

DRAFT TEST GUIDELINE

Androgenised Female Stickleback Screen (AFSS)

INTRODUCTION

1. This protocol describes a 21-day *in vivo* screening assay for identifying endocrine active chemicals with (anti)androgenic activity in fish using female sticklebacks (*Gasterosteus aculeatus*). The current 21-day fish assay for screening chemicals with potential endocrine disrupting activity cannot clearly identify androgen antagonists due to the lack of a suitable end-point in the fathead minnow, the medaka or the zebrafish (1). In addition, the detection of androgen agonists in the above assay is possible only in the fathead minnow and the medaka via an indirect endpoint, reduction in plasma vitellogenin levels (2). This protocol is in principle identical to the new OECD Guideline No. 230 (21-day Fish Assay: A short-term screening for oestrogenic and androgenic activity and aromatase inhibition), with two major differences; only female fish are used and all groups except controls (water, solvent and test compound at the highest concentration used) receive 5µg/L dihydro-testosterone (DHT), in addition to the test compound. DHT is used in order to induce a fully controlled moderate level of the androgen regulated protein spiggin in the female stickleback kidney, to allow the detection of antiandrogens. The androgenised female stickleback screen (AFSS) exposes fish to chemicals for 21 days. This draft guideline identifies specific mechanisms of hormonal disruption, specifically androgen receptor agonists and antagonists. The validation work (3) has been reviewed by a panel of experts. The concept for this guideline is derived from work on the three-spined stickleback (4-8), since the presence of the specific biomarker for androgens is present only in this species (9, 4).

2. This draft test guideline describes an *in vivo* screening assay where sexually mature female sticklebacks are exposed to chemicals(s) during a limited part of their life-cycle (21 days). The protocol does not require an *in situ* pre-exposure period and measures one biomarker endpoint as indicator of (anti)androgenic activity, the levels of spiggin in the female stickleback kidneys. Other apical endpoints measured include survival and body weight.

3. This protocol serves as an *in vivo* screening assay for certain endocrine modes of action and its application should be seen in the context of the “OECD Conceptual Framework for the Testing and Assessment of Endocrine Disrupting Chemicals”.

INITIAL CONSIDERATIONS AND LIMITATIONS

4. Spiggin is normally produced by the kidney of breeding sticklebacks in response to circulating endogenous androgen. It is briefly stored in the urinary bladder from where it is excreted by contractions and used as a cementing material for the construction of a nest. Spiggin is almost undetectable in the kidney of immature male and female sticklebacks because they lack sufficient circulating androgen; however, the kidney is capable of synthesising and excreting spiggin in response to exogenous androgen stimulation (10, 4).

- 1 5. The measurement of spiggin serves for the detection of chemicals with androgenic mode of action.
2 The detection of androgen agonists is possible via the measurement of spiggin induction in female
3 sticklebacks, and it has been well documented in the scientific peer-reviewed literature (4-6, 10-15).
4 Reduction of spiggin levels has also been demonstrated following exposure to androgen antagonists, both
5 in intact male stickleback using a short-term reproductive assay (16-18) and in the androgenised
6 (masculinised) female stickleback screen (3, 5-6). The stickleback reproduction (breeding) protocol has
7 been proved to be difficult to reproduce in non-expert laboratories, due to the difficulties in fully
8 controlling the reproductive status of males under laboratory conditions. The AFSS on the other hand is
9 better suited as an endocrine screen due to its simplicity and proven reproducibility in several laboratories.
10 The fish are simultaneously treated with a model androgen (dihydro-testosterone, DHT) at 5µg/L and a
11 range of concentrations of the putative antiandrogen. Antiandrogenic activity is detected by the degree of
12 reduction/inhibition of spiggin induction by the DHT treatment. The biological basis of the spiggin
13 response following androgenic and antiandrogenic treatment is well established. However, it is possible
14 although not documented, that production of spiggin in females can also be affected by general toxicity and
15 non-endocrine toxic modes of action, e.g. nephrotoxicity (in a similar manner that hepatotoxicity can affect
16 vitellogenin production).
- 17 6. Spiggin protein levels can be measured by a specific Enzyme-Linked Immunosorbent Assay
18 (ELISA) method using immunochemistry for the quantification of spiggin in kidneys collected from
19 individual sticklebacks (4). [Annex 3](#) provides the recommended procedures for sample collection for
20 spiggin analysis and [Annex 4](#) provides a validated protocol for spiggin analysis. The spiggin ELISA has
21 demonstrated acceptable inter-laboratory reproducibility during a previous validation exercise (14).
- 22 7. Definitions used in this draft Test Guideline are given in [Annex 1](#).

23

24 **PRINCIPLE OF THE TEST**

- 25 8. Overviews of the relevant bioassay conditions are provided in [Annex 2](#) to this protocol. The assay
26 is normally initiated with fish sampled from populations that are in spawning condition to facilitate
27 selection of female fish. Spawning conditions can be readily induced in sticklebacks by temperature and
28 photoperiod manipulations. Guidance on the age of fish and on the reproductive status is provided in the
29 section on Selection of fish. It should be noted that we recommend the use of sexually mature females
30 because sexual dimorphism in this species is present only when the fish are in active breeding; the
31 reproductive status of the female (i.e., immature, early vitellogenic, later vitellogenic, spend) does not
32 affect the female response to the treatment. At test termination, sex is confirmed by macroscopic
33 examination of the gonads following ventral opening of the abdomen with scissors. The assay is conducted
34 using a range of chemical exposure concentrations (five test concentrations are recommended), as well as a
35 water control, a solvent control, a positive control where DHT alone is administered at 5µg/L, and a
36 negative control where the test chemical is administered alone at the highest concentration tested. Two
37 vessels per treatment (each containing 5 female fish) are used. DHT is readily biodegradable in aqueous
38 solutions; hence the test can only be conducted using flow-through conditions and a carrier solvent. In
39 addition, since most of the androgen antagonists identified to date are highly hydrophobic molecules, the
40 use of solvent carrier facilitates their administration. The exposure is conducted for 21-days and sampling
41 takes place at the end of this period. Endpoints include survival, whole body wet weight and kidney
42 spiggin levels.

43

1 **TEST ACCEPTANCE CRITERIA**

- 2 9. For a test to be valid the following conditions apply:
- 3 - the mortality in the water and solvent controls does not exceed 10 per cent at the end of the
 - 4 exposure period;
 - 5 - the dissolved oxygen concentration must be between 60 and 100 per cent of the air saturation
 - 6 value (ASV) throughout the test;
 - 7 - the water temperature must not differ by more than $\pm 1.5^{\circ}\text{C}$ between test chambers or between
 - 8 successive days at any time during the test, and should be within the temperature range of 16-
 - 9 18°C .
 - 10 - evidence must be available to demonstrate that the mean measured concentrations of the test
 - 11 substance in solution have been satisfactorily maintained within $\pm 20\%$ of the nominal
 - 12 concentrations.

13 **DESCRIPTION OF THE METHOD**

14 *Apparatus*

- 15 10. Normal laboratory equipment and especially the following:
- 16 (a) dissolved oxygen and pH meters;
 - 17 (b) equipment for determination of water hardness and alkalinity;
 - 18 (c) adequate apparatus for temperature control and preferably continuous monitoring;
 - 19 (d) tanks made of chemically inert material (e.g. glass, stainless steel) and of a suitable capacity in relation
 - 20 to the recommended loading and stocking density (see [Annex 2](#)); It is desirable that test chambers be
 - 21 randomly positioned in the test area. The test chambers should be shielded from unwanted disturbance.
 - 22 (e) suitably accurate balance (i.e. accurate to $\pm 0.5\text{mg}$).

23 *Water*

- 24 11. Any water in which the test species shows suitable long-term survival and growth may be used as
- 25 test water. It should be of constant quality during the period of the test. The pH of the water should be
- 26 within the range 6.5 to 8.5, but during a given test it should be within a range of ± 0.5 pH units. It is
- 27 recommended that dilution water hardness should be above 140 mg/l (as CaCO_3). In order to ensure that
- 28 the dilution water will not unduly influence the test result (for example by complexation of test substance),
- 29 samples should be taken at intervals for analysis. Measurements of heavy metals (e.g. Cu, Pb, Zn, Hg, Cd,
- 30 Ni), major anions and cations (e.g. Ca, Mg, Na, K, Cl, SO_4), pesticides (e.g. total organophosphorus and
- 31 total organochlorine pesticides), total organic carbon and suspended solids should be made, for example,
- 32 every three months where a dilution water is known to be relatively constant in quality. Some chemical
- 33 characteristics of acceptable dilution water are listed in [Annex 5](#).

34 **Test solutions**

- 35 12. Test solutions of the chosen concentrations are prepared by dilution of a stock solution. Since
- 36 DHT displays low solubility and stability in aqueous solutions the use of solvent carrier is unavoidable. In
- 37 addition, many suspected antiandrogenic compounds are also highly hydrophobic hence the use of solvent
- 38 carrier benefits the practical aspects of their administration too. A solvent control group should be run in
- 39 parallel, at the same solvent concentration as the chemical treatments. The choice of solvent will be
- 40 determined by the chemical properties of the substance; for guidance consult the OECD Guidance
- 41 Document on aquatic toxicity testing of difficult substances and mixtures (19). The validation data (3)
- 42 were produced using methanol at $1000\mu\text{g/L}$ but other solvents such as ethanol, acetone or DMSO have also
- 43 been used effectively for the administration of DHT in aquaria. However, the OECD Guidance Document

1 recommends that a maximum of 100µl/L of solvent should be observed in the aquaria whilst a recent
2 review recommends that the solvent concentration in the aquaria should not exceed 20µl/L (20). These
3 levels are achievable in the AFSS if stock solutions are made in 100% solvent and high dilution water flow
4 rates are used. Nevertheless, statistical analysis of a thousands of kidney samples for spiggin from
5 different exposures where solvents were employed at this high level indicated that there were no
6 differences in spiggin content between water control and solvent control female fish. The core endpoint
7 employed by the test is based on a robust mechanistic response and does not appear to be affected by the
8 high levels of solvent in the aquaria. It is recommended however, that the solvent concentration be
9 minimised wherever technically feasible.

10 13. A flow-through test system should be used. Such a system continually dispenses and dilutes a
11 stock solution of the test substance (e.g. metering pump) in order to deliver a series of concentrations to the
12 test chambers. In the test vessels that receive both DHT and the test substance, we recommend combining
13 the two stock solutions to provide the desired concentrations. This is because the degree of reduction in
14 spiggin levels by the test substance is directly related to the levels of DHT that induce spiggin production
15 in the female kidney. By combining the stock solutions of DHT and the test compound slight differences
16 in the flow rates between DHT solutions and test compound solutions that can adversely affect the
17 response are avoided. In addition, the test becomes less labour intensive, as fewer flow rates need to be
18 checked and calibrated on a daily basis. The flow rates of stock solutions and dilution water should be
19 checked at intervals, preferably daily, during the test and should not vary by more than 15% throughout the
20 test. Care should be taken to avoid the use of low-grade plastic tubing or other materials that may contain
21 biologically active substances. When selecting the material for the flow-through system, possible
22 adsorption of the test substance to this material should be considered.

23 14. Semi-static test conditions should be avoided unless there are compelling reasons associated with
24 the test chemical (e.g., stability, limited availability, high cost or hazard). The preferred renewal procedure
25 in the semi-static technique involves changing a proportion (at least two thirds) of the test water every 24
26 hours whilst retaining the test organisms in the test vessels. In this case, DHT at 5µg/L must be replaced by
27 17α-methyltestosterone (MT) at 0.5µg/L, since the latter steroid is stable in aqueous solutions over time
28 (6). Aromatisation of MT to oestrogens has been reported in some fish species (21-22) but we have never
29 observed vitellogenin induction in male sticklebacks after exposure to MT or DHT (own unpublished
30 data).

31 ***Holding and selecting the fish***

32 15. The only species that can be used is the three-spined stickleback (*Gasterosteus aculeatus*) as the
33 androgen biomarker protein spiggin is not present in other teleost species.

34 16. Test fish should ideally be selected from a laboratory population of a single stock, preferably from
35 the same spawning, which has been acclimated for at least one week prior to the test under conditions of
36 water quality and illumination similar to those used in the test (note, this acclimation period is not an *in*
37 *situ* pre-exposure period). It is important to avoid using animals from the wild as they are often parasitised
38 by plerocercoids of *Schistocephalus solidus*, which delays and/or inhibits sexual maturation in male fish
39 (23) and results in the same phenotype as a gravid female; both effects may result in selecting parasitised
40 males rather than females for the test.

41 17. Only female fish can provide meaningful information in this draft test guideline as they lack high
42 levels of endogenous androgens that could affect the response. In order to reduce the number of fish used
43 in the test, separation of sexes prior to the test is therefore essential. Sticklebacks display strong sexual
44 dimorphism (the males develop blue irises and red throats) only during their breeding season; hence the
45 fish population used in the test must be adult fish (over 30 weeks of age assuming they have been cultured
46 at 17±2°C throughout their life span) that are reproductively mature. If the fish supplier does not guarantee
47 a female only population, selection is easily achievable in laboratory conditions by applying adequate

1 photoperiod regime (18 hours light: 6 hours dark). Since social hierarchies are strong in this species, only
2 few males in a single holding vessel will display nuptial coloration at one time. The easily recognised
3 dominant males should be gradually removed on a daily basis, allowing the subordinate fish to become
4 dominant. The time needed for this selection depends on the stocking density, the lower the density the
5 more male fish will develop nuptial coloration at one time. As a guide, we recommend the use of 0.5 g/l
6 over a two-week period under high photoperiod to ensure an all female population. Female fish can be
7 further identified by their gravid appearance. Alternatively, fish can be sexed using DNA techniques (24,
8 25); clipping one of their 3 dorsal spines can provide enough material for this analysis. A sex ratio of 1:1
9 should be assumed in a mixed population, although often we observe a slightly biased sex ratio towards
10 females. At least 8 female fish per treatment levels are needed to provide statistical power in the AFSS.
11 Fish should be fed *ad libitum* throughout the holding period and during the exposure phase. Note- fish
12 should not be fed within 12 hours of necropsy.

13 18. Following a 48-hour settling-in period, mortalities are recorded and the following criteria applied:

- 14 • mortalities of greater than 10% of population in seven days: reject the entire batch;
- 15 • mortalities of between 5% and 10% of population: acclimation for seven additional days; if more than 5%
16 mortality during second seven days, reject the entire batch;
- 17 • mortalities of less than 5% of population in seven days: accept the batch.

18 19. Fish should not receive treatment for disease in the two-week period preceding the test, or during
19 the exposure period.
20

21 **TEST DESIGN**

22 20. At least five concentrations of the chemical (along with DHT at 5µg/l), a water control (although
23 the validation data suggest that there is not need for a water control), a solvent control, a DHT (positive
24 control) and the highest concentration of the chemical tested with no DHT (negative control) are used per
25 experiment (all in duplicate test vessels). The data may be analysed in order to determine statistically
26 significant differences between treatment and control responses. Calculation of these statistical parameters
27 will be useful in order to establish whether any further longer term testing for adverse effects (namely,
28 survival, development, growth and reproduction) is required for the chemical.

29 21. At initiation of the experiment on day-0, five females from the non-exposed population are
30 sampled for the measurement of kidney spiggin. At termination of the assay after 21 days of exposure, all 5
31 female fish in each vessel are killed for the measurement of kidney spiggin.
32

33 ***Selection of test concentrations***

34 22. For the purposes of this test, the highest test concentration should be set by the maximum tolerated
35 concentration (MTC) determined from a range finder or from other toxicity data, or 10 mg/l whichever is
36 lowest (26). The MTC is defined as the highest test concentration of the chemical, which results in less
37 than 10% mortality. Using this approach assumes that there are existing empirical acute toxicity data or
38 other toxicity data from which the MTC can be estimated. Estimating the MTC can be inexact and
39 typically requires some professional judgment.

40 23. Three test concentrations, spaced by a constant factor not exceeding 10, (in addition to the water,
41 solvent, positive and negative control) are required. A range of spacing factors between 3.2 and 10 is
42 recommended. A typical test should include the following treatments (all in duplicate vessels):

- 43 • Water control
- 44 • Solvent control (solvent the at same level as in the treatment vessels)
- 45 • Negative control (test chemical at high concentration)
- 46 • Positive control (DHT at 5 µg/l)

- 1 • High test chemical concentration +DHT at 5 µg/l
- 2 • Medium test chemical concentration +DHT at 5 µg/l
- 3 • Low test chemical concentration +DHT at 5 µg/l

5 **PROCEDURE**

6 ***Selection and weighing of test fish***

7 24. It is only moderately important to minimise variation in weight of the fish at the beginning of the
8 assay. This is because spiggin units per kidney are divided to the body weight to normalise the response.
9 Suitable size range is 0.7-1.7g. For the whole batch of fish used in the test, the range in individual wet
10 weights at the start of the test should be kept to within $\pm 30\%$ of the arithmetic mean wet weight. It is
11 recommended to weigh a subsample of the fish stock before the test in order to estimate the mean weight.

12 ***Conditions of Exposure***

13 *Duration*

14 25. The test duration is 21 days with no pre-exposure period needed.

15 *Feeding*

16 26. The fish should be fed *ad libitum* with appropriate food ([Annex 2](#)) at a sufficient rate to maintain
17 body condition. Care should be taken to avoid microbial growth and water turbidity. The daily ration may
18 be divided into two or three equal portions for multiple feeds per day, separated by at least three hours
19 between each feed. The ration is based on the initial total fish weight for each test vessel. Food should be
20 withheld from the fish for 12 hours prior to the day of sampling.

21 27. Fish foods should be evaluated for the presence of contaminants including heavy metals,
22 organochlorine pesticides, polycyclic aromatic hydrocarbons (PAHs) and polychlorinated biphenyls
23 (PCBs).

24 28. Uneaten food and faecal material should be removed from the test vessels each day by carefully
25 cleaning the bottom of each tank using suction.

27 *Light and temperature*

28 29. The photoperiod during the test should be 12 hours dark:12 hours light (light intensity 540 to 1000
29 lux) and the water temperature should be 16-18°C (see [Annex 2](#)).

31 ***Frequency of Analytical Determinations and Measurements***

32 30. Prior to initiation of the exposure period, proper function of the chemical delivery system should
33 be ensured. All analytical methods needed should be established, including sufficient knowledge on the
34 substance stability in the test system. During the test, the concentrations of the test substance are
35 determined at regular intervals, as follows: the flow rates of diluent and toxicant stock solution should be
36 checked preferably daily but as a minimum twice per week, and should not vary by more than 20%
37 throughout the test. It is recommended that the actual test chemical concentrations be measured in all
38 vessels at the start of the test and at weekly intervals thereafter.

1 31. It is recommended that results are based on measured concentrations. However, if concentrations
2 of the test substance in solution have been satisfactorily maintained within $\pm 20\%$ of the nominal
3 concentration throughout the test, then the results can either be based on nominal or measured values.

4 32. Samples may need to be filtered (e.g. using a 0.45 μm pore size) or centrifuged. If needed, then
5 centrifugation is the recommended procedure. However, if the test material does not adsorb to filters,
6 filtration may also be acceptable.

7 33. During the test, dissolved oxygen, temperature, and pH should be measured in all test vessels at
8 least once per week. Total hardness and alkalinity should be measured in the controls and one vessel at the
9 highest concentration at least once per week. Temperature should preferably be monitored continuously in
10 at least one test vessel.

11 *Observations*

12 34. A number of general (survival, behaviour and appearance) and a single core biomarker response
13 are assessed over the course of the AFSS. Measurement and evaluation of these endpoints and their utility
14 are described below:

15 *Survival*

16 35. Fish should be examined daily during the test period and any mortality should be recorded and the
17 dead fish removed as soon as possible. Dead fish should not be replaced in either the control or treatment
18 vessels. Sex of fish that die during the test should be confirmed by macroscopic evaluation of the gonads.

19 *Behaviour and appearance*

20 36. Any abnormal behaviour (relative to controls) should be noted; this might include signs of general
21 toxicity including hyperventilation, uncoordinated swimming, loss of equilibrium, and atypical quiescence
22 or feeding. Additionally external abnormalities (such as haemorrhage, discoloration) should be noted. Such
23 signs of toxicity should be considered carefully during data interpretation since they may indicate
24 concentrations at which biomarkers of endocrine activity are not reliable. Such behavioural observations
25 and gross morphological observations may also provide useful qualitative information to inform potential
26 future fish testing requirements. Chemicals with certain modes of action may cause abnormal occurrence
27 of secondary sex characteristic in animals of the opposite sex; for example, androgen receptor agonists,
28 such as MT and DHT can cause female sticklebacks to develop territorial aggressiveness and nuptial
29 colouration.
30

31 *Humane killing of fish*

32 37. At day 0 and day 21 at conclusion of the exposure, the fish should be euthanised with appropriate
33 amounts of Tricaine (Tricaine methane sulfonate, Metacain, MS-222 (CAS.886-86-2), 100-500 mg/L
34 buffered with 300 mg/L NaHCO_3 (sodium bicarbonate, CAS.144-55-8) to reduce mucous membrane
35 irritation; the fish are then individually weighed as wet weights (blotted dry) and the kidney is excised for
36 spiggin level determination ([Annex 3](#)).

37 *Sampling of fish for spiggin evaluation*

38 38. The kidney from each fish is excised ([Annex 3](#)) and placed in individually labelled 2ml tubes with
39 screw caps (do not use Eppendorf type tubes as the spiggin measurement protocol involves heating up in
40 the presence of a strong denaturing buffer, so high pressure is built up which can force open the caps of

1 Eppendorf tubes). The measurement of spiggin protein in the kidney should be based upon a validated
2 homologous ELISA method, using homologous spiggin standard and homologous antibodies.

3 39. Quality control of spiggin analysis will be accomplished through the use of standards, blanks and
4 at least duplicate analyses. Each ELISA plate used for spiggin assays should include the following quality
5 control samples: at least 8 calibration standards covering the range of expected spiggin concentrations, and
6 at least one non-specific binding assay blank (analysed in duplicate). At least two aliquots (well-duplicates)
7 of each sample dilution will be analysed. Well-duplicates that differ by more than 20% should be re-
8 analysed.

9 40. The correlation coefficient (R^2) for calibration curves should be greater than 0.99. However, a
10 high correlation is not sufficient to guarantee adequate prediction of concentration in all ranges. In addition
11 to having a sufficiently high correlation for the spiggin calibration curve, the concentration of each
12 standard, as calculated from the calibration curve, should all fall between 70 and 120 % of its nominal
13 concentration. If the nominal concentrations trend away from the calibration regression line (e.g. at lower
14 concentrations), it may be necessary to split the calibration curve into low and high ranges or to use a
15 nonlinear model to adequately fit the absorbance data. If the curve is split, both line segments should have
16 $R^2 > 0.99$.

17 41. The limit of detection (LOD) is defined as the concentration of the lowest analytical standard,
18 and limit of quantification (LOQ) is defined as the concentration of the lowest analytical standard
19 multiplied by the lowest dilution factor.

20

21 **DATA AND REPORTING**

22 **EVALUATION OF BIOMARKER RESPONSES BY ANALYSIS OF VARIANCE** 23 **(ANOVA)**

24 42. To identify potential endocrine activity of a chemical, responses are compared between treatments
25 and control groups using analysis of variance (ANOVA). An appropriate statistical test should be
26 performed between the dilution water and solvent controls for spiggin. Guidance on how to handle dilution
27 water and solvent control data in the subsequent statistical analysis can be found in OECD, 2006c (27).
28 The biological response of any male fish present in the vessels should be removed from analysis. The data
29 are logarithmically transformed prior to performing the ANOVA. Dunnett's test (parametric) on multiple
30 pair-wise comparisons or a Mann-Whitney with Bonferroni adjustment (non-parametric) may be used for
31 non-monotonous dose-response. Other statistical tests may be used (e.g. Jonckheere-Terpstra test or
32 Williams test) if the dose-response is approximately monotone. A statistical flowchart is provided in
33 Annex 6 to help in the decision on the most appropriate statistical test to be used. Additional information
34 can also be obtained from the OECD Document on Current Approaches to Statistical Analysis of
35 Ecotoxicity Data (23).

36 **REPORTING OF TEST RESULTS**

37 43. Study data should include:

38 *Testing facility:*

- 39 • Responsible personnel and their study responsibilities

- 1 • Each laboratory should have demonstrated proficiency using DHT as a model androgen and
2 Flutamide as a model antiandrogen.

3 *Test Substance:*

- 4 • Characterization of test substance
5 • Physical nature and relevant physicochemical properties
6 • Method and frequency of preparation of test concentrations
7 • Information on stability and biodegradability

8 *Solvent:*

- 9 • Characterization of solvent (nature, concentration used)
10 • Justification of choice of solvent

11 *Test animals:*

- 12 • Species and strain
13 • Supplier and specific supplier facility
14 • Age of the fish at the start of the test and reproductive/spawning status
15 • Details of animal acclimation procedure
16 • Whole body wet weight of the fish at the start of the exposure (from a sub-sample of the fish
17 stock)

18 *Test Conditions:*

- 19 • Test procedure used (test-type, loading rate, stocking density, etc.);
20 • Method of preparation of stock solutions and flow-rate;
21 • The nominal test concentrations, weekly measured concentrations of the test solutions and
22 analytical method used, means of the measured values and standard deviations in the test vessels
23 and evidence that the measurements refer to the concentrations of the test substance in true solution;
24 • Dilution water characteristics (including pH, hardness, alkalinity, temperature, dissolved oxygen
25 concentration, residual chlorine levels, total organic carbon, suspended solids and any other
26 measurements made);
27 • Photoperiod (duration and intensity);
28 • Water quality within test vessels: pH, hardness, temperature and dissolved oxygen concentration;
29 • Detailed information on feeding (e.g. type of food(s), source, amount given and frequency and
30 analyses for relevant contaminants if available (e.g. heavy metals, PCBs, PAHs and
31 organochlorine pesticides).

32 *Results*

- 33 • Evidence that the controls met the acceptance criteria of the test;
34 • Data on mortalities occurring in any of the test concentrations and control;
35 • Statistical analytical techniques used, treatment of data and justification of techniques used;
36 • Data on biological observations of gross morphology and behaviour and spiggin levels;
37 • Results of the data analyses preferably in tabular and graphical form;
38 • Incidence of any unusual reactions by the fish and any visible effects produced by the test substance
39

GUIDANCE FOR THE INTERPRETATION AND ACCEPTANCE OF THE TEST RESULTS

44. This section contains a few considerations to be taken into account in the interpretation of test results for the various endpoints measured. The results should be interpreted with caution where the test substance appears to cause overt toxicity or to impact on the general condition of the test animal.

45. In setting the range of test concentrations, care should be taken not to exceed the Maximum Tolerated Concentration to allow a meaningful interpretation of the data. It is important to have at least one treatment where there are no signs of toxic effects. Signs of disease and signs of toxic effects should be thoroughly assessed and reported. For example, it is possible (although not documented) that production of spiggin in females can also be affected by general toxicity and non-endocrine toxic modes of action, e.g. nephrotoxicity. However, interpretation of effects may be strengthened by other treatment levels that are not confounded by systemic toxicity.

46. There are a few aspects to consider for the acceptance of test results. As a guide, the spiggin levels in control groups (water, solvent) and the positive control (DHT alone at 5µg/l) should be distinct and separated by about two orders of magnitude. Examples of the range of values encountered in control and treatment groups are available in the literature and the validation report (3-6).

47. If a laboratory has not performed the assay before or substantial changes (e.g. change of fish supplier) have been made it is advisable that a technical proficiency study is conducted. In practice, each laboratory is encouraged to build its own historical data for control (water and solvent, positive and negative) females; these can be compared to available data from the validation studies (3-6) to ensure laboratory proficiency.

48. In general, spiggin response is positive (the substance has antiandrogenic activity) if there is a statistically significant decrease in female spiggin levels ($p < 0.05$), in the treated groups (at least at the highest dose tested) compared to the positive control group (DHT alone) whilst the mean response of spiggin levels in the control groups (water and solvent) and in the negative control group (test substance at the highest dose tested) is below 200 spiggin units/g body weight and in the absence of signs of general toxicity. Spiggin response is also positive (the substance has androgenic activity) if there is a significant increase ($p < 0.05$) in female spiggin levels in the treated groups (at least in the highest concentration tested) compared to the positive control group (DHT-treated) and/or a significant increase in spiggin levels ($p < 0.05$) is observed in the negative control group (test substance at the highest dose tested) compared to the water and solvent control group. A positive result is further supported by the demonstration of a biologically plausible relationship between the dose and the response curve. As mentioned earlier, the spiggin decrease may not entirely be of endocrine origin; however a positive result should generally be interpreted as evidence of endocrine activity *in vivo*, and should normally initiate actions for further clarification.

LITERATURE

1

- 2 1. OECD (2006b). Report of the Initial Work Towards the Validation of the 21-Day Fish Screening
3 Assay for the Detection of Endocrine active Substances (Phase 1B). OECD Environmental Health
4 and Safety Publications Series on Testing and Assessment No.61, ENV/JM/MONO(2006)29.
- 5 2. OECD (2006a). Report of the Initial Work Towards the Validation of the 21-Day Fish Screening
6 Assay for the Detection of Endocrine active Substances (Phase 1A). OECD Environmental Health
7 and Safety Publications Series on Testing and Assessment No.60, ENV/JM/MONO(2006)27.
- 8 3. Katsiadaki I (2009). The androgenised female stickleback screen (AFSS). Report to the OECD
9 secretariat covering retrospective validation of a large dataset.
- 10 4. Katsiadaki I, Scott AP, Hurst MR, Matthiessen P, Mayer I (2002). Detection of environmental
11 androgens: A novel method based on ELISA of spiggin, the stickleback (*Gasterosteus aculeatus*)
12 glue protein. *Environmental Toxicology and Chemistry*; 21(9):1946-1954.
- 13 5. Katsiadaki I, Scott S, Mayer I (2002). The potential of the three-spined stickleback, *Gasterosteus*
14 *aculeatus* L., as a combined biomarker for oestrogens and androgens in European waters. *Marine*
15 *Environmental Research*; 54(3-5):725-728.
- 16 6. Katsiadaki I, Morris S, Squires C, Hurst MR, James JD, Scott AP (2006). A sensitive, *in vivo* test
17 for the detection of environmental anti-androgens, using the three-spined stickleback (*Gasterosteus*
18 *aculeatus*). *Environmental Health Perspectives*; 114(suppl. 1):115-121.
- 19 7. Jolly C, Katsiadaki I, Le Belle N, Mayer I, Dufour S (2006). Development of a stickleback kidney
20 cell culture assay for the screening of androgenic and anti-androgenic endocrine disrupters.
21 *Aquatic Toxicology*; 79(2):158-166.
- 22 8. Jolly C, Katsiadaki I, Morris S, Le Belle N, Dufour S, Mayer I, Pottinger TG, Scott AP (2009).
23 Detection of the anti-androgenic effect of endocrine disrupting environmental contaminants using
24 *in vivo* and *in vitro* assays in the three-spined stickleback. *Aquatic Toxicology*; 92:228-239.
- 25 | 9. Jakobsson S, Borg B, Haux C, Hyllner SJ (1999). An 11-ketotestosterone induced kidney-secreted
26 protein: the nest building glue from male three-spined stickleback, *Gasterosteus aculeatus*. *Fish*
27 *Physiology and Biochemistry*; 20:79-85.
- 28 10. Hoar WS (1963). Hormones and the reproductive behaviour of the male three-spined stickleback,
29 *Gasterosteus aculeatus*. *Animal Behaviour*; 10:247-266.
- 30 11. Hahlbeck E, Katsiadaki I, Mayer I, Adolfsson-Erici M, James JD, Bengtsson B-E (2004). The
31 juvenile three-spined stickleback (*Gasterosteus aculeatus* L.) as a model organism for endocrine
32 disruption II - kidney hypertrophy, vitellogenin and spiggin induction. *Aquatic Toxicology*;
33 70:311-326.

