and C. M. Boyd. 1967. The oxygen consumption and swimming activity of the amphipod, *Gammarus oceanicus*, at different temperatures. Comp. Biochem. and Physiol. 23: 233-242.