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2 **Marine Fisheries Enhancement: 3 Coming of Age in the New 4 Millennium**

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8 **Article Outline**

9 Glossary
10 Definition of the Subject
11 Introduction
12 Scientific Development of Marine Fisheries
13 Enhancement
14 Responsible Approach to Marine Fisheries
15 Enhancement
16 Legacy from the Past
17 Progress in Marine Fisheries Enhancement
18 Future Directions
19 Bibliography

20 **Glossary**

21 **Anadromous** Species that spawn in freshwater,
22 then their offspring gradually make their way into
23 estuaries or the sea, where they remain during
24 much of the subadult and adult stages of the life
25 cycle, before returning to rivers and streams to
26 spawn.
27 **Catadromous** Species whose females release their eggs
28 at sea, then the offspring move as larvae or early
29 juveniles into estuaries, rivers, and streams where
30 they spend the juvenile stage of the life cycle.
31 **Marine** Species that spawn in sea water, including
32 those that spend most of their lives at sea and
33 catadromous fishes, which spawn in seawater, then
34 enter freshwater nursery habitats.

Marine fisheries enhancement Release of aquacultured 35
marine organisms into seas and estuaries to increase 36
or restore abundance and fishery yields in the wild. 37

Outbreeding depression Caused when offspring from 38
crosses between individuals from different 39
populations or subpopulations (stocks) have 40
lower fitness than progeny from crosses between 41
individuals from the same population/stock. 42

Recruitment The process of joining an existing 43
population. Species *recruit* to the juvenile stages in 44
nursery habitats; juveniles subsequently *recruit* to 45
adult stages in adult habitats. Species *recruit* to 46
a fishery when they reach the minimum size fished. 47

Reintroduction Temporary release of cultured 48
organisms with the aim of reestablishing a locally 49
extinct population. 50

Restocking Release of cultured juveniles into wild 51
population(s) to restore severely depleted spawning 52
biomass to a level where it can once again provide 53
regular, substantial yields. 54

Sea ranching Release of cultured juveniles into 55
unenclosed marine and estuarine environments 56
for harvest at a larger size in “put, grow, and take” 57
operations. 58

Stock enhancement The release of cultured juveniles 59
into wild populations to augment the natural 60
supply of juveniles and optimize harvests by 61
overcoming limitations in juvenile recruitment. 62

Supplementation Moderate release of cultured fish 63
into very small and declining populations, with 64
the aim of reducing extinction risk and conserving 65
genetic diversity. Supplementation serves primarily 66
conservation aims and specifically addresses 67
sustainability issues and genetic threats in small 68
and declining populations. 69

70 **Definition of the Subject**

Marine fisheries enhancement (aka “stock enhance- 71
ment”) is the use of hatchery-reared saltwater 72

73 organisms to increase abundance and fishery yields in
74 the wild. “Conservation hatcheries” also produce and
75 stock depleted, threatened, or endangered organisms –
76 to help preserve species in decline. The practice began
77 in the latter part of the nineteenth century when fish
78 hatcheries were first developed but understanding of
79 the ecology and management of wild stocks into which
80 the hatchery-reared organisms were released was very
81 limited. Early stock enhancement thus has gone
82 through a series of fits and starts and misfires. In the
83 century after its birth, the technologies required for
84 scientific inquiry of the effects and effectiveness of
85 stocking hatchery-reared organisms were lacking.
86 The science needed to guide reliable use of cultured
87 aquatic organisms in conservation and resource man-
88 agement remained undeveloped. Then, at the close of
89 the twentieth century, new mariculture, tagging, and
90 genetic technologies surfaced and rapid advances were
91 made in the science underpinning marine stock
92 enhancement.

93 As growth in human population size approaches
94 the carrying capacity of the planet in this century, and
95 the world increasingly turns to the oceans to farm and
96 harvest food [1], sustainable fishery yields and
97 conservation of natural resources face unparalleled chal-
98 lenges. Over the past two decades, marine fisheries
99 enhancement has been transformed from a tentative,
100 poorly developed management tool to a maturing
101 science. Some believe research funding for this field
102 would be better spent on traditional fishery manage-
103 ment. But today’s seafood producers, fishery managers,
104 and “. . . conservationists need all the tools that biology,
105 ecology, diplomacy and politics can muster if endangered
106 species are to survive beyond the next century,” [2] and
107 fisheries are to continue to support a viable seafood
108 industry and sport pastime. This entry traces the emer-
109 gence and progress of marine fisheries enhancement,
110 and offers a prescription for future direction.

111 The term *stock enhancement* is originally derived
112 from efforts to augment wild fish sub-populations,
113 or “stocks,” by releasing cultured fishes into aquatic
114 environments. Stocking cultured organisms is one of
115 the tools available for managing aquatic natural
116 resources. It has been used with varying degrees
117 of success to help increase abundance of habitat- or
118 recruitment-limited stocks to help restore depleted
119 populations, augment fisheries and help recover

120 threatened or endangered species. There has been
121 much debate over the effectiveness of stock enhance-
122 ment as a fisheries management tool. However, most of
123 the scientific evaluation of stocking is quite recent [3],
124 as is a code of responsible practices that help
125 guide effective application [4–6], and marine fisheries
126 enhancement is finally poised for effective use.

127 In the USA, from the 1880s through the early 1950s,
128 stocking hatchery-reared marine fishes was a principal
129 approach used by the US Fish Commission (renamed
130 Bureau of Fisheries in 1903, Bureau of Commercial
131 fisheries in 1956, and later the National Marine Fisher-
132 ies Service) for maintaining fishery stocks. But by the
133 1950s the practice of stocking marine fishes to manage
134 US fisheries was curtailed for lack of evidence of its
135 effectiveness in fisheries management [7]. Stocking was
136 replaced by harvest management to control total catch
137 and sustain fisheries. Stocking of freshwater habitats
138 continued (particularly with salmonids into rivers),
139 although the scientific basis for many of the manage-
140 ment decisions needed for stocking salmonids was
141 clearly lacking and did not begin to be addressed until
142 the mid-1970s.

143 In the decade following 1975, scientists began to
144 evaluate survival and fishery contributions of stocked
145 salmon enabled by advances in fish tagging technology
146 [8, 9]. Quantitative evaluation of marine fish stocking
147 began in earnest in the 1980s and 1990s. The science
148 underlying fisheries enhancement has since evolved to
149 the point where, in some situations, stocking can be
150 a useful fishery management tool to help restore
151 depleted stocks and increase abundance in recruit-
152 ment-limited fisheries [6]. Effective use of enhance-
153 ment, though, requires full integration with harvest
154 and habitat management, and a good understanding
155 by stakeholders and resource managers of the oppor-
156 tunities where enhancement can be used successfully as
157 well as its limitations [5, 6]. Principles for guiding the
158 successful use of marine fisheries enhancement to help
159 sustain aquatic resources are now being employed to
160 design new enhancements and reform existing efforts.
161 What follows is a brief overview of those principles and
162 progress made in using hatchery-reared organisms to
163 help sustain marine resources.

164 Introduction

165 Marine fisheries enhancement is happening around
166 the world and in some countries on a massive scale
167 (e.g., China). However, in many countries the careful
168 assessment of genetic and ecological risks is lagging
169 behind implementation, putting wild stocks, the sea-
170 food supply, and sport fisheries at risk. The science of
171 marine enhancement is still in its infancy compared to
172 other fields of fisheries science, but now shows good
173 potential to (1) increase fishery yield beyond that
174 achievable by exploitation of the wild stock alone,
175 (2) help restore depleted stocks, (3) provide protection
176 for endangered species, and (4) provide critical infor-
177 mation on the natural ecology, life history and envi-
178 ronmental requirements of valuable marine species.

179 Stock enhancement has often been used as a generic
180 term referring to all forms of hatchery-based fisheries
181 enhancement. Bell et al. [3] and Lorenzen et al. [6]
182 classified the intent of stocking cultured organisms in
183 aquatic ecosystems into various basic objectives.
184 Together, they considered five basic types, listed here
185 from the most production-oriented to the most con-
186 servation-oriented:

- 187 1. Sea ranching – *recurring release of cultured juveniles*
188 *into unenclosed marine and estuarine environments*
189 *for harvest at a larger size in “put, grow, and take”*
190 *operations. The intent here is to maximize produc-*
191 *tion for commercial or recreational fisheries. Note*
192 *that the released animals are not expected to con-*
193 *tribute to spawning biomass, although this can*
194 *occur when harvest size exceeds size at first*
195 *maturity or when not all the released animals are*
196 *harvested.*
- 197 2. Stock enhancement – *recurring release of cultured*
198 *juveniles into wild population(s) to augment the*
199 *natural supply of juveniles and optimize harvests by*
200 *overcoming recruitment limitation in the face of*
201 *intensive exploitation and/or habitat degradation.*
202 Stock enhancements can increase abundance and
203 fisheries yield, supporting greater total catch than
204 could be sustained by the wild stock alone [10].
205 However, such increases may be offset, at least in
206 part, by negative ecological, genetic, or harvesting
207 impacts on the wild stock component. Stock
208 enhancements tend to attract greater numbers of

fishers, which can offset expected increase in each
individual's catch-per-unit-effort (CPUE) [5, 11].

3. Restocking – *time-limited release of cultured*
juveniles into wild population(s) to restore severely
depleted spawning biomass to a level where it can
once again provide regular, substantial yields [12].
Restocking requires release number to be substan-
tial relative to the abundance of the remaining wild
stock, and close ecological and genetic integration
of wild and cultured stocks, combined with very
restricted harvesting [6].
4. Supplementation – *moderate releases of cultured fish*
into very small and declining populations, with the
aim of reducing extinction risk and conserving genetic
diversity [13, 14]. Supplementation serves primarily
conservation aims and specifically addresses
sustainability issues and genetic threats in small
and declining populations [6].
5. Reintroduction – *involves temporary releases with*
the aim of reestablishing a locally extinct population
[15]. Continued releases should not occur, as they
could interfere with natural selection in the newly
established population. Fishing should also be
restricted to allow the population to increase in
abundance rapidly [6].

Scientific development of marine fisheries enhance-
ment was lacking throughout most of the twentieth
century. Although stocking cultured marine fishes
began in the nineteenth century, the technology was
limited to stocking only eggs and larvae. There were no
published accounts of the fate of released fish until
empirical studies of anadromous salmonids began to
be published in the mid-1970s [16, 17], followed by the
first studies (published in English) of stocked marine
invertebrates in 1983 [18, 19] and marine fishes in 1989
[20].

During the past two decades, the field of marine
fisheries enhancement has advanced considerably.
Science in this field is rapidly growing, in part because
of critical examination and debate about the efficacy of
enhancement and the need for quantitative evaluation
(e.g., [21, 22]), and in part because of advances made in
aquaculture, genetics, tagging, and fishery modeling
technologies, which have enabled quantitative studies
and predictions of stocking effects. A clear process has
emerged for developing, evaluating, and using

255 enhancement [4–6]. Together, this process and the
256 rapid growth of knowledge about enhancement effects
257 should enable responsible and effective use of enhance-
258 ment in marine fisheries management and ocean
259 conservation.

260 **Scientific Development of Marine Fisheries** 261 **Enhancement**

262 **Scientific and Strategic Development**

263 Since 1989, progress in marine fisheries enhancement
264 has occurred at two levels – scientific advances and
265 adoption of a careful and responsible approach to
266 planning and organizing enhancement programs and
267 manipulating abundance of marine species using
268 aquacultured stocks. Much of the progress made in
269 the 1990s was scientific and involved an expansion of
270 field studies to evaluate survival of released fish
271 and improve the effectiveness of release strategies. The
272 earliest studies on effectiveness of stocking *marine*
273 fishes, published in English in the scientific literature,
274 were in Japan [20, 23–26] and Norway [27–31],
275 followed by studies in the USA [32–39], and Australia
276 [40]. Progress made with invertebrates is well covered
277 by Bell et al. [12].

278 Following the initial publications of scientific
279 studies of marine fish enhancement, the number of
280 peer-reviewed publications and symposia in this field
281 began to escalate ([41–52], and see abstracts in [53]).
282 It is now clear that stocking marine organisms can be
283 an effective addition to fishery management strategies,
284 but only when certain conditions are met. For stocking
285 to be productive and economical, and help ensure
286 sustainability of wild stocks, careful attention must
287 be given to several key factors and stocking must be
288 thoroughly integrated with fisheries management [6].
289 It is clear that stocking can be harmful to wild stocks
290 if not used carefully and responsibly.

291 Aside from scientific gains in this field, the other
292 level of progress made in the past two decades has
293 been the evolution of a strategic “blueprint” for
294 enhancements, such as the principles discussed in
295 “a responsible approach to marine stock enhancement”
296 [4, 6]. By the early 1990s, salmon enhancement in the
297 US Pacific Northwest, which had been underway for
298 a century, was beginning to incorporate reforms that
299 were needed to improve efficiencies and protect wild

stocks from genetic hazards that can lead to loss of 300
genetic diversity and fitness. Concerns had been 301
mounting over uncertainty about the actual effective- 302
ness of salmon hatcheries and impacts on wild stocks. 303
Concerns about wild stock impacts were twofold, 304
including ecological effects of hatchery fish, such as 305
competitive displacement, and genetic issues, such as 306
translocation of salmon stocks, domestication and 307
inbreeding in the hatchery and associated outbreeding 308
depression, and loss of genetic diversity related to 309
hatchery breeding practices (e.g., [54, 55]). Meanwhile, 310
special sessions on marine stock enhancement began 311
appearing at major fisheries and mariculture confer- 312
ences in the early 1990s [41–44]. These sessions took 313
a sharp turn from past approaches, where the principal 314
focus in conference presentations about stock enhance- 315
ment had been mainly on Mariculture research topics 316
alone. The conveners of the special sessions on stock 317
enhancement in the 1990s recruited presenters who 318
worked on evaluating the effects and effectiveness of 319
stocking hatchery organisms into the sea and interac- 320
tions of hatchery and wild stocks. The special sessions 321
focused on the “questions of the day” in marine 322
enhancement and fostered debate in the marine 323
enhancement research community about many of the 324
reform issues being considered in salmon enhance- 325
ment. The early 1990s was a period of rapid develop- 326
ments in enhancements, characterized by engagement 327
of multiple scientific disciplines in a field that had 328
previously been guided largely by a single discipline – 329
aquaculture. 330

331 The salmon experience and reforms underway in 331
salmon enhancement made it clear that a careful and 332
multidisciplinary approach was needed in the develop- 333
ment and use of marine enhancement. Many involved 334
in developing new marine fisheries enhancement 335
projects were paying close attention to the debate that 336
had emerged over salmon hatcheries. Following the 337
1993 special session on “fisheries and aquaculture 338
interactions” held at a mariculture conference in 339
Torremolinos, Spain [44], several of the presenters 340
(including scientists from Japan, Norway, the USA, 341
and Italy [United Nations Food and Agriculture 342
Organization, FAO]) met and formed an “Internation- 343
al Working Group on Stock Enhancement,” and 344
affiliated the workgroup with the World Aquaculture 345
Society. At that inaugural working group meeting, 346

347 a decision was made to publish a platform paper to
348 frame the question, “what is a responsible approach to
349 marine stock enhancement?” This paper was presented
350 at the 1994 American Fisheries Society symposium,
351 “Uses and Effects of Cultured Fishes in Aquatic
352 Ecosystems,” and published in the 1995 peer-reviewed
353 symposium proceedings [4]. The paper recommended
354 ten principles for developing, evaluating, and
355 managing marine stock enhancement programs. The
356 Responsible Approach paper afforded a model for
357 developing and managing new enhancement programs
358 and refining existing ones. It has also helped frame
359 research questions in the emerging science of marine
360 fisheries enhancement.

361 The International Working Group on Stock
362 Enhancement (IWGSE) was instrumental in advancing
363 the science of marine fisheries enhancement in the
364 1990s. The working group focused primarily on
365 highlighting ongoing stock enhancement research
366 around the world and fostering awareness of the
367 Responsible Approach in their publications and pre-
368 sentations. International awareness and new research in
369 the field was aided by the broad international makeup
370 of the working group. Membership grew and soon
371 included scientists from Australia, Canada, China,
372 Denmark, Ecuador, Italy, Japan, Norway, Philippines,
373 Solomon Islands, Spain, the UK, and the USA. Initially,
374 the primary communication vehicle used by the work-
375 ing group was the special sessions on stock enhance-
376 ment, which it planned and convened annually in
377 various countries at the international conference of
378 the World Aquaculture Society. The working group
379 promoted a synergy among its members and the influ-
380 ence of the group expanded as members planned addi-
381 tional workshops and symposiums in their own
382 countries and brought IWGSE scientists into the plan-
383 ning process.

384 The period 1990–1997 was a fertile time that gave
385 birth to a rapid expansion of science in marine fisheries
386 enhancement, which continues to this day, aided since
387 1997 in large part by the International Symposium
388 on Stock Enhancement and Sea Ranching (ISSESR).
389 The first ISSESR, held in 1997 in Bergen, Norway,
390 was the brainchild of the Norwegian PUSH program
391 (Program for Development and Encouragement of Sea
392 Ranching) and the Norwegian Institute of Marine
393 Research (IMR). In 1995, IMR scientists invited

394 IWGSE scientists to become involved in the Interna-
395 tional Scientific Committee charged with planning
396 the program for the first ISSESR. The first ISSESR,
397 and the series of follow-up symposia that it launched
398 (see www.SeaRanching.org), have encouraged and
399 brought about fundamental advancements in the field
400 of marine enhancement – by networking the scientists
401 working in this specialized field, highlighting their
402 work at the ISSESR, and publishing their peer-reviewed
403 articles in the symposium proceedings. The 3–5 day
404 ISSESR has now become a regular scientific symposium
405 event, hosted by a different country every 4–5 years.
406 Following the first ISSESR in Bergen [47], subsequent
407 symposiums in the series were held in Kobe, Japan
408 in 2002 [49], in Seattle, USA in 2006 [52], and in
409 Shanghai, China in 2011 [53]. The fifth ISSESR will
410 be held in Sydney, Australia in 2015 or 2016. Inquiries
411 from scientists in different countries interested
412 in hosting the sixth one are already being received
413 by the organizing group. Following the first ISSESR,
414 the IWGSE scientists continued the efforts they started
415 in the working group through their involvement in the
416 International Scientific Committees for the ISSESR
417 and steering committees for other stock enhancement
418 symposia (e.g., [46, 48, 51]). In 2010, a refined and
419 updated version of the Responsible Approach was
420 published [6] and presented at the fourth ISSESR.

421 As in any new science, lack of a paradigm and
422 consensus on the key issues retard progress. The
423 ISSESR and other marine enhancement symposia and
424 working groups have helped to place scientific focus on
425 critical uncertainties and communicate results of new
426 science in this field at symposiums and in the scientific
427 literature. They have also provided a forum for debate
428 on the issues, and increased networking of scientists,
429 resource managers, students, and educators working in
430 this field worldwide. The focus on key issues is nurtur-
431 ing this new field of science.

432 **Technological and Tactical Constraints**

433 Although marine enhancements do show promise as an
434 important tool in fisheries management, why has this
435 field taken so long to develop and why have marine
436 enhancement programs often failed to achieve their
437 objectives? The scientific development of marine
438 fisheries enhancement has long been impeded by lack

439 of the technologies needed to evaluate effects of stock-
440 ing cultured fish. Although marine enhancements
441 began in the 1880s, until the advent of the coded-wire
442 tag in the mid-1960s [8], there was no way to identify
443 treatment groups and replicates in experimental
444 releases of juvenile cultured fish [56]; and quantitative
445 marking methods for multiple experimental groups of
446 postlarvae and very small juveniles (<50 mm in length)
447 came much later (e.g., [57]). To make matters worse,
448 scientific development of marine enhancement was
449 also stymied by lack of adequate technology for
450 culturing marine fishes. Rearing methods for larval
451 and juvenile marine fishes, many of which require live
452 feeds during the larval stage, remained undeveloped
453 until the mid- to late 1970s, when breakthroughs finally
454 began to be achieved in rearing a few marine species
455 past metamorphosis [58]. By the mid-1980s mass
456 production of juveniles had been achieved for several
457 species of marine fishes. Even today, though, many
458 marine fishes cannot yet be cultivated to the juvenile
459 stage in the quantities needed for stocking. Without
460 the availability of juveniles grown to a wide range of
461 sizes, fundamental questions about density depen-
462 dence, hatchery-wild fish interactions and cost-yield
463 efficiency of size-at-release and other release variables
464 cannot be addressed in field experiments. Thus, even
465 the basic technologies needed to develop and under-
466 stand the potential of marine enhancement have been
467 unavailable until relatively recent times for some fishes
468 and have yet to be developed for others.

469 Technology has not been the only constraint to
470 successful development of marine fisheries
471 enhancement. The effective use of stocking cultured
472 marine organisms in fisheries management has been
473 hindered by lack of understanding of the effect of
474 releases on fish population dynamics and a lack of
475 related, quantitative assessment tools [10]. Moreover,
476 there has been a lack of essential governance and
477 fisheries management considerations in planning,
478 designing, implementing, and evaluating enhancement
479 programs [6, 59]. A symptom of this is the relentless
480 concern among stakeholders and hatchery managers
481 alike about the numerical magnitude of fish released,
482 rather than on the effective contribution of the hatch-
483 ery program to fisheries management goals. Certainly,
484 a hatchery needs to meet some release quotas, but
485 the numbers of fish released is a misleading statistic

486 for gauging success or comparing effectiveness among
487 enhancement programs. Yet, from the very beginning,
488 progress has been judged by the number of eggs,
489 yolk-sac larvae or juveniles stocked, rather than by the
490 number of fish added to the catch or to spawning stock
491 biomass. The thinking behind this approach apparently
492 is “grow and release lots of hatchery fish and of
493 course they’ll survive and add to the catch,” without
494 realizing the need to optimize release strategies
495 (e.g., [39, 60, 61]) (e.g., to know what size-at-release,
496 release habitat and release magnitude combination has
497 the greatest impact on population size, fishery yields,
498 and economics), or that the impact from stocking could
499 in fact be a negative one on wild stocks (such as replace-
500 ment of wild fish by hatchery fish) if certain precautions
501 are not taken. This attitude has been pervasive and exists
502 even today among many stakeholders and enhancement
503 administrators. In fact, research now shows that sur-
504 vival and recruitment to the fishery following hatchery
505 releases is a complex issue that requires much greater
506 understanding about the fishery, hatchery fish perfor-
507 mance, and biological and ecological factors in the wild
508 than simply “the catch is down, thus releasing large
509 numbers of fish will bring it back up.” And quite often
510 large release magnitudes are achieved by releasing mil-
511 lions of postlarvae, rather than fewer but larger juve-
512 niles. But releases of postlarvae alone may be effective,
513 yet can also be totally ineffective, depending on condi-
514 tions at the release site [62].

515 The key to successful use of stocking is to plan
516 enhancement programs from a fisheries/resource man-
517 agement perspective, using a broad framework and
518 scientific approach [6, 59]. The probability of achieving
519 effective results is greatly increased when stakeholders
520 are engaged from the outset in planning *new* programs,
521 using a framework that is structured, multilayered,
522 participatory, and makes good use of science, to design,
523 implement, and analyze enhancement fisheries systems
524 [6]. Incorporating the key principles in the Responsible
525 Approach into the frameworks of *existing* programs as
526 well is likely to improve performance.

527 **Responsible Approach to Marine Fishery** 528 **Enhancement**

529 In retrospect, the slow development of marine fish
530 culture (a century behind salmonid aquaculture) has

531 helped marine stock enhancement programs avoid
532 some of the mistakes of the past made with salmon
533 stock enhancement, where lack of understanding of
534 genetic issues during most of the twentieth century
535 led to inadvertent domestication and inbreeding
536 in salmon hatchery populations, leading to reduced
537 fitness in wild stocks. Marine finfish juvenile produc-
538 tion technology lagged behind freshwater and anadro-
539 mous fish culture by a century. Thus, mass release into
540 the sea of juvenile marine fishes large enough to survive
541 and enter the breeding population did not begin until
542 the 1980s. The relatively recent capabilities to conduct
543 marine fisheries enhancement emerged at about the
544 same time that geneticists realized that hatchery prac-
545 tices with salmonids (1) could reduce genetic diversity
546 in the hatchery and ultimately, enhanced wild stocks,
547 owing to inadequate broodstock management, (2) have
548 caused translocations of salmon genes into environ-
549 ments where they are less fit, and (3) have contributed
550 to loss of local adaptations in the wild population.
551 Today, population genetics is much better understood
552 and broodstock genetics and hatchery practices
553 can be better managed to address these concerns
554 (e.g., [63–65]). Thus, marine enhancement programs
555 need careful guidance from qualified geneticists.
556 The Puget Sound and Coastal Washington Hatchery
557 Reform Project in the USA has been instrumental in
558 reforming salmon enhancements [66]. This group
559 affords a model for managing enhancement hatcheries
560 in the twenty-first century.

561 As progress was being made in the early 1990s to
562 better understand the genetic structure of stocks and
563 how to manage genetics in hatcheries, realizing the
564 need for reform in approaches to enhancing non-
565 salmonids was just beginning. In the mid-1990s,
566 Cowx [67], for enhancements in freshwater systems,
567 and Blankenship and Leber [4], for enhancements in
568 marine and estuarine systems, published papers calling
569 for a broader, more systematic, reliable, and account-
570 able approach to planning stock enhancement
571 programs. Prompted both by the salmonid hatchery
572 reform movement and by the WAS IWGSE, the ten
573 principles presented in Blankenship and Leber ([4]
574 Table 1) gained widespread acceptance as the “Respon-
575 sible Approach” to stocking marine organisms and
576 provided a platform for subsequent discussions on
577 planning, conducting, and evaluating marine

enhancements (e.g., [6, 12, 22, 51, 52, 68–70]). Since 578
1995, the awareness of the Responsible Approach has 579
steadily increased and has helped guide hatchery and 580
reform processes for marine enhancements worldwide 581
[11, 36, 37, 39, 60, 62, 69–90]. 582

The Responsible Approach provides a conceptual 583
framework and logical strategy for using aquaculture 584
technology to help conserve and increase natural 585
resources. The approach prescribes several key compo- 586
nents as integral parts of developing, evaluating and 587
managing marine fisheries enhancement programs. 588
Each principle is considered essential to manage 589
enhancements in a sustainable fashion and optimize 590
the results obtained [4, 6]. 591

A major development since the publication of the 592
original “Responsible Approach” has been increasing 593
interest from fisheries ecologists in understanding and 594
quantifying the effects of hatchery releases from 595
a fisheries management perspective. This has led to 596
the development of fisheries assessment models that 597
can be used to evaluate stocking as a management 598
option alongside fishing regulations [5, 10]. At the 599
same time, approaches to fisheries governance 600
underwent major changes that allow enhancements to 601
become more integrated into the management frame- 602
work and in some cases, were driven by interest in 603
enhancement approaches [59]. 604

Walters and Martell [5] discuss four main ways that 605
a marine enhancement program can end up causing 606
more harm than good: (1) the replacement of wild with 607
hatchery recruits, with no net increase in the total stock 608
available for harvest (competition/predation effects); 609
(2) unregulated fishing-effort responses to the presence 610
of hatchery fish that cause overfishing of the wild stock; 611
(3) “overexploitation” of the forage resource base for 612
the stocked species, with attendant ecosystem-scale 613
impacts; and (4) genetic impacts on the long-term 614
viability of the wild stock. They stress that it is critical 615
to monitor the impacts of enhancement as the program 616
develops to have evidence in hand if debate about the 617
efficacy of the program does surface. To help guide 618
developing programs, they provide and discuss 619
a “Code of Responsible Conduct” as critical steps in 620
marine fisheries enhancement program design 621
(Table 2). 622

In 2010, Lorenzen, Leber, and Blankenship [6] 623
published an updated version of the Responsible 624

625 Approach to refine the original key principles and
 626 include five additional ones (Table 3). The key princi-
 627 ples added in the updated version bring stakeholders
 628 more firmly into the planning process; place much
 629 stronger emphasis on a-priori evaluation of the poten-
 630 tial impact of enhancements using quantitative models;
 631 place marine fishery enhancements more firmly within
 632 the context of fishery management systems; emphasize
 633 design of appropriate aquaculture rearing systems and
 634 practices; and incorporate institutional arrangements
 635 for managing enhancements. Lorenzen et al. [6] pro-
 636 vide comprehensive discussions for each of the 15 key
 637 principles listed in Table 3. Readers are urged to consult
 638 Lorenzen et al. [6] for additional detail, as it is beyond
 639 the scope, here, to repeat their discussions of each
 640 principle.

641 The 15 principles in the updated Responsible
 642 Approach include the broad range of issues that need
 643 to be addressed if enhancements are to be developed or
 644 reformed responsibly [6]. Clearly, marine enhance-
 645 ment programs are multidisciplinary and their effective
 646 use requires specialist knowledge and skills from
 647 diverse fields (Table 4). Forming interdisciplinary
 648 teams of the various specialists required is an impor-
 649 tant factor in employing the Responsible Approach in
 650 developing, reforming, and executing marine enhance-
 651 ments. For effective design of enhancement programs,
 652 specialists in each area of expertise listed in Table 4
 653 should be included in the planning teams.

654 It should be clear that without a careful monitoring
 655 system in place, marine enhancements simply cannot
 656 be managed. Monitoring is essential to understand the
 657 impacts of enhancement, to manage release strategies
 658 so that they are efficient and designed well enough to
 659 achieve the goals of the program, to protect against
 660 misuse of stocking (as discussed in 5 and 6), resulting
 661 in harm to wild stocks, and to document success or
 662 failure in meeting enhancement program objectives.
 663 Walters and Martel [5] list several key monitoring
 664 requirements for managing fishery enhancements
 665 well: (1) mark all (or at least a high and known pro-
 666 portion of) fish released from hatcheries; (2) mark as
 667 many wild juveniles as possible at the same sizes/loca-
 668 tions as hatchery fish are being released; (3) experimen-
 669 tally vary hatchery releases over a wide range from year
 670 to year and from area to area, probably in on/off alter-
 671 nation (temporal blocking) so as to break up the

672 confounding of competition/predation effects with
 673 shared environmental effects; (4) monitor changes
 674 in total recruitment to, production of, and fishing
 675 effort in impacted fisheries, not just the percentage
 676 contribution of hatchery fish to production;
 677 (5) monitor changes in the fishing mortality rates of
 678 both wild and hatchery fish directly, through carefully
 679 conducted tagging programs that measure short-term
 680 probabilities of capture; and (6) monitor reproductive
 681 performance of hatchery-origin fish and hatchery-wild
 682 hybrid crosses in the wild. Sound management-action
 683 design and monitoring is the essence of adaptive
 684 management [91] and adaptive management enables
 685 refinements, progress, and success in marine enhance-
 686 ment programs [4, 6, 11, 92].

687 Marine fisheries enhancement is a powerful tool
 688 that requires careful and interdisciplinary planning to
 689 control its effects. The process of transforming marine
 690 enhancement from an idea before its time into an
 691 effective resource management and sea ranching tool
 692 involves adopting a clear prescription for responsible
 693 use. As marine enhancement comes of age in this new
 694 millennium, agencies and stakeholders have a growing
 695 library of protocols for enhancement at their disposal
 696 and the responsibility to use them. The Responsible
 697 Approach and Code of Responsible Conduct provide
 698 healthy prescriptions for controlling the outcome of
 699 enhancements. These principles need to be adopted
 700 and used well, in order to increase and ensure the
 701 readiness of this tool to aid in conservation and to
 702 increase fishery yields when it is needed. Growth in
 703 human population size is fast approaching a critical
 704 level, and much greater attention will be placed in this
 705 century on obtaining food from the sea [1]. It is unwise
 706 to not be ready with marine enhancement to help sus-
 707 tain depleted, threatened, and endangered species, help
 708 maintain wild stocks in the face of increasing fishing
 709 pressure, help sustain sports fisheries, and help increase
 710 fishery yields.

Legacy from the Past 711

Allure of a Quick Fix 712

713 Marine enhancement programs are often seen as
 714 a “quick fix” for a wide variety of problems in marine
 715 resource management. At best, they may be an
 716 important new component of marine ecosystem

717 management; if not implemented responsibly, though,
 718 they may lull fishery managers into false confidence
 719 and thus lead to inaction and delay in the development
 720 of other fisheries management and restoration pro-
 721 grams [5, 6].

722 Although marine fisheries enhancement is certainly
 723 not a quick fix, it can be a powerful tool for resource
 724 management when conditions warrant the use of this
 725 tool and if the time and care needed are taken to
 726 develop enhancement programs well. Unfortunately,
 727 the allure of a quick fix has often prompted
 728 stakeholders and managers to skip or ignore several
 729 elements needed to allow those programs to succeed,
 730 leading to wholesale failure of such efforts. The field of
 731 marine fisheries enhancement is littered with examples
 732 of enhancement projects that failed to achieve their
 733 potential for lack of a careful enough or quantitative
 734 approach (e.g., see accounts discussed in [7, 21, 62, 72,
 735 93–95]). Most of the failures can be traced back to
 736 attempts to use enhancements when they were not
 737 warranted or failure to consider several, if not most,
 738 of the principles now incorporated in the “Responsible
 739 Approach” and “Code of Responsible Conduct” for
 740 marine fisheries enhancement.

741 **Isolation from the Fisheries Science Community**

742 Historically, marine fisheries enhancements have been
 743 conducted more or less isolated from other forms of
 744 fisheries management. Enhancement hatcheries have
 745 often been promoted by stakeholders and government
 746 mandates without the necessary funding or authoriza-
 747 tion behind them to do much more than produce and
 748 release fish without funds for monitoring impacts and
 749 adaptive management needed to increase the effective-
 750 ness of enhancements. Such programs are often built
 751 and implemented from a vantage point within resource
 752 management agencies that has little or no connectivity
 753 with the existing fishery management process. This has
 754 stymied development of this field in two ways – first, by
 755 compelling hatcheries to operate within resource
 756 management agencies largely independent from stock
 757 assessment and fisheries monitoring programs, or
 758 even worse, within different agencies altogether.
 759 Second, such isolation has fostered development of
 760 a production-oriented operational mode, and thwarted
 761 development of an enhancement-oriented mode [92].

Part of this isolation from fishery management also
 stems from the poor track record of the early marine
 hatcheries as an effective way to recover depleted fish
 stocks, coupled with the lack of scientific development
 of marine fisheries enhancement for so long into the
 twentieth century. This has understandably led to bias
 against fishery enhancements. Many of today’s fishery
 scientists have been schooled to understand that stock
 enhancement has not worked, based in part on the
 lingering legacy from past failures and in part on lack
 of awareness of new marine fisheries enhancement
 science, as few citations have yet appeared in fisheries
 science textbooks. With many of the scientific achieve-
 ments in fisheries enhancement having occurred only
 over the past decade or so, this is understandable. But
 in light of the need to couple fisheries enhancement
 with fisheries management systems, lack of awareness
 of progress in this field is an obstacle that may be
 resolved only by compilation of more and more success
 stories over time. Thus, it is imperative that existing
 and developing enhancement programs alike incorpo-
 rate modern concepts about how to plan and conduct
 enhancements so they are enabled for success.

Progress in Marine Fisheries Enhancement

Lessons Learned from Marine Enhancement Programs

Much progress has now been made in understanding
 how to manage enhancement more effectively. Bartley
 and Bell [96] considered progress made from three
 decades of stocking initiatives and summarized and
 discussed lessons learned. These are listed here, below
 [96], with a brief clarification or caveat on each.

Deciding When and How to Apply the Release of Cultured Juveniles

1. Objective assessment of the need for releases is crucial –and requires an evaluation of the status of the fishery, modeling of stocking impact to determine if stocking can help achieve the goals, coupled with consideration of whether there are recruitment limitations and adequate habitat available for stocking.
2. Releases of cultured juveniles for restocking and stock enhancement need to be made at the scale of self-replenishing populations –releases will not be

806 effective unless the spatial extent of target
 807 populations has been identified; thus prior to
 808 conducting releases of hatchery organisms, clear
 809 identification of genetically discrete stocks should
 810 be determined.