- 1 12. Björkblom C, Olsson P-E, Katsiadaki I, Wiklund T (2007). Estrogen- and androgen- sensitive
2 bioassays based on primary cell and tissue slice cultures from the three-spined stickleback
3 (*Gasterosteus aculeatus*). *Comparative Biochemistry and Physiology Part C*; 146:431-442.
- 4 13. Nagae M, Kawasaki F, Tanaka Y, Ohkubo N, Matsubara T, Soyano K, Hara A, Arizono K, Scott
5 AP, Katsiadaki I (2007). Detection and assessment of androgenic potency of endocrine-disrupting
6 chemicals using three-spined stickleback, *Gasterosteus aculeatus*. *Environmental Sciences*; 14
7 (5):255-261
- 8 14. Allen YT, Katsiadaki I, Pottinger TG, Jolly C, Matthiessen P, Mayer I, Smith A, Scott AP, Eccles
9 P, Sanders MB, Pulman KGT, Feist S (2008). Intercalibration exercise using a stickleback
10 endocrine disrupter screening assay. *Environmental Toxicology and Chemistry*; 27(2):404-412.
- 11 15. Hogan NS, Wartman CA, Finley MA, van der Lee JG, van den Heuvel MR (2008). Simultaneous
12 determination of androgenic and estrogenic endpoints in the threespine stickleback (*Gasterosteus*
13 *aculeatus*) using quantitative RT-PCR. *Aquat.ic Toxicology*; 90:269-276.
- 14 16. Katsiadaki I, Sanders MB, Sebire M, Nagae M, Soyano K, Scott AP (2007). Three-spined
15 stickleback: an emerging model in environmental endocrine disruption. *Environmental Sciences*;
16 14(5):263-283.
- 17 17. Sebire M, Allen Y, Bersuder P, Katsiadaki I (2008). The model antiandrogen flutamide suppresses
18 the expression of typical male stickleback reproductive behaviour. *Aquatic Toxicology*; 90:37-47.
- 19 18. Sebire M, Scott AP, Tyler CR, Cresswell J, Hodgson DJ, Morris S, Sanders MB, Stebbing PD,
20 Katsiadaki I (2009). The organophosphorous pesticide, fenitrothion, acts as an anti-androgen and
21 alters reproductive behavior of the male three-spined stickleback, *Gasterosteus aculeatus*.
22 *Ecotoxicology*, 18:122-133.
- 23 19. OECD (2000) Guidance Document on Aquatic Toxicity Testing of Difficult Substances and
24 Mixtures. Environmental Health and Safety Publications. Series on Testing and Assessment. No.
25 23. Paris
- 26 20. Hutchinson TH, Shillabeer N, Winter MJ, Pickford DB (2006). Acute and chronic effects of carrier
27 solvents in aquatic organisms: A critical review *Aquatic Toxicology*, 76:69-92.
- 28 21. Pawlowski S, Sauer A, Shears JA, Tyler CR, Braunbeck T (2004). Androgenic and estrogenic
29 effects of the synthetic androgen 17alpha-methyltestosterone on sexual development and
30 reproductive performance in the fathead minnow (*Pimephales promelas*) determined using the
31 gonadal recrudescence assay. *Aquatic Toxicology*; 68(3):277-291.
- 32 22. Andersen L, Goto-Kazeto R, Trant JM, Nash JP, Korsgaard B, Bjerregaard P (2006). Short-term
33 exposure to low concentrations of the synthetic androgen methyltestosterone affects vitellogenin
34 and steroid levels in adult male zebrafish (*Danio rerio*). *Aquatic Toxicology*; 76(3-4):343-352.
- 35 23. Rushbrook BJ, Katsiadaki I, Barber I (2007). Spiggin production is inhibited in males sticklebacks
36 infected with *Schistocephalus solidus*. *Journal of Fish Biology*; 71:298-303.
- 37 24. Griffiths R, Orr KJ, Adam A, and Barber I (2000). DNA sex identification in the three-spined
38 stickleback, *J. Fish Biol.* 57:1331-1334.

- 1 25. Peichel CL, Ross JA, Matson CK, Dickson M, Grimwood J, Schmutz J, Myers RM, Mori S,
2 Schluter D, Kingsley DM (2004). The Master Sex-Determination Locus in Three spine
3 Sticklebacks is on a Nascent Y Chromosome. *Currents Biology*, 14:1416-1424.
- 4 26. Hutchinson TH, Bogi C, Winter MJ, Owens JW (2009). Benefits of the maximum tolerated dose
5 (MTD) and maximum tolerated concentration (MTC) concept in aquatic toxicology. *Aquatic*
6 *Toxicology*, 91, Issue 3:197-202.
- 7 27. OECD (2006c). *Current Approaches in the Statistical Analysis of Ecotoxicity Data: A Guidance to*
8 *Application*. OECD environmental Health and Safety Publications Series on Testing and
9 Assessment No.54. ENV/JM/MONO(2006)18.

10 ANNEX 1

11 ABBREVIATIONS & DEFINITIONS

13 ELISA: Enzyme-Linked Immunosorbent Assay

14 Loading rate - the wet weight of fish per volume of water.

15
16 Stocking density - is the number of fish per volume of water.

17
18 DHT-dihydrotestosterone

19
20 MT- 17 α -Methyltestosterone

21
22 MTC: Maximum Tolerated Concentration, representing about 10% of the LC₅₀

1

ANNEX 2

2

EXPERIMENTAL CONDITIONS FOR THE AFSS

1. Species	Three-spined stickleback (<i>Gasterosteus aculeatus</i>)
2. Test type	Flow-through
3. Water temperature	17 ± 2°C
4. Illumination quality	Fluorescent bulbs (wide spectrum)
5. Light intensity	540-1000 lux
6. Photoperiod (dawn / dusk optional)	12 h light, 12 h dark
7. Loading rate	<5 g per L
8. Test chamber size	10 L (minimum)
9. Test solution volume	8 L (minimum)
10. Volume exchanges of test solutions	Minimum of 6 daily
11. Age of test organisms	See paragraph 17 (>30 weeks)
12. Approximate wet weight of adult fish (g)	Females: 1.2 ± 40%
13. No. of fish per test vessel	5 (all females)
14. No. of treatments	= 5 (plus appropriate controls)
15. No. vessels per treatment	2 minimum
16. No. of fish per test concentration	10 females
17. Feeding regime	Frozen bloodworm once or twice daily (ad libitum)
18. Aeration	None unless DO concentration falls below 60% ASL
19. Dilution water	Clean surface, well or reconstituted water or dechlorinated tap water
20. Acclimation period	7 days
21. Chemical exposure duration	21-d
22. Biological endpoints	- Survival - Weight - Spiggin

23. Test acceptability

Dissolved oxygen $\geq 60\%$ of saturation; mean temperature of $17 \pm 2^\circ\text{C}$; 90% survival of fish in the controls; measured test concentrations within 20% of mean measured values per treatment level.

1

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ANNEX 3

2

(REMOVED BECAUSE OF SIZE)

3

ANNEX 4**SOP: QUANTIFICATION OF KIDNEY SPIGGIN PROTEIN (MODIFIED FROM KATSIADAKI ET AL, 2002a).***Consumables/Equipment*

High Protein Binding (Polystyrene)-Flat-bottom 96 well microplates

Low Protein Binding (Polypropylene)-Round-bottom 96 well microplates

Plate sealers: Costar®, Catalogue Number 3095, 100/bag, non sterile (Sigma/Fisher)

Multi-pipettes (12 and 8 channel) and multipipette trays

Plate Washer: Program to wash 3 times using 300ul for each well, Consult operating manual.

Plate reader at 405nm.

*Chemicals*Denaturing Buffer: 100 mM Tris-HCl (pH:8.5), 10mM EDTA, 8M Urea, 2% SDS, 200mM β -mercaptoethanol (Sigma does a Tris-HCl EDTA 10X easy to prepare T9285)

Coating Buffer: 0.05 M sodium bicarbonate-carbonate; pH 9.6; 1 Tablet in 100ml DW [Sigma C3041]

Washing Buffer: 0.1 M sodium phosphate [72mM di-basic, 28mM monobasic] 140 mM NaCl, 27mM potassium chloride, 0.05% Tween 20 (v/v). Dissolve first all constituents in 1 L DW and then add the remaining water. Tween is difficult to handle as it's very viscous to be volumetrically measured using convectional pipettes. We use a plastic graduated Pasteur pipette where the end is cut with scissors to allow suction.

Note: You need roughly 3L wash buffer per 10 plates

Chemical	1L	2L	3L	4L	5L
NaH ₂ PO ₄ (MW: 120)	3.36	6.71	10	13.44	16.80
Na ₂ HPO ₄ (MW:142)	10.2	20.4	30.6	40.8	51
NaCl	8.2	16.4	24.6	32.8	41
KCl	2g	4g	6g	8g	10g
Tween 20	0.5ml	1ml	1.5ml	2ml	2.5ml

25

Assay Buffer: Washing Buffer + 0.1% BSA (w/v) = **0.5g per 500ml** + 0.15 mM sodium azide
(Dissolve **0.065g** in **1ml** wash buffer and ADD **70 μ l** to **500 ml** Assay buffer)

28

Spiggin Standard (SS): Spiggin standard (5,000 units/ml) is available at Cefas Weymouth. For the standard curve:

Create S1 (HIGH) by adding **50 μ l** of SS into **450 μ l** assay buffer.

1 **Create S2 (LOW)** by adding **10µl** of SS into **490µl** assay buffer.

2 For coating: Add **100µl** of SS into **100mls** of coating buffer (see above). Use
3 **100µl** per well to coat (10ml per plate).

4 Antisera: **1° antibody**: Polyclonal anti-spiggin (raised in a rabbit) is available from Cefas at 1/100 dilution.
5 Dilute further as follows: 100µl of the antiserum to 20mls assay buffer (working
6 dilution of 1/20,000). You would need to add 65 µl per well (135µl). This will give
7 a final dilution of antiserum of approximately 1/60,000.

8 **2° antibody**: Alkaline phosphatase conjugated Anti-rabbit IgG whole molecule (Sigma A3937).
9 Dilute 1/15,000 (1µl per 15ml of assay buffer). You would need to add 150µl to all
10 wells. Be aware that the fresher this preparation the faster the reaction the
11 following morning with the substrate. Ideally prepare 6 hours before addition to
12 the plates, particularly when a large number of plates are involved.

13 Substrate (tracer) pNPP Kit (1 tablet of 0.2 M Tris and 1 tablet of pNPP per 20ml DW), Sigma
14 N2770. Follow manufacturers instructions.

15
16 *Kidney preparation for the spiggin ELISA*

- 17 1) Place each sample in a 2ml freestanding tube (Fisher: FB56123) with a gasket sealed screw cap
18 (Fisher: FB56133) and add 200 µl of denaturing buffer. Do not use eppendorf tubes. If kidney size is
19 visually judged to be too big to be solubilised into 200µl (i.e. this volume is not enough to fully cover
20 the tissue), use 400µl instead and record. Only in rare cases (usually big males with substantial kidney
21 hypertrophy) the addition of 400µl is required.
- 22 2) Place the tubes in a rack and heat at 80°C for 45 minutes. Vortex samples after 20min to facilitate
23 tissue digestion. Again, in exceptional cases you may need to extend heating to more than 45 minutes.
24 Do this only for the kidneys that have not been fully coaxed after this period. Assay samples
25 immediately after digestion or store at -80°C until ready to assay. If samples are to be assayed next
26 morning, they can be left overnight in the fridge (4°C).

27
28 *ELISA Procedure*

29
30 **DAY 1: STEP 1 – Coating wells with spiggin.**

- 31 1) Use High Protein Binding (Polystyrene) flat-bottom 96 well microplates
32 2) Dilute SS 1:1000 with coating buffer (100µl in 100ml)
33 3) Add 100µl of coating solution to each well by reverse pipetting (multi-pipette)
34 4) Seal plates, wrap in wet paper and store overnight at 4°C
35

36 **DAY 1: STEP 2 – Sample dilutions and incubation with 1° antiserum**

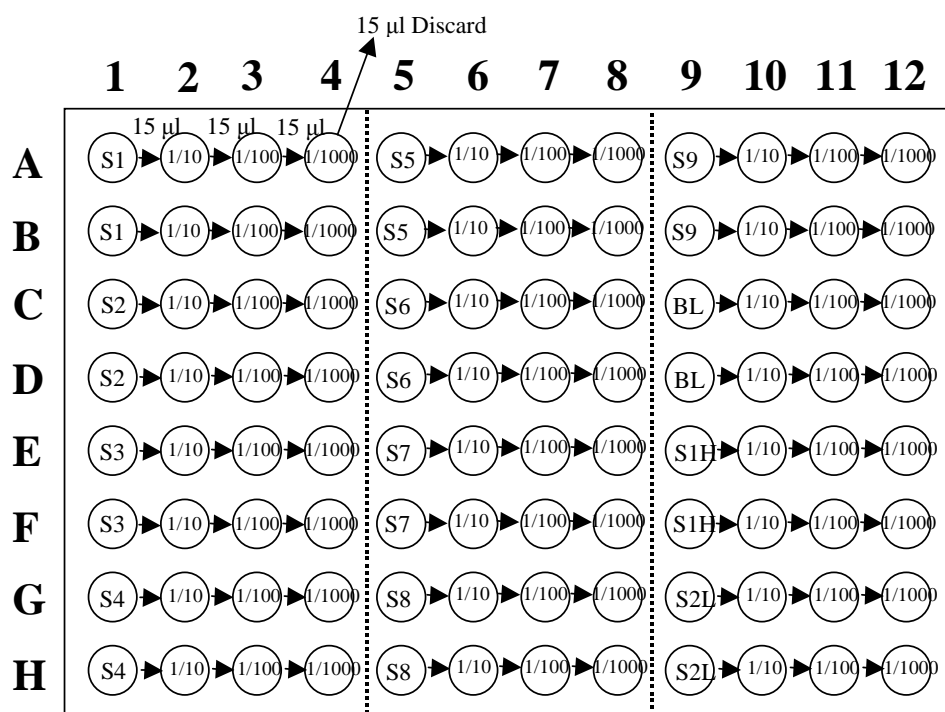
- 37 1) Use Low Protein Binding (Polypropylene) round-bottom 96 well microplates
38 2) Add 135 µl of assay buffer to each well by reverse pipetting
39 3) Dilute SS: S1 HIGH 1:10=500 Units/ml; S2 LOW 1:50=100 Units/ml
40 4) Add 15 µl of sample to wells in column 1, 5 and 9 (in duplicate)
41 5) Add 15 µl of denaturing buffer in column 9 (
42 6) Add 15 µl of HIGH Spiggin standard (in duplicate)
43 7) Add 15 µl of LOW Spiggin standard (in duplicate)
44 8) Mix using multi-pipette (10x) and transfer 15 µl to next column*
45 9) Repeat 3 times and change pipette tips between different columns
46 10) Discard last 15 µl. All wells should have 135µl.

} *See Figure 1*

- 11) Dilute 1° antiserum 1:20,000 in assay buffer as described (note the antiserum is usually provided already in 1/100 dilution so dilute a further 1/200 only).
- 12) Add 65 µl of 1° antiserum to each well containing sample dilutions and standard dilutions. Note this is providing a final dilution of the antiserum in the plate of 1/60,000.
- 13) Place on plate shaker for about 4 min. Take care to avoid spillage by increasing speed gradually.
- 14) Seal plates, wrap in wet paper and incubate overnight at 4°C.

* Mixing can be facilitated by placing the plate on the plate shaker while transferring samples between columns.

Figure 1: Spiggin ELISA plate layout



DAY 2: Transfer incubations to high binding plates.

- 1) Rinse the wells of the coated plates 3X with washing buffer
- 2) Starting from last column (column 12) transfer 150µl of the sample incubations (in the low binding plates) to the corresponding wells on the coated plates (the high binding). Discharge pipettes tips after transferring column 9 and before starting transferring column 8. Repeat for columns 8 and 4.
- 3) Seal plates, wrap in wet paper, place in a plastic bag and incubate for 4-6h at room temperature.
- 4) In the afternoon, rinse wells 3X with washing buffer.
- 5) Add 150µl of 2° antibody (anti-rabbit alkaline phosphatase) diluted 1:15,000 in assay buffer to all wells. You need 15ml buffer / plate.
- 6) Seal plates, wrap in wet paper, place in a plastic bag and incubate overnight at 4°C
- 7) Prepare 0.2 M Tris buffer from pNPP Kit (by dissolving 1 tablet in 20ml DW), mix and store at 4°C. We found that preparation of the substrate buffer the day before reduces the amount of cloudiness in the final buffer and gives better results.

1 **DAY 3**

- 2 1) Remove pNPP tablets from freezer and warm to room temperature (1 per 20ml)
- 3 2) Remove plates and wash 3X with distilled water (Note that we do not use wash buffer for this wash).
- 4 3) Dissolve pNPP tablet in 0.2 M Tris buffer (prepared the evening before) but be aware that colour
- 5 development is affected by light. Cover flask with foil or dark paper while dissolving.
- 6 4) Add 150µl of pNPP to each well as quickly as possible by reverse pipetting
- 7 5) Allow colour to develop (~40min) until standards read 2.0-2.4 optical density (by checking the first
- 8 plate every 5 min)
- 9 6) Take the reading and save the file

10

11 *Calculation of spiggin units*

12 The reading taken directly from the file represents spiggin units/ml of sample digest. Quite often more
13 than one value is within the standard curve so an average value should be calculated. The closer the
14 absorbance reading to the middle of the standard curve, the more accurate the calculated value.

15

16 Calculate “spiggin units /kidney” by multiplying the spiggin units/ml (value from plate reader) by 0.2
17 (representing the 200µl of buffer or 0.4 if 400µl were added) followed by 100 (this represents the dilutions
18 made to the original standard made using fully hypertrophied kidneys from males).

19 Divide “spiggin units/kidney” by the body weight of the fish to obtain the preferred expression of Spiggin
20 Units /g of body weight. Usually up to 100units/g of body weight means there is practically no glue in the
21 kidney. Values over 500 units are indicative of spiggin presence in the kidney. Samples that fall in
22 between these values should be re-assayed to confirm if there was a slight contamination from near-by
23 high values or a real low reading.

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ANNEX 5

SOME CHEMICAL CHARACTERISTICS OF ACCEPTABLE DILUTION WATER

SUBSTANCE	CONCENTRATIONS
Particulate matter	<20mg/L
Total organic carbon	<2mg/L
Unionised ammonia	<1µg/L
Residual chlorine	<10µg/L
Total organophosphorus pesticides	<50ng/L
Total organochlorine pesticides plus polychlorinated biphenyls	<50ng/L
Total organic chlorine	<25 ng/L

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ANNEX 6

Decision flowchart for the statistical analysis