811 3. There are no generic methods for restocking and
 812 stock enhancement –largely because of wide varia-
 813 tion in life history among different species and
 814 variation in ecological conditions among release
 815 sites.

816 4. Very large numbers of juveniles are often needed for
 817 effective stock enhancement –this is particularly so
 818 for offshore stocks, which can be comprised of
 819 a huge number of individuals; more modest releases
 820 may suffice for localized enhancement of inshore
 821 stocks or those comprised of multiple stocks that
 822 occur on relatively small scales.

823 5. Large areas are needed for stock enhancement of
 824 some species –and this can result in user conflict,
 825 particularly for sea ranching, where large areas are
 826 leased and protected by the enhancement program
 827 (e.g., [97]); in other cases, limited dispersal of
 828 adults and larvae indicates stocking in smaller
 829 areas can be effective, for example, common
 830 snook along Florida’s Gulf Coast [98].

831 6. Invertebrates offer good opportunities for
 832 restocking and stock enhancement –because inver-
 833 tebrates are often comprised of self-recruiting
 834 populations that occur at small scales.

835 **Integrating Interventions with Other Management**
 836 **Measures**

837 7. Problems that caused lower production must be
 838 addressed before release of juveniles – particularly
 839 in the case of degraded, lost, or insufficient habitat.
 840 With better management of the wild resources, the
 841 scope for augmentation of total production
 842 declines; enhancement becomes a very site specific
 843 tool when habitat has been lost, or something
 844 needs rebuilding, or there are species of particu-
 845 larly high value [94].

846 8. Biotechnical research must be integrated with insti-
 847 tutional and socio-economic issues – ownership
 848 rights and control and use of enhanced stocks need
 849 to be well understood by the greater institutional,
 850 social, economic, and political environment [99].

9. Successful stock enhancement programs are often 851
 run by cooperatives and the private sector – where 852
 there is increased incentive in sharing the costs of 853
 fisheries enhancement. 854

10. The costs and time frames involved in restocking 855
 programs can be prohibitive – hatchery costs, 856
 which can be considerable, are particularly diffi- 857
 cult to bear in smaller countries and developing 858
 countries. 859

Monitoring and Evaluation 860

11. Development of cost-effective tagging methods is 861
 critical to efficient evaluation of stock enhance- 862
 ment – refining and monitoring the effects and 863
 effectiveness of marine enhancements cannot be 864
 done without a way to distinguish hatchery from 865
 wild stocks and distinct release groups. 866

12. Large-scale releases of hatchery-reared juveniles 867
 can affect genetic [fitness] of wild populations – 868
 genetic hazards can be caused by hatchery-wild 869
 fish interactions and these need to be minimized. 870

Reducing the Cost of Juveniles 871

13. Costs of stocking programs can be reduced by 872
 “piggybacking” production of juveniles for release 873
 on existing aquaculture – this could reduce or 874
 eliminate the need for expensive new hatchery 875
 construction for enhancement programs, as long 876
 as appropriate broodstock management protocols 877
 are in place for conserving wild-stock genetics. 878

14. Wild [postlarvae] can provide an abundant, low- 879
 cost source of juveniles for stock enhancement 880
 programs – this can sometimes be an effective 881
 way to reduce costs and eliminate genetic issues; 882
 successful scallop enhancement in Japan is based 883
 on collection of wild seed stock. 884

15. The costs of restocking can be reduced greatly for 885
 some species by relocating adults to form a viable 886
 spawning biomass – rebuilding spawning aggrega- 887
 tions by concentrating broodstock can be effective 888
 for depleted stocks with limited larval dispersal, 889
 but care must be taken to avoid comingling dif- 890
 ferent stocks (i.e., avoid translocation of exoge- 891
 nous genes). 892

Improving Survival in the Wild 893

16. Predation is the greatest hurdle to survival of 894
 released juveniles – care must be taken to 895

986 understand ecology of the species and ecosystem
987 at the release site and pilot experiments are needed
988 to develop optimal release strategies to maximize
989 survival.

990 17. Excessive releases of juveniles cause density-
991 dependent mortality – density has a strong effect
992 on growth and survival in the wild; planning
993 release magnitude must take into account the car-
994 rying capacity at release locations. This requires
995 adaptive management and an experimental frame-
996 work for releases.

997 18. Small-scale experiments to test methods for
998 releasing juveniles can give misleading results –
999 “commercial scale” releases are needed to test
1000 assumptions made from small-scale release
1001 experiments.

1002 19. Good survival of released juveniles at one site is no
1003 guarantee that the methods can be transferred to
1004 other sites – stocking effectiveness will vary with
1005 release location and what works at one site may
1006 not be effective at another.

1007 **Other Manipulations to Increase Abundances**

1008 20. Artificial habitats can be used to increase the car-
1009 rying capacity for target species – and may enable
1010 increased production at release sites where there
1011 are resource (food, refuge, space) limitations.

1012 21. Yields of some species can be increased by provid-
1013 ing suitable settlement habitat and redistributing
1014 juveniles from areas of heavy settlement – for
1015 example, redistribution can be used to reduce
1016 density effects and increase probability of success-
1017 ful recruitment when moved to a location with
1018 greater availability of food, refuge, or settlement
1019 habitats. But care must be taken to avoid genetic
1020 hazards associated with comingling stocks.

1021 **Examples of Progress Made in Marine Enhancement**

1022 As science and constructive debate have advanced in
1023 this field, there are many signs of progress. Some
1024 explicit examples of progress made in marine enhance-
1025 ment over the past couple of decades are presented
1026 below, ranging in scale from local experimental inves-
1027 tigation of release strategies and density-dependent
1028 effects on hatchery and wild stocks (e.g., [100]) to
1029 documented replenishment impact in large-scale
1030 enhancement efforts (e.g., [101, 102]). This is but

a sample of examples and is by no means 941
a comprehensive list. There are many more examples 942
in the peer-reviewed proceedings from the ISSESR and 943
other stock enhancement conferences [41–53] and 944
other journal articles. 945

1. Adoption of a science-based responsible approach 946
to marine stock enhancement has now become 947
widespread, resulting in a much more assess- 948
ment-driven and precautionary approach than 949
ever before (a few examples include Refs. [4, 6, 950
10, 12, 20, 22, 27–29, 33, 37–39, 59–61, 68, 69, 72, 951
75, 84, 86, 87, 89, 96, 103–106]). This has been 952
enabled, in part, by advances in tagging technol- 953
ogy (e.g., [8] and see examples in [9, 56]) and in 954
development of new marine aquaculture technol- 955
ogies that can now provide juvenile fishes for 956
marine enhancement research. 957
2. Networking of Scientists involved in this rapidly 958
advancing field has been fostered by various sym- 959
posia and working groups, for example, the World 960
Aquaculture Society Working Group on Stock 961
Enhancement and the scientific committees for 962
the International Symposium on Stock Enhance- 963
ment and Sea Ranching (www.SeaRanching.org). 964
3. There is a much better appreciation of the impor- 965
tance of managing marine fishery enhancements 966
from a fisheries management perspective (e.g., [6, 967
59, 107]). 968
4. New tools are available for modeling stock 969
enhancement effects and effectiveness [10, 82, 970
108–110]. 971
5. At least two experimental field studies have now 972
been conducted to evaluate density-dependent 973
interactions of stocked hatchery and wild fish; 974
these provide evidence that increased production 975
can be achieved in juvenile nursery habitats with- 976
out displacing wild fish, but not necessarily with- 977
out displacing some of the hatchery fish [33, 100]. 978
6. There is now clear evidence and a prescription of 979
techniques for improving post-release survival 980
(often with a doubling effect or more) of stocked 981
marine fishes, and optimizing release strategies to 982
maximize stocking efficiency and control impacts 983
(e.g., [26, 36, 37, 39, 60–62, 70, 72, 100–115]). 984
There is also ample evidence that in habitats with 985
limited carrying capacity or intense predation, 986

- 987 regardless of release strategy used, little can be
 988 done to improve survival of hatchery fish and
 989 stocking simply cannot increase production [106,
 990 116, 117].
- 991 7. It is now fairly clear that marine enhancements
 992 may be cost effective only if (a) the supply of
 993 recruits is generally limiting, (b) there is adequate
 994 habitat to support an increased supply of juve-
 995 niles, (c) cultured juveniles represent a large por-
 996 tion of recruitment, (d) fishing is regulated
 997 appropriately, and (e) other management mea-
 998 sures (catch regulations and habitat restoration)
 999 are insufficient to restore catch rates [96].
- 1000 8. Stock enhancement of some species of marine fin-
 1001 fish has been successful at the scale of large bays, for
 1002 example, Hirame flounder and red sea bream in
 1003 Japan [72, 106] when there is sufficient carrying
 1004 capacity at release sites. Carrying capacity varies
 1005 considerably among release sites, and thus must be
 1006 evaluated and taken into account using monitor-
 1007 ing and adaptive management for each release site.
- 1008 9. Scallop sea ranching has been a large success in
 1009 Japan, New Zealand, and China, where property
 1010 rights and large ocean leases have created strong
 1011 incentives for careful management by fishermen
 1012 and owners of the sea ranching operations
 1013 [72, 101, 102, 118]. For example, near Dalian,
 1014 China, Zhangzidao Fishery Group leases
 1015 2,000 km² of ocean-bottom-to-ocean-surface for
 1016 sea ranching. In 2010, Zhangzidao harvested an
 1017 average of 150 t/day of ocean scallops from their
 1018 sea ranching operations (over 50,000 t/year)
 1019 (Wang Qing-yin, personal communication 2011).
- 1020 10. Property rights have also provided incentives for
 1021 bivalve culture in the State of Washington, USA,
 1022 where clam sea ranching operations have
 1023 remained economically and environmentally sus-
 1024 tainable for over three decades [119].
- 1025 11. Pilot experiments with black bream in an Austra-
 1026 lian estuary have documented quite good survival
 1027 and recruitment to the fishery. The latest phase of
 1028 this project reveals strong rationale for long-term
 1029 monitoring of enhancement impact [87, 120].
- 1030 12. Restocking success with red drum in a South
 1031 Carolina estuary [77, 121]. Pilot experiments
 1032 revealed surplus productive capacity in the Ashley
 River in South Carolina, where fishery landings of
 red drum were doubled over a few years.
13. Pilot experiments to evaluate blue crab enhance-
 ment potential in Maryland and Virginia led to
 improvements in traditional fishery management,
 with information learned through stocking
 research [70, 114]. Pilot experiments can be used
 to provide critical information on the natural
 ecology, life history, and environmental require-
 ments of valuable marine species [122].
14. Perhaps the largest scale enhancement success for
 fishes is Japanese chum salmon restocking – a
 special tool for a circumstance in which the habitat
 had almost totally been lost [94].

Future Directions

Over the past two decades, there has been a rapid
 expansion of knowledge about marine fisheries
 enhancement systems and the effects and effectiveness
 of stocking a wide variety of marine organisms for sea
 ranching, stock enhancement and restocking. Many
 gaps in knowledge have now been filled. Well thought
 out approaches now provide a roadmap for effective
 use of enhancements. When models show potential for
 stocking, efforts to deploy marine enhancements can
 be successful if the principles in the roadmap are care-
 fully employed. The basic reason that marine enhance-
 ment programs do not have more of a track record of
 success stories yet is that implementing them well is
 a complex endeavor that demands attention to multi-
 ple factors spanning many disciplines. Rarely have
 these been pulled together in an enhancement pro-
 gram. The Hatchery Reform Project in the Pacific
 Northwest USA, which includes an independent scien-
 tific review panel (“Hatchery Scientific Review
 Group”) is a good example [123]. Because of their
 efforts, salmonid hatchery reforms now underway are
 bringing many of the principles of the Responsible
 Approach into play. The Norwegian PUSH program
 is another good example. In that case, information
 gained from quantitative assessments of enhancement
 showed that stocking would not be an economical way
 to enhance cod in Norway, thus saving years of wasteful
 spending that could have occurred there, had monitor-
 ing and adaptive management not been a central part
 of the enhancement system.

1078 Successful examples of fisheries enhancement are
1079 truly group efforts, involving stakeholders, agency offi-
1080 cials, and individuals with expertise in the principal
1081 sub-disciplines needed. Suffice to say that at this
1082 point in time few, if any, marine fisheries enhancement
1083 programs have enlisted all of the key elements of the
1084 Responsible Approach and Code of Responsible Con-
1085 duct. But these principles are now well described and
1086 laid out in a systematic manner. It is reasonable to
1087 expect that if the Responsible Approach is used as the
1088 blueprint for planning and executing enhancements,
1089 and if the initial appraisal and goal setting stage indi-
1090 cates moving ahead, then there is ample opportunity
1091 for success in applying marine fisheries enhancements,
1092 as long as dedicated attention is focused on applying
1093 each of the key elements.

1094 So how will marine enhancement advance to the
1095 next level – emergence of a rapidly growing body of
1096 success stories in restocking, stock enhancement, and
1097 sea ranching? Listed below are a few factors that are
1098 now needed to transition this field to the next level,
1099 where marine enhancements are well integrated into
1100 resource management systems and used wisely and
1101 appropriately.

1102 **Enabling Factors for Increasing Successful Marine** 1103 **Enhancements**

- 1104 1. *Greater awareness is needed among all stakeholders of*
1105 *the issues, pitfalls, progress, and opportunities in this*
1106 *field.* The concepts underlying effective enhance-
1107 ments need to be translated into lay language and
1108 used to inform stakeholders. This will help all stake-
1109 holders recognize the various issues and parameters
1110 needed for effective enhancements. Pivotal among
1111 stakeholders are public officials who fund enhance-
1112 ment programs, as they need to understand what it
1113 takes to develop an effective program or reform
1114 existing ones. New enhancement programs that
1115 may not be funded well enough to implement all
1116 of the key principles in the Responsible Approach
1117 would do well to use the results of Stage 1 in [Table 3](#)
1118 to document the potential for success, but not pro-
1119 ceed beyond Stage 1 until adequate funding is
1120 available.
- 1121 2. *Use of Adaptive management is one of the most*
1122 *important principles for guiding successful*

enhancement programs. Active adaptive manage- 1123
ment [91] is critical for gauging the effectiveness 1124
of, improving, and managing fisheries systems in 1125
the face of uncertainty. However, it is often 1126
dismissed by enhancement programs or given low 1127
priority for lack of funding or when enhancement is 1128
viewed as a quick fix. But, this important principle 1129
is used to optimize release strategies, to identify and 1130
deal with ecological or genetic impacts on wild 1131
stocks, to refine the enhancement process and identi- 1132
fy the results of improvements, to evaluate and 1133
improve progress towards goals and objectives, and 1134
to monitor and improve economic impact. Active 1135
adaptive-management is an essential component of 1136
managing enhancement programs; it empowers 1137
management teams to understand and control the 1138
impacts of enhancements well. Without it, enhance- 1139
ment programs at best rely on hope to achieve their 1140
potential (but cannot) and at worst are doomed to 1141
failure. Australia is employing active adaptive man- 1142
agement principles early in the development stage 1143
as part of ongoing work to evaluate enhancement 1144
potential for a wide range of species [124]. 1145

3. *Adapt the Responsible Approach to local circum-* 1146
stances. The Responsible Approach is purposely 1147
vague on how to implement it. This is partly 1148
because not all elements are needed under all situ- 1149
ations, but most will be. Fitting the process to 1150
particular circumstances is in itself a key part of 1151
implementing the Responsible Approach by engag- 1152
ing the various stakeholders in planning [6]. As 1153
progress continues in this field, additional princi- 1154
ples will emerge that need to be included, for exam- 1155
ple, to account for needs of regional fishery 1156
management plans in response to climate change. 1157
4. *Seek assistance from established workers in the field.* 1158
For new and developing enhancement programs, or 1159
existing ones seeking to design and implement 1160
reforms, there is a broad and expanding network 1161
of workers in this field who could be queried for 1162
advice on various enhancement issues. The ISSES 1163
website is a good source for identifying individuals 1164
with specific kinds of expertise, by perusing presen- 1165
tation abstracts or locating published proceedings 1166
from past ISSES conferences [125]. If researchers 1167
or workers in the field are contacted, but do not 1168

1169 have time to provide advice, they usually will help
 1170 identify others who can.

1171 This entry may help expand awareness among fish-
 1172 ery stakeholders, other natural-resource stakeholders,
 1173 scientists, and fishery managers alike about the pitfalls,
 1174 challenges, and progress made in using marine hatch-
 1175 ery releases as one of the tools in resource management
 1176 and seafood production. Readers are referred to the
 1177 articles and symposium proceedings cited herein to
 1178 gain a better understanding of the issues, lessons
 1179 learned, and progress.

1180 The debate focused on enhancement is a healthy
 1181 one, for it is fostering steady improvements and
 1182 reforms in existing programs, and careful planning
 1183 and design in new ones. With each advance made, the
 1184 potential seen by our forefathers to use hatcheries as
 1185 a tool for recovering depleted stocks, increasing abun-
 1186 dance in recruitment-limited stocks, and producing
 1187 seafood by sea ranching is coming closer to fruition.
 1188 One of the greatest lessons learned from the past is that
 1189 the emphasis on expanding hatchery fish production
 1190 for marine enhancement should not be allowed to take
 1191 the focus off of the objective – increasing yields in
 1192 fisheries and recovering stocks in restoration programs.
 1193 Clearly, marine fisheries enhancement is a strong tool
 1194 to add to the fishery management toolbox. But only
 1195 careful analysis of conditions of the wild stock and the
 1196 fishery will guide when and where it is appropriate to
 1197 use enhancements in addition to other management
 1198 options, and when to stop. As Albert Einstein once said,
 1199 “a perfection of means, and confusion of aims, seems to
 1200 be our main problem.” With the focus shifted to out-
 1201 comes in marine enhancement programs, the appro-
 1202 priate means should fall into place, aided by healthy
 1203 debate and prescriptions for a responsible approach to
 1204 marine fisheries enhancement.

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t1.1 **Marine Fisheries Enhancement: Coming of Age in the New Millennium. Table 1** The ten principles of a responsible approach to marine stock enhancement [4]

t1.2	1	Prioritize and select target species for enhancement by ranking and applying criteria for species selection
t1.3	2	Develop a management plan that identifies how stock enhancement fits with the regional plan for managing stocks
t1.4	3	Define quantitative measures of success to track progress over time
t1.5	4	Use genetic resource management to avoid deleterious genetic effects on wild stocks
t1.6	5	Implement a disease and health management plan
t1.7	6	Consider ecological, biological, and life history patterns in forming enhancement objectives and tactics; seek to understand behavioral, biological, and ecological requirements of released and wild fish
t1.8	7	Identify released hatchery fish and assess stocking effects on the fishery and on wild stock abundance
t1.9	8	Use an empirical process for defining optimal release strategies
t1.10	9	Identify economic objectives and policy guidelines, and educate stakeholders about the need for a responsible approach and the time frame required to develop a successful enhancement program
t1.11	10	Use adaptive management to refine production and stocking plans and to control the effectiveness of stocking

Marine Fisheries Enhancement: Coming of Age in the New Millennium. Table 2 Code of responsible conduct for marine stock enhancement [5]

t2.1	• Make certain that management priorities and acceptable trade-offs are absolutely clear
t2.2	• Do careful stock assessments to show that the target stock is recruitment overfished or can no longer rear successfully in the wild
t2.3	• Show that enhanced fish can recruit successfully in the wild
t2.4	• Show that total abundance is at least initially increased by the hatchery fish contribution
t2.5	• Show that fishery regulations are adequate to prevent continued overfishing of the wild population, unless there has been an explicit decision to “write off” the wild population
t2.6	• Show that the hatchery production system is actually sustainable over the long run, when it is to be a permanent component of the production system
t2.7	

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t3.1 **Marine Fisheries Enhancement: Coming of Age in the New Millennium. Table 3** The updated responsible approach (From [6])

t3.2	Stage I: Initial appraisal and goal setting	
t3.3	1	Understand the role of enhancement within the fishery system [new]
t3.4	2	Engage stakeholders and develop a rigorous and accountable decision making process [new]
t3.5	3	Quantitatively assess contributions of enhancement to fisheries management goals
t3.6	4	Prioritize and select target species and stocks for enhancement
t3.7	5	Assess economic and social benefits and costs of enhancement
t3.8	Stage II: Research and technology development including pilot studies	
t3.9	6	Define enhancement system designs suitable for the fishery and management objectives [new]
t3.10	7	Design appropriate aquaculture systems and rearing practices [new]
t3.11	8	Use genetic resource management to maximize effectiveness of enhancement and avoid deleterious effects on wild populations.
t3.12	9	Use disease and health management
t3.13	10	Ensure that released hatchery fish can be identified
t3.14	11	Use an empirical process for defining optimal release strategies
t3.15	Stage III: Operational implementation and adaptive management	
t3.16	12	Devise effective governance arrangements [new]
t3.17	13	Define a management plan with clear goals, measures of success, and decision rules
t3.18	14	Assess and manage ecological impacts
t3.19	15	Use adaptive management

t4.1 **Marine Fisheries Enhancement: Coming of Age in the New Millennium. Table 4** Key areas of expertise needed in marine fisheries enhancement

t4.2	• Fisheries science
t4.3	• Fisheries management
t4.4	• Adaptive management
t4.5	• Marine aquaculture
t4.6	• Population genetics
t4.7	• Aquatic animal health
t4.8	• Population ecology
t4.9	• Behavioral ecology
t4.10	• Community ecology
t4.11	• Resource economics
t4.12	• Social science and institutional analysis and design
t4.13	• Statistics and experimental design
t4.14	• Tagging technology
t4.15	• Communications and outreach